Environmental Research & Education Foundation

Lighting a path to sustainable waste management practices

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Leachate Webinar

Aerobic Treatment Technology Approaches

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Outline

- **Recap of main issues in previous leachate courses**
- **Focus on types of aerobic treatment**
- **Pros and cons of each major treatment technology**
- **Unit sizing and cost**
- **“Soft” factors in process selection**
- **Decision method**
- **References and support tools**

- Leachate, as defined in 40 CFR 258.2, is liquid that has passed through or emerged from solid waste and contains soluble, suspended, or miscible materials removed from such waste.

Growing Interest in On-Site Leachate Treatment

- **Tighter permit regulations for pretreatment and direct discharge**
  - Conventional pollutants
  - Nonconventional – UV interference
  - Others - Perfluorochlorocarbons , PPCP, nano
  - Ash/E&P wastes
- **Nutrients in discharge**
  - Ammonia & total nitrogen
  - rDON
- **Treatment technology based limits**
- **Surcharges**
- **Capacity Issues (flow)**

Categorical Standards

- **Categorical Pretreatment Standards; ELGs – Revisions?**
  - 40 CFR136 & 445
  - monitor for 3 metals, 7 organic pollutants, BOD5, TSS, ammonia and pH.
- **RCRA Subtitle D Effluent Limits – Existing facilities 445.21**
  - Effluent limitations attainable by the application of the best practicable control technology currently available (BPT).

EFFLUENT LIMITATIONS

Regulated parameter	Maximum daily [1]	Maximum monthly avg. [1]
BOD	140	37
TSS	88	27
Ammonia (as N)	10	4.9
a-Terpineol	0.033	0.016
Benzoic acid	0.12	0.071
p-Cresol	0.025	0.014
Phenol	0.026	0.015
Zinc	0.20	0.11
pH	2)	(2)

[1] Milligrams per liter (mg/L, ppm)
[2] Within the range 6 to 9.

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Leachate Management other than On-site Biological Treatment

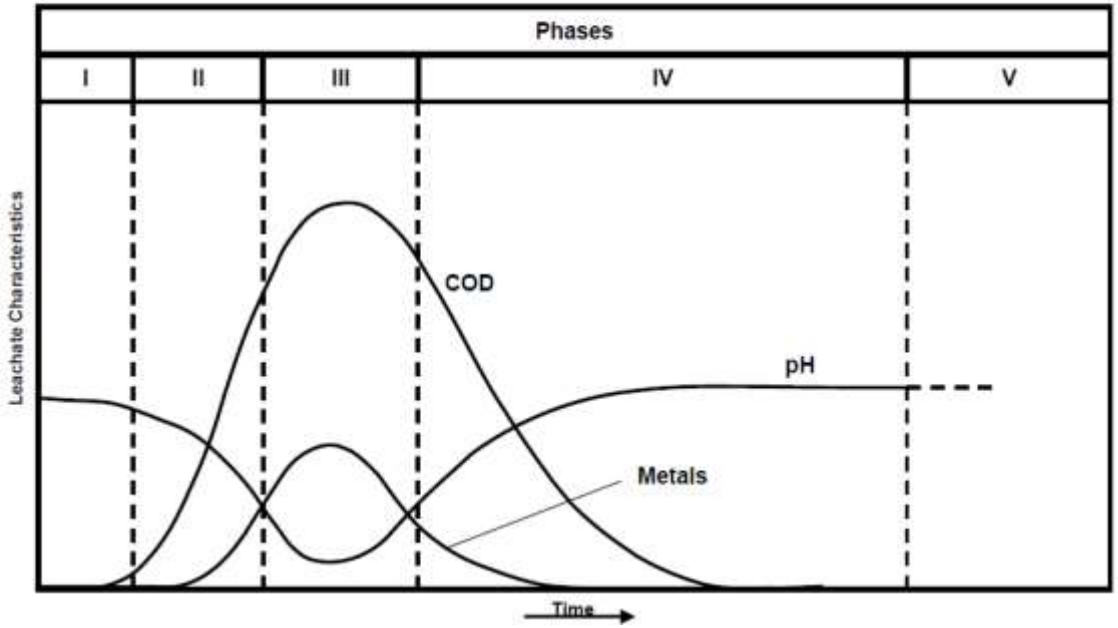
- **Municipal Discharge without treatment**
- **Physical Chemical**
  - Membrane – Nano/RO
  - Chemical Precipitation
  - Chemical Oxidation Systems – ozone, H_2O_2 , UV, catalysts
  - Air Stripping
  - Ion Exchange
  - GAC
  - Filtration
- **Passive Systems**
  - Constructed Wetlands
  - Phytoremediation

Direct discharge to Surface Water

- **TBEL**
  - BAT / Best Professional judgment / ELGs
- **TMDL**
  - Impaired water bodies where water quality not met with technology-based effluent limitations on point sources
- **WQBEL**
  - If TBEL not stringent enough to meet state WQS
  - Based on water body use
  - Mass balance for some pollutants
  - Mixing zone rules and limitations
- **WET**
  - Acute/Chronic toxicity limits

Leachate Characteristics

- Leachate Composition
- Variability of Leachate Quantities and Characteristics
- Leachate Parameters
- Characterizing Landfill Leachate by Landfill Age & Operation – Open vs Closed Cells
- What do you need to achieve – Effluent limits/standards?
- Why bench scale/pilot scale tests?



1- Initial
2 -Transition
3 - Acid Forming
4- Methane Fermentation
5 - Maturation

Role of Phases in Leachate Generation,
Tchobanoglous and Kreith 2002

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Leachate Characteristics

► Leachate Parameters

- Biochemical Oxygen Demand – Soluble/total CBOD, BOD_{tot}, BOD_{ult}
- Chemical Oxygen Demand – COD – Soluble/Total
- BOD/COD Ratio
- pH
- TDS
- Suspended Solids
- Ammonia Nitrogen
- Total Nitrogen
- VOC, Phenols
- Pesticides
- Others?

Leachate Characteristics, Other

- Metals
- TDS
- Color/UV
- rDON
- Emerging Constituents
- Odors
- Surfactants/Foam
- Temperature
- Corrosion
- Sulfate, Total Sulfur, Reactive Sulfur Compounds
- Radiation
- Health & Safety Issues

Considerations for Aerobic Processes to Treat Leachate

- **Highly Variable Waste**
- **High concentrations of Ammonia Nitrogen**
- **Activated Sludge Processes - Attached/Suspended**
- **Combination of Technologies after Aerobic Processes**
  - Ex. - Activated Carbon for organics, pesticides
    - treat landfill leachates to remove of dissolved organics
    - a more expensive treatment options
  - Filtration/RO/ Reject Management
  - Residual Management & Return Flows
- **Selection Criteria**
- **Design Considerations – Models, Aeration, Cautions**
- **Heating/Cooling**
- **Odor**
- **UVT**
- **Emerging Constituents**

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Key Design Considerations

- Leachate quality/quantity
- Land availability
- Disposal options
- Discharge limits
- Climate
- LFG availability
- Site preference
- Utilities
- Temperature
  - Heating
  - Cooling
- Standby Power
  - Genset
  - Dual feeds- Independent Pump Stations
- Instrumentation/automation
- Foam control
- UVT
- Corrosion
- Landfill life
- Air emissions
- POTW capacity
- POTW processes
- POTW effluent limits
- Energy costs
- Residual mgmt. & disposal
- Minimization potential
- Stakeholder issues
- Odor Control
- Odors/noise/traffic
- Site operation considerations
- Equipment access
- Cleaning ease
- Washdowns – hoses
- On-site Lab
- Data collection - KPI

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Aerobic Biological Treatment Technologies

Attached Growth

Static Fixed Film

Trickling Filters
Web Media
BAF
A2O Submerged
BAF
Bioprocess H20
Deep Bed Filters

Dynamic Fixed Film

RBC
Plastic Seaweed
IFAS
MBBR
BAF

Suspended Growth

Activated Sludge

Continuous

Oxidation Ditch
Conventional AS
Extended Aeration
MBR
Others
Step Feed
Timeswitch
Bardenpho
Ludzak Ettinger
Sharon
In-Nitri
Bioaugmentation (BAR)
Bioaugmentation
Enhanced (BABE)
UCT/MUCT

Batch

SBR
MBR

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Aerobic Biological Treatment Technologies Commonly Used for Leachate Treatment

Attached Growth

Static Fixed Film

Trickling Filters
Web Media
BAF
A2O Submerged
BAF
Bioprocess H20
Deep Bed Filters

Dynamic Fixed Film

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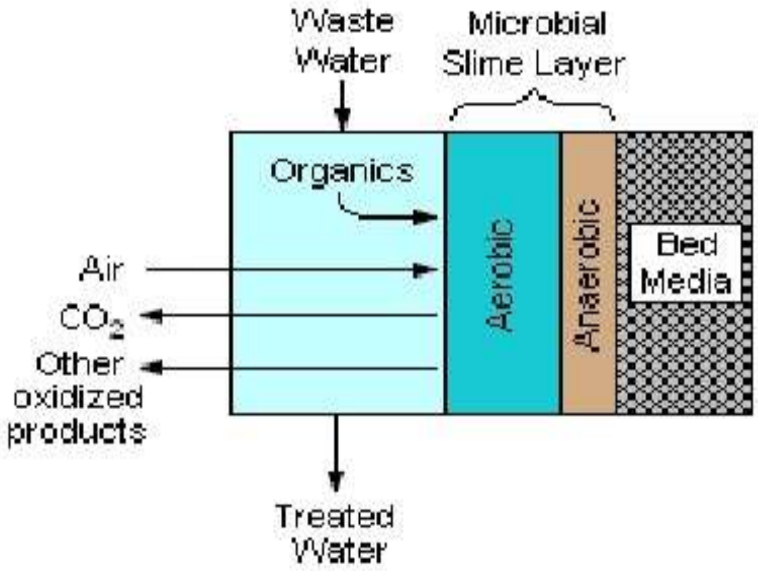
Bioaugmentation Enhanced (BABE)
UCT/MUCT

Batch

SBR
MBR

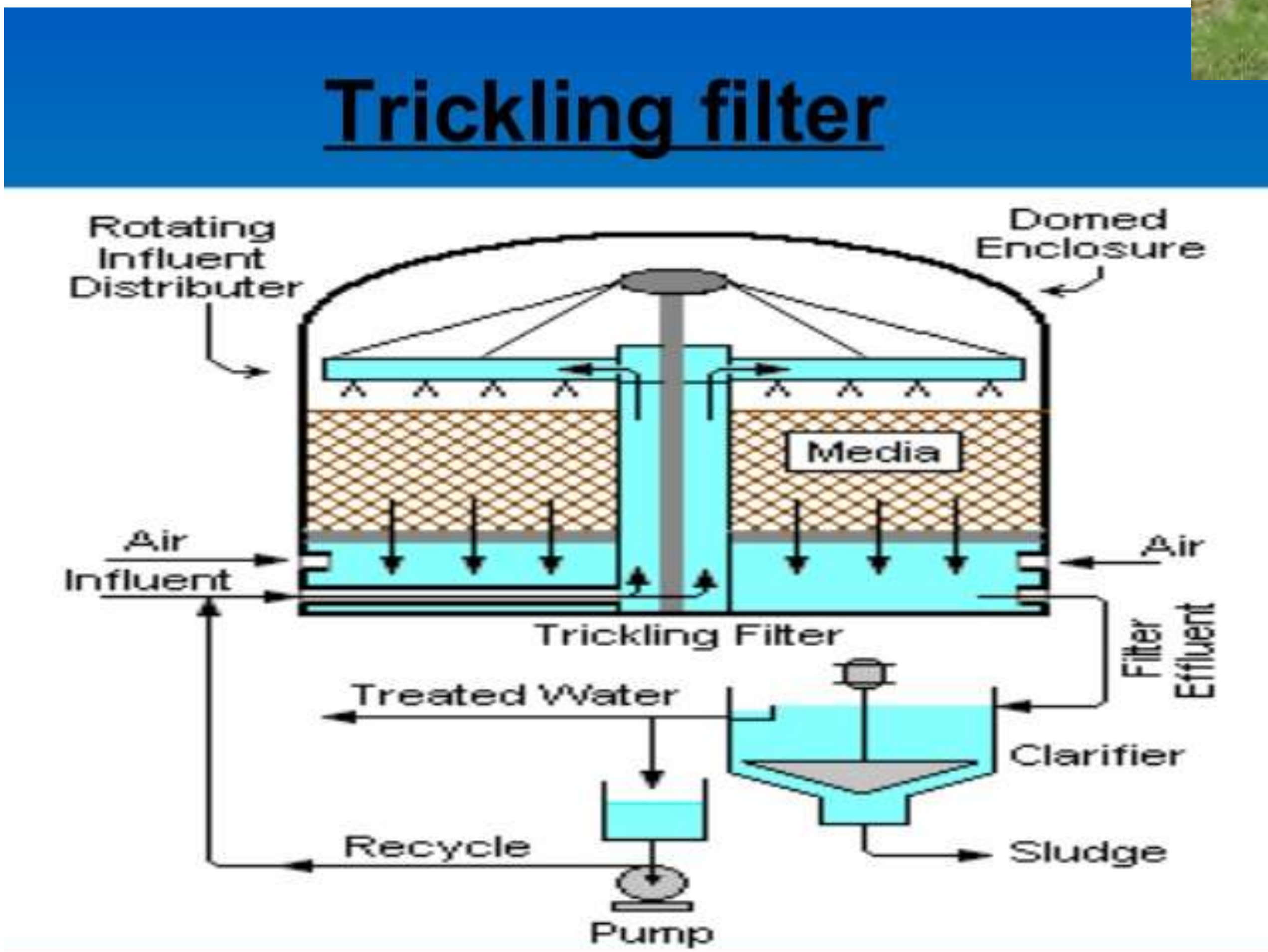
Fixed Film Systems - Static & Dynamic Systems

