Volume 1 : Edition 11 – Wastewater Management Fundamentals and Biology Calculation Nov 30, 2021

Dear Water Warriors,

Wastewater is the focus of attention for Industry & Municipality. Unlike many other processes this needs understanding of Biology, a subject not comfortable to engineers.

A good wastewater recycle design must focus on Impurities disposal and rest is any way fresh Waughter, pure pristine and future.

This issue of '**Waughter**', we discuss basic terminologies and biological terms and calculations in Aerobic biology.

Nidhi Jain
Editor Waughter

Effluent Treatment Plant, Sewage Treatment Plant, more commonly known as ETP/STP rely largely on health of biological species that do wonder for us. In this edition: Highlights:

- Terminologies MLSS, MLVSS, FM, SRT
- Activated Sludge Modelling
- Before you Treat Biologically: Role of PT
- Flow Balancing
- Quick Calculation on Aeration Tank

Wastewater Constituents & Terminologies?

Refresh a few terms before we progress

Term	Explaination
FOG	Fat Oil & Grease
TSS	Particulates not dissolved - Dust, Fiber,
TDS	Inorganics Soluble e.g NaCl, $CaCO_3$
iTSS	Particulates Organics forming Ash - precipitates, Fe_3O_4, SiO_2
vTSS	Organic Particulates, $C_5H_7NO_2$, Protein
COD	Chemical Oxygen Demand - O_2 Consumed be total C available in waste water
pCOD	Particulate COD e.g. Fruit Pulp
sCOD	Organics that are Soluble e.g. Sugar
bsCOD	The Biodgradable fraction of soluble COD
nbCOD	Non Biodegradable fraction of COD can be particulate or soluble
BOD	Bio-Chemical O_2 demand of waste water. O_2 will be cosumed by bugs for oxidation, Synthesis & Endogenous Respiration.
DO	Dissolved Oxygen in Water, The chief aquatic life managing wonder. We work hard to ensure our aquatic bodies have DO.
NH3-N	Ammonical Nitrogen, Inorganic Nitrogen that is in reduced state and will deplete O_2 if not managed
TKN	Total Kjeldahl Nitrogen - is the sum or all reduced nitrogen Organic or Inorganic
Org-N	Organic Nitrogen in reduced state
NO_3	Nitrates - Nitrogen in Oxidised form
P	Phosphorus can be inorganic or Organic, is resposible for Eutrofication (Algae bloom) comes from Detergent & Fertilizer
Autotrophs	Bacteria that feed on CO_2, like tree
Hetrotrops	Bacteria that feed on Organic Carbon, like Humans

The Key to a successful of Aerobic Process?

Food Soluble Biodegradable Organic material bsCOD. For simplicity people take BOD mg/l as Food.

Flow As Constant as Possible. If not possible, liner propagating (Constant Ramp Up & Down)

Oxygen Operator to be sure enough oxygen is being provided in the aeration tanks for the microorganisms - 1.8 – 3 mg/l. Since O_2 demand can be varying based on Food available, always have VFD with Air blowers to optimize energy.

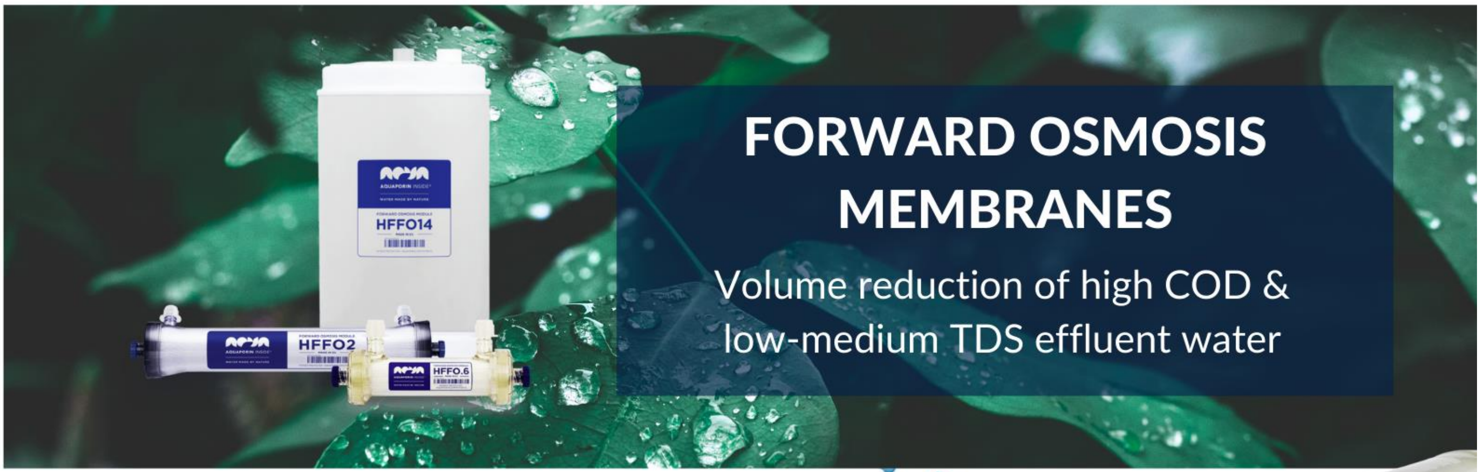
Temperature Most microorganisms do best under moderate temperatures (10-25 ºC).

pH between 6.0-9.0.

