A3-USA
Water and Wastewater Membranes

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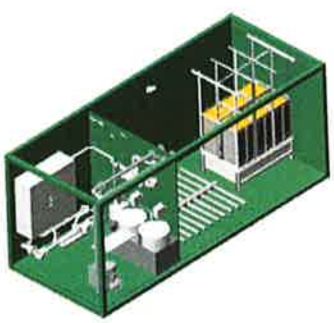
MEMBRANE BIOREACTOR - ENGINEERING REPORT

PROJECT: Croton Overlook, Yorktown Heights, NY

DATE: May 1, 2011



A3-USA OFFERS THE LATEST TECHNOLOGY COMBINED WITH THE ADVANTAGES THAT A SMALL COMPANY PROVIDES - PERSONALIZED SERVICE, ATTENTION TO DETAIL, AND LOW COST

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Introduction

An A3-USA Membrane Bioreactor (MBR) system is proposed to treat municipal wastewater that will be generated by the Croton Overlook development in Yorktown Heights, NY. MBR technology is the current state-of-the-art technology available. It will produce a consistent high quality effluent exceeding the regulatory effluent limits for Croton Overlook. MBRs are operated at a high mixed liquor suspended solids concentration (MLSS) and sludge age which reduces/eliminates odors in the plant.

The MBR system will be delivered pre-assembled and wired onto a skid, and covered with a building. All essential equipment such as influent screens, pumps, blowers, membrane modules are designed for redundancy.

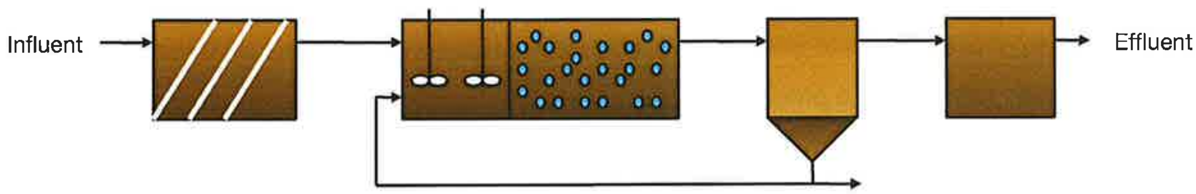
The influent and effluent criteria used for design are listed in the table below.

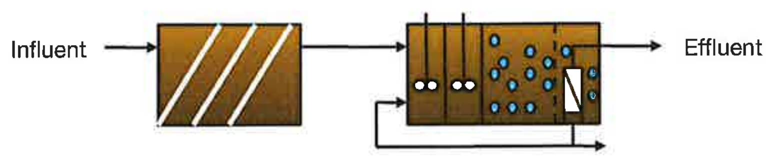
	Influent	**Effluent**
Wastewater source	municipal wastewater	-
Average daily flow (ADF)	16,800 gpd	-
Monthly maximum average daily flow (MADF)	21,000 gpd	-
Hourly peak flow (HPF)	1,400 gph	-
BOD	150 - 400 mg/l	< 5 mg/l
TSS	50 - 400 mg/l	< 5 mg/l
NH_4-N	15-40 mg/l	< 1 mg/l
TN	20 - 55 mg/l	<12 mg/l
TP	8 - 12 mg/l	< 0.2 mg/l
Turbidity	-	< 0.2 NTU
pH	6.5 - 8	-
Temperature	50 - 75 Fahrenheit	-

Basics of MBR Technology

Membrane bioreactors combine conventional biological activated sludge processes with membrane filtration. The membranes are directly submerged in the activated sludge. The activated sludge (biomass) is separated from the liquid as it passes through the membranes and is retained in the biological reactor. Conventional sedimentation processes are not required. The small membrane pores retain suspended matter, bacteria, and viruses (pathogens). The result is a high quality effluent that can be reused.

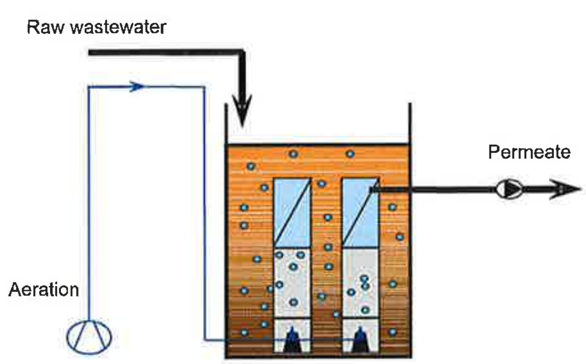
Shown below is a schematic for conventional treatment plants and MBR treatment plants.





Conventional treatment plant versus MBR

Membranes are arranged (packaged) in modules for easy installation and maintenance. Aeration devices are located at the bottom of membrane modules. Air bubbles create a cross flow parallel to the membrane surface also generate biomass degradation. The flow across the membranes creates a shear force that limits build-up (cake layer control) on the membrane surface and keeps an optimum biofilm thickness. The pressure difference between the mixed liquor and the membrane (transmembrane pressure) forces the liquid through the membrane.



MBR arrangement

The use of MBR yields to the following benefits:

- Operation at higher MLSS (mixed liquor suspended solid) concentration resulting in a more robust process
- Compact footprint
- Easy upgrade and expansion by adding membrane modules
- Increased sludge age improves treatment capability
- Modular plants simplify upgrades and expansion of existing plants
- Fully automated operation
- Ease of operation and less operator attention
- Lower waste sludge production
- Sludge generated from process requires less thickening due to the high solid content
- Disinfection is reduced or eliminated
- Provides consistent, superior effluent quality independent of flow variations (heavy rain), floating sludge, etc.
- Effluent is reusable / recyclable

In recent years MBR plants using low-pressure submerged membranes have become cost effective. The combination of an activated sludge process and membrane technology allows removal of carbon, phosphorous and nitrogen, but it also removes some toxins (carcinogenic, mutagenous, and hormonally active) and bio-accumulative micro-contaminants. Pollutants that cannot be eliminated by a membrane bioreactor can be eliminated by post-treatment such as nanofiltration or reverse osmosis. Table 1 lists achievable effluent values for a MBR plant. Nitrogen and phosphorous removal depend on the plant layout, including arrangement of the anoxic / aerobic basins, chemical addition for phosphorous removal, and carbon addition for a secondary anoxic basin.

Process Design Description

The MBR system is comprised of four major treatment steps:

- Screening
- Anoxic Tank
- Membrane Tank
- Aerobic Sludge Treatment

The raw sewage (Q) will be collected in a pump station (3,500 gallons) that acts also as an EQ basin and is pumped to two 2-mm fine screens. Each screen is able to handle peak capacity and can be taken out of service via stainless steel knife gate valves. The screened raw sewage flows via gravity into the Anoxic Tank, where it is mixed with the activated sludge of the MBR system.

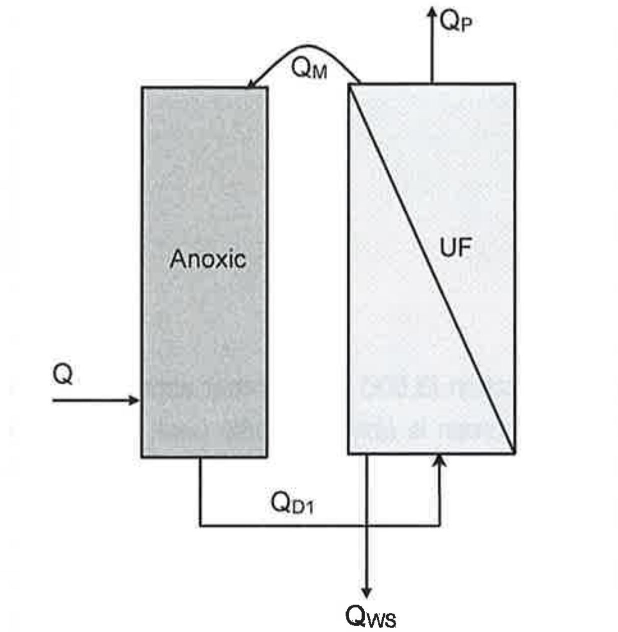
External recycle pumps transport the mixed liquor (Q_{D1} ~82 gpm) from the Anoxic Tank (3,970 gallons) to the Membrane Tank (4,500 gallons) at a recycle rate of 6 Times Q. The high recycle rate supports nitrate removal and controls the mixed liquor suspended solids (MLSS) concentration inside the Membrane Tank.

An external chemical feed system adds Alum to the influent flow for phosphorous removal. Further, an additional chemical feed system (sodium hydroxide) is installed for ph adjustment due to the low alkalinity of the wastewater influent.

The mixed liquor (Q_M ~70 gpm) flows via gravity from the Membrane Tank to an area of the Anoxic Tank separated by a baffle wall. This baffle minimizes oxygen carry-over from the Membrane Tank to the Anoxic Tank and increases the denitrification rate. The Membrane Tank is equipped with three single stack membrane modules including aeration modules. Each aeration module consists of 5 fine bubble tube diffusers that produce 29 acfm. The generated air is used for biological degradation and membrane surface scouring.

The treated effluent, the permeate (Q_P), that is forced through the membranes by permeate pumps, will leave the plant at a rate of the incoming flow (average rate of Q, ~12 gpm, but is VFD controlled). Periodically, sludge (Q_{WS}) will be wasted directly from the Membrane Tank into the Aerobic Sludge Treatment Tank (4,400 gallons).

The average flows and mixed liquor suspended solids concentrations are illustrated in the flow diagram and table below.