- **Microorganisms on substrates – rocks, sand, plastic media are cultured**
- **Leachate is spread over or submerged into the substrate**
- **Nutrients and organic matter absorbed by microorganisms**
- **Can provide carbonaceous and nitrification**
- **Can be combined with suspended growth (MBBR, IFAS)**
- **Slime growth layer grows and "sloughs off", new slime layer grows**
- **Slough material flows to clarifier and is removed**



- **Ammonia toxicity**
- **Chloride toxicity**
- **pH can be challenging, especially for nitrification**
- **Alkalinity addition may be required at depth**

Trickling Filter



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Trickling Filter

- Design commonly uses NRC equations for volume, sizing, flow, recirculation, loading, efficiencies
- Recirculation = Portion of the TF effluent recycled from a clarifier through the filter
- Recirculation ratio – R = returned flow Qr / influent flow Q
- OK for medium to high strengths flows, but limited to 75% +/-BOD removal; two stage common

S.No.	Design Feature	Low Rate Filter	High Rate Filter
1.	Hydraulic loading, $m^3/m^2.d$	1 - 4	10 - 40
2.	Organic loading,kg BOD / m^3.d	0.08 - 0.32	0.32 - 1.0
3.	Depth, m.	1.8 - 3.0	0.9 - 2.5
4.	Recirculation ratio	0	0.5 - 3.0 (domestic wastewater) up to 8 for strong industrial wastewater.

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Trickling Filter

Advantages:

- The simplicity and efficiency (meaning also low cost) of allowing the leachate to trickle under the influence of gravity over the media.

Disadvantages:

- Possible high rate of build-up of organic matter.
- Possibility of ammonia nitrogen overload causing loss of organic biomass (slime) loss from media. Control and monitoring difficult within body of media.
- Iron and calcium build-up and H&S concerns for operators during cleaning works
- Air flow through TF depends on atmospheric conditions – upflow/downflow. Stagnant can cause increased odors

- **Bottom Line – Not Recommended**

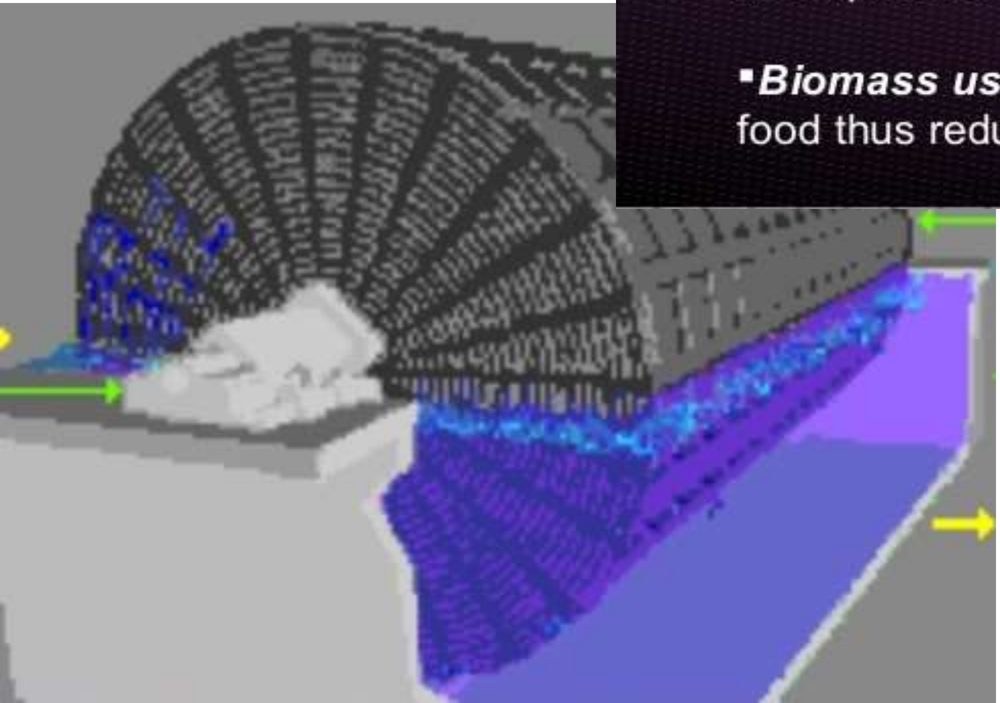
RBC

ROTATING BIOLOGICAL CONTACTOR

- ❑ Consists of a series of **closely spaced plastic circular disks**
- ❑ Disks are **submerged** in wastewater and rotated slowly through it.
- ❑ **Operation**, biological growths become attached to the surfaces of the disks and form a slime layer over the entire wetted surface.

- The ***rotation of the disks*** contacts the biomass in the wastewater ,then with the atmosphere for adsorption of oxygen.

- ***Biomass uses the oxygen*** & organic matter for food thus reducing the BOD in the wastewater.



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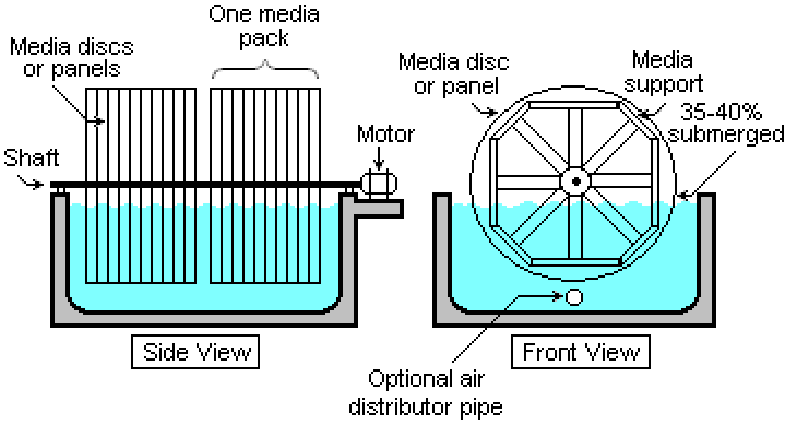
RBC Design Criteria

- **Diameter – 2-6 m**
- **Thickness - -10 mm**
- **Disc spacing 30-40 mm**
- **Speed of rotating shaft – 1-10 rpm**
- **Disc submergence – 40% dia**
- **Thickness biofilm – 2-4 mm**
- **Organic load – 3-10 gm BOD/m^2 disc surface**
- **Hydraulic load – 0.02 – 0.16 m^3/m^2/day**
- **Sludge production – 0.5 – 0.8 kg/kg BOD removed**
- **HRT – 0.5 – 2 hours**
- **Frequently used in the UK**
- **Caution- high concentrations of metals (Iron, others) and toxic materials adhere to surfaces and impede biological activity!**
- **Weight considerations on shaft and bearings caused failures in early applications**
- **Aeration cannot be varied based on influent load**

RBC

Advantages

- Simple Operation
- Potentially Lower Power –Blowers?
- Fixed Film means Aerobic & Anaerobic Combined



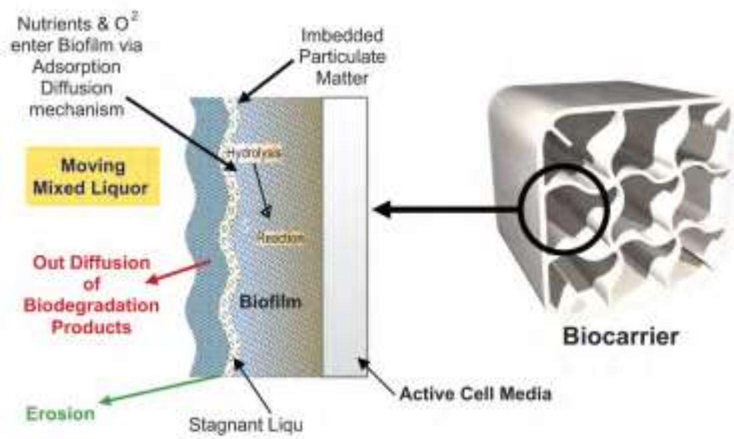
Disadvantages

- Often Teamed with Other Processes
- Mechanical Wear Problems
- Expensive Construction

- Bottom Line - Often Other Technologies More Cost Effective

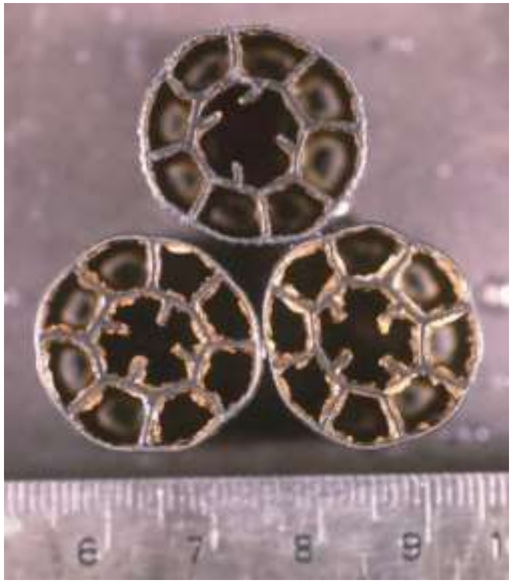
MBBR – Moving Bed Bioreactor

- ► **Carrier Elements – Polyethylene & other materials**
- ► **Slightly less dense S.G.<1**
- ► **Biofilm thickness continually sloughed**
- ► **Simple Operation**
- ► **Low footprint**
- ► **Depends on # Cells**
  - BOD/COD
  - Nitrification
  - Denitrification



MBBR Design Criteria

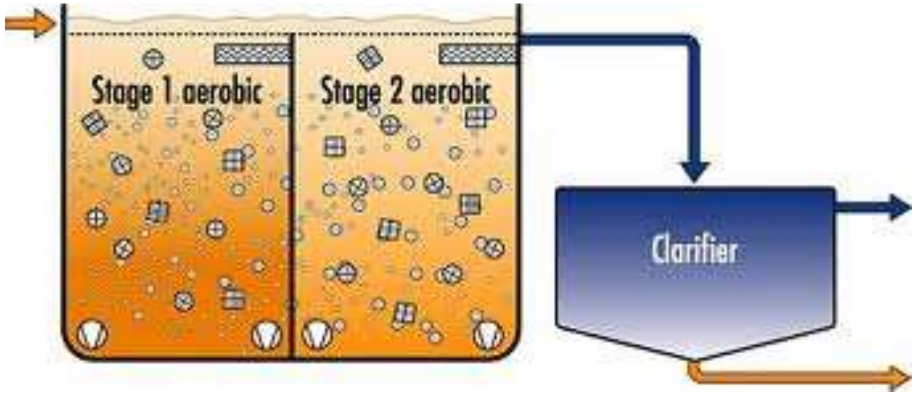
- **Organic surface loading rate (g BOD/m²d)**
  - Normal rate : 10 – 13 g BOD_5/m ^{2}d @25^{o}C
- **Surface area of carrier (m^2/m^3)**
  - 400 – 680 m^2/m^3 for Active Cell Media
- **The Biomedia carrier filling fraction (%)**
  - Normally : 50 – 67 % (minimum 30%)
  - Less dense than water,0.93-0.95 SG,
  - provide a large protected surface for bacteria culture.
- **Mixing Energy is a critical control for biological growth**
- **Attached growth only – No suspended growth**