Nutrients C:N:P of 100:5:1 to be maintained as basic cell structure of bugs $C_5H_7NO_2$ need C & N

Toxicity Simply No. Higher the toxic organic molecules, slower is bugs growth.

OUR **ZLD** OFFERINGS



FORWARD OSMOSIS MEMBRANES

Volume reduction of high COD & low-medium TDS effluent water

INDUSTRIAL HIGH PRESSURE NF MEMBRANES

COD reduction, colour removal high COD & high TDS effluent

CIRTEC GALICOS

Low maintenance and low OPEX innovative evaporator

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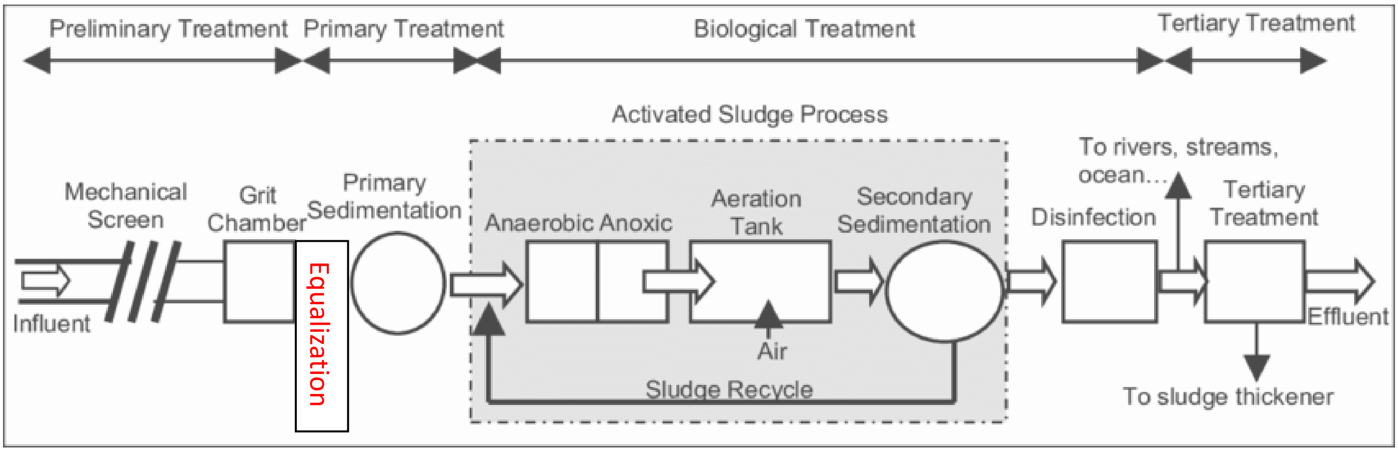
Technology, Treatment Goal & Schematic?