Q	11.7	gpm
Q_M	70.0	gpm
Q_{ws}	0.1	gpm
Q_{D1}	81.7	gpm
Q_P	11.5	gpm
X_B	11,065	mg/l
X_M	12,886	mg/l
$X_{Average}$	12,000	mg/l

$$0 = \begin{pmatrix} Q_{D1} - Q \cdot a \\ Q_{D1} - Q_M - Q \\ Q_{D1} - Q_M - Q_P - Q_{WS} \end{pmatrix}$$

$$X_M = \frac{Q_{D1}}{Q_M + Q_{WS}} \cdot X_B$$

Flow diagram

Detailed Equipment & Tank Design

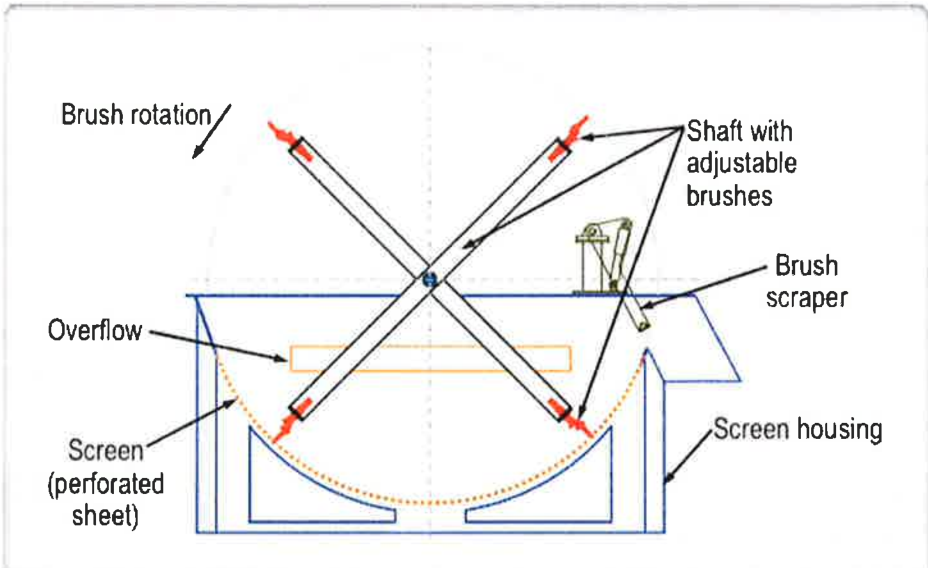
Screens (Pre-treatment)

The pre-treatment stage must remove all particles from the raw wastewater stream that are detrimental to the membranes or other plant equipment downstream. Hairs, fiber tissues and fats/grease in high concentrations promote clogging of membranes. Other materials may damage the membrane by high mechanical stress or sharp edges.

The Croton Overlook plant will be equipped with two CONTEC fine screens having perforated plates with opening sizes of 2 mm. In contrast to conventional bar screens, perforated screens are able to retain longer thin objects, such as hair, tooth picks, etc.


CONTEC™ fine screens

Wastewater enters the screen at a flanged inlet and flows into a horizontal semicircular perforated screen panel. The screen panel retains the solids, and the screened water flows by gravity into the anoxic tank. A set of slowly rotating brushes attached to a central shaft transports the solids from the top of the perforated plate to an ejection slot. A mechanical scraper cleans the brushes without an additional drive. The redundant screen set-up is connected to a single screening conveyor/press that includes a bagging system to reduce odor and increase ease of maintenance.



Functional schematic

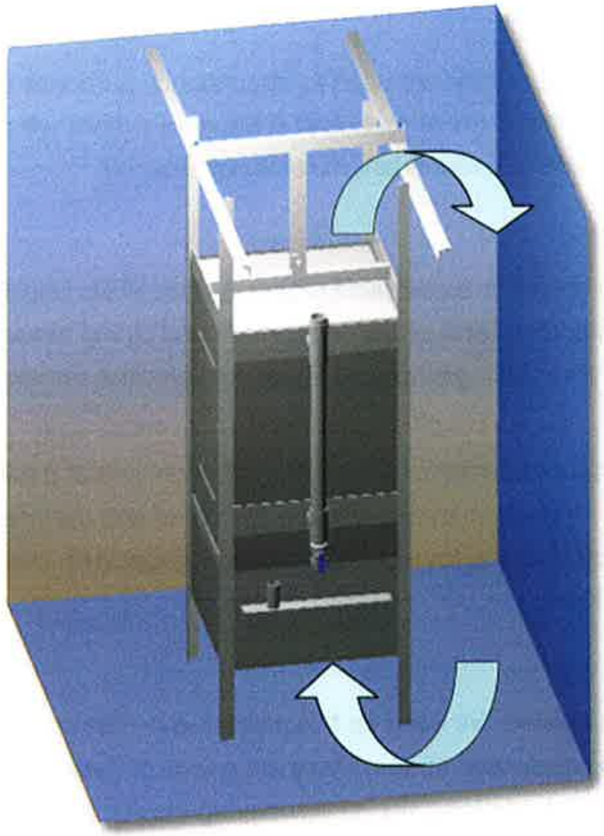
Bioreactor design

Basin design

MBR basin design is similar to conventional wastewater treatment plants. Nevertheless, the use of membrane permits a significant higher MLSS concentration. The Croton Overlook MBR plant uses an average MLSS concentration of 12,000 mg/l which leads to a sludge age (SRT) of 46 days.

The following design aspects are considered for the basin layout:

- Displacement volume of membranes are subtracted from overall tank volume
- Membrane basins can have oxygen levels of over 5 mg/l. A high recycle rate to an anoxic tank may cause an oxygen carry-over problem. To avoid this, an additional tank section was created inside the anoxic tank via baffle wall.
- The membrane tank is design based on single stack membrane module arrangement. It is vital to design for sufficient space below, above and next to the membrane modules in order to guarantee the creation of a rolling circular cross flow through the membrane module (see figure below).
- A design F/M (Food / microorganism) ratio of 0.042 (BOD load) is used. During start-up phase and low flow events, the MLSS concentration will be lowered in order to keep a constant F/M ratio in the system. The MLSS concentration should not go below 8,000 mg/l inside the membrane tank.
- An unaerated (anoxic tank) biomass volume of 48% is applied to achieve best possible NO_3 removal rates.



Rolling circular cross flow through membrane module

Membrane biofilm

During plant operation, a thin biofilm of organic and inorganic contents (such as microorganism, EPS/ SMP, etc.) adheres to the membrane surface. This biofilm enhances the selectivity of the membrane (more bacteria are retained). It is important to limit biofilm and cake layer growth (density and thickness), otherwise filtrate flux increases and consequently membrane performance decreases.

The biofilm layer is controlled via:

- pre-treatment
- pump operation = > intermittent run of permeate pumps
- membrane aeration
- membrane module layout
- cleaning strategies and intervals

Sewage pumps & mixers

Two dry-pit process recycle pumps are used for redundancy purposes and ease of maintenance. Only a single mixer is installed inside the anoxic tank. A failure of a mixer will not effect the process operation short term, and consequently, a redundant mixer is not required.

Permeate pumps

Two redundant Moyno eccentric screw pumps operated via VFDs (variable frequency drives) are used. These pumps are bi-directional and reduce equipment and piping requirements (no extra cleaning line & pumps are needed). Permeate piping is designed for velocities not exceeding 5 fps to minimize pipe loses.

Permeate pumps are operated intermittently with a filtration time of 8 minutes and a stand-by / relaxation time of 2 minutes. Relaxation time is required to control and minimize cake layer growth on the membrane surface. Note that the total pressure measured between membrane and permeate pump increases with higher flows.

Blowers

Rietschle side channel blowers are used for this plant due to their compact design and quiet operation. Air piping velocities do not exceed 45 fps. There are a total of three blowers being used: One duty membrane blower, one duty sludge / sludge dewatering blower, and one stand-by blower for either tank. The membrane blower's operation is monitored by a flow meter to guarantee sufficient flow to the membrane modules. If the MBR blowers malfunction, the permeate pumps must stop. The air introduced by the tube diffusers generates a shear force at the membrane surface and controls cake layer growth. If insufficient aeration occurs, a thick cake layer is created on the membrane.

Aeration equipment

Membrane modules employ fine bubble tube diffusers. The biological oxygen demand is determined using α values of 0.4 due to higher MLSS values of MBR plants.

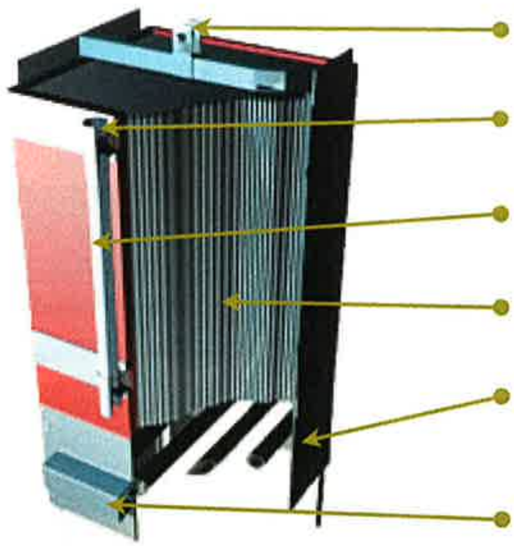
Instrumentation

The following parameters will be constantly monitored (analog signals):

- Plant influent flow
- Anoxic tank level
- Transmembrane pressure
- Permeate flow
- Membrane tank air flow

Membrane module characteristics

A3's plate ultrafiltration modules use flat sheet membranes arranged in parallel. Multiple flat sheet membranes are imbedded into a grouting material with a fixed distance of 7 mm (1/4"). The other two sides of the membrane module are PVC plates. The individual flat sheet membranes have a porous supporting structure that is covered with a protecting fleece and a PES (Polyether Sulfone) membrane on both sides. The treated permeate is collected inside the supporting structure and drawn to an attached permeate pipe and finally discharged.



A3 membrane module

The required number of membrane modules is determined by the daily average and hourly peak flow, and the permitted membrane flux (J). A continuous membrane flux of 7 to 14.6 gal/(ft^2*d) is assumed with a maximum flux of 23 to 29 gal/(ft^2*d) for not more than 2 hours. When calculating the membrane flux, the standby / relaxation time (T_s) and operating time (T_o) of the permeate pumps must also be considered:

$$J = \frac{Q_{ave,d}}{\#Modules \cdot A_{M,eff}} \cdot \left(\frac{T_o + T_s}{T_o} \right)$$

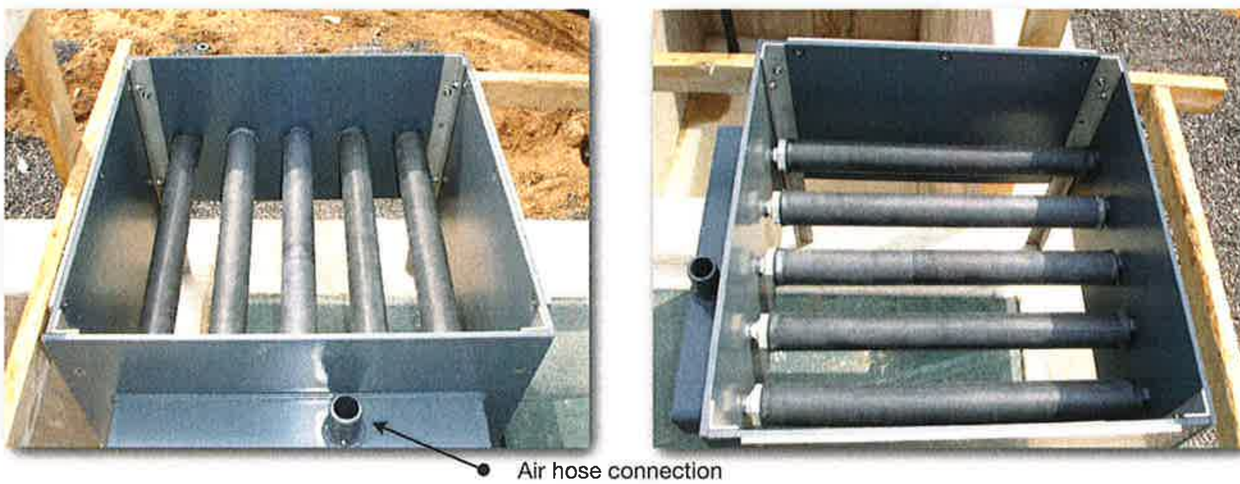
where $Q_{ave,d}$ is the daily average flow entering the plant and $A_{M,eff}$ the effective membrane surface per membrane module.

There are various influent / MLSS characteristics such as wastewater consistency, particle distribution, temperature, duration of events, MLSS concentration, etc. that influence the trans-membrane pressure (TMP) of a membrane module.

The Croton Overlook MBR plant was designed using three U70 membrane modules having a combined surface area of 2,260 ft^2 resulting in an average nominal flux rate of 9.3 gfd. The nominal flux rate considers the relaxation factor of 1.25.

Aeration module

Aeration modules are completely enclosed on the sides to create a defined flow pattern. When applying air to fine bubble diffusers near their flow limits, medium sized air bubbles are generated. Fine bubble tube diffusers are not subject to plugging and do not require back flushing.



Aeration module for the U70 membrane modules

Operation & Maintenance

Cleaning

Membrane modules must be cleaned periodically in order to control biofilm growth and other deposition on and within the membrane. During the cleaning procedure, the permeate is pumped into a cleaning tank and a chemical (e.g. sodium hypochlorite or citric acid) is added. This cleaning solution is transported back into the membrane module with permeate pumps operating in reverse. The cleaning solution remains in the membrane module between 30 to 180 minutes depending on the cleaning procedure and completely soaks (diffuses) through the membrane. The membrane aeration modules create a shear force during the cleaning procedure. Afterwards, the cleaning solution is removed from the membranes via permeate pumps and pumped either back to the influent or effluent of the plant depending on specific site requirements (pH-value, local regulations, etc).

O&M Cost

Energy Cost

	Quantity (Duty)	Daily run time (hrs)	Nominal motor power (hp)	Brake motor percentage	Brake motor power (hp)	Brake motor power (kW)	Annual energy consumption (kWh)	Annual energy cost
Membrane blowers	1	18	7.5	80%	6.0	4.5	29,418	$4,413
Aerobic blowers	0	0	0	0%	0.0	0.0	0	$0
Sludge blowers	1	18	1.75	80%	1.4	1.0	6,864	$1,030
Permeate pumps	1	15	2	50%	1.0	0.7	4,086	$613
Recycle pumps	1	24	1	80%	0.8	0.6	5,230	$784
Influent pumps	1	10	2	75%	1.5	1.1	4,086	$613
Screen(s)	1	12	0.06	80%	0.0	0.0	157	$24
Press	1	12	1	80%	0.8	0.6	2,615	$392
Mixer(s)	1	24	2	80%	1.6	1.2	10,460	$1,569
UV system	0	-	-	-	-	-	0	$0
Control panel & MCC	1	-	-	-	-	-	2,000	$300
Misc. items	1	-	-	-	-	-	3,000	$450
Local energy cost	$0.15	per kWH						**$10,187**

Chemical Cost

	gallons / year	Price per gallon	Total Annual Cost
Micro C (Carbon Source)	0	$2.75	$0
Alum [$Al_2(SO_4)_3 \cdot 14H_2O$]	166	$2.20	$366
Sodium Hypochlorite (12.5%)	32	$2.00	$65
Citric Acid (25%)	18	$5.00	$90
Sodium Hydroxide (50%)	128	$2.35	$301
			$821

MBR Treatment Plant Maintenance Items

- conventional equipment maintenance such as
  - oil & filter changes
  - tightening or replacing belts
  - sensor calibration
  - visual checks
  - emptying screen debris
  - cleaning screen when needed

- membrane module cleaning
  - 2-3 times a year
  - fully automated: reverse running permeate pumps introduce cleaning solution into membrane modules; cleaning solution will saturate membrane modules for 2-3 hours
  - standard cleaning with sodium hypochlorite (0.4%); depending on the hardness of the water citric acid cleaning may be needed as well

Reinvestment Cost

Inflation	0.0%	
Interest/Bond rate	2.0%	
	Approximate annual cost	**Expected life time**
Membrane blowers	$305	20
Aeration blowers	$0	20
Sludge blowers	$53	20
Permeate pumps	$211	20
Influent Pumps	$0	20
Recycle pumps	$81	20
Waste sludge pumps	$0	20
Screen(s) and press	$0	25
Mixer(s)	$258	12
Control panel & MCC	$1,143	15
Controls	$366	10
Membranes	$1,479	10
Valves / Misc.	$528	10
	$4,423	

Reinvestment Cost

Reinvestment cost or funded depreciation is many times ignored during daily operation of a wastewater treatment plant, but it is definitely impacting annual operations long term. Listed to the left are approximate annual reinvestment cost in combination with the individual life time of certain equipment. These cost might be conservative, since fairly often equipment can be refurbished without being completely replaced.

A3 MaxFlow™ Sludge Dewatering

A3 offers sludge dewatering for small wastewater treatment plants having no onsite dewatering equipment (belt filter presses, decanters, etc.). A3's unique membrane dewatering process achieves a significant reduction of excess sludge volume (up to 3% MLSS). The cost of disposing waste sludge is often the largest O&M cost portion for small treatment plants. Especially conventional activated sludge plants neglect to account for these cost after upgrading to a new treatment plant. Even for MBR plants, which already produce 3-4 times less sludge than conventional plants, installing a simple membrane sludge dewatering equipment reduces O&M cost drastically and can have a payback of less than a year.

Summary O&M Cost

Cost per gallon to haul & dispose of waste sludge	$0.10	
	Annual O&M Cost w/o membrane sludge dewatering	Annual O&M Cost with membrane sludge dewatering
Energy Cost	$10,187	$10,187
Routine Inspection	$0	$0
Repair Cost	$221	$221
Chemical Cost	$821	$821
Reinvestment Cost	$4,423	$4,423
Sludge hauling/disposing cost	$6,420	$3,210
	$22,074	**$18,863**

Annual O&M Cost w/o & with membrane sludge dewatering

Detailed Process Calculations



CALCULATION SCENARIO I




Biological Process Calculation

Summary of Influent, Effluent, and Operating Characteristics

Parameter	Symbol	Unit	Values
Average daily flow	Q_i	gpd	16,800
Max. monthly average daily flow	$Q_{i, max,o}$	gpd	21,000
Peak flow	$Q_{i, max,p}$	gpm	23
Peak factor	-	-	2.0
Average daily flow	Q_i	m_3/d	64
Max. monthly average daily flow	$Q_{i, max,o}$	m_3/d	79
Hourly peak flow	$Q_{i, max,h}$	m^3/h	5
Influent BOD concentration	$S_{ti,BOD}$	mgBOD/l	150
Influent COD concentration	$S_{ti,COD}$	mgCOD/l	240
Influent TSS	$S_{ti,TSS}$	mgTSS/l	50
Biodegradable COD	S_{bi}	mgCOD/l	187
Total BOD in	FS_{ti}	kgBOD/d	10
Total COD in	FS_{ti}	kgCOD/d	15
BOD/COD ratio	-	-	1.60
Influent NH_4 concentration	N_{ai}	$mgNH_4/l$	15
Influent TKN concentration	N_{ti}	mgN/l	20
Influent FSA fraction	$f_{N'a}$	-	0.75
Influent P concentration	P_{ti}	mgP/l	8
Site pressure / elevation	$p_{a,i}$	psu	14.2
Temperature	T	°C	12
pH	-	-	7.0
H_2CO_3 alkalinity	Alk_i	mg/l as $CaCO_3$	40
Influent ISS	X_{IOi}	mgISS/l	47.8
Reactor volume	$V_{P,chosen}$	gallons	8,242
Sludge age	SRT	d	44
Waste Sludge	FX_t	lb/d	13
Waste Sludge	Q_w	gpd	188
Food to microorganism ratio	F/M_{used}	kgCOD/kgMLSS	0.045
Food to microorganism ratio	F/M_{used}	kgBOD/kgMLSS	0.036
Effluent P	P_{te}	mgP/l	0.5
Effluent BOD	$S_{te,BOD}$	mgBOD/l	<3
Effluent ammonia	N_{ae}	mgN/l	0.9
Effluent nitrate	N_{ne}	mgN/l	0.0
Total effluent N (N_{ne} + N_{te})	N	mgN/l	1.5
Effluent nitrate @ fxdm & opt. recycle rate	N_{ne^*}	mgN/l	3.0
Total effluent N (N_{ne^*} + N_{te})	N*	mgN/l	4.5
Nominal hydraulic retention time	HRT_n	h	11.8
Actual hydraulic retention time	HRT_a	h	1.7

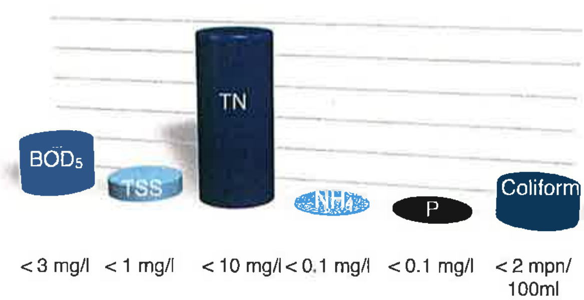
State-of-the-Art Technology

The application of membrane bioreactor (MBR) technology represents the state-of-the-art technology for treating biological wastewater. While conventional treatment processes focus on the degradation of organic contaminants and nutrients such as nitrogen and phosphorous, MBRs also reject turbidity and microorganisms. This generates high-quality reuse water. MBR plants are extremely compact in size due to their high level of biomass and elimination of clarifiers. Further, the modular nature of membrane modules provides for very flexible plant concepts that can "grow", allowing investments to be made only when needed.

MBR Process

Membrane bioreactors combine conventional biological activated sludge processes with membrane filtration. The membranes are directly submerged in the activated sludge. The activated sludge (biomass) is separated from the liquid as it passes through the membranes and is retained in the biological reactor. Conventional sedimentation processes are not required. The small membrane pores retain suspended matter, bacteria, and viruses (pathogens). Membranes are arranged (packaged) in modules for easy installation and maintenance. Aeration devices are located at the bottom of membrane modules. Air bubbles create a cross flow parallel to the membrane surface and generate biomass degradation. The flow across the membranes creates a shear force that limits build-up on the membrane surface.

Achievable Effluent Values with proposed plant



Constants

Parameter	Symbol	Unit	Values
TKN/COD ratio	f_{ns}	mgTKN/mgCOD	0.08
Carbon source addition (Micro C)	B_{MicroC}	lb/d	0
Unbiodegradable particular COD	$f_{S'up}$	-	0.15
Unbiodegradable soluble COD	$f_{S'us}$	-	0.07
Readily bio. org. fraction (RBCOD)	$f_{Sb's}$	-	0.25
VSS/TSS of activated sludge	f_i	mgVSS/mgTSS	0.75
COD/VSS of activated sludge	f_{cv}	kgCOD/kgVSS	1.48
True synthesis fraction	f_s^0	-	0.57
Yield coefficient	Y_{Hv}	mgVSS/mgCOD	0.40
Temperature sensitivity coefficient	Θ_b	-	1.029
Endo. respiration rate (decay)	b_H	gVSS/gVSSd	0.24
Endogenous respiration rate T	b_{HT}	gVSS/gVSSd	0.19
Endogenous residue fraction	f_H	-	0.20
ISS content of OHOs	f_{iOHO}	-	0.15
Yield coefficient	Y_A	mgVSS/mgFSA	0.1
Endogenous respiration rate	b_A	1/d	0.04
Endo. respiration rate - Temp	b_{AT}	1/d	0.032
Temperature sensitivity coefficient	Θ_n	-	1.123
Nitri. pH sensitivity coefficient	K_I	-	1.13
Nitri. pH sensitivity coefficient	K_{max}	-	9.5
Nitri. pH sensitivity coefficient	K_{II}	-	0.3
Max. specific growth rate at 20°C	μ_{Am}	1/d	0.45
Max. spec. growth rate - Temp/pH	μ_{AmTpH}	1/d	0.15
Half saturation coefficient	K_n	mgFSA/l	1
Half saturation coefficient - Temp	K_{nT}	mgFSA/l	0.40
Sludge age calculated	SRT_{calc}	d	40
Unbio. soluble orgN fraction	$f_{N'ous}$	-	0.03
Unbio. particular orgN fraction	f_n	-	0.12
Unbio. particular orgP fraction	f_P	mgP/mgVSS	0.05

$$HRT_n = \frac{V_P}{Q_i} \qquad HRT_a = \frac{HRT_n}{+m+a} \qquad SRT = \frac{V_P}{Q_w}$$

$$b_{AT} = k_{A20}\left(\theta_b\right)^{(T-20)}$$

$$\mu_{AmTpH} = \mu_{Am20}\left(\theta_n\right)^{(T-20)} K_I \frac{K_{max} - pH}{K_{max} + K_{II} - pH} for\_ph > 7.2$$

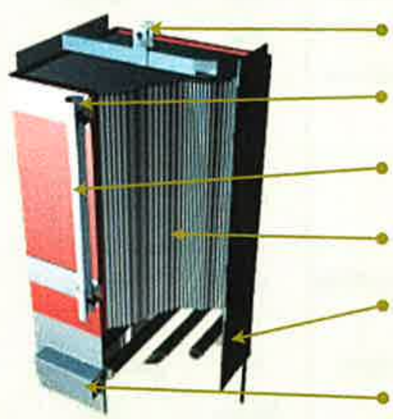
$$\mu_{AmTpH} = \mu_{Am20}\left(\theta_n\right)^{(T-20)} \quad (pH-7.2)$$

$$_{nT} = {}_{n20}\left(\theta_n\right)^{(T-20)}$$

$$SRT_{calc} = 30 \cdot 1.1^{(15-T)}$$

MBR Benefits

- Continuous superior effluent quality
- Compact footprint
- Scalable
- Class A reuse water
- Easy operation
- Low maintenance
- Disinfection equipment is reduced or eliminated
- Fully automated operation
- Operation at an average MLSS of 10,000 - 15,000 g/l
- Increased sludge age approves treatment capability
- Lower waste sludge production



Biological Mass Balance

Parameter	Symbol	Unit	Values
Influent biodegradable COD mass	FS_{bi}	kgCOD/d	12
Influent particular unbio. COD mass	FX_{Ivi}	kgVSS/d	2
Influent particular inorg. COD mass	FX_{IOi}	kgISS/d	3
Sludge age	SRT	d	44
Mixed liquor suspended solids	X_t	mgTSS/l	8,500
Active organism mass	MX_{BHv}	kgVSS	22
Endogenous residue mass	MX_{EHv}	kgVSS	37
Unbiodegradable particular mass	MX_{Iv}	kgVSS	67
Volatile suspended solids mass	MX_v	kgVSS	127
Inorganic suspended solid mass	MX_{IO}	kgISS	136
Total suspended solids mass	MX_t	kgTSS	262
Active fraction - VSS	f_{avOHO}	-	0.176
Active fraction - TSS	f_{at}	-	0.13
Mass/Sludge TSS wasted	FX_t	KgTSS/d	6
Mass/Sludge VSS wasted	FX_v	kgVSS/d	5
Effluent COD	S_{te}	mgCOD/l	16.8
COD mass out (effluent and waste)	FS_{te}	kgCOD/d	1.1
Mass/Sludge COD wasted	FX_{COD}	kgCOD/d	4
Reactor volume	V_P	gallons	8,158
Reactor volume	V_P	m^3	31
Food to microorganism ratio	F/M	$kgFS_{bi}/kgMLSS$	0.045
Food to microorganism ratio	F/M	kgBOD/kgMLSS	0.036

$$FS_{bi} = Q_i S_{ti}(1 - f_{S'us} - f_{S'up}) + B_{MicroC} \qquad FX_{Ivi} = \frac{FS_{ti} f_{S'up}}{f_{cv}}$$

$$FX_{IOi} = Q_i X_{IOi}$$

$$MX_{BHv} = FS_{bi}\frac{Y_{Hv} SRT}{(1 + b_H SRT)} \qquad MX_{EHv} = f_H b_H MX_{BHv} SRT$$

$$MX_{Iv} = FX_{Ivi} SRT \qquad MX_v = MX_{BHv} + MX_{Ev} + MX_{Iv}$$

$$MX_{IO} = FX_{IOi} SRT + f_{iOHO} MX_{BHv} \qquad MX_t = MX_v + MX_{IO}$$

$$f_{avOHO} = \frac{MX_{BHv}}{MX_v} \qquad f_{at} = f_i f_{av} \qquad f_i = \frac{MX_v}{MX_t}$$

$$FX_t = \frac{MX_t}{SRT} \qquad FX_v = FX_t f_i$$

$$S_{te} = S_{le} = f_{S'us} S_{ti} \qquad FS_{te} = S_{te} Q_{ti}$$

$$FX_{COD} = \frac{MX_v f_{cv}}{SRT}$$

$$V_P = \frac{MX_t}{X_t} \qquad F/M = \frac{FS_{ti}}{V_P X_t}$$

Biological Oxygen Demand

Parameter	Symbol	Unit	Values
Mass carbonaceous oxygen demand	FO_C	kgO_2/d	10
Carbonaceous oxygen utilization rate	O_c	kgO_2/d	0.32
Nitrification oxygen demand	FO_n	kgO_2/d	4
Total oxygen demand	FO_t	kgO_2/d	14
Oxygen recovered by denitrification	FO_d	kgO_2/d	2
Net total oxygen demand (AOR)	FO_{td}	kgO_2/d	11
Oxygen saturation @ operating temp.	c_s	mg/l	10.9
Desired oxygen level	c_x	mg/l	1.5
Transfer coefficient	α	-	0.4
Diffuser water depth	DWD	feet	7.3
Oxygen transfer efficiency	OTE	%	1.5
Standard total oxygen demand (SOR)	SOR	kgO_2/d	36
Required air flow	Q_{air}	scfm	29
Oxygen requir. per volume & depth	OS	$gO_2/(Nm^3 \cdot m_D)$	12
Required air flow, alternative	$Q_{air,alter.}$	scfm	33

$$FO_C = FS_{bi}\left[\left(1 - f_{cv} Y_{Hv}\right) + \left(1 - f_H\right) b_H \frac{Y_{Hv} f_{cv} SRT}{\left(1 + b_H SRT\right)}\right]$$

$$O_C = \frac{FO_C}{V_P} \qquad FO_n = 4.57 FN_{ne}$$

$$FO_t = FO_C + FO_n \qquad FO_d = 2.87\left(N_C - N_{ne}\right) Q_i$$

$$c_s = e^{-0.0209T}$$

$$SOR = \frac{1}{\alpha}\frac{c_s}{c_s\left(\frac{p_{a,1}}{p_{atm}}\right) - c_x} AOR(FO_{td})$$

$$Q_{air} = SOR\left(\frac{RT}{6.66 p_{a,1} OTE \cdot D}\right) \qquad Q_{air,alter.} = \frac{SOR}{D\frac{OS}{1000}}$$

Tank/Basin Inside Dimensions

Parameter	Length [ft]	Width [ft]	Diameter [ft]	Height [ft]	Liquid level [ft]	Volume [cf]	Volume [gallons]
Anoxic I	7.0	0.0	9.0	0.0	0.0	531	3,970
Anoxic II	0.0	0.0	0.0	0.0	0.0	0	0
Aerobic	0.0	0.0	0.0	0.0	0.0	0	0
Membrane	10.0	0.0	9.0	0.0	0.0	604	4,518
Sludge	8.0	0.0	9.0	0.0	0.0	591	4,422
EQ (Pump Station)	0.0	0.0	0.0	0.0	0.0	0	0

Membrane Module Layout

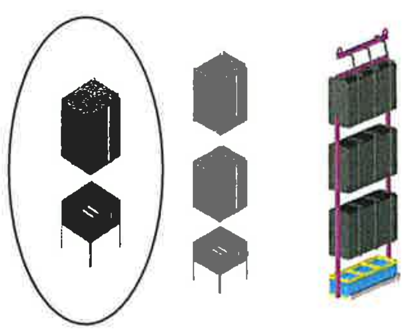
Parameter	Symbol	Unit	Values
Permeate on cycle	T_o	minute	8
Permeate off cycle (relaxation)	T_s	minute	2
Effective membrane module surface	$A_{m,eff}$	m^2	70
Effective membrane module surface	$A_{m,eff}$	ft^2	753
Total number of membrane modules	N_M	-	3
Total membrane module surface	A_{total}	m^2	210
Total membrane module surface	A_{total}	ft^2	2,260
Nominal average flux	$Q_{ave,n}$	lmh	15.8
Nominal monthly max. average flux	$Q_{ave,n,max,mo}$	lmh	19.7
Nominal peak flux (including duty cycles)	$Q_{peak,n}$	lmh	31.5
Nominal average flux	$Q_{ave,n}$	gfd	9.3
Nominal monthly max. average flux	$Q_{ave,n,max,mo}$	gfd	11.6
Nominal peak flux (including duty cycles)	$Q_{peak,n}$	gfd	18.6
Total membrane module displacement vol.	$V_{modules}$	ft^3	33
Total membrane module displacement vol.	$V_{modules}$	gallons	247
Aeration modules	A#	-	3
Membrane module aeration requirement	Q_{am}	acfm	29
Total membrane modules aeration requirement	$Q_{am.total}$	acfm	88
Membrane diffuser water depth	DWD_m	feet	7.3
Oxygen requirement per volume & depth	OS	$gO_2/(Nm_3 {}^* m_D)$	12
Standard oxygen rate, membrane aeration	SOR_m	lbO_2/d	210
Standard oxygen rate, membrane aeration	SOR_m	kgO_2/d	96

Tank Volumes

Parameter	Unit	Values
Total tank volume	gallons	8,242
Unaerated tank percentage	%	48%
Membrane modules volume	gallons	247
F/M_{used}	kgCOD/ kgMLSS	0.045
F/M_{used}	kgBOD/ kgMLSS	0.036

Weir Design

Parameter	Unit	Values
Level over weir	inches	1.0
Weir length	ft	2.0
Velocity	fps	0.94



Membrane modules Type U70-002 single stack layout is chosen for this design

Air Piping & Blower Design

Parameter	Symbol	Unit	Membrane	Aerobic	Sludge
Minimum air flow for membrane modules	$Q_{A,re}$	acfm	88	29	18
Chosen air flow for membrane modules - actual	$Q_{A,\ chosen}$	acfm	100	0	26
Chosen air flow for membrane modules - inlet	$Q_{A,chosen}$	scfm	111	0	28
Chosen air flow for membrane modules - piping	$Q_{A,chosen}$	acfm	82	0	21
Pipe pressure	p_b	psi	5.0	0.0	5.0
Pipe losses	H	psi	0.30	0.00	0.13
Equivalent length in pipe looses	L_p	feet	850	0	750
Internal pipe diameter	d_i	inches	3.3	2.3	2.3
Standard temperature	T_1	K	293	293	293
Pipe temperature	T_2	K	319	293	319
Constant	f	-	0.02	0.13	0.03
Air velocity	v	fps	23.6	0.0	12.6
Atmospheric pressure	$p_{a,l}$	psi	14.2	14.2	14.2
Absolute pressure	p_2	psi	19.2	14.2	19.2
Pressure due to tank liquid level	$p_{DWD,m}$	psi	3.2	3.2	3.7
Pressure due to aeration device	p_{DWD}	psi	1.0	0.9	0.5
Pressure due to pipe losses	$p_{DWD,S}$	psi	0.3	0.0	0.1
Total pipe losses	p_t	psi	4.4	4.1	4.3

Equivalent for fitting losses

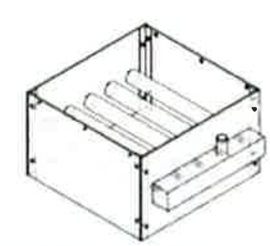
	Membrane piping			Aeration Piping			Sludge Piping		
	k	Quantity	Subtotal	k	Quantity	Subtotal	k	Quantity	Subtotal
Ball valve	0.10	0	0.00	0.10	0	0.00	0.10	0	0.00
Swing check	2.50	1	2.50	2.50	1	2.50	2.50	1	2.50
Butterfly valve	0.50	2	1.00	0.50	2	1.00	0.50	2	1.00
45° Elbow	0.35	0	0.00	0.35	0	0.00	0.35	0	0.00
90° Elbow	0.25	4	1.00	0.25	4	1.00	0.25	4	1.00
Tee through	0.60	2	1.20	0.60	2	1.20	0.60	2	1.20
Tee branch	1.80	1	1.80	1.80	1	1.80	1.80	1	1.80
Exit	1.00	0	0.00	1.00	0	0.00	1.00	0	0.00
	750		7.50	625		7.50	625		7.50

$$H = 9.82 \cdot 10^{-8} \frac{\left(f \cdot L_p T_2 Q_{A,chosen}\right)}{\left(p_2 d_i\right)^5}$$

$$f = \frac{0.029 d_i^{0.027}}{Q_{A,chosen}^{0.148}}$$

$$T_2 = T_1 \left(\frac{p_2}{p_{a,1}}\right)^{0.283}$$

Generally, rotary lobe blowers are used for double and triple membrane stacked modules, side channel blowers for single stack layout



Aeration module type B70-002 for membrane module type U70-002

Nitrogen Removal

Parameter	Symbol	Unit	Values
Factor of safety	S_f	-	1.25
Influent unbio. soluble organic N	N_{ousi}	mgN/l	0.6
Influent unbio. particular org. N	N_{oupi}	mgN/l	2.9
Influent biodegradable organic N	N_{obi}	mgN/l	4.4
Effluent unbio. soluble organic N	N_{ouse}	mgN/l	0.6
NH4 concentration avail. for nitri.	N_{an}	mgN/l	13.9
Effluent ammonia	N_{ae}	mgN/l	0.9
Effluent TKN	N_{te}	mgN/l	1.5
N concentration into sludge prod.	N_s	mgN/l	5.5
Nitrification capacity	N_c	mgN/l	13.0
Mass nitrifiers	MX_A	kgVSS	2
Mass nitrogen into sludge prod.	FN_S	kgN/d	0
Mass of nitrate generated per day	1	kgN/d	1
Temperature sensitivity coefficient	Θ_{nk1}	-	1.2
Temperature sensitivity coefficient	Θ_{nk2}	-	1.08
Temperature sensitivity coefficient	Θ_{nk3}	-	1.029
Denitrification rates at 20°C	k_1	-	0.7
Denitrification rates at 20°C	k_2	-	0.101
Denitrification rates at 20°C	k_3	-	0.072
Denitrification rates	k_{1T}	-	0.163
Denitrification rates	k_{2T}	-	0.055
Denitrification rates	k_{3T}	-	0.057
Denitrification potential RBCOD	$D_{p1RBCOD}$	$mgNO_3$-N/l	6.6
Denitrification potential SBCOD	$D_{p1SBCOD}$	$mgNO_3$-N/l	9.2
Denitrification potential RBCOD	$D_{p3RBCOD}$	$mgNO_3$-N/l	0.0
Denitrification potential SBCOD	$D_{p3SBCOD}$	$mgNO_3$-N/l	0.0
Minimum sludge age for nitri.	SRT_m	d	22
Permissible unaer. sludge mass fraction	f_{xm}	-	0.54
Design unaerated sludge mass fraction	f_{xt}	-	0.48
Minimum primary anoxic mass fraction	f_{x1min}	-	0.12
Primary anoxic mass fraction	f_{x1}	-	0.48
Secondary anoxic mass fraction	f_{x2}	-	0
Denitrification potential primary tank	D_{p1}	mgN/l	15.8
Denitrification potential secondary tank	D_{p2}	mgN/l	0.0
Denitrification potential due to recycle rate @ ($f_{xm} = f_{xdm}$)	D_{p^*}	mgN/l	11.1
DO in a recycle	O_a	mgO_2/l	0
DO in m recycle	O_m	mgO_2/l	0
Underflow/membrane recycle ratio	m	-	6
Recycle ratio	a	-	0
Effluent nitrate	N_{ne}	mgN/l	0.0
Effluent nitrate @ f_{xdm} & recycle rate	N_{ne^*}	mgN/l	3.0

$$N_{ousi} = N_{ouse} = f_{N'a} N_{ti} \qquad N_{oupi} = \frac{f_n f_{S'up} S_{ti}}{f_{cv}}$$

$$N_{obi} = N_{ti}\left(1 - f_{N'a} - f_{N'ous}\right) \qquad N_{an} = N_{ti} - N_S - N_{ousi}$$

$$N_{ae} = \frac{K_{nT}\left(b_{AT} + \frac{1}{SRT}\right)}{\mu_{AmTpH}\left(1 - f_{xt}\right) - \left(b_{AT} + \frac{1}{SRT}\right)}$$

$$N_{te} = N_{ae} + N_{ouse} \qquad N_S = \frac{f_n MX_v}{Q_i SRT}$$

$$N_C = N_{ti} - N_S - N_{te} \qquad MX_A = \frac{FN_{ne} Y_A SRT}{\left(1 + b_{AT} SRT\right)}$$

$$FN_S = Q_i N_S \qquad FN_{ne} = Q_i N_{ne}$$

$$K_{jT} = k_j \theta^{(T-20)}$$

$$D_{p1RBCOD} = \frac{f_{Sb's} S_{bi}\left(1 - f_{cv} Y_{Hv}\right)}{2.86} \qquad D_{p1SBCOD} = \frac{K_{2T} f_{x1} MX_{BH}}{Q_i}$$

$$D_{p3SBCOD} = \frac{K_{3T} f_{x3} MX_{BH}}{Q_i}$$

$$SRT_m = \frac{1}{\mu_{AmTpH}\left(1 - f_{xt}\right) - b_{AT}} \qquad f_{xm} = \frac{1 - S_f\left(b_{AT} + \frac{1}{SRT}\right)}{\mu_{AmTpH}}$$

$$f_{x1\min} = \frac{f_{Sb's} S_{bi}\left(1 - f_{cv} Y_{Hv}\right)\left(1 + b_{HT} SRT\right)}{2.86 K_{1T} Y_{Hv} SRT}$$

$$f_{xt} = f_{x1} + f_{x2}$$

$$D_{p1} = D_{p1RBCOD} + D_{p1SBCOD}$$

$$D_{p3} = D_{p3RBCOD} + D_{p3SBCOD}$$

$$N_{ne} = N_{al} - N_{ae} + \frac{aO_a}{2.86} + \frac{sO_S}{2.86} - D_{p1} - D_{p2}$$

$$N = N_{te} - N_{ne}$$

Alkalinity

Parameter	Symbol	Values	Parameter
Alkalinity Nitrification as CaCO3 (consumed)	Alk_{Nitri}	mg/l as $CaCO_3$	1
Alkalinity Denitrification as CaCO3 (recovered)	$Alk_{Denitri}$	mg/l as $CaCO_3$	0
Alkalinity ef	Alk_e	mg/l as $CaCO_3$	50
Alkalinity inf	Alk_i	mg/l as $CaCO_3$	40
Alkalinity Alum (consumed)	Alk_{Alum}	mg/l as $CaCO_3$	13
Alkalinity Total	Alk_{total}	mg/l as $CaCO_3$	-24
Alkalinity Added	Alk_{added}	mg/l as $CaCO_3$	74
Alkalinity Added	$XAlk_{added}$	lb/d	10.3
Density caustic solution (50%)	-	lb/gal	12.8
Alkalinity recovered	$Alk_{recovered}$	$lbCaCO_3/lb$	0.4
Caustic needed	-	lb/d	4.1
Caustic needed	-	gpd	0.3

$$Alk_{Nitri} = Q_i\left(N_{ne} + N_{ae}\right)7.14$$

$$Alk_{Denitri} = Q_i N_{ne} 3.57$$

$$Alk_{Alum} = Q_i 7.14 S_{Alum} 0.45$$

$$Alk_{total} = Alk_i - Alk_e - Alk_{Denitri} + Alk_{Nitri} - Alk_{Alum}$$

Phosphorous Removal

Parameter	Symbol	Values	Parameter
Influent P	P_{ti}	mgP/l	8.0
Effluent P	P_{te}	mgP/l	0.5
P into sludge production	P_s	mgP/l	2.3
P used for biological process	P_{bio}	mgP/l	2.8
P precipitated	P_{prec}	mgP/l	2.4
Precipitation chemical	B_{Alum}	lb/d	4.0
Precipitation chemical	Solution	gal/d	0.4
Density Alum	z_{AL}^{3+}	lb_{AL}/lb_{prec}	0.0997
Density Iron	z_{FE}^{3+}	lb_{FE}/lb_{prec}	0.0766
Alum efficiency	-	g/kg	40
Chemical precipitation sludge	-	lb/d	0.8

$$P_{bio} = 0.015 \cdot S_{ti,COD}\left(1 - f_{S'up} - f_{S'us}\right)$$

$$P_S = \frac{f_P N_S}{f_n}$$

$$B_{Alum} = P_{prec} 1.2 \frac{Q_i}{z}$$

$$P_{prec} = P_{ti} - P_{te} - P_S - P_{bio}$$

CALCULATION SCENARIO II

Biological Process Calculation

Summary of Influent, Effluent, and Operating Characteristics

Parameter	Symbol	Unit	Values
Average daily flow	Q_i	gpd	16,800
Max. monthly average daily flow	$Q_{i, max,o}$	gpd	21,000
Peak flow	$Q_{i, max,p}$	gpm	23
Peak factor	-	-	2.0
Average daily flow	Q_i	m_3/d	64
Max. monthly average daily flow	$Q_{i, max,o}$	m_3/d	79
Hourly peak flow	$Q_{i, max,h}$	m^3/h	5
Influent BOD concentration	$S_{ti,BOD}$	mgBOD/l	250
Influent COD concentration	$S_{ti,COD}$	mgCOD/l	400
Influent TSS	$S_{ti,TSS}$	mgTSS/l	250
Biodegradable COD	S_{bi}	mgCOD/l	312
Total BOD in	FS_{ti}	kgBOD/d	16
Total COD in	FS_{ti}	kgCOD/d	25
BOD/COD ratio	-	-	1.60
Influent NH_4 concentration	N_{ai}	mgNH_4/l	34
Influent TKN concentration	N_{ti}	mgN/l	45
Influent FSA fraction	$f_{N'a}$	-	0.76
Influent P concentration	P_{ti}	mgP/l	10
Site pressure / elevation	$p_{a,i}$	psu	14.2
Temperature	T	°C	12
pH	-	-	7.0
H_2CO_3 alkalinity	Alk_i	mg/l as $CaCO_3$	40
Influent ISS	X_{IOi}	mgISS/l	47.8
Reactor volume	$V_{P,chosen}$	gallons	8,242
Sludge age	SRT	d	46
Waste Sludge	FX_t	lb/d	17
Waste Sludge	Q_w	gpd	176
Food to microorganism ratio	F/M_{used}	kgCOD/kgMLSS	0.053
Food to microorganism ratio	F/M_{used}	kgBOD/kgMLSS	0.042
Effluent P	P_{te}	mgP/l	0.5
Effluent BOD	$S_{te,BOD}$	mgBOD/l	<3
Effluent ammonia	N_{ae}	mgN/l	0.9
Effluent nitrate	N_{ne}	mgN/l	6.6
Total effluent N (N_{ne} + N_{te})	N	mgN/l	8.9
Effluent nitrate @ fxdm & opt. recycle rate	N_{ne^*}	mgN/l	4.3
Total effluent N (N_{ne^*} + N_{te})	N*	mgN/l	6.5
Nominal hydraulic retention time	HRT_n	h	11.8
Actual hydraulic retention time	HRT_a	h	1.7

State-of-the-Art Technology

The application of membrane bioreactor (MBR) technology represents the state-of-the-art technology for treating biological wastewater. While conventional treatment processes focus on the degradation of organic contaminants and nutrients such as nitrogen and phosphorous, MBRs also reject turbidity and microorganisms. This generates high-quality reuse water. MBR plants are extremely compact in size due to their high level of biomass and elimination of clarifiers. Further, the modular nature of membrane modules provides for very flexible plant concepts that can "grow", allowing investments to be made only when needed.

MBR Process

Membrane bioreactors combine conventional biological activated sludge processes with membrane filtration. The membranes are directly submerged in the activated sludge. The activated sludge (biomass) is separated from the liquid as it passes through the membranes and is retained in the biological reactor. Conventional sedimentation processes are not required. The small membrane pores retain suspended matter, bacteria, and viruses (pathogens). Membranes are arranged (packaged) in modules for easy installation and maintenance. Aeration devices are located at the bottom of membrane modules. Air bubbles create a cross flow parallel to the membrane surface and generate biomass degradation. The flow across the membranes creates a shear force that limits build-up on the membrane surface.

Achievable Effluent Values with proposed plant

< 3 mg/l | < 1 mg/l | < 10 mg/l | < 0.1 mg/l | < 0.1 mg/l | < 2 mpn/100ml

Constants

Parameter	Symbol	Unit	Values
TKN/COD ratio	f_{ns}	mgTKN/mgCOD	0.11
Carbon source addition (Micro C)	B_{MicroC}	lb/d	0
Unbiodegradable particular COD	$f_{S'up}$	-	0.15
Unbiodegradable soluble COD	$f_{S'us}$	-	0.07
Readily bio. org. fraction (RBCOD)	$f_{Sb's}$	-	0.25
VSS/TSS of activated sludge	f_i	mgVSS/mgTSS	0.75
COD/VSS of activated sludge	f_{cv}	kgCOD/kgVSS	1.48
True synthesis fraction	f_s^0	-	0.57
Yield coefficient	Y_{Hv}	mgVSS/mgCOD	0.40
Temperature sensitivity coefficient	Θ_b	-	1.029
Endo. respiration rate (decay)	b_H	gVSS/gVSSd	0.24
Endogenous respiration rate T	b_{HT}	gVSS/gVSSd	0.19
Endogenous residue fraction	f_H	-	0.20
ISS content of OHOs	f_{iOHO}	-	0.15
Yield coefficient	Y_A	mgVSS/mgFSA	0.1
Endogenous respiration rate	b_A	1/d	0.04
Endo. respiration rate - Temp	b_{AT}	1/d	0.032
Temperature sensitivity coefficient	Θ_n	-	1.123
Nitri. pH sensitivity coefficient	K_I	-	1.13
Nitri. pH sensitivity coefficient	K_{max}	-	9.5
Nitri. pH sensitivity coefficient	K_{II}	-	0.3
Max. specific growth rate at 20°C	μ_{Am}	1/d	0.45
Max. spec. growth rate - Temp/pH	μ_{AmTpH}	1/d	0.15
Half saturation coefficient	K_n	mgFSA/l	1
Half saturation coefficient - Temp	K_{nT}	mgFSA/l	0.40
Sludge age calculated	SRT_{calc}	d	40
Unbio. soluble orgN fraction	$f_{N'ous}$	-	0.03
Unbio. particular orgN fraction	f_n	-	0.12
Unbio. particular orgP fraction	f_P	mgP/mgVSS	0.05

$$HRT_n = \frac{V_P}{Q_i} \qquad HRT_a = \frac{HRT_n}{1+m+a} \qquad SRT = \frac{V_P}{Q_w}$$

$$b_{AT} = k_{A20}\left(\theta_b\right)^{(T-20)}$$

$$\mu_{AmTpH} = \mu_{Am20}\left(\theta_n\right)^{(T-20)} K_I \frac{K_{max} - pH}{K_{max} + K_{II} - pH} \_for\_ph > 7.2$$

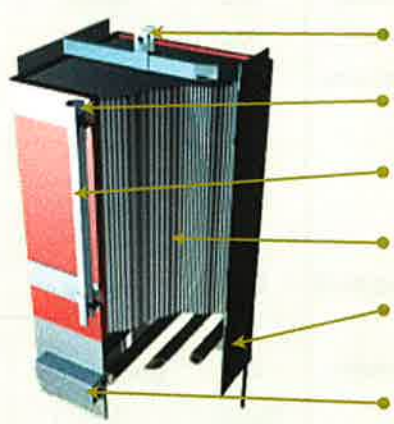
$$\mu_{AmTpH} = \mu_{Am20}\left(\theta_n\right)^{(T-20)} \quad (pH-7.2)$$

$$K_{nT} = k_{n20}\left(\theta_n\right)^{(T-20)}$$

$$SRT_{calc} = \quad (15-T)$$

MBR Benefits

- Continuous superior effluent quality
- Compact footprint
- Scalable
- Class A reuse water
- Easy operation
- Low maintenance
- Disinfection equipment is reduced or eliminated
- Fully automated operation
- Operation at an average MLSS of 10,000 - 15,000 g/l
- Increased sludge age approves treatment capability
- Lower waste sludge production



Biological Mass Balance

Parameter	Symbol	Unit	Values
Influent biodegradable COD mass	FS_{bi}	kgCOD/d	20
Influent particular unbio. COD mass	FX_{Ivi}	kgVSS/d	3
Influent particular inorg. COD mass	FX_{IOi}	kgISS/d	3
Sludge age	SRT	d	46
Mixed liquor suspended solids	X_t	mgTSS/l	12,000
Active organism mass	MX_{BHv}	kgVSS	38
Endogenous residue mass	MX_{EHv}	kgVSS	66
Unbiodegradable particular mass	MX_{Iv}	kgVSS	119
Volatile suspended solids mass	MX_v	kgVSS	222
Inorganic suspended solid mass	MX_{IO}	kgISS	145
Total suspended solids mass	MX_t	kgTSS	368
Active fraction - VSS	f_{avOHO}	-	0.169
Active fraction - TSS	f_{at}	-	0.13
Mass/Sludge TSS wasted	FX_t	KgTSS/d	8
Mass/Sludge VSS wasted	FX_v	kgVSS/d	6
Effluent COD	S_{te}	mgCOD/l	28.0
COD mass out (effluent and waste)	FS_{te}	kgCOD/d	1.8
Mass/Sludge COD wasted	FX_{COD}	kgCOD/d	7
Reactor volume	V_P	gallons	8,091
Reactor volume	V_P	m^3	31
Food to microorganism ratio	F/M	$kgFS_{bi}$/kgMLSS	0.054
Food to microorganism ratio	F/M	kgBOD/kgMLSS	0.043

$$FS_{bi} = Q_i S_{ti}(1 - f_{S'us} - f_{S'up}) + B_{MicroC} \qquad FX_{Ivi} = \frac{FS_{ti} f_{S'up}}{f_{cv}}$$

$$FX_{IOi} = Q_i X_{IOi}$$

$$MX_{BHv} = FS_{bi} \frac{Y_{Hv} SRT}{(1 + b_H SRT)} \qquad MX_{EHv} = f_H b_H MX_{BHv} SRT$$

$$MX_{Iv} = FX_{Ivi} SRT \qquad MX_v = MX_{BHv} + MX_{Ev} + MX_{Iv}$$

$$MX_{IO} = FX_{IOi} SRT + f_{iOHO} MX_{BHv} \qquad MX_t = MX_v + MX_{IO}$$

$$f_{avOHO} = \frac{MX_{BHv}}{MX_v} \qquad f_{at} = f_i f_{av} \qquad f_i = \frac{MX_v}{MX_t}$$

$$FX_t = \frac{MX_t}{SRT} \qquad FX_v = FX_t f_i$$

$$S_{te} = S_{le} = f_{S'us} S_{ti} \qquad FS_{te} = S_{te} Q_{ti}$$

$$FX_{COD} = \frac{MX_v f_{cv}}{SRT}$$

$$V_P = \frac{MX_t}{X_t} \qquad F/M = \frac{FS_{ti}}{V_P X_t}$$

Biological Oxygen Demand

Parameter	Symbol	Unit	Values
Mass carbonaceous oxygen demand	FO_C	kgO_2/d	17
Carbonaceous oxygen utilization rate	O_c	kgO_2/d	0.54
Nitrification oxygen demand	FO_n	kgO_2/d	10
Total oxygen demand	FO_t	kgO_2/d	26
Oxygen recovered by denitrification	FO_d	kgO_2/d	5
Net total oxygen demand (AOR)	FO_{td}	kgO_2/d	21
Oxygen saturation @ operating temp.	c_s	mg/l	10.9
Desired oxygen level	c_x	mg/l	1.5
Transfer coefficient	α	-	0.4
Diffuser water depth	DWD	feet	7.3
Oxygen transfer efficiency	OTE	%	1.5
Standard total oxygen demand (SOR)	SOR	kgO_2/d	68
Required air flow	Q_{air}	scfm	55
Oxygen requir. per volume & depth	OS	$gO_2/(Nm^3 {*} m_D)$	12
Required air flow, alternative	$Q_{air,alter.}$	scfm	62

$$FO_C = FS_{bi}\left[\left(1 - f_{cv} Y_{Hv}\right) + \left(1 - f_H\right) b_H \frac{Y_{Hv} f_{CV} SRT}{\left(1 + b_H SRT\right)}\right]$$

$$O_C = \frac{FO_C}{V_P} \qquad FO_n = 4.57 FN_{ne}$$

$$FO_t = FO_C + FO_n \qquad FO_d = 2.87\left(N_C - N_{ne}\right) Q_i$$

$$c_s = e^{-0.0209T}$$

$$SOR = \frac{1}{\alpha} \frac{c_s}{c_s\left(\frac{p_{a,1}}{p_{atm}}\right) - c_x} AOR(FO_{td})$$

$$Q_{air} = SOR\left(\frac{RT}{6.66 p_{a,1} OTE \cdot D}\right) \qquad Q_{air,alter.} = \frac{SOR}{D\frac{OS}{1000}}$$

Tank/Basin Inside Dimensions

Parameter	Length [ft]	Width [ft]	Diameter [ft]	Height [ft]	Liquid level [ft]	Volume [cf]	Volume [gallons]
Anoxic I	7.0	0.0	9.0	0.0	0.0	531	3,970
Anoxic II	0.0	0.0	0.0	0.0	0.0	0	0
Aerobic	0.0	0.0	0.0	0.0	0.0	0	0
Membrane	10.0	0.0	9.0	0.0	0.0	604	4,518
Sludge	8.0	0.0	9.0	0.0	0.0	591	4,422
EQ (Pump Station)	0.0	0.0	0.0	0.0	0.0	0	0

Membrane Module Layout

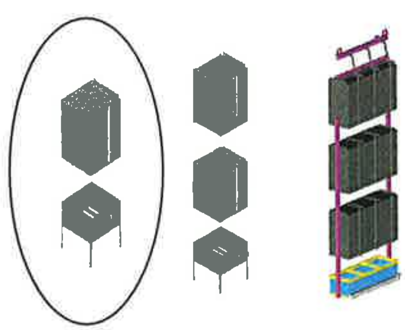
Parameter	Symbol	Unit	Values
Permeate on cycle	T_o	minute	8
Permeate off cycle (relaxation)	T_s	minute	2
Effective membrane module surface	$A_{m,eff}$	m^2	70
Effective membrane module surface	$A_{m,eff}$	ft^2	753
Total number of membrane modules	N_M	-	3
Total membrane module surface	A_{total}	m^2	210
Total membrane module surface	A_{total}	ft^2	2,260
Nominal average flux	$Q_{ave,n}$	lmh	15.8
Nominal monthly max. average flux	$Q_{ave,n,max,mo}$	lmh	19.7
Nominal peak flux (including duty cycles)	$Q_{peak,n}$	lmh	31.5
Nominal average flux	$Q_{ave,n}$	gfd	9.3
Nominal monthly max. average flux	$Q_{ave,n,max,mo}$	gfd	11.6
Nominal peak flux (including duty cycles)	$Q_{peak,n}$	gfd	18.6
Total membrane module displacement vol.	$V_{modules}$	ft^3	33
Total membrane module displacement vol.	$V_{modules}$	gallons	247
Aeration modules	A#	-	3
Membrane module aeration requirement	Q_{am}	acfm	29
Total membrane modules aeration requirement	$Q_{am.total}$	acfm	88
Membrane diffuser water depth	DWD_m	feet	7.3
Oxygen requirement per volume & depth	OS	$gO_2/(Nm_3{*}m_D)$	12
Standard oxygen rate, membrane aeration	SOR_m	lbO_2/d	210
Standard oxygen rate, membrane aeration	SOR_m	kgO_2/d	96

Tank Volumes

Parameter	Unit	Values
Total tank volume	gallons	8,242
Unaerated tank percentage	%	48%
Membrane modules volume	gallons	247
F/M_{used}	kgCOD/ kgMLSS	0.053
F/M_{used}	kgBOD/ kgMLSS	0.042

Weir Design

Parameter	Unit	Values
Level over weir	inches	1.0
Weir length	ft	2.0
Velocity	fps	0.94



Membrane modules Type U70-002 single stack layout is chosen for this design

Air Piping & Blower Design

Parameter	Symbol	Unit	Membrane	Aerobic	Sludge
Minimum air flow for membrane modules	$Q_{A,re}$	acfm	88	55	18
Chosen air flow for membrane modules - actual	$Q_{A,\ chosen}$	acfm	100	0	26
Chosen air flow for membrane modules - inlet	$Q_{A,chosen}$	scfm	111	0	28
Chosen air flow for membrane modules - piping	$Q_{A,chosen}$	acfm	82	0	21
Pipe pressure	p_b	psi	5.0	0.0	5.0
Pipe losses	H	psi	0.30	0.00	0.13
Equivalent length in pipe looses	L_p	feet	850	0	750
Internal pipe diameter	d_i	inches	3.3	2.3	2.3
Standard temperature	T_1	K	293	293	293
Pipe temperature	T_2	K	319	293	319
Constant	f	-	0.02	0.13	0.03
Air velocity	v	fps	23.6	0.0	12.6
Atmospheric pressure	$p_{a,l}$	psi	14.2	14.2	14.2
Absolute pressure	p_2	psi	19.2	14.2	19.2
Pressure due to tank liquid level	$p_{DWD,m}$	psi	3.2	3.2	3.7
Pressure due to aeration device	p_{DWD}	psi	1.0	0.9	0.5
Pressure due to pipe losses	$p_{DWD,S}$	psi	0.3	0.0	0.1
Total pipe losses	p_t	psi	4.4	4.1	4.3

Equivalent for fitting losses

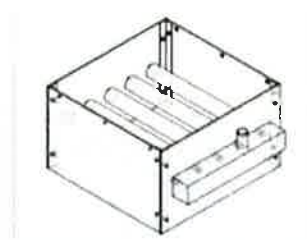
	Membrane piping			Aeration Piping			Sludge Piping		
	k	Quantity	Subtotal	k	Quantity	Subtotal	k	Quantity	Subtotal
Ball valve	0.10	0	0.00	0.10	0	0.00	0.10	0	0.00
Swing check	2.50	1	2.50	2.50	1	2.50	2.50	1	2.50
Butterfly valve	0.50	2	1.00	0.50	2	1.00	0.50	2	1.00
45° Elbow	0.35	0	0.00	0.35	0	0.00	0.35	0	0.00
90° Elbow	0.25	4	1.00	0.25	4	1.00	0.25	4	1.00
Tee through	0.60	2	1.20	0.60	2	1.20	0.60	2	1.20
Tee branch	1.80	1	1.80	1.80	1	1.80	1.80	1	1.80
Exit	1.00	0	0.00	1.00	0	0.00	1.00	0	0.00
	750		7.50	625		7.50	625		7.50

$$H = 9.82 \cdot 10^{-8} \frac{\left(f \cdot L_p T_2 Q_{A,chosen}\right)}{\left(p_2 d_i\right)^5}$$

$$f = \frac{0.029 d_i^{0.027}}{Q_{A,chosen}^{0.148}}$$

$$T_2 = T_1 \left(\frac{p_2}{p_{a,1}}\right)^{0.283}$$

Generally, rotary lobe blowers are used for double and triple membrane stacked modules, side channel blowers for single stack layout



Aeration module type B70-002 for membrane module type U70-002

Nitrogen Removal

Parameter	Symbol	Unit	Values
Factor of safety	S_f	-	1.25
Influent unbio. soluble organic N	N_{ousi}	mgN/l	1.35
Influent unbio. particular org. N	N_{oupi}	mgN/l	4.9
Influent biodegradable organic N	N_{obi}	mgN/l	9.7
Effluent unbio. soluble organic N	N_{ouse}	mgN/l	1.35
NH4 concentration avail. for nitri.	N_{an}	mgN/l	34.5
Effluent ammonia	N_{ae}	mgN/l	0.9
Effluent TKN	N_{te}	mgN/l	2.2
N concentration into sludge prod.	N_s	mgN/l	9.1
Nitrification capacity	N_c	mgN/l	33.7
Mass nitrifiers	MX_A	kgVSS	4
Mass nitrogen into sludge prod.	FN_S	kgN/d	1
Mass of nitrate generated per day	1	kgN/d	2
Temperature sensitivity coefficient	θ_{nk1}	-	1.2
Temperature sensitivity coefficient	θ_{nk2}	-	1.08
Temperature sensitivity coefficient	θ_{nk3}	-	1.029
Denitrification rates at 20°C	k_1	-	0.7
Denitrification rates at 20°C	k_2	-	0.101
Denitrification rates at 20°C	k_3	-	0.072
Denitrification rates	k_{1T}	-	0.163
Denitrification rates	k_{2T}	-	0.055
Denitrification rates	k_{3T}	-	0.057
Denitrification potential RBCOD	$D_{p1RBCOD}$	$mgNO_3$-N/l	11.0
Denitrification potential SBCOD	$D_{p1SBCOD}$	$mgNO_3$-N/l	15.5
Denitrification potential RBCOD	$D_{p3RBCOD}$	$mgNO_3$-N/l	0.0
Denitrification potential SBCOD	$D_{p3SBCOD}$	$mgNO_3$-N/l	0.0
Minimum sludge age for nitri.	SRT_m	d	22
Permissible unaer. sludge mass fraction	f_{xm}	-	0.55
Design unaerated sludge mass fraction	f_{xt}	-	0.48
Minimum primary anoxic mass fraction	f_{x1min}	-	0.11
Primary anoxic mass fraction	f_{x1}	-	0.48
Secondary anoxic mass fraction	f_{x2}	-	0
Denitrification potential primary tank	D_{p1}	mgN/l	26.5
Denitrification potential secondary tank	D_{p2}	mgN/l	0.0
Denitrification potential due to recycle rate @ ($f_{xm} = f_{xdm}$)	$D_{p'}$	mgN/l	28.9
DO in a recycle	O_a	mgO_2/l	0
DO in m recycle	O_m	mgO_2/l	0
Underflow/membrane recycle ratio	m	-	6
Recycle ratio	a	-	0
Effluent nitrate	N_{ne}	mgN/l	6.6
Effluent nitrate @ f_{xdm} & recycle rate	$N_{ne'}$	mgN/l	4.3

$$N_{ousi} = N_{ouse} = f_{N'a} N_{ti} \qquad N_{oupi} = \frac{f_n f_{S'up} S_{ti}}{f_{cv}}$$

$$N_{obi} = N_{ti}\left(1 - f_{N'a} - f_{N'ous}\right) \qquad N_{an} = N_{ti} - N_S - N_{ousi}$$

$$N_{ae} = \frac{K_{nT}\left(b_{AT} + \frac{1}{SRT}\right)}{\mu_{AmTpH}\left(1 - f_{xt}\right) - \left(b_{AT} + \frac{1}{SRT}\right)}$$

$$N_{te} = N_{ae} + N_{ouse} \qquad N_S = \frac{f_n MX_v}{Q_i SRT}$$

$$N_C = N_{ti} - N_S - N_{te} \qquad MX_A = \frac{FN_{ne} Y_A SRT}{\left(1 + b_{AT} SRT\right)}$$

$$FN_S = Q_i N_S \qquad FN_{ne} = Q_i N_{ne}$$

$$K_{jT} = k_j \theta^{(T-20)}$$

$$D_{p1RBCOD} = \frac{f_{Sb's} S_{bi}\left(1 - f_{cv} Y_{Hv}\right)}{2.86} \qquad D_{p1SBCOD} = \frac{K_{2T} f_{x1} MX_{BH}}{Q_i}$$

$$D_{p3SBCOD} = \frac{K_{3T} f_{x3} MX_{BH}}{Q_i}$$

$$SRT_m = \frac{1}{\mu_{AmTpH}\left(1 - f_{xt}\right) - b_{AT}} \qquad f_{xm} = \frac{1 - S_f\left(b_{AT} + \frac{1}{SRT}\right)}{\mu_{AmTpH}}$$

$$f_{x1min} = \frac{f_{Sb's} S_{bi}\left(1 - f_{cv} Y_{Hv}\right)\left(1 + b_{HT} SRT\right)}{2.86 K_{1T} Y_{Hv} SRT}$$

$$f_{xt} = f_{x1} + f_{x2}$$

$$D_{p1} = D_{p1RBCOD} + D_{p1SBCOD}$$

$$D_{p3} = D_{p3RBCOD} + D_{p3SBCOD}$$

$$N_{ne} = N_{ai} - N_{ae} + \frac{aO_a}{2.86} + \frac{sO_S}{2.86} - D_{p1} - D_{p2}$$

$$N = N_{te} - N_{ne}$$

Alkalinity

Parameter	Symbol	Values	Parameter
Alkalinity Nitrification as CaCO3 (consumed)	Alk_{Nitri}	mg/l as $CaCO_3$	8
Alkalinity Denitrification as CaCO3 (recovered)	$Alk_{Denitri}$	mg/l as $CaCO_3$	3
Alkalinity ef	Alk_e	mg/l as $CaCO_3$	50
Alkalinity inf	Alk_i	mg/l as $CaCO_3$	40
Alkalinity Alum (consumed)	Alk_{Alum}	mg/l as $CaCO_3$	6
Alkalinity Total	Alk_{total}	mg/l as $CaCO_3$	-20
Alkalinity Added	Alk_{added}	mg/l as $CaCO_3$	70
Alkalinity Added	$XAlk_{added}$	lb/d	9.7
Density caustic solution (50%)	-	lb/gal	12.8
Alkalinity recovered	$Alk_{recovered}$	lb$CaCO_3$/lb	0.4
Caustic needed	-	lb/d	3.9
Caustic needed	-	gpd	0.3

$$Alk_{Nitri} = Q_i\left(N_{ne} + N_{ab}\right)7.14$$

$$Alk_{Denitri} = Q_i N_{ne} 3.57$$

$$Alk_{Alum} = Q_i 7.14 S_{Alum} 0.45$$

$$Alk_{total} = Alk_i - Alk_e - Alk_{Denitri} + Alk_{Nitri} - Alk_{Alum}$$

Phosphorous Removal

Parameter	Symbol	Values	Parameter
Influent P	P_{ti}	mgP/l	10.0
Effluent P	P_{te}	mgP/l	0.5
P into sludge production	P_s	mgP/l	3.8
P used for biological process	P_{bio}	mgP/l	4.7
P precipitated	P_{prec}	mgP/l	1.0
Precipitation chemical	B_{Alum}	lb/d	1.7
Precipitation chemical	Solution	gal/d	0.2
Density Alum	$z_{AL^{3+}}$	lb_{AL}/lb_{prec}	0.0997
Density Iron	$z_{FE^{3+}}$	lb_{FE}/lb_{prec}	0.0766
Alum efficiency	-	g/kg	40
Chemical precipitation sludge	-	lb/d	0.3

$$P_{bio} = 0.015 \cdot S_{ti,COD}\left(1 - f_{S'up} - f_{S'us}\right)$$

$$P_S = \frac{f_p N_S}{f_n}$$

$$B_{Alum} = P_{prec} 1.2 \frac{Q_i}{z}$$

$$P_{prec} = P_{ti} - P_{te} - P_S - P_{bio}$$

CALCULATION SCENARIO III

Biological Process Calculation

Summary of Influent, Effluent, and Operating Characteristics

Parameter	Symbol	Unit	Values
Average daily flow	Q_i	gpd	16,800
Max. monthly average daily flow	$Q_{i,\,max,o}$	gpd	21,000
Peak flow	$Q_{i,\,max,p}$	gpm	23
Peak factor	-	-	2.0
Average daily flow	Q_i	m_3/d	64
Max. monthly average daily flow	$Q_{i,\,max,o}$	m_3/d	79
Hourly peak flow	$Q_{i,\,max,h}$	m^3/h	5
Influent BOD concentration	$S_{ti,BOD}$	mgBOD/l	400
Influent COD concentration	$S_{ti,COD}$