MBBR

Advantages

- Simple Operation
- Small Footprint
- Reliable and Robust Treatment
- Reduced Sludge Generation
- No Recycle



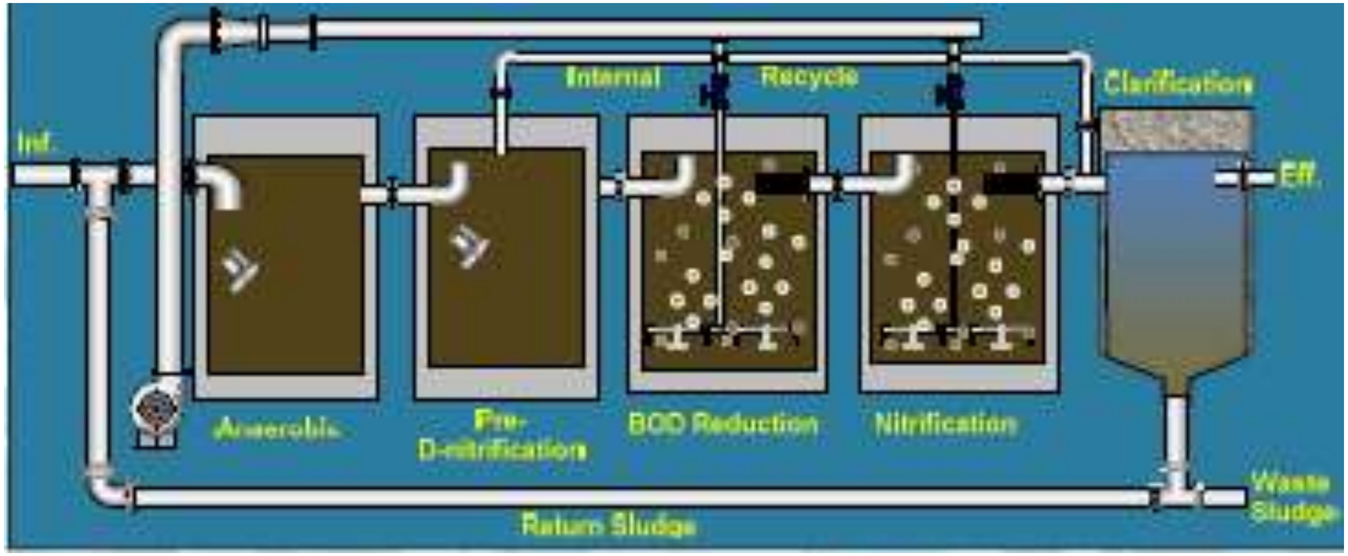
Disadvantages

- Costs can be high – especially if multiple units

- **Bottom Line – Effective Technology**

IFAS – Integrated Fixed Film Activated Sludge

- **Includes Return Activated Sludge from Clarifier**
  - MBBR needs no return
- **Combines Fixed Film & Activated Sludge**
- **Can achieve nitrification/denitrification**
  - Not affected by low suspended solids sludge age
- **Phosphorous removal by tailored suspended solids sludge age**

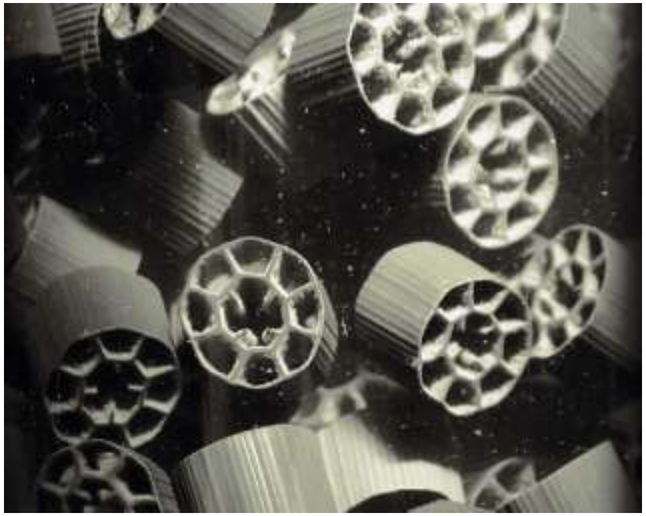


From Headworks BIO

IFAS – Integrated Fixed Film Activated Sludge

Advantages

- Small Footprint with High SRT
- Combines Fixed Film & Activated Sludge
- Robust Operation – Possibly simpler than AS
- Can achieve nitrification/denitrification
  - Not affected by low suspended solids sludge age
- Phosphorous removal by tailored suspended solids sludge age



Disadvantages

- Return Activated Sludge from Clarifier
- Costs can be High for CAPEX/OPEX

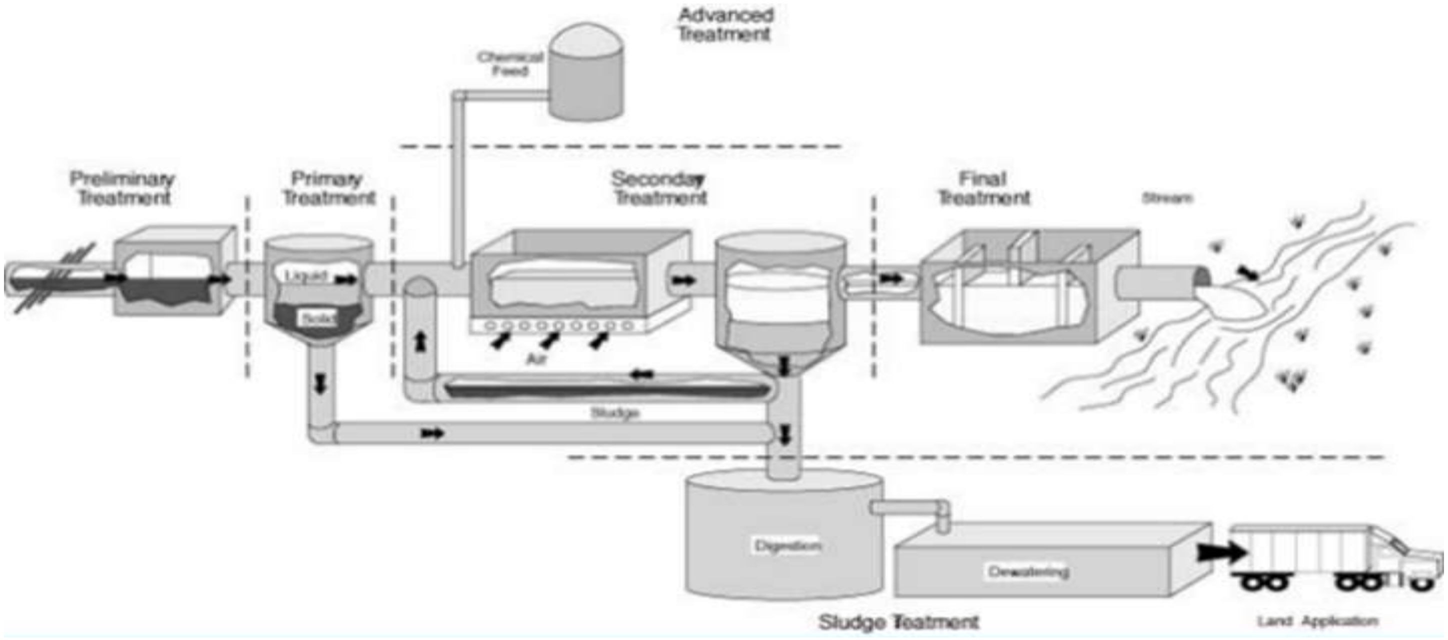
- Bottom Line – Effective Technology

Suspended Growth Systems

- **Conventional Activated Sludge**
- **Membrane Bioreactors (MBR)**
- **Sequencing Batch Reactors (SBR)**
- **Nitrification Alternatives**
  - Other Modifications

Activated Sludge Basics

- Mixed Community of microorganisms
- Both aerobic and anaerobic bacteria may exist
- Heterotrophic and autotrophic bacteria exist
- Biological floc is formed



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Suspended Growth Treatment

- **Aeration Tank – oxygen is introduced**
  - Needs biomass (mixed liquor)
  - Single or multi-stage
- **Aeration Source**
  - Compressed air
  - Surface aerators
  - Submerged turbine aerators
  - Pure oxygen
- **Clarification**
  - Wasting excess biomass (WAS)
  - Return remaining biomass (RAS)

Advantages / Disadvantages

ADVANTAGES

- BOD removal – high 90%
- Oxidation/Nitrification
- Biological phosphorous removal possible
- Temperature Dependent
- Very common process
- Recommend Screening first

DISADVANTAGES

- No color removal – possibly increase by forming colored intermediates
- Nutrient removal may require several stages/ Land Intensive
  - Heterotrophic versus autotrophic populations
- Energy intensive
- Close operation attention needed
- **BOTTOM LINE – Possible option**

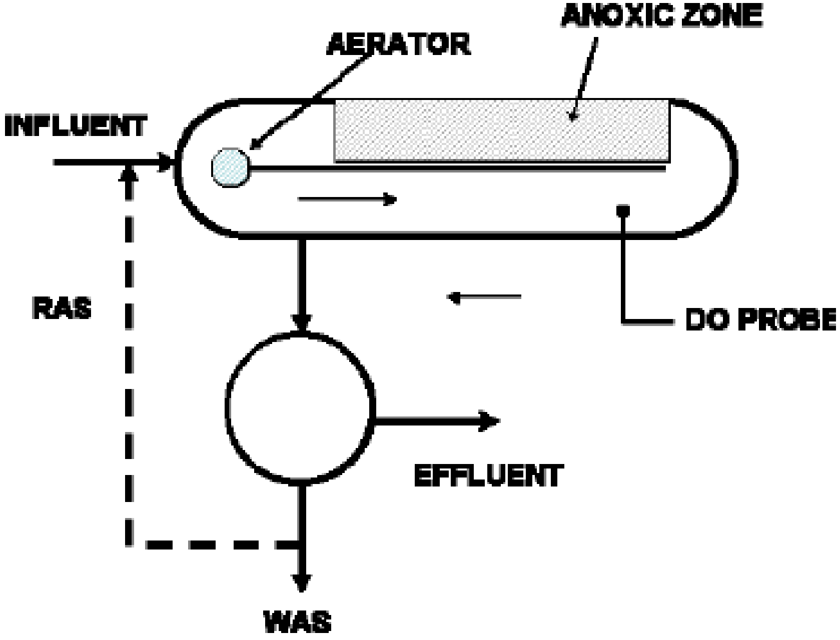
Activated Sludge Alternative Processes
Numerous types

- Oxidation Ditch
- Conventional Activated Sludge (complete mix)
- Contact Stabilization
- Step aeration
- Extended aeration
- Nutrient removal types

- **AERATION TYPES**
  - Diffused aeration – coarse bubble/fine bubble
  - Spray Aeration
  - Jet aeration
  - Turbine aeration
  - Surface aeration

Oxidation Ditch

- Continuous circulation waste & biomass
- DO added by brush aerator, rotors, diffused aerator or vertical shaft aerator
- Achieve simultaneous carbon, nitrogen & phosphorous removal
- Multiple configuration of 1 -3 concentric racetracks
- Circulates at 0.3 m/s or more
- Needs external clarifier
- Nitrox, Pasveer, Orbal, Biodeniro mfgs.
- VT2 – Dual Pasveer ditches – 30% flow to sidestream anaerobic