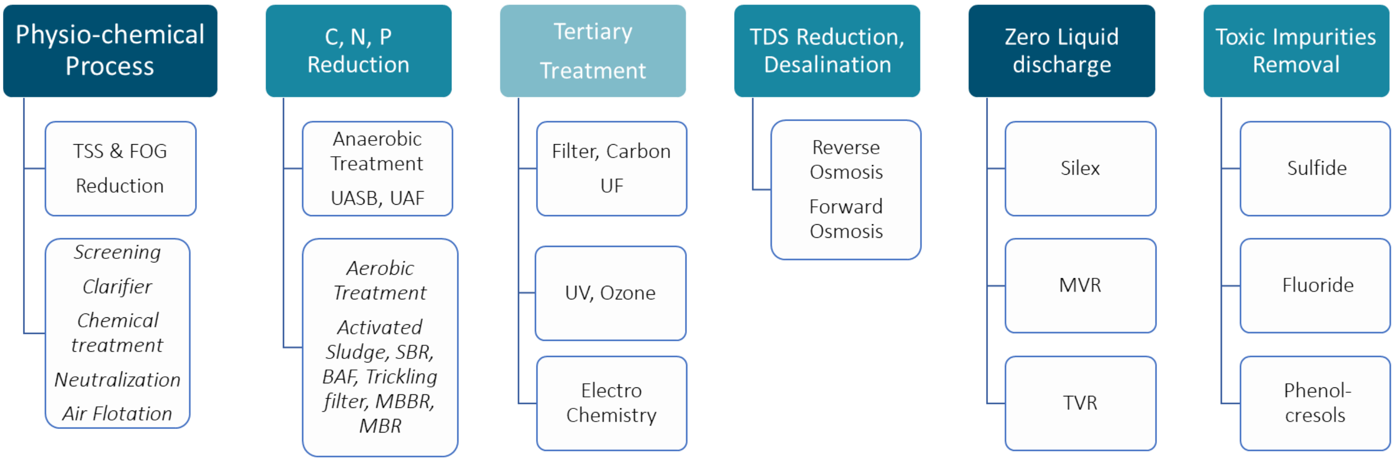


We don't control what comes from plant, hence section up to Equalization is designed on Max flow Possible.

Settling or Floating or both. Based on effluent constituents, one need to decide if Floating or Settling is preferred.

For Biological C removal we have 2 choices, Anaerobic that produces CH_4 (Energy) or Aerobic that emits CO_2. Future would be all Anaerobic.

Tertiary treatment process is selected based on final reuse of water: Gardening or recycle to Cooling Towers can't have same thinking.

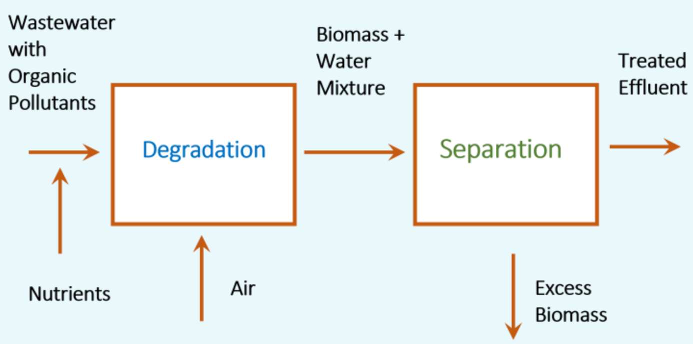


Fundamental diagram: Aerobic Biodegradation?

Since our focus this month is Aerobic Solutions, lets take a deep dive into it. Two Key Steps:

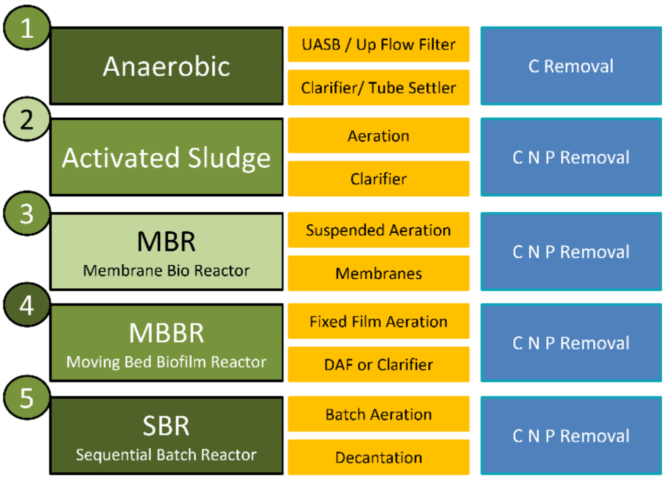
Biodegradation Bacteria « eat » the pollution ($C_5H_7NO_2$: New Cell Tissue)

Separation Treated water is separated from the purifying bacteria (e.g., By sedimentation/ Floatation or Filtration)



Biodegradation: Major Process

The 5 Process referred below cover almost entire wastewater degradation via biological process. Anaerobic has a distinct preference for C removal alone while all other aerobic processes remove C, N, P.



The Fundamental degradation process remains same as explained in previous page though the Separation mechanism is different in each process. Further in Moving Bed Biofilm reactor MBBR Bacteria are fixed to surface and in all others, we have suspended growth, meaning they grow while moving all across aeration tank.

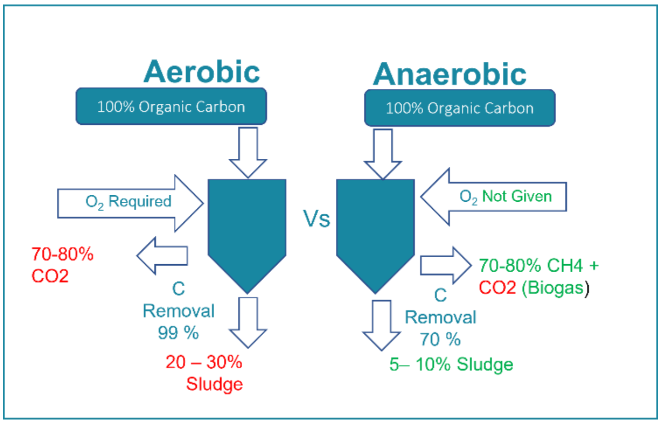
Before you treat: biologically?

Since Biological process need Bugs to eat food (bsCOD) and make water pollution free, one should check the readiness for bugs to do the job:

The idea of all above is to ensure Bugs (Hetrotrops & Autotrophs focus on C, N P removal only.

Anaerobic Vs Aerobic degradation

We are aware of great efficiency of aerobic process, and we can literally remove all carbonaceous pollutants. It is at a cost of producing CO_2 that has global warming potential. On the other hand, Anaerobic process can produce bio-methane that is increasingly being considered as future fuel.

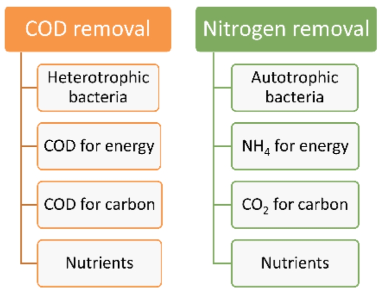


The C portion in municipal waste can be enriched by adding the solid organic based available from vegetables, animal dung, flowers etc and future fuel can be created. Understand Nagpur is taking lead and creating some infrastructure for generation of Gas and operating City buses on this fuel.

Role of Heterotrophs & Autotrophs

Heterotrophs, need Carbon for Energy, Carbon for Food, Nutrients and O_2 thus responsible for COD removal. This process produces enough CO_2

Autotrophs on the other hand draw energy from NH_3-N oxidation and consume as food CO_2 liberated by Heterotrophs while degrading COD.

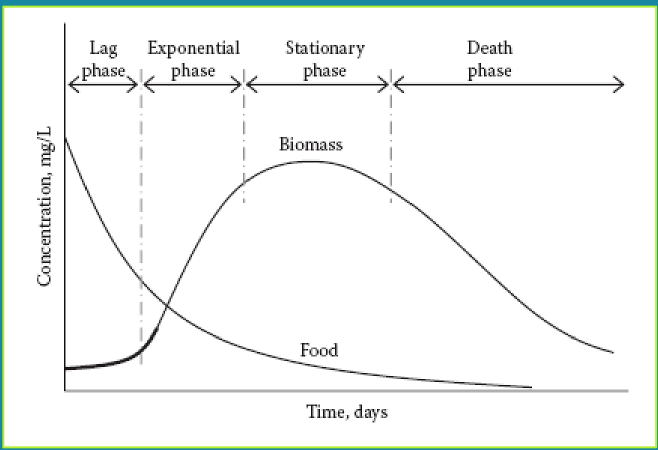


Rotifer

What is Biomass?

Biomass refers to microbes present/ added in the water whereas the substrate refers to the nutrients or organic matter that make up the wastewater and provide food for the bacteria cells.

The rate of biomass growth increases with the decrease in the utilization of substrate.

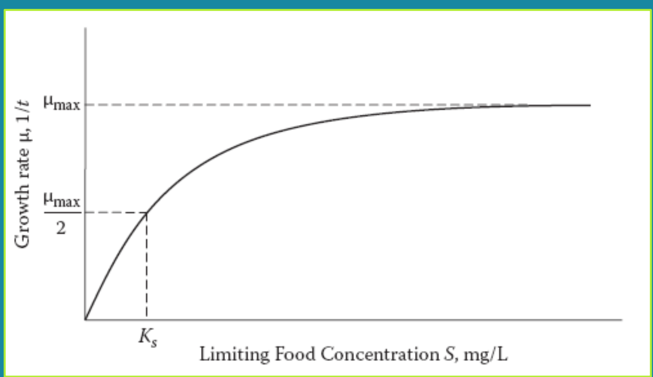


Here, COD and VSS represent the organic matter and new cells respectively.

Typical values of Y for aerobic processes range from 0.4 to 0.8 kg VSS/ kg BOD_5, while for anaerobic process it ranges from 0.08 to 0.2 kg VSS/kg BOD_5

Growth phase:

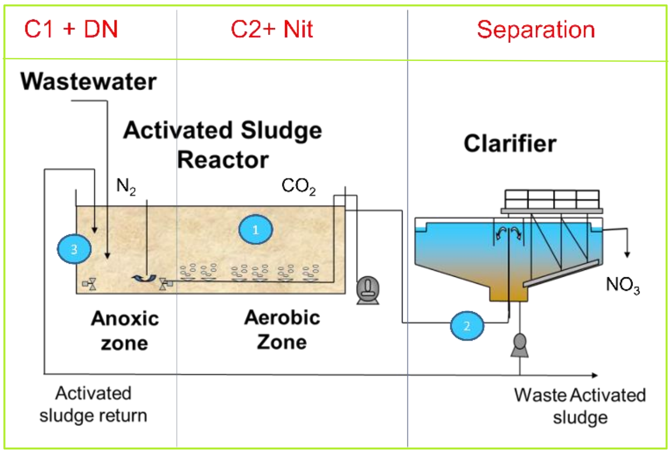
The growth rate of biomass depends on the concentration of biomass and specific growth rate. Specific growth rate of biomass can be defined by the Monod model which predicts



that the value of specific growth rate depends on the substrate concentration. Specific growth rate increases with the concentration of growth limiting substrate until it reaches a maximum value This graph indicates that the specific growth is the hyperbolic function of substrate.

Basic Activated Sludge Model?

Let's have a quick look at the basic activated sludge process and then discuss a few new terms in relation to that:



The Wastewater enters the system with pollutant. Imagin if Bugs are present to start with, HetroB will grow and convert C known as C Removal:

1. COD to CO_2 → Effects Alkalinity
2. COD to $C_5H_7NO_2$ → Produces more Biomass

If we keep returning sludge (Biomass) from seperation step back to Aeration tank, biomass concentration (MLSS – Mixed liquor Suspend Solids) will increse. Actually to indication of Biomass is MLVSS that is MLSS – Precipitates and iTSS.

Since we are not wasting sludge, it's aging in Aeration tank. Sludge age means time that on an average biomass remains in Aeration Tank. As CO_2 concetration increases, typically after 5 days AutotrophB will start in action and in 2 simple stems will produce NO_2^- and then NO_3^{--}, this step is Nitrification.

1. The Effluent is Aerated, COD & NH_3-N is oxidized and NO_3 is produced. Nitrification + Part COD2
2. While Biomass is separated in Clarification, we have NO_3 available in Sludge water. They are returned to a Tank, where O_2 is not present. NO_3 Return
3. In Anoxic Condition NO_3, COD are available, HetroB are returned but no O_2, now bugs consume O_2 from NO_3 and releases N_2. De-Nit + Part COD1

Aeration Tank Design for COD Removal?

The fundamental sizing for aeration Tank is done based on few guidelines:

- F:M Ratio (0.1-0.3)
- MLSS (2000 – 4000 mg/l)
- Hydraulic Retention Time (HRT 4 – 12h)
- Sludge Age (5 – 15d)

- Rise Rate $m^3/h.m^2$ (0.6 -1.2)
- Wier Loading Rate (80 – 120 m^3/d per m)
- RAS Flow rate (depends on De-Nitrification or 100%)

Design based on BOD data

If Feed is 350 mg/l, Flow rate 20 m^3/h and outlet Bod required is 20 mg/l, design aeration Tank?

Step 1 BOD Removed per day = (350 – 20) * 20 *24
= 158400 gm/d
= 158.4 kg/d

Step 2 Select MLSS ~ 3000 mg/l ~ 3 gm/l ~ 3 kg/m^3

Step 3 Select F/M Ratio ~ 0.25

F/M = BOD removed per day ÷ Biomass available
$0.25 = 158.4 \div (3\ kg/m^3 * AT_{Vol}\ m^3)$

Solving, $AT_{Vol} = 211.2\ m^3$

Step 4 Consider HRT ~ 12 h

$AT_{Vol} = 12 * \text{Flow rate} = 12 * 20 = 240\ m^3$

Step 5 Consider Sludge Age is 10 days. Now this step needs to know Growth (Constant Y ~ 0.5) & Death Constant (K_d ~ 0.06) for Heterotrophs.

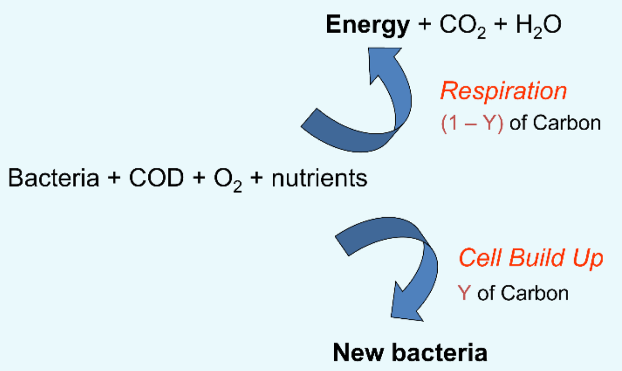
AT_{Vol} = Y * Q * BOD Removed * MCRT ÷ (1+K_d*MCRT) ÷ MLSS
= 792000 ÷ 1.6 ÷ 3000
= 165 m^3

So to satisfy all three conditions, the Aeration Tank volume selected shall be higher of the three i.e.
240 m^3/d

(Please download xls from www.aktionconsultancy.com)

What is BOD?

Lets understand the below reactions:



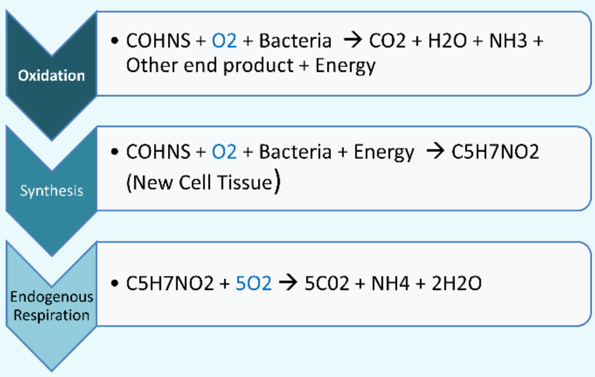
Bactera feed on soluble organic molecule and *Burn* Carbon to produce CO_2. This release Energy. This activity is known as oxidation or Respiration.

If Energy is available, bacteria feed on COD again and accumulate the C in the body to form $C_5H_7NO_2$ This step is known as Synthesis.

With time, age some bacteria will die. The dead bacteria is pCOD ($C_5H_7NO_2$), that again needs O_2 to repeat above 2 steps till all C is converted to CO_2. This step is known as Endogenous Respiration.

Let's Experiment for BOD?

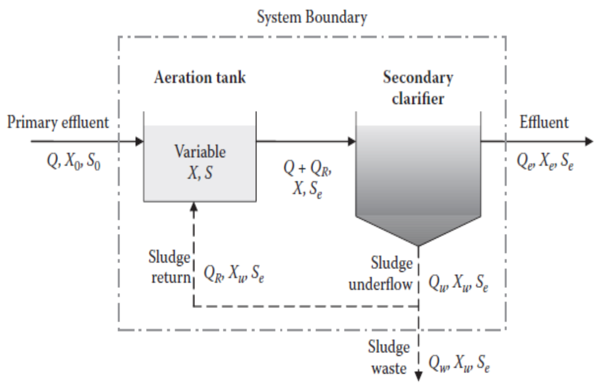
When we test BOD we calculate O_2 consumed in three steps below.



Remember NH_3 must remain in reduced form. BOD is the sum of all above oxygen in mg/l. BOD is not pollution, pollution is COHNS that is measured as COD by a different method explained in Waughter Vol 1 Edition 2.

Activated Sludge Modeling?

Unlike Physio-Chemical process, the ASP design model is slightly complicated as it converts a Soluble Impurity bSCOD to a Particulate $C_5H_7NO_2$. Let's understand this with ease:



Read below table for clarity on above:

Parameter	Unit	Symbol
Waste water flow rate	m^3/h	Q
Mixed liquor suspended solids concentration (MLSS) bacteria concentration	mg/l	X
Concentration of recycled activated sludge	mg/l	X_r
Effluent suspended solids concentration	mg/l	Xe
Waste sludge flow rate	m^3/h	Q_w
Return sludge flow rate	m^3/h	Q_r
Concentration of dissolved pollutants such as BOD	mg/l	So
Concentration of dissolved pollutants in the aerated tank and the effluent	mg/l	S
Volume of the aerated tank	m^3	V
Growth rate of the bacteria	-	Y
Hydraulic retention time	h	θ
Sludge age (sludge retention time)	d	θ_C
Decay rate of the bacteria	-	K_d
Food to microorganism ratio	-	F/M

In sludge recycle scheme, mass balance of entire system is done first and then of individual unit is achieved. Here the Q stands for flow rate, X stands for biomass and S stands for substrate(bCOD).

Conducting mass balance on flow rate, biomass, and substrate will give the overall flow of the system, recirculation rate, and the volume of each unit in design aspect.

For steady state the rate of accumulation is zero. Rate of growth of biomass of entire system is also considered as zero to simplify the design aspect.

Hence the overall mass balance equation then become:

Rate of flow in – Rate of flow out = 0

$Q - Q_w - Q_e = 0$

The flow rate of the inlet is provided from which the output flow rate is determined from the above equation.

For biomass mass balance:

$Q\ X_0 - Q_w\ X_u - Q_e\ X_e = 0$

From analysing the bCOD content in the influent, F/M is calculated which gives the amount of biomass to be present in the system for effective removal of bCOD as per design calculation. This leads to achieve the output biomass concentration and provide the efficiency of the system.

For each unit like aeration tank, the rate of biomass growth is considered as there is an increase in this unit which later decreases in secondary clarifier, making the overall biomass growth in system constant.

For aeration tank the biomass mass balance is:

$Q\ X + Q_R\ X_u - (Q + Q_R)\ X + dX/dt = 0$

For secondary clarifier, the biomass balance is:

$(Q + Q_R)\ X - Q_e\ X_e - Q_u\ X_u - dX/dt = 0$

The difference in rate of biomass growth dX/dt sign is that in aeration as the rate of biomass growth increases the sign is positive whereas in clarifier there is a decrease in biomass growth.

After calculation of the output efficiency, if one is not satisfied then change in F/M ratio, SRT, HRT, Volumetric loading can deviate the system to our benefit.

Metabolism

Anoxic: C Removal and O_2 Supply by NO_3

Aerobic: C, N, P Removal and O_2 Supply by Air

Anaerobic: C Removal in absence of O_2

We are not Finished Yet?

F/M Ratio:

Ratio of food to micro-organisms in the reactor. Mass of BOD removed in the reactor to the mass of micro-organisms in the reactor.

$$\frac{F}{M} = \frac{QS_o}{VX}$$

where,

F/M = food to microorganism ratio, mg BOD/mg VSS · d

So = BOD_5 concentration of substrate entering the reactor, mg/l

S = BOD_5 concentration of substrate leaving the reactor, mg/l

F/M shows the microbial growth phase. Lower F/M of about 0.05 indicates decay phase while a high F/M of around 1 indicates growth phase. Lower the F/M ratio, higher is the BOD removal.

Conventional ASP are operated at F/M ratio of 0.2 to 0.4. Here, the VSS or MLVSS represent the microbial mass in the reactor.

Volumetric Loading Rate:

Volumetric BOD or Volumetric Organic loading rate is defined as the mass of substrate/food applied per unit volume of the reactor.

$$V_L = \frac{Q\ S_o}{V}$$

where;

VL = volumetric loading rate, kg BOD_5/m^3

So = substrate concentration entering the reactor, kg BOD_5/m^3

Q = flow rate entering the reactor, m^3/d

V = reactor volume, m^3

Hydraulic Retention time:

The average time for which the effluent remains in the reactor before it is discharged for further processing.

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

where;

θ = hydraulic retention time, d

V = volume of reactor, m^3

Q = volumetric flow rate, m^3/d

HRT in conventional ASP process ranges from 3 to 7 days whereas it can reduce in high-rate processes.

The loading rate of aeration tank or the designing depends on this four main factor:

1. Hydraulic Retention time
2. Sludge Retention time
3. Food/Micro-organisms ratio
4. Volumetric Loading Rate

The environment for the growth of bacteria plays an important role. The factors responsible for microbial growth include pH, temperature, alkalinity, type of substrate/food, presence of toxins, dissolved oxygen concentration, etc.

$$X = \frac{YQ\theta_c(S_o - S)}{V(1 + k_d\theta_c)}$$

$$Q_r = Q\{\frac{X}{X_r - X}\}$$

$$\theta_c = \frac{XY}{Q_wX_r + (Q - Q_w)X_e}$$

$$\frac{F}{M} = \frac{QS_o}{VX}$$

My plant faces white, thick, billowing or foam on aeration tank surface.

Then there are many causes which are mentioned here Under:

Cause 1

Overloaded aeration tank (low MLSS) due to process start-up.

Necessary Check

Check aeration tank COD loading (kg/d) and MLVSS (kg) in aeration tank. Calculate F/M ratio try to be in 0.15 - 0.25 range.

Remedies

After calculating you will find that the F/M ratio is high and the (kg) MLVSS inventory is low. Therefore, do not waste sludge from the process or maintain the minimum WAS rate possible.

Necessary Check

Check secondary clarifier effluent for solids carryover. Effluent will look cloudy.

Remedies

Maintain sufficient RAS rates to minimize solids carry over especially during peak flow periods. In some extreme cases use natural coagulants.

Cause 2

Highly toxic waste, such as biocides from cooling towers.

Necessary Check

Take MLSS sample and test for metals, biocides, and temperature

Remedies

Re-establish new culture of activated sludge. Obtain seed sludge from other plants, if possible.

My plant faces Sludge clumps rising to and dispersing on clarifier surface. Bubbles noticed on clarifier surface.

Cause 1

Denitrification in clarifier: Less possibility but can happen if you still have high BOD post aeration.

Necessary Check

- Check for increase in clarifier effluent nitrate level.
- Check loading parameters.
- Check DO and temperature levels in the aeration tank.
- Check CFFR and sludge blanket depth.
- Check nutrient (urea) addition rates.

Remedies

Maintain WAS rates to keep process within proper MCRT and F/M ratio.

Cause 2

Septicity occurring in Clarifier: Most Often

Necessary Check

Maintain DO at minimum level

Remedies

Maintain DO at minimum level (1.8 mg/l). Be sure adequate mixing is provided in the aeration tank. Decrease nitrogen addition rate.

F/M Ratio, is it that important to our treatment plant?

If the biomass is in rapid growth stage, i.e., a high F/M, the biofilm excretes an adhesive matrix substance is not produced in sufficient quantities to maintain good gluing of MLSS (flocculation). A highly turbid, dispersed growth effluent results.

Conversely, with a very low organic loading, i.e., low F/M values, the organisms do not produce the enough biofilm excrete.

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What to do when clouds of billowing homogenous sludge rising and extending throughout the clarifier. Mixed liquor settles slowly and compacts poorly in settleability test, but supernatant is clear?

Cause 1

Improper organic loading or DO level.

Necessary Check

Check and monitor trend changes which occur in the following:

- Decrease in MLVSS mg/l
- Decrease in MCRT, Sludge Age
- Increase in F/M ratio
- Change in DO levels
- Sudden SVI increase from normal or decrease in SVI

Remedies

Decrease WAS rates by not more than 10% per day until process approaches normal operating parameters. Increase DO level throughout aeration tank greater than 1.0 mg/l, preferably 1.8 to 3 mg/l.

Cause 2

Filamentous organisms.

Necessary Check

Perform microscopic examination of mixed liquor and return sludge. If possible, try to identify type of filamentous organisms, either fungal or bacterial.

Remedies

Spray 1% solution of NaOCl and kill unwanted growth.

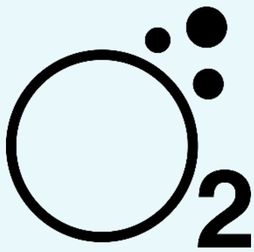
Coming to DO, have you wondered how much DO is good for plant. How we maintain OPEX for plant?

Generally, Activated Sludge can survive for 4-6 hrs. of anaerobic conditions, but aeration has to maintain. DO of 1-2 mg/l is enough oxygen to the microorganisms to sustain normal biodegradation. In case Nitrification is the goal DO need to > 2.0 mg/l in nitrification tank.

DO levels of 2.0 to 3.0 mg/l are necessary to withstand influent organic variations (to aeration basin) of up to 50 percent.

Adjust the DO level by controlling the number of blowers in service, or by changing the blower RPM via VFD.

If you think to increase DO to make the microbial activities faster than it is a Myth! You are just wasting you power and expense.



What are the conditions for aeration Basin if the plant has to stop for few days?

- One blower in operation
- No sludge wasting
- For shutdown of three days or less, pump primary effluent into basin as feed. Begin at a BOD loading of 50 kg/d for two days.
- Then feed 100 kg/d for two days. After this, the load can increase to 150-190 kg/d until any stored wastewater is worked off.
- For shutdown periods of more than three days, feed system a minimum synthetic or stored feed of 50 kg BOD/d, consisting of a readily degradable substrate, such as Sugar, Jaggery, Molasses. Startup can proceed as with normal operation.

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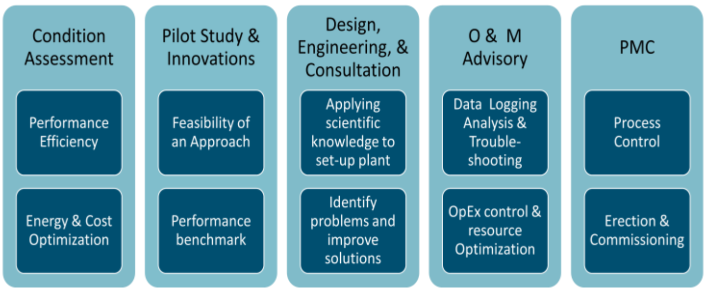
Let's talk about Aktion Indiaa

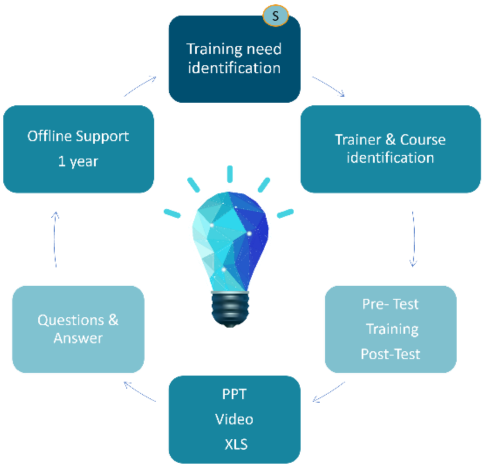
Our world is Water. We at Aktion Consultancy provide knowledge management Solutions on:

Our Knowledge is aimed to Ensure ?

Our B_2C Customers look forward to our help in 5 Core areas



And our not-for-Profit effort is:



जल जीवन जननी !!

Our world is Waughter

The technical knowledge share attempt of Aktion Consultancy and the contents in the magazine shall be qualified by Sanjeev Srivastava our Technology Lead.

Our 12th edition of Volume 1 focuses on: Operation and maintenance of ETP and Recycle Plant

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