Wastewater Treatment Processes Webinar Series

Date: June 5, 2023

Topic: Fixed Film Processes

www.efcnetwork.org

This program is made possible under a cooperative agreement with US EPA.

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Let's start with a definition

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"Fixed Film"

Microorganisms treating waste and living in solids, slimes or films attached (or "fixed") to media in the treatment process

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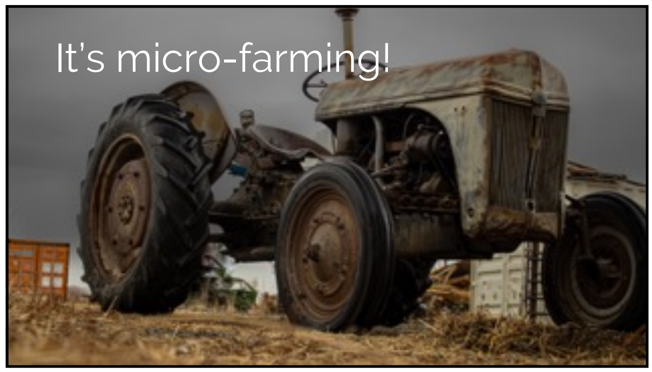

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"Trickling Filters"

Aka biofilters or biotowers

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Fish Tank Version

Image source: https://www.saltwateraquarium.com/open-box-premier-series-wet-dry-filtration-system-175-24-x-12-x-18-pro-clear-aquatic-systems

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Koi Pond Version

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Process

- Trickling filter biofilms will typically have aerobic and facultative bacteria
- Trickling filters generally involve BOD removal in aerobic conditions but can also achieve nitrification in the presence of oxygen under the right circumstances
- Some filters can do both BOD removal and nitrification in a single filter, in other cases these two processes are achieved in separate filter
- In single stage operations heterotroph bacteria will outcompete nitrifying bacteria in the upper portion of the filter as long as there is BOD available, and the nitrifying biomass will grow in the lower portion of the filter.
- The ability to do both processes in a single stage, and the efficiency of the nitrification process is dependent on loading rates

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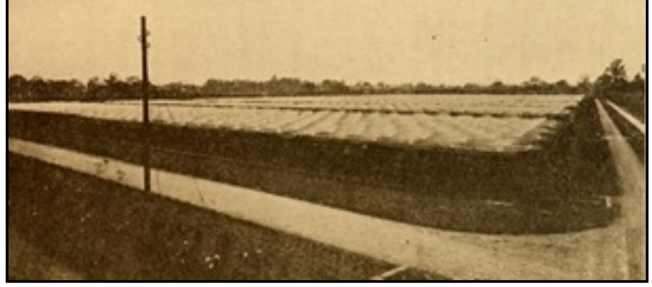
Birmingham Trickling Filter 1919



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Activated Sludge, 1913

Fig. 115. Experimental Plant at Brooklyn, N. Y., showing Phelps Aerating Tank (courtesy of G. T. Hammond).

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Effluent Quality

Trickling Filter, 1909:

TABLE XCV

ANALYSES OF SEWAGE AND EFFLUENT AT READING

Parts per million. (Fuller, 1909.)

	Suspended solids.	Oxygen consumed.	Nitrogen as nitrates.	Dissolved oxygen.	Bacteria per c.c.
Screened sewage	165	57	....	....	3,100,000
Septic effluent	43	26	....	....	1,800,000
Filter effluent	....	....	4.5	....	600,000
Settled effluent	20	15	5	6.5	670,000

Activated Sludge, 1915:

TABLE CII

RESULTS OF AERATION OF MILWAUKEE SEWAGE FOR VARIOUS PERIODS

(Milwaukee, 1915.)