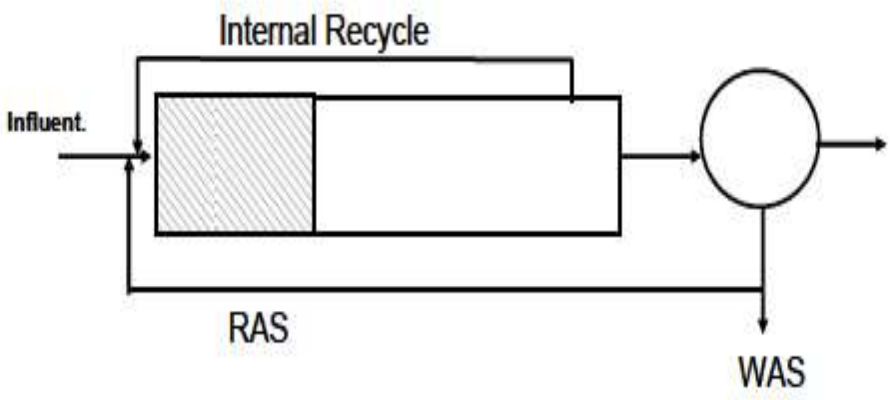


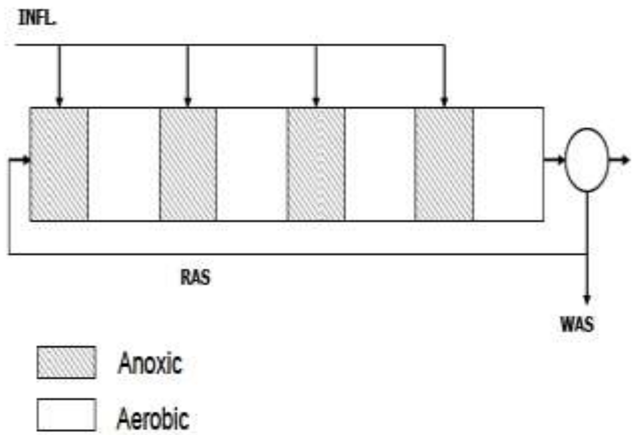
Multi-Stage Suspended Growth

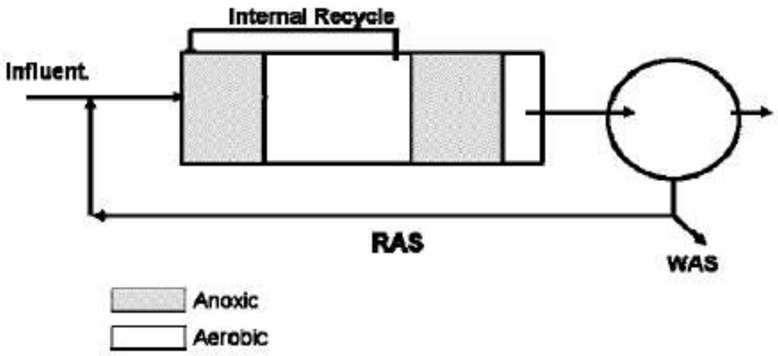
- Ludzack Ettinger
- Modified Ludzack Ettinger
- Step Feed
- Bardenpho
- Sharon & In-Nitri

Single reactor High Activity Ammonia Removal

Requires sidestream from anaerobic reactor – 2-3 day HRT







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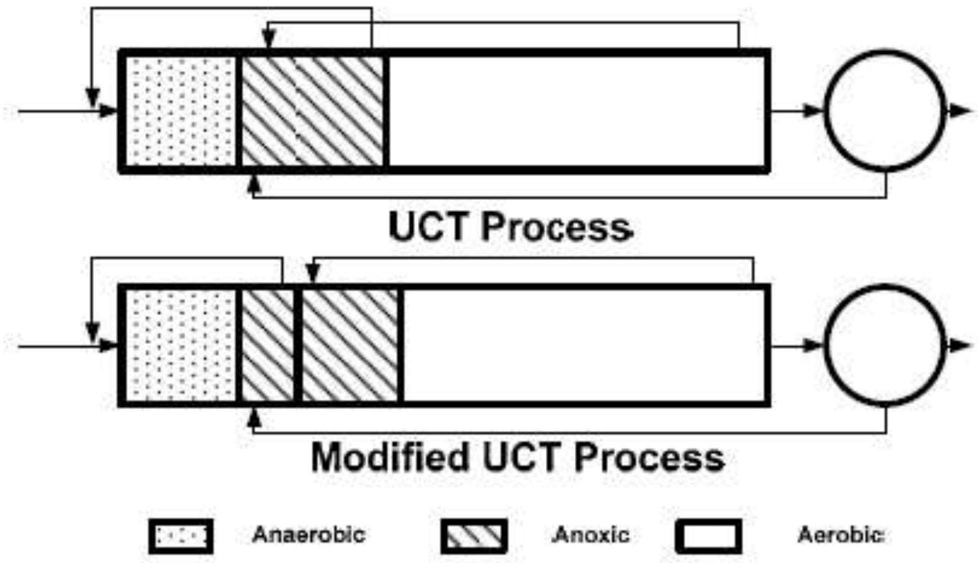
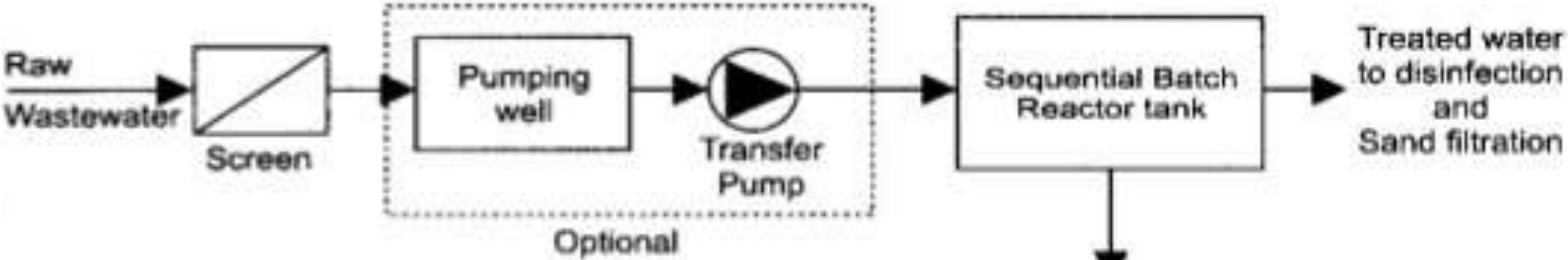
Other Single Stage Processes

- Bio-Augmentation Regeneration/Reaeration (BAR)
- Bio-Augmentation Batch Enhanced (BABE)
- Mainstream Autotrophic Recycle Enhanced N-Removal (Maureen)
- UCT/MUCT

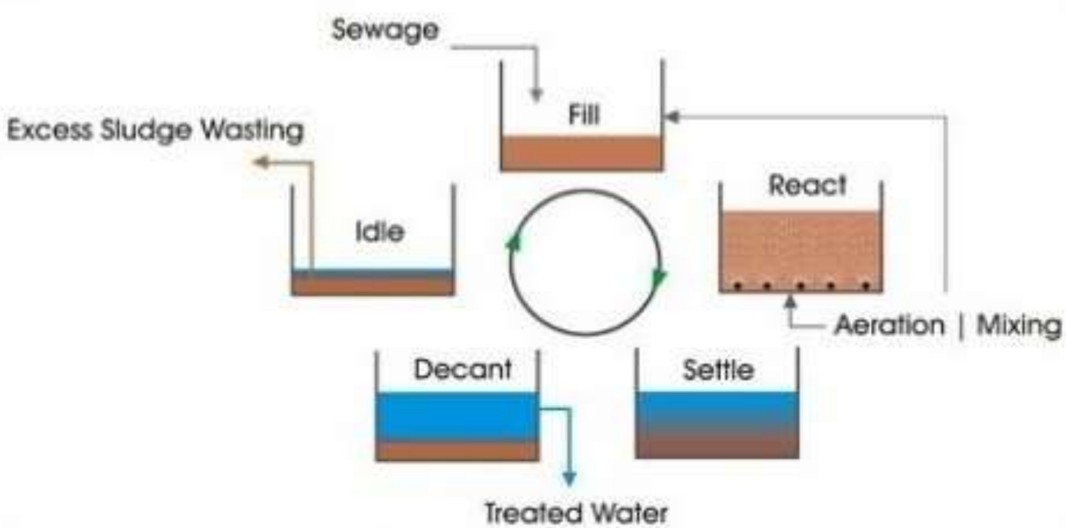


Sequenced Batch Reactor (SBR)



Salient Features:

- No Equalization Tank
- No Primary or Secondary Settling Tank
- No Return Sludge Pumps
- No Aerobic/Anaerobic Sludge Digester Tank



SBR Advantages / Disadvantages

Advantages

- Equalization, primary clarification (in most cases), biological treatment, and secondary clarification can be achieved in a single reactor vessel.
- Operating flexibility and control.
- Minimal footprint.
- Potential capital cost savings by eliminating clarifiers and other equipment.

Disadvantages

- Higher level of sophistication required, especially for larger systems, of timing units, sophisticated controls, automated switches, and automated valves.
- Potential of discharging floating or settled sludge during the DRAW or decant phase with some SBR configurations.
- Potential plugging of aeration devices during selected operating cycles, depending on the aeration system used by the manufacturer.
- Potential requirement for equalization after the SBR, depending on the downstream processes.
- High TDS may cause settling problems

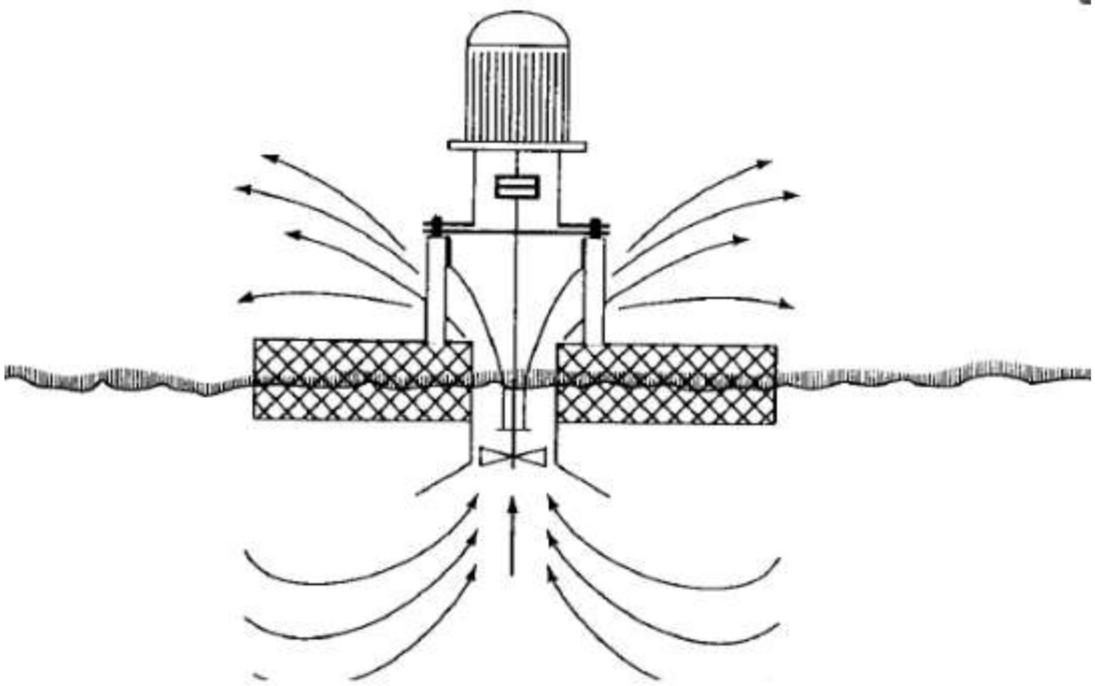
Bottom Line – SBR can be a good approach for Leachate Treatment

Diffused Aeration

- Air pumped through diffusers to generate small bubbles
- Rising bubbles transfer oxygen and bottom water to surface
- Fine bubbles – 0.2 cm dia / coarse bubbles – 2.5 cm dia

Surface Aeration

- Aerates and mixes surface so increased interface between liquid and air



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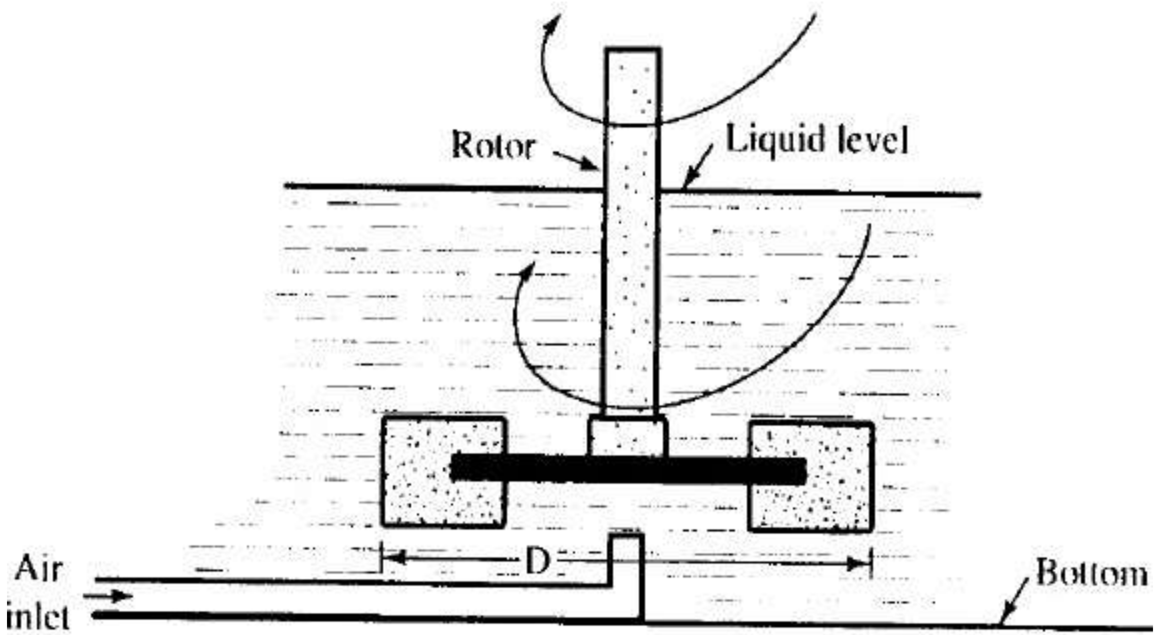
Mechanical Aeration

- Coarse bubble injected into bottom, turbine sears bubbles
- Higher efficiency than diffused aeration



Turbine Aeration

- High-performance submerged turbine aerator and mixer with a vertical shaft and is designed to mix and transfer oxygen in waste water with high efficiency
- Needs crane to remove/service unit

Surface Aeration Design

- **Eckenfelder & Ford Equations**
  - No depth consideration in formula
- **Pilot testing recommended for design parameters**
- **N=actual oxygen transfer rate (lb/hr)**
- **N_0= manufacturer transfer rate for clean water**
- **C_w=saturation value oxygen in wastewater, operating conditions**
  - 9.17 = saturation DO for clean water, 20 deg C
- **C_1= design oxygen concentration in aeration basin**
- **T = Temperature, degree C**
- a**= oxygen correction factor for wastewater**

$$N = N_0 \left(\frac{C_w - C_1}{9.17} \right) \cdot (1.02)^{T-20} \cdot \alpha$$

Jet Aeration

- Jet Aeration Systems Often Used for Leachate Treatment
- Needs Blowers (VFD)/External Pumps @ Fixed Speed

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Design Concepts

- **Design Models Available**
- **Pilot tests recommended to obtain design parameters**
- **Volume/dimension tanks**
- **Amount oxygen/power for aeration**
- **Quantity of sludge produced**
- **Volume and dimensions of clarifiers/membranes**
- **Parameters**
  - F/M
  - a = mass transfer coefficient O_2 wastewater to tap water
  - b = maximum saturation O_2 to tap water
  - Oxidation, Nitrification and Endogenous Respiration
  - SRT
  - HRT

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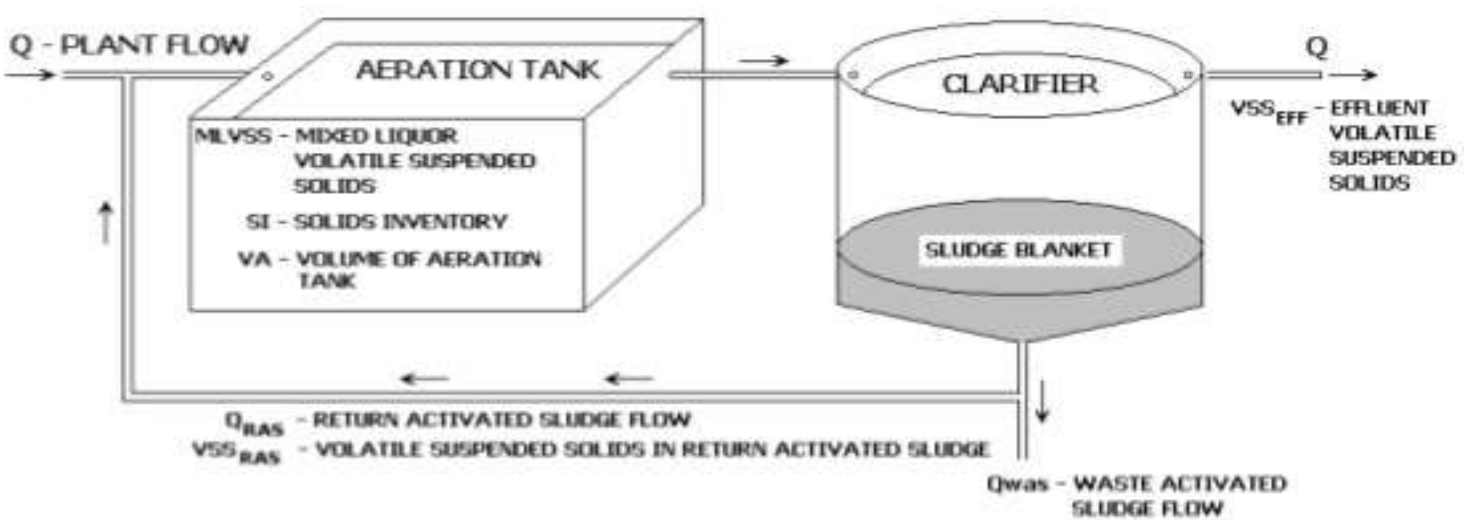
Activated Sludge Parameters

- Influent Flow Q_0 mgd
- Influent BOD, S_0
- Influent SS, X_0
- Aeration Tank Volume, V
- Aeration Tank Volatile Suspended Solids, MLVSS mg/l
- RAS Flow, Q_{RAS}
- Volatile SS in Return flow, VSS_{RAS}
- Effluent flow Q_e
- Effluent Volatile Suspended Solids, VSS_{eff}



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Activated Sludge Parameters

- **F/M ratio**
  - Pounds of BOD under aeration
  - Conventional activated sludge 0.2 – 0.4
  - Extended Aeration 0.04 – 0.1
- **Loading lb BOD/1000 CF**
  - Complete Mix – 20-40
  - Extended Aeration 5 -15
- **HRT**
  - Hydraulic retention time, hours
  - Complete mix – 4 -8 hours
  - Extended aeration – 20 -30 hours + (High strength, PPCP)
- **SRT/MCRT (Total v. Volatile)**
  - Solids retention time
- **% Volatile Solids – 50 – 75%**
  - Volatile in aeration tank – live biomass

Oxygen Requirements

- **20-55 m^3 air/ kg BOD removed for F/M>0.3**
- **70-115 m^3 air/kg BOD removed for F/M <0.3**
- **Mixing – 10-14 Kw/1000m^3 tank volume for surface aeration**
- **Pressure difference top to bottom of tank**
- **$P_{surface}$ = 14.7 (1-0.032*alt)**
  - $P_{surface}$ = in PSI
  - ALT - altitude in thousands of feet above sea level

- **$P_{bottom} = P_{surface}$ + (62.4H/144) (psi)**
  - H = tank depth in feet

Aeration Design Example – Tank Volume

- **Volume for Complete Mix Aeration Activated Sludge**
  - 0.3 mgd
  - Influent BOD – 31,000 mg/l (67% volatile = 21,000 mg/l)
  - Loading (VL) – 10 lb BOD/day/1000 cf
- **$V = (8.34 * S_0 * Q_0 / VL)1000$**
  - = 8.34*21,000*0.3*1,000/100
  - = 525,000 cf
  - = 3.93 MG
  - Say 4 tanks @ 1 MG each tank

Aeration Design - Hydraulics

- **HRT**
  - 525,000 cf * 7.48/1,000,000 = 4 MG (Vol)
  - 24 * 4 MG/0.3 MGD = 320 hours = 13.3 days

- **F/M ratio**
  - =(8.34*S_0*Q_0)/(8.34*%Vol*MLVSS*Vol)
  - =(8.34*21,000 mg/l*0.3 MGD)/8.34*10,000 mg/l * 4MG)
  - =52,542/333,600
  - = 0.15 lb BOD_{vol}/day/lb MLVSS

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Aeration Process – Sludge Recycle

- **For 0.3 MGD plant with 4 MG aeration tanks MBR**
  - Influent BOD_{vol}=21,000 mg/l
  - MLVSS = 10,000 mg/l
  - MLSS = 15,000 mg/l
  - RAS Concentration = 20,000 mg/l
  - TSS = 200 mg/l influent
  - SRT = 12 days

- **Calculate Sludge Recycle**
  - Q_1= Q (MLSS- TSS)/(RAS – MLSS)
  - =0.3(15,000-200)/(20,000-15,000)
  - =0.78 MGD = 542 gpm sludge recycle rate

Aeration Process - WAS

- V_{was} **= V*MLSS/(SRT*RAS concentration)**
  - = 4 MG*15,000 mg/l /(12*20,000)
  - =0.25 MGD
  - =174 gpm
- **F/M check**
  - = 21,000mg/l*0.3MG/(10,000 mg/l MLVSS*4 MG)
  - =0.1575 lb BOD/day/lb MLVSS

Process Design Calculation

Assuming no BOD reduction in primary clarification:

31,000 mg/l BOD influent = 31,000 mg/l effluent from the clarifier.

The BOD mass loading following primary sedimentation is at 31,000 mg/l at a flow rate of 300,000 gpd:

*BOD mass loading = 0.3 mgd * 31,000 mg/l *8.34 = 77,562 # BOD/day*

If the aeration units function as complete mixed conventional treatment, a food to microorganism ration (F/M) could range from 0.15 to 0.4 #/day.

THEREFORE;

Assume a F/M ratio of 0.15 lb BOD/lb MLVSS:

The 4 million gallon tanks (939,000 gallons each after reduction for freeboard) = 14,197,680 liters. At 0.15 F/M ratio:

MLVSS = 77,562 lb BOD/(0.15 F/M) = 517,080 lb MLVSS under aeration

The loading of 77,562 lb BOD = (2517,080 lb)(454 gm/lb)(1,000 mg/gm) = $2.3475X10^{11}$ mg MLSS

Concentration of MLVSS = $2.3475\ X10^{11}$ mg MLVSS /14,197,680 liters = 16,534 mg/l

Process Design Calculations, Con't

The following parameters were supplied by MTS Corporation, the chosen supplier of the Jet Aeration system components. MTS recommended an oxygen supply based on an air flow of 17,120 scfm. Independent calculations provided an amount of air higher than MTS' recommendation.

MTS provided the following factors:

Alpha = 0.85 (Submerged aeration from Mfg – Use 0.7 to account for salinity)

Beta = 0.9 (conservative?)

C = 4.6 (for nitrification)

At 1.25lb Oxygen/lb BOD gives; (77,652lbs BOD)(1.25lb oxygen/lb BOD) = 97,065lb O2 /day carbonaceous demand.

Endogenous = (0.08)*(16,534 mg/l)*(4 MG)*(8.34) = 44,126/day

Nitrification: (4.6)*(0.3mg)*(1,000 mg/l ammonia)*(8.34) = 11,509 lb O2/day

AOR = (152,700 lbs/day)/ 24 = 6,362 lb/hr oxygen

SOTR correction for temperature, altitude, alpha, Beta corrections = 2.2 (AOTR)

At 0.0175 lb O2/ CFM air

7 % efficiency per meter at depth (assume 30 feet or 9 meter)

Air flow = [(6,362 lb/hr)(2.2)] / [(0.0175)(0.07)(9 meter)] = 1,269,514 CF/hr for Total BOD demand.

Air flow = 1,269,514 CF/Hr/60 min/hr = 21,158 scfm,

Aeration Model Parameters

- Flow at 300,000 gpd

Alpha	0.70	
Site Barometric Pressure	740	mm Hg
Temperature	35	C
Steady State DO	1.0	mg/L
Standard Oxygen Transfer Efficiency	1.3	percent per foot
Diffuser Submergence	29	feet
Standard Oxygen Transfer Efficiency	37.00	percent
Decay Coefficient	0.06	mg MLVSS/mg day
Theoretical Yield	0.80	mg MLVSS/mg BOD
Yobs	0.3	Sludge Yield

Aeration Model - Loading – Sensitivity to f/m

Influent BOD_5, mg/L	Influent BOD_{ULT}, (BOD_5/0.68) mg/L	Influent TSS, mg/L	Flow, mgd	BOD5 loading, #/day	BOD_{ULT} loading, #/day	f/m ratio	4 tanks, mg	# MLVSS	MLVSS Conc mg/l	MLSS Conc mg/l
31,000	45,588	2,600	0.30	77,562	114,062	0.10	3.76	775,620	24,760	30,950
31,000	45,588	2,600	0.30	77,562	114,062	0.15	3.76	517,080	16,507	20,634
31,000	45,588	2,600	0.30	77,562	114,062	0.20	3.76	387,810	12,380	15,475
31,000	45,588	2,600	0.30	77,562	114,062	0.25	3.76	310,248	9,904	12,380
31,000	45,588	2,600	0.30	77,562	114,062	0.30	3.76	258,540	8,253	10,317
31,000	45,588	2,600	0.30	77,562	114,062	0.35	3.76	221,606	7,074	8,843

Aeration Model – Aeration Demand

		Oxygen Requirements / Air Flow						
f/m Ratio	Y_{obs} Assumed	Carbonaceous O_2 Demand #/day	Endogenous #/day	Nitrification #/day	Total #/day	SOR, #/hr	Air Flow, scfh	Air Flow scfm
0.10	0.30	96,592	62,025	11,509	170,486	7,104	1,417,499	23,625
0.15	0.30	96,592	41,350	11,509	149,811	6,242	1,245,598	20,760
0.20	0.30	96,592	31,012	11,509	139,474	5,811	1,159,648	19,327
0.30	0.30	96,592	20,675	11,509	129,136	5,381	1,073,698	17,895
0.40	0.30	96,592	15,506	11,509	123,967	5,165	1,030,723	17,179
0.50	0.30	96,592	12,405	11,509	120,866	5,036	1,004,938	16,749

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Aeration Model, Sludge Production

	Sludge Production								
f/m ratio	Primary Sludge Production #/day	WAS #/day (based on Y_{obs})	Total Sludge Produced, #/day (*1.25 for mlss to mlvss)	MG/day to Thickener	GPM to Thickener	GPM to Screw Press	tons DS/Day	Tons wet sludge/day @ 17% ds	tons/yr wet
0.10	6,505	23,269	35,591	0.152	105	35	17.80	104.68	38,208
0.15	6,505	23,269	35,591	0.208	144	48	17.80	104.68	38,208
0.20	6,505	23,269	35,591	0.264	184	61	17.80	104.68	38,208
0.25	6,505	23,269	35,591	0.321	223	74	17.80	104.68	38,208
0.30	6,505	23,269	35,591	0.377	262	87	17.80	104.68	38,208
0.35	6,505	23,269	35,591	0.433	301	100	17.80	104.68	38,208

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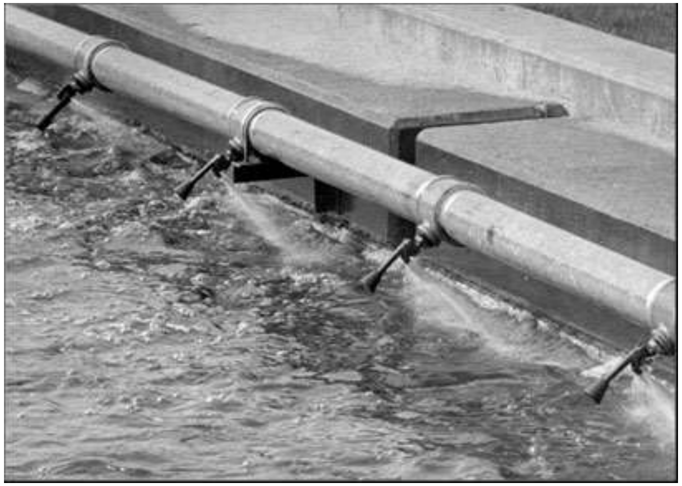
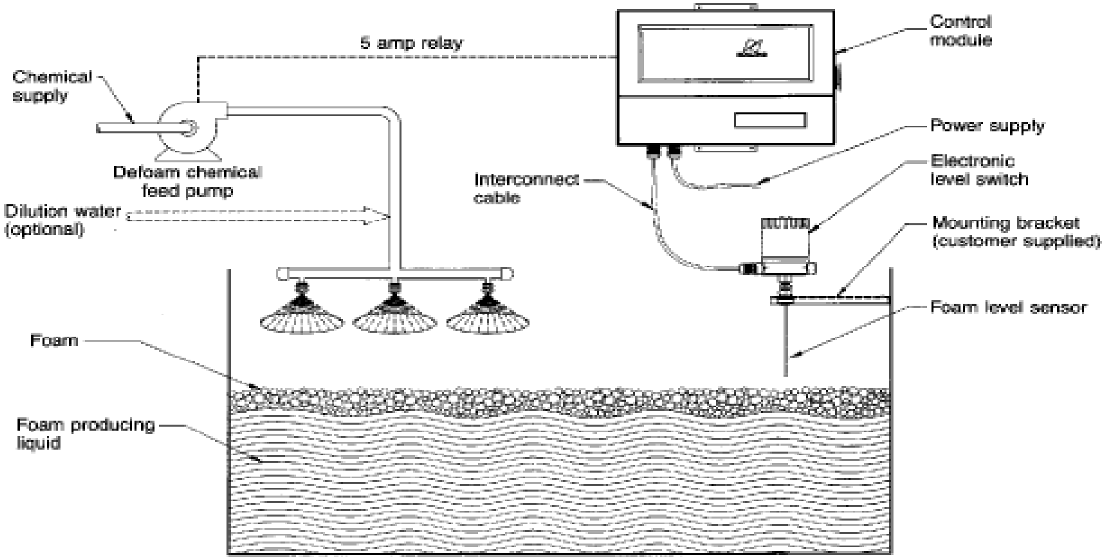
Aeration Model – Sludge Disposal

f/m ratio	Loads /yr at 12 T/load	Loads/day	Sludge Age	Calculated Y obs
0.10	3,184	9	33.33	0.27
0.15	3,184	9	22.22	0.34
0.20	3,184	9	16.67	0.40
0.25	3,184	9	13.33	0.44
0.30	3,184	9	11.11	0.48
0.35	3,184	9	9.52	0.51

Activated Sludge Design Criteria

- ► **Min. 2 tanks**
- ► **Depth – 12-30 ft. diffuse aeration**
  3-18 ft. surface aeration
- ► **Freeboard 3-5 feet +**
  - Foaming can be intense
  - Spray water for defoaming
  - Defoamer selection critical
  - Silicone based not compatible with ultrafilter membrane
  - Oil based can raise effluent oil/grease
  - Some have very high BOD ~ 1,000,000 mg/l





Activated Sludge Control

- **Aeration rate**
- **Return Sludge rate**
- **Waste Sludge rate**
- **Control of these variables in proper environment leads to good sludge quality**
  - Physical
  - Chemical
  - Biological
  - Nutritional requirements

Temperature Model

Why mesophilic versus thermophilic (125 – 150 deg F)?

- Materials Of Construction
- Corrosion
- UF, other equipment shut down
- Foaming
- Speed of reaction
- Nitrification

STEADY-STATE TEMPERATURE MODEL

- Modification of original temperature model developed by Y. Argaman and C. E. Adams, Jr., WEFTEC 2004 paper written by Victor J. Boero
- The model can be used for completely mixed basins, totally or partially above ground, covered or not, aerated (diffused air or surface aeration) or not, with steam addition or not.
- Based on steady-state heat and mass balances for air and water.

Temperature Model - Input

CLIMATOLOGICAL

Latitude (North > 0, South < 0)		$Lat := 39.$
Day of year - Range from 1 (January 1st) through 365 (December 31st)		$Day := 180$
Wind velocity		$Vw := 2 \cdot mph = 89.408 \frac{cm}{s}$
Cloud cover - Range from 1 (clear sky) to 10 (completely covered)		$Cc := 1$
Average temperature	$Taa := 35\ °C$	$Taa = 95.00\ °F$
Humidity (fraction)		$\phi aa := 0.75$
Elevation		$E := 500 \cdot ft$
Ground temperature When no site specific data are available may select valued based on: Northern USA: 40 to 60·F Southern USA: 60 to 75°F	$Tg := 20\ °C$	$Tg = 68.00\ °F$
Night (Yes or No)		$Night := \text{"No"}$

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Temperature Model Input Con't

► BASIN *GEOMETRY*

Cover = 1 if covered; Cover = 0 if not covered; $Cover := 1$

Height of basin $Hb := 33.69 \cdot ft$

Height of liquid in basin $Hlb := 15 \cdot ft$

Area at the top of the basin $At := 4155 \cdot ft^2$

Area at the liquid surface $Als := 4155 \cdot ft^2$

Area at the floor surface $Afs := 4155 \cdot ft^2$

Area of the sidewall below water level & below ground level $= 0 \cdot m^2$

Area of the sidewall below water level and above ground level $= 6912 \cdot ft^2$

Area of the sidewall above water level and below ground level $= 0 \cdot ft^2$

Area of the sidewall above water level and above ground level $= 786 \cdot ft^2$

Sidewall thickness $= 0.25 \cdot in$

Roof thickness $= 125 \cdot in$

Sidewall insulation thickness $= 0 \cdot in$

Roof insulation thickness $= 0 \cdot in$

Temperature Model

► ***HEAT TRANSFER***

Sidewall heat conductance

Roof heat conductance

Sidewall insulation heat conductance

Roof insulation heat conductance

Liquid-wall heat transfer coefficient

Wall-exterior air heat transfer coefficient

Interior air-roof heat transfer coefficient

Roof-exterior air heat transfer coefficient

Overall floor heat transfer coefficient

Temperature Model

► *BIOLOGICAL/CHEMICAL*

COD removed in the basin in lbs/day

Observed sludge yield (COD basis)

Aerobic: 0.42 (default)

Anoxic: 0.25 (default)

Anaerobic: 0.15 (default)

Yobs:=0.60 (Input estimate from previous model)

Specific heat of COD utilization

Aerobic/Anoxic: 3000 cal/gm

Anaerobic: 300 cal/gm

AMMONIA NITROGEN OXIDATION

SULFIDE SULFUR OXIDATION

SULFITE OXIDATION

BISULFITE OXIDATION

ALGAE GROWTH

Temperature Model – Heat Gains

Summary

Influent water

Compressed air Short-wave radiation

Long-wave radiation

Mechanical

Biological

Steam

HEAT EXCHANGE (NEGATIVE cal/day)

Heat Total

$THG := HIW + HCA + HSSR + HLAR + HM + HB + HSteam + HExch$

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Temperature Model – Heat Losses

Effluent water

Effluent air

Long-wave radiation

Sidewall conduction and convection

Roof conduction and convection

Floor conduction day

Air-water conduction and convection

Water evaporation

Diffused air

Total

Temperature Model – Heat Balance

Total Heat Gain -	**2.237 x 10^{10} cal/day**
Heat Loss -	**2.237 x 10^{10} cal/day**
Balance -	**Tw= 45.15 deg C (113.3 deg F)**

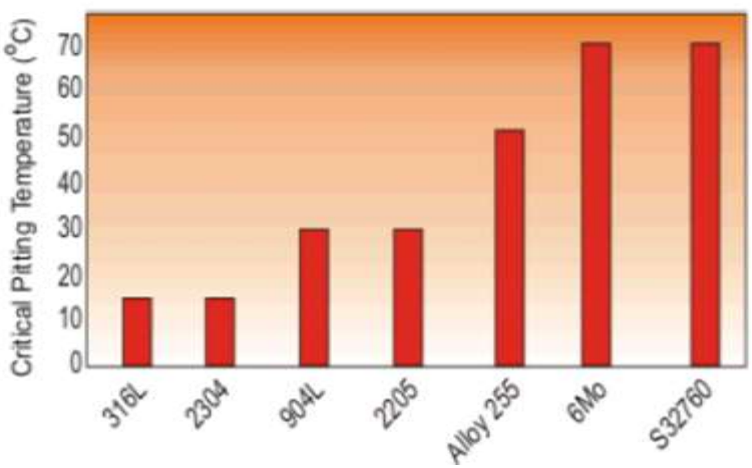
Adjust heat exchange to 35 deg C for efficient mesophilic thermal operation

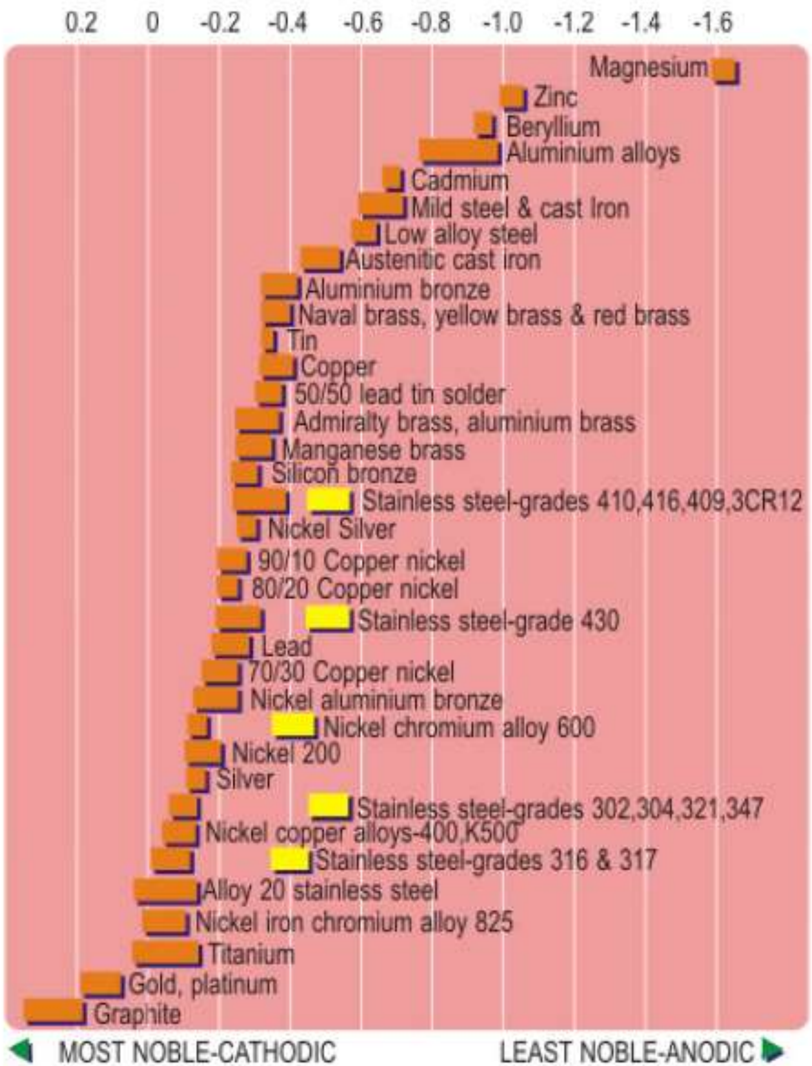
Heat Exchange = -4.4 MMBTU/hr

Design = cooling tower/heat exchange modules

Corrosion Considerations

- Chlorides/Temperature
- Pitting Corrosion
- Pitting Resistance Equivalent Number
  - (PRE)
- Crevice Corrosion
- Stress Corrosion Cracking
- Sulfide Stress Corrosion
- Stress Level
- Intergranular Corrosion
- Galvanic Corrosion
- Contact Corrosion





Material Resistance to Chloride

Material	Composition Ranges						Pitting Resistance Equivalent (PRE)	
	Cr		Mo		N		Min.	Max.
AISI 316	16	18	2	3	-	-	22.6	27.9
AISI 316L	16	18	2	3	-	-	22.6	27.9
AISI 316 L, >2.5% Mo	16	18	2.5	3	-	-	24.3	27.9
AISI 317	18	20	3	4	-	0.1	27.9	34.8
AISI 317L	18	20	3	4	-	0.1	27.9	34.8
Alloy 20	19	21	2	3	-	-	25.6	30.9
Alloy 825	19.5	23.5	2.5	3.5	-	-	27.8	35.1
22Cr Duplex	22	23	3	3.5	0.14	0.2	34.1	37.8
25Cr Duplex	24	26	3	5	0.24	0.32	37.7	47.6
Al-6XN®	20	22	6	7	0.18	0.25	42.7	49.1
254 SMO™	19.5	20.5	6	6.5	0.18	0.22	42.2	45.5
Alloy 625	20	23	8	10	-	-	46.4	56
Alloy C276	14.5	16.5	15	17	-	-	69	80

$$PRE = (\%\ Cr) + 3.3 \cdot (\%\ Mo) + 16 \cdot (\%N)$$

"Making an Impression with Compression." *Oilfield Technology* 7.11 (November 2014).

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Selection Criteria and Key Considerations

- Leachate quality/quantity
- Land availability
- Disposal options
- Discharge limits
- Climate
- LFG availability
- Site operation considerations
- Site preference
- Utilities
- Temperature
  - Heating
  - Cooling
- Standby Power
  - Genset
  - Dual feeds- Independent Pump Stations
- Instrumentation/automation
- Foam control
- UVT
- Corrosion
- Landfill life
- Air emissions
- POTW capacity
- POTW processes
- POTW effluent limits
- Energy costs
- Residual mgmt & disposal
- Minimization potential
- Stakeholder issues
- Odor Control
- Odors/noise/traffic
- Equipment access
- Cleaning ease
- Washdowns – hoses
- On-site Lab
- Data collection - KPI

Comparison of Biological Treatment Processes

- Leachate Treatment Effectiveness
- Benefits
- Drawbacks
- Cost Considerations
- Treatment Stages & Communication Status
- Decision Selection Tool

Comparative Options

Treatment process	Young leachate	Medium leachate	Old leachate	Space utilization	Installation and operational cost	Requiring less skilled personnel
Biological						
Activated sludge	Good	Fair	Poor	Poor	Expensive	No
RBC	Good	Fair	Poor	Good	Expensive	Yes
SBR	Good	Fair	Poor	Good	Less expensive	No
Reed beds	Fair	Fair	Good	Poor	Less expensive	Yes
BAF	Good	Fair	Fair	Good	Expensive	Yes
Lagoons	Good	Fair	Poor	Poor	Expensive	Yes
UASB	Good	Fair	Fair	Good	Less expensive	Yes
AF	Good	Fair	Fair	Good	Expensive	Yes
MBBR	Good	Fair	Poor	Poor	Expensive	No
MBR	Good	Fair	Fair	Poor	Expensive	No
Physicochemical						
Coag. & flocculation	Poor	Fair	Fair	Fair	Less expensive	No
Precipitation	Poor	Fair	Poor	Fair	Less expensive	No
Adsorption	Poor	Fair	Good	Good	Less expensive	No
Flotation	Poor	Fair	Fair	Poor	Expensive	Yes
Chem. Oxidation	Poor	Fair	Fair	Good	Expensive	No
Ammonia stripping	Poor	Fair	Fair	Poor	Expensive	No
Membrane process						
Microfiltration	Poor	Poor	Poor	Good	Expensive	Yes
Ultrafiltration	Fair	Fair	Fair	Good	Expensive	Yes
Nanofiltration	Good	Good	Good	Good	Expensive	Yes
Reverse Osmosis	Good	Good	Good	Good	Expensive	Yes

New leachate treatment methods
Jude Ifeanyichukwu Madu, Sweden, 2008

Comparative Aerobic Technologies

MBBR	RBC	Activated Sludge	SBR	IFAS	MBR
Low residual suspended solids	Low residual suspended solids	Requires residual suspended solids	Requires residual suspended solids	Requires residual suspended solids	Requires residual suspended solids
Self regulating Few operator adjustments	Self regulating Few operator adjustments	Operator adjusts MLSS levels	Operator adjusts MLSS levels	Operator adjusts MLSS levels	Operator adjusts MLSS levels
Single pass flow through	Single pass flow through	MLSS sludge recycled through plant	Possible MLSS recycle, usually not	MLSS sludge recycled through plant	MLSS sludge recycled through plant
4 hour retention time	16 hour retention time	24 hour+ retention time	12 hour cycle	4 hour retention time	24 hour+ retention time
Not affected by high flows	Media stripped by high flows	MLSS flushed by high flows	Little affect by high flows – shortens run time	Not affected by high flows	Up to limit of membrane
Moderate mechanical equipment	High mechanical equipment	Moderate mechanical equipment	Low mechanical equipment	Moderate mechanical equipment	High mechanical equipment
Stable nutrient removal	Unstable nutrient removal	Unstable nutrient removal	Stabile nutrient Removal	Stabile nutrient Removal	Stabile nutrient Removal

Comparative Aerobic Technologies

Comparison	MBBR	RBC	Activated Sludge	SBR	IFAS	MBR
Capital Investment	Low to medium	High	High	Low	Medium	High
Footprint	Low	High	High	Low	Medium	High
Flow Tolerance	Good	Poor	Poor	Good	Good	Fair
Aeration Blowers	Required	None	Required	Required	Required	Required
Recirculation pumps	Not required	Not required	Required	Not required	Required	Required
Chemical usage	Low	Moderate	Moderate	Low	Low	Moderate
Operator difficulty	Low	Low	High	Low – Moderate	Moderate	High

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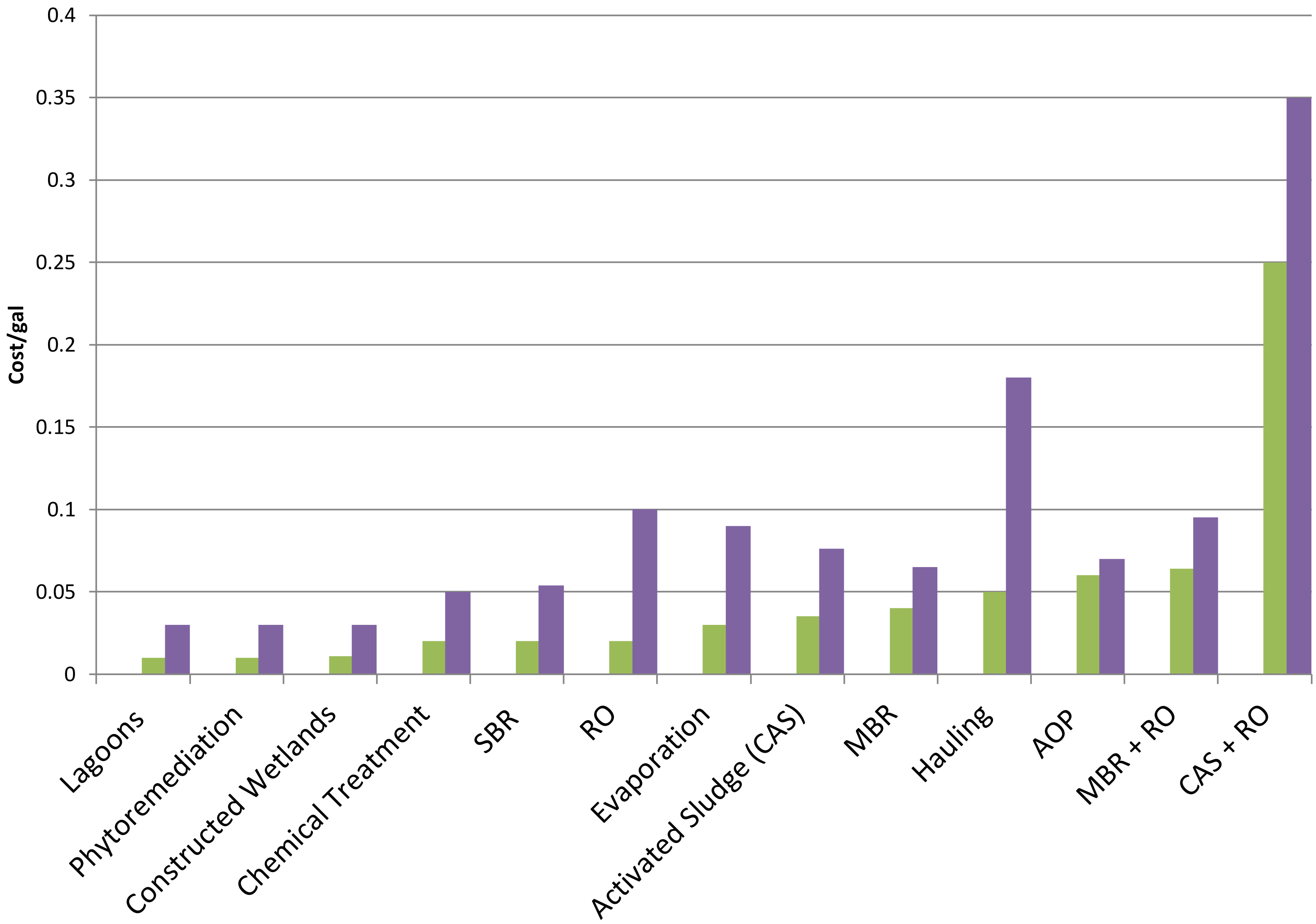
Leachate Disposal Costs

Alternatives built on combination of technologies

- **Very site dependent / Sewer or direct discharge / Residual management**
- **Costs from various sources**

CONSTRUCTION & O/M	
Lagoons	**$0.01 – $0.03/gal**
Constructed Wetlands	**$0.01 - $0.03/gal**
Phytoremediation	**$0.01 - $0.03/gal**
Chemical Treatment	**$0.02 -$0.05/gal**
Conventional Activated Sludge (CAS)	**$0.035 - $0.076/gal**
MBR	**$0.04 – $0.065/gal**
SBR (EPA 1998, adjusted)	**$0.02 - $0.054/gal**
RO	**$0.02 - $0.10/gal**
MBR + RO	**0.064 - $0.095/gal**
CAS + RO	**$0.25 - $0.35/Gal**
Evaporation	**$0.03 - $0.09/gal**
AOP	**$0.06 - $0.07/gal**
Hauling (distance/disposal)	**$0.039 - $0.18/gal**

TREATMENT COSTS (CAPEX & OPEX)



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Fatal Flaw Technology Comparisons

	Effluent Reliability /	Operability	Construction Cost	Expandability	Maintenance Cost	Operator Friendline	Hydraulic sensitivity	Waste generation	Waste load sensitiv	Flexibility	Implementability	Ease of maintenanc	Odor / offsite Envir	Noise	Visual impacts	Footprint	Construction Timing
Trickling Filter	F	L	M	L	M	H	H	M	H	L	F	H	M	L	M	M	M
MBBR (no RAS)	M	H	M	L	H	H	H	L	H	H	L	M	M	L	L	L	L
RBC	F	M	L	L	L	M	L	L	M	L	M	L	M	L	L	F	L
Activated Sludge	M	L	L	M	H	H	M	L	M	M	H	H	L	L	L	H	L
SBR	L	L	M	M	H	H	M	H	L	M	M	L	L	M	M	M	H
IFAS	H	L	M	M	H	H	M	M	L	M	M	L	M	M	M	M	H
MBR	H	L	H	M	H	M	M	M	L	M	M	L	M	M	M	M	H

Evaluation Criteria

Heading	Multiplier	Comment
Commercially Proven	10	Fundamental
Operability (ease of)	8	Simplicity and operators?
Hydraulic Variability	5	Feed tank should buffer this
Waste Loading Variability	5	Feed tank should buffer this
Chemical Storage & Delivery (extent, hazard, compliance requirements, complexity)	7	Impacts footprint and distances to premises boundaries; System security.
Secondary Waste	6	created? difficult/cost to manage?
Footprint (small)	4	Critical for this site
Power Requirement (low)	7	Small flows - all relatively low
Capital Cost Risk (low)	9	Accuracy of preliminary estimate
O&M Cost Risk (low)	9	Accuracy of preliminary estimate
Start-up Period (low)	3	"initial commissioning" or "start up after a process trip"?

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Summary of the Consideration Ranking Definitions and Weighting Used for Technology Review

Considerations	Rankings	Multiplier	Definition
Commercially Available	5	10	Frequently Used
	3		Often, but not Frequently Used
	1		Infrequent, but commercially available
Operability	5	8	Moderate operator attention and expertise
	3		Requires full operator attention and expertise
	1		Requires full operator attention and expertise
Hydraulic Variability	5	5	Capable of handling wide flow variations
	3		Moderate upset due to flow variations
	1		Process unable to perform with flow variation
Waste Loading Variability	5	5	Handling large water quality variations
	3		Moderate upset from water quality variations
	1		Process upset without large equalization to address water quality variation
Chemical Storage & Delivery	5	7	Chemical storage and delivery not required
	3		Chemical storage and delivery required
	1		Hazardous chemical storage and delivery

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	3		Chemical storage and delivery required
	1		Hazardous chemical storage and delivery

Summary of the Consideration Ranking Definitions and Weighting Used for Technology Review (Con't)

Considerations	Rankings	Multiplier	Definition
Secondary Waste	5	6	Produces no waste that needs further treatment/disposal
	3		Produces waste that needs disposal
	1		Produces waste that needs further treatment prior to disposal
Footprint	5	4	Requires small footprint
	3		Require moderate footprint
	1		Require large footprint
Power Requirement	5	7	Requires little energy
	3		Requires moderate energy
	1		Requires high energy
Capital Cost Risk	5	9	Low capital cost
	3		Moderate capital cost
	1		High capital cost
O&M Cost Risk	5	9	Low O&M cost
	3		Moderate O&M cost
	1		High O&M cost
Start-up Period	5	3	No start-up period required
	3		Moderate start-up period required
	1		Long start-up period required

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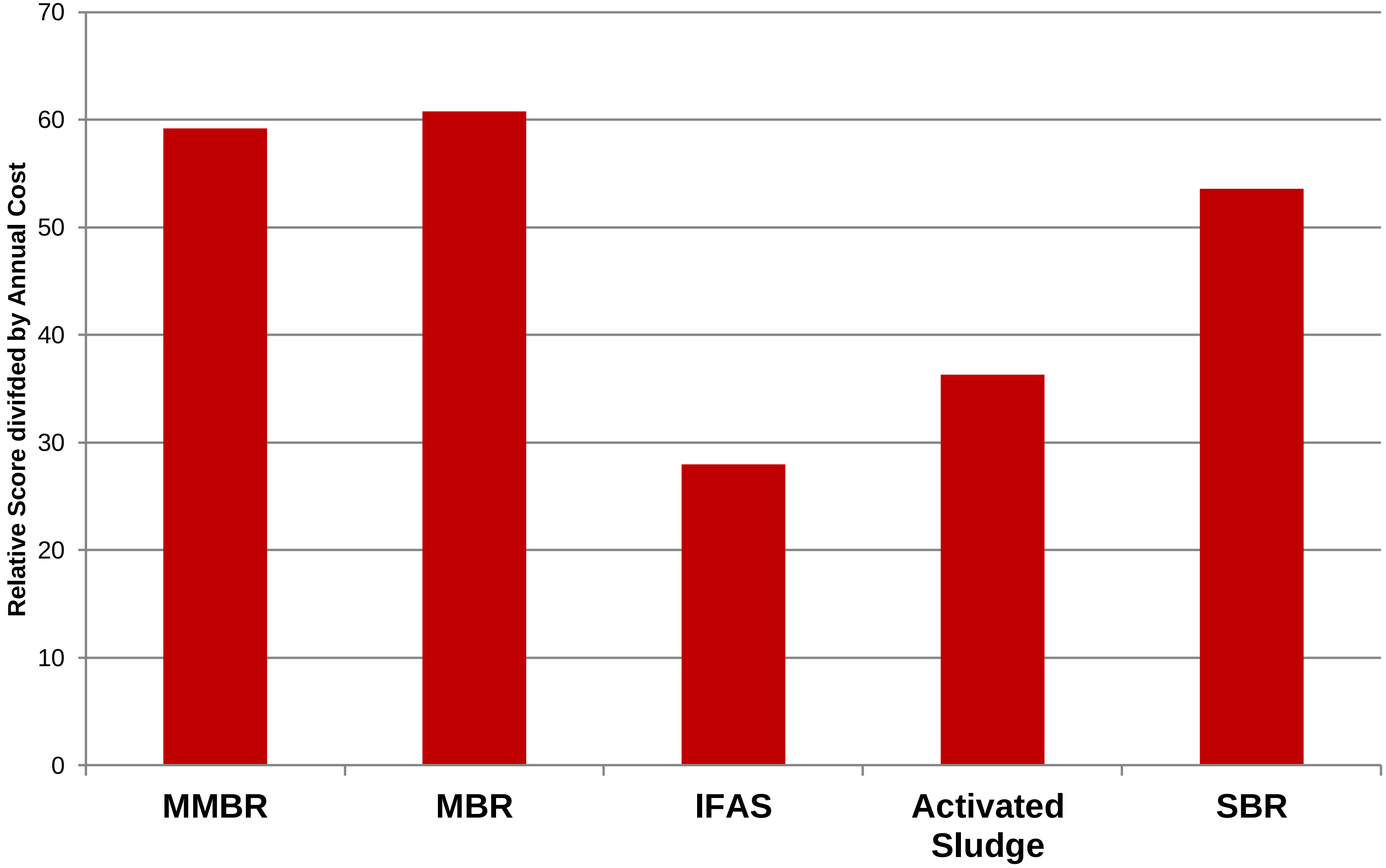
	3		Require moderate footprint
	1		Require large footprint
Power Requirement	5	7	Requires little energy
	3		Requires moderate energy
	1		Requires high energy
Capital Cost Risk	5	9	Low capital cost probability
	3		Moderate capital cost probability
	1		High capital cost probability
O&M Cost Risk	5	9	Low O&M cost probability
	3		Moderate O&M cost probability
	1		High O&M cost probability
Start-up Period	5	5	No start-up period required
	3		Moderate start-up period required
	1		Long start-up period required

Rankings With Cost Risk and CAPEX

Alternative	Meets Effluent Requirements	Commercially Available	Construction Time	Operability	Hydraulic Variability	Waste Load Variability	Chemical Storage & Delivery	Secondary Waste	Footprint	Power	Capital Cost Risk	O&M Cost Risk	Startup Period	Summation Scores	Sum Divided by Annual cost/1,000,000
Ranking	10	10	10	8	5	5	7	6	4	7	9	9	5		
Multiplier (1-5)															
MMBR	30	50	30	40	15	15	21	30	8	14	27	18	5	304	59.2
MBR	50	50	30	40	25	25	21	30	8	14	27	9	25	355	60.8
IFAS	30	30	20	24	15	15	14	18	4	21	9	9	15	224	28.0
Activated Sludge	40	50	20	24	15	15	14	18	4	21	9	9	15	254	36.3
SBR	20	50	30	16	5	5	21	24	16	21	18	27	15	268	53.6

Alternatives Score Divided by CAPEX



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