Aeration period, hours	0	1	2	3	4	5
Cubic feet air per gal.	0	0.66	1.33	1.99	2.66	3.22
Stability, hours	0	2	33	120+	120+	120+
Per cent removal of bacteria	0	52	81	92	95	98
Ammonia N, p.p.m.	22	17	15	11	7	5
Nitrite N, p.p.m.	0.08	.....	0.95	1.75	2.20	2.50
Nitrate N, p.p.m.	0.08	0.04	0.70	2.80	5.60	8.20
Dissolved oxygen, p.p.m.	.....	0.30	1.90	4.30	5.90	6.70
Cost per million gallons	.....	$1.40	$2.82	$4.25	$5.64	$8.10

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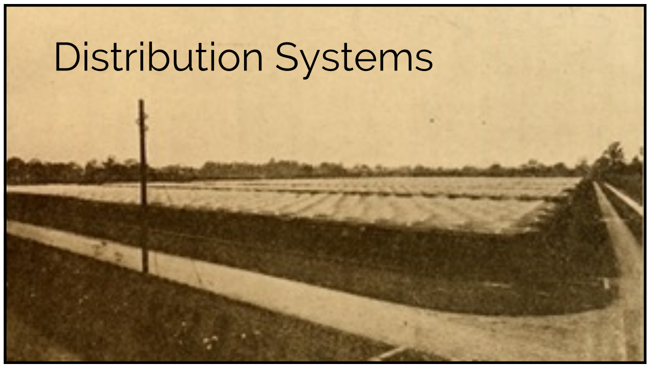

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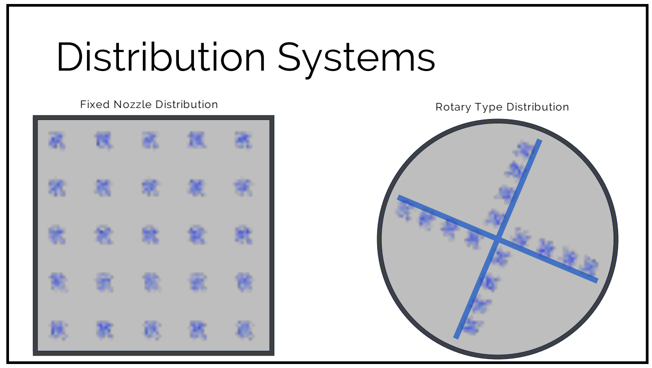

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Distribution Systems

Fixed Spray Heads:

- Similar to lawn sprinklers arranged in a pattern
- Not as common in the US
- Extensive piping requirements
- Pumping system for even distribution
- Difficult access for maintenance and repair

Rotating Arm:

- 2 or more rotating horizontal pipe "distributor arms"
- Water distributed through orifices on one side of pipes
- Typically move using force of wastewater flowing out
- Can be motorized to control rotational speed

Either way, the goal is uniform hydraulic load per area for optimum efficiency.

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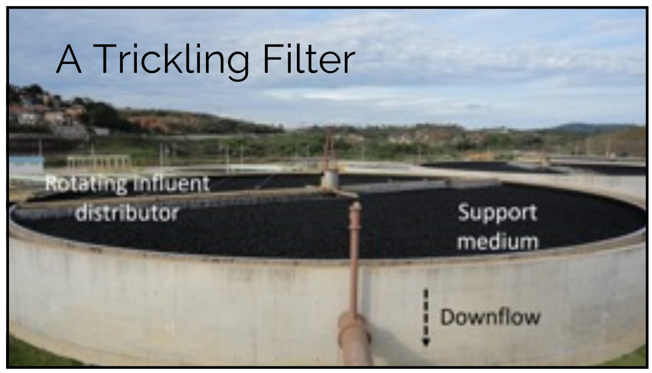

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Filter Media

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Rock Media

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Synthetic Filter Media

Figure 1.10 Plastic Random Dump Trickling Filter Media [7]

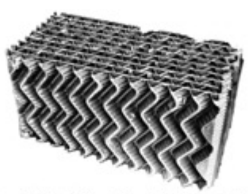

Figure 1.9 Plastic Cross Flow Trickling Filter Media [6]

Bureau of Safe Drinking Water, Department of Environmental Protection
Wastewater Treatment Plant Operator Training 1-11

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Media Characteristics

Media Type	Nominal Size (ft)	Surface Area (ft^2 of surface / ft^3 of media	Void Ratio (Volume of void/vol of media) x 100	Dry Weight (lb/ft^3)
River Rock	0.08 - 0.25	15 - 19	35 - 50	80 - 90
Slag Rock	0.25 – 0.42	14	100	60
Random	varies	30 - 32	92 - 95	1.7 - 3
Vertical Flow	2' x 2' x 4'	27 - 40	92 - 95	1.5 – 2.8
Cross Flow	2' x 2' x 2'	30 - 68	95	1.5 – 2.8

Adapted from Table 6.1 Operation of Wastewater Treatment Plants, Vol 1, 8th edition, Sacramento State 2019

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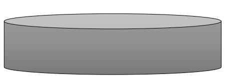
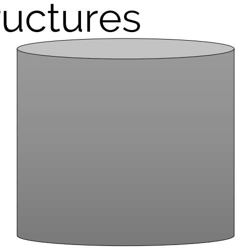
Containment Structures



Rock Media: Shorter (typically less than 10 feet, sides of concrete or brick



Cross and Vertical Flow Media: Can be very tall (up to 40+ feet), media is self supporting, sides may be steel or fiberglass

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Underdrain

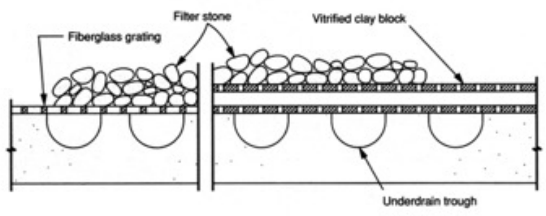

Figure 1.11 Trickling Filter Underdrain System [8]

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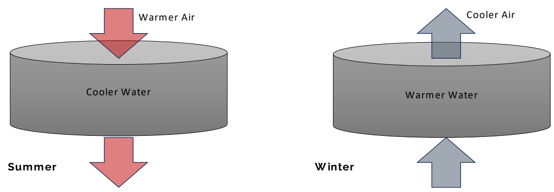
Seasonal Air Flow Changes



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Design Characteristics & Efficiency

Organic Loading Rate

- How much organic matter (BOD) is fed into the system in relation to the media volume
- Expressed as:

$$\frac{lbs\ of\ BOD}{1000\ ft^3\ Media}$$

Hydraulic Loading Rate

- How much water is fed through the system per day in relation the media surface area
- Expressed as:

$$\frac{GPD}{ft^2}$$

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Organic Loading Rate per Day

$$OLR\left[\frac{lbs\ of\ influent\ BOD}{1{,}000\ ft^3\ of\ media\ \cdot day}\right] = \frac{Q_{in}\left[\frac{gal}{day}\right] \times \frac{3.785L}{gal} \times BOD\ concentration\ \left[\frac{mg}{L}\right] \times \frac{1kg}{1{,}000{,}000\ mg} \times \frac{2.205\ lb}{kg}}{\frac{V\ [ft^3]}{1000}}$$

OLR = Trickling filter organic loading rate
Q_{in} = Influent flow rate
V = Volume of Media

OR

$$OLR = \frac{Q_{in}\left[\frac{Mgal}{day}\right] \times \frac{8.34\ L \cdot lb}{mg\ \cdot Mgal} \times BOD\ concentration\ \left[\frac{mg}{L}\right]}{\frac{V\ [ft^3]}{1000}}$$

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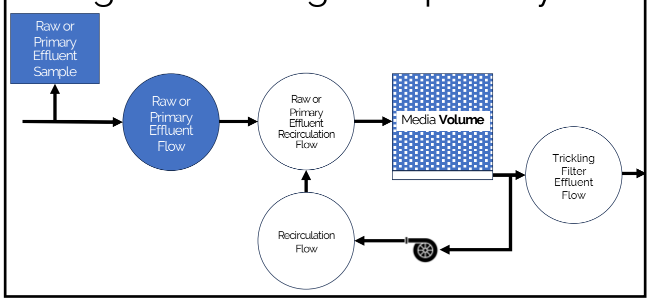
Organic Loading Rate per Day



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Hydraulic Loading Rate per Day

$$HLR\left[\frac{gal\ of\ influent}{ft^2\ of\ media\ \cdot day}\right] = \frac{Q_{in}\left[\frac{gal}{day}\right] + Q_r\left[\frac{gal}{day}\right]}{A_{surface}[ft^2]}$$

HLR = Trickling filter hydraulic loading rate
Q_{in} = Influent flow rate
Q_r = recirculation flow rate
$A_{surface}$ = Media surface area

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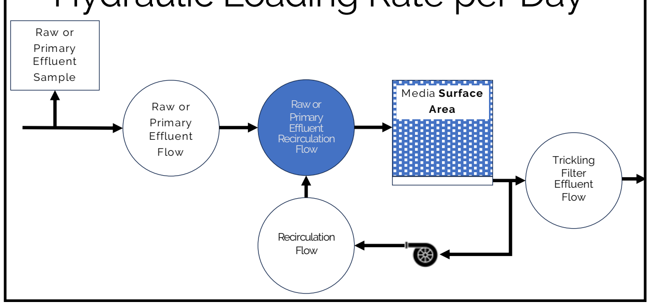
Hydraulic Loading Rate per Day



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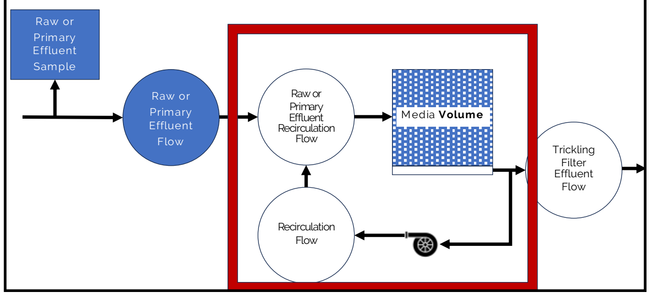
Recirculation



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Recirculation

- Producing hydraulic sheer to slough solids
- Dilute wastewater to lower BOD concentrations
- Dilute toxic wastes that might be received
- Increasing contact time of water in the filter
- Increasing hydraulic loading to reduce flies, snails and other nuisances
- Reseeding the filter with microbes
- Providing uniform distribution of flow
- Preventing the filters from drying out
- Returning DO (dissolved oxygen) to the top of the filter
- Matching the hydraulic loading rate to the recommended specs for plastic media

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Recirculation Ratio

$$TF\ recirculation\ ratio = \frac{Q_r\,[\frac{gal}{day}]}{Q_{in}\,[\frac{gal}{day}]}$$

Q_r = Recirculation flow rate
Q_{in} = Influent flow rate

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Recirculation Ratio

$$TF\ recirculation\ ratio = \frac{10\,[\frac{Mgal}{day}]}{5\,[\frac{Mgal}{day}]} = 2$$

Q_r = Recirculation flow rate
Q_{in} = Influent flow rate

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Dosing Rate (Spülkraft Rate)

$$DR\,[\frac{in}{pass}] = \frac{HLR\left[\frac{gal}{ft^2\ of\ media \cdot day}\right] \times \frac{12\ in}{ft}}{\frac{7.48\ gal}{ft^3} \times N \times w\ \left[\frac{rev}{min}\right] \times \frac{1{,}440\ min}{day}}$$

DR = Dosing rate
HLR = Trickling filter hydraulic loading rate
N = Number of arms
w = Rotational speed

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Dosing Rate (Spülkraft Rate)

Organic Loading Rate (lbs BOD/1,000ft³/day)	Normal Operation Dosing Rate (in/pass)	Flushing Operation Dosing Rate (in/pass)
<25	1-3	4
50	2-6	6
75	3-9	9
100	4-12	12
150	6-18	18
200	8-24	24

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Removal Efficiency

$$E\,[\%] = \frac{C_{in}\left[\frac{mg}{L}\right] - C_{out}\left[\frac{mg}{L}\right]}{C_{in}\left[\frac{mg}{L}\right]}$$

E = Removal Efficiency
C_{in} = Influent BOD Concentration
C_{out} = Effluent BOD Concentration \

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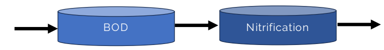
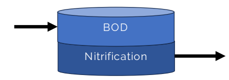
Operation

Two Stage Operation:



Single Stage Operation:



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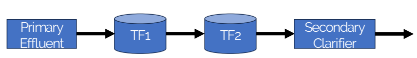
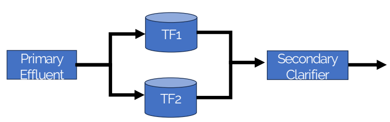
Operation

Series Operation:



Parallel Operation:



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Filter Classification

Low, Intermediate, High, Roughing, Nitrifying

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Design Characteristics & Efficiency: Low-Rate Filters

Wastewater Source	Media type	Media Depth (ft)	Organic Loading Rate (lb BOD_5/ d/1000 ft^3)	Hydraulic Loading Rate (GPD/ft^2)	BOD Removal Rates (%)	Combined Process required for Secondary treatment	Combined Process required for Tertiary treatment
Primary Effluent	Rock	3 - 8	<25	28 -86	80 - 90	No	Yes
Primary Effluent	Random Plastic	3 - 8	<25	720 – 1,728	80 - 90	No	Yes

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Design Characteristics & Efficiency: Intermediate-Rate Filters

Wastewater Source	Media type	Media Depth (ft)	Organic Loading Rate (lb BOD_5/ d/1000 ft^3)	Hydraulic Loading Rate (GPD/ft^2)	BOD Removal Rates (%)	Combined Process required for Secondary treatment	Combined Process required for Tertiary treatment
Primary Effluent	Rock	6 - 8	25 - 40	25 - 100	50 - 70	Unlikely	Yes
Primary Effluent	Random Plastic, Cross & Vertical	20 - 40	25 - 40	720 – 1,728	50 - 70	Unlikely	Yes

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Design Characteristics & Efficiency: High-Rate Filters

Wastewater Source	Media type	Media Depth (ft)	Organic Loading Rate (lb BOD_5/ d/1000 ft^3)	Hydraulic Loading Rate (GPD/ft^2)	BOD Removal Rates (%)	Combined Process required for Secondary treatment	Combined Process required for Tertiary treatment
Primary Effluent	Rock	3 - 5	40 - 100	100 - 1000	65 - 85	Likely	Yes
Primary Effluent	Plastic Cross or Vertical Flow	20 - 40	40 - 100	350 – 2100	65 - 85	Likely	Yes

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Design Characteristics & Efficiency: Roughing Filters

Wastewater Source	Media type	Media Depth (ft)	Organic Loading Rate (lb BOD_5/ d/1000 ft^3)	Hydraulic Loading Rate (GPD/ft^2)	BOD Removal Rates (%)	Combined Process required for Secondary treatment	Combined Process required for Tertiary treatment
Primary Effluent	Plastic Vertical Flow	20 - 40	100 - 300	400 - 4200	40 – 65	Yes	Yes

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Design Characteristics & Efficiency: Nitrifying Filters

Wastewater Source	Media type	Media Depth (ft)	Organic Loading Rate (lb BOD_5/ d/1000 ft^3)	Hydraulic Loading Rate (GPD/ft^2)	BOD Removal Rates (%)	Combined Process required for Secondary treatment	Combined Process required for Tertiary treatment
Secondary Effluent	Plastic Cross Flow	20 - 40	N/A	720 – 2,160	0.5 – 3 mg NH_4-N/L	N/A	N/A

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Design Characteristics & Efficiency: Nitrifying

- Typically, nitrification with trickling filters is done in two-stage process for optimization
- Nitrification can take place in a single filter if the organic loading rate is relatively low
- And when
  - heterotrophic bacteria colonize the upper portion of the filter
  - autotrophic bacteria colonize the lower portion of the filter

Single Stage Nitrifying Trickling Filter Nitrification Efficiencies

Media Type	Loading Rate (lb BOD/1,000 ft^3)	% Nitrification
Random Rock	3 - 10	85 - 95
Random Plastic	12 - 18	75 - 85
Sheet Plastic	6 - 12	85 -95

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Sampling Requirements

Parameter	Sampling Frequency	Location(s)	Typical Ranges
TSS	Daily or Weekly	Influent Primary effluent Final Effluent	150 – 400 mg/L 60 – 150 mg/L 15 - 40 mg/L
BOD5	Weekly	Influent Primary effluent Final Effluent	150 – 400 mg/L 100 – 380 mg/L 15 - 40 mg/L
COD	Daily or Weekly	Influent Primary effluent Final Effluent	300 – 800 mg/L 200 – 380 mg/L 60 - 120 mg/L
DO	Daily or Continuously	Filter underflow Filter effluent	3.0 – 8.0 mg/L 1.5 – 2.0 mg/L
pH	Daily or Continuously	Influent Effluent	6.8 – 8.0 7.0 – 8.5
Temperature	Daily or Continuously	Influent	Seasonal
Chlorine residual before dechlorination	Daily	Secondary Effluent	0.5 – 2.0 mg/L
Coliform bacteria or *E. coli* after dechlorination	Weekly	Final Effluent	50-700 MPN/100mL

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Operation & Maintenance

Odor:

Some Causes:
- Septic influent
- Poor filter ventilation
- Excessive organic loading
- Dry zones
- Anaerobic conditions

Some Solutions:
- Reducing organic load with recirculation
- Increasing mechanical air flow
- Improve maintenance on rotary arms
- Increase dosing rates to wash out excess biological growth
- Troubleshoot primary treatment

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Operation & Maintenance

Filter Ponding:

Causes:
- Excessive organic loading leading to excessive growth
- Uneven distribution of influent flow in the media
- Accumulation of debris on the top of the filter
- Excessive insects, snails, moss, algae
- Insufficient void space

Some Solutions:
- Calibrate organic and hydraulic loading rates and removal efficiency
- Slow down rotating arm to increase dosing rate and better manage sloughing
- Flood filter to loosen and flush out excessive growth
- Screen or replace media
- Add treatment units

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Operation & Maintenance

Sample Tasks (not an exhaustive list)	Frequency
Check that rotary distribution system is running smoothly	Daily
Check bearing oil levels	Weekly
Clean distribution arm orifices	Weekly
Time rotational speed	Monthly
Flush distributor arms	Monthly
Adjust distributor arm levels	Seasonally
Conduct pan tests to test distribution of wastewater over filter surface	As needed

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Advantages & Disadvantages

- Low energy requirements
- Low maintenance requirements
- Ability to treat variable organic loads & toxic substances

- Can generate odors
- Can have issues with macrofauna (insects, flies, snails)
- Temperature sensitivity
- Icing in cold weather
- Low flows can immobilize distributor arms in unmotorized systems

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Rotating Biological Contactor ("RCB")

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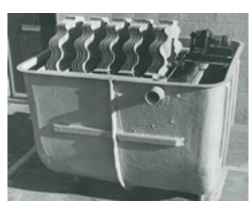
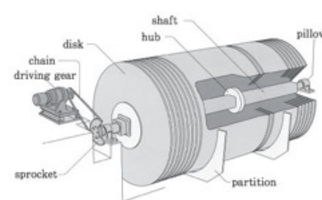
RCB's in 1955





http://www.igreenion.com/rotating-biological-contactor.html

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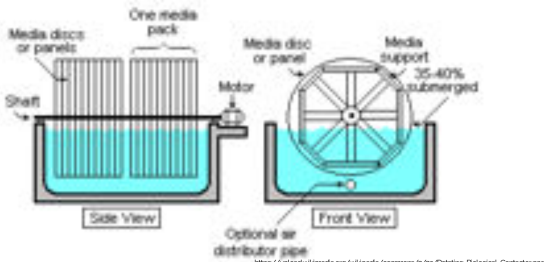
RBC Schematic



https://upload.wikimedia.org/wikipedia/commons/3/3c/Rotating_Biological_Contactor.png

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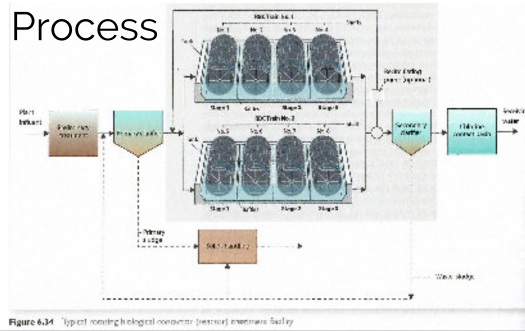
RBC Process



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RBC Media Characteristics

Characteristic	Standard Density	High Density
Surface Area	90,000 - 110,000 ft^2/shaft	120,000 - 165,000 ft^2/shaft
Common use	BOD Removal	Nitrification
Optimal Biofilm Thickness	0.04 – 0.06 in	0.015 - .03 in
Percent of Weight Occupied by biofilm	60 – 80%	60 – 80%

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Important Parameters

Organic Loading Rate

- How much organic matter (BOD) is fed into the system in relation to the media volume
- Expressed as:

$$\frac{lbs\ of\ BOD}{1000\ ft^3\ Media}$$

Hydraulic Loading Rate

- How much water is fed through the system per day in relation the media surface area
- Expressed as:

$$\frac{GPD}{ft^2}$$

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Removal Efficiency

$$E\,[\%] = \frac{C_{in}\left[\frac{mg}{L}\right] - C_{out}\left[\frac{mg}{L}\right]}{C_{in}\left[\frac{mg}{L}\right]}$$

E = Removal Efficiency
C_{in} = Influent BOD Concentration
C_{out} = Effluent BOD Concentration \

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Recirculation

$$recirculation\ ratio = \frac{Q_r\left[\frac{gal}{day}\right]}{Q_{in}\left[\frac{gal}{day}\right]}$$

Q_r = Recirculation flow rate
Q_{in} = Influent flow rate

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BOD Removal and Nitrification

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RBC Parameters

Parameter	BOD Removal Only	BOD Removal and Nitrification	Nitrification Only
Wastewater Source	Primary Effluent	Primary Effluent	Secondary Effluent
Media type	Standard Density (100,000 ft^2/shaft)	Standard Density (100,000 ft^2/shaft)	High Density (150,000 ft^2/shaft)
Surface Area	36 ft^2/ft^3	36 ft^2/ft^3	55 ft^2/ft^3
Organic Load Rate to Overall Reactor (lb/BOD/d/1000ft^3)	3-4	3-4	< 0.5
Organic Load Rate to First Stage (lb/BOD/d/1000ft^3)	4-6	3-4	

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RBC Parameters

Parameter	BOD Removal Only	BOD Removal and Nitrification	Nitrification Only
Hydraulic Loading Rate (gpd/ft^2)	1-3	1-3	1-2.5
Hydraulic Retention Time (hr)	0.7-1.5	1.5-4	1.2-3
Effluent BOD	15-30	7-15	7-15
Effluent NH4-N		<2	1-2

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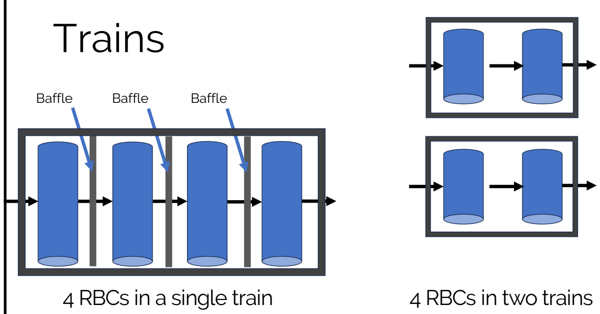
Trains



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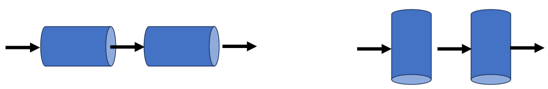
Direction of Flow



Flow parallel to the shaft

Flow perpendicular to the shaft

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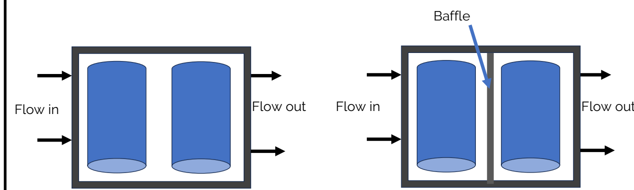
Modes



2 RBCs one stage

2 RBCs in two stages

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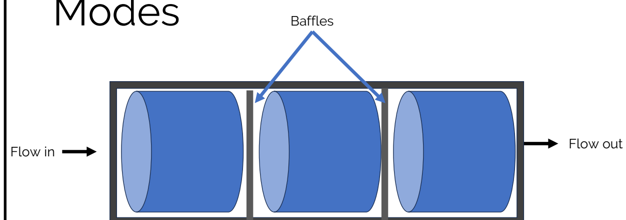
Modes



1 RBCs with 3 stages and perpendicular floiw

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Some Limitations

- RBCs typically require lower organic loading rates than trickling filters
- They don't provide as much flexibility as trickling filters when it comes to operating over a wide range of organic loading
- They can't be used as roughing filters or as high-rate reactors

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Operation & Maintenance

Sample Tasks (not an exhaustive list)	Frequency
Check for hot shafts and bearings; listen for unusual noises in shaft and bearings	Daily
Grease mainshaft and drive bearings	Weekly
Inspect chain drives, mainshaft bearings and drive bearings	Monthly
Change oil in speed reducer and inspect belt drives	Every 3 months
Clean magnetic drains in speed reducers	Every 6 months
Grease motor bearings	Annually

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Office Hour Details

Time: Every Tuesday from: 9:00 AM to 10:00 AM PDT
10:00 AM to 11:00AM MDT
11:00 AM to Noon CDT
Noon to 1:00 PM EDT

Reach out via email: ajbarney1@unm.edu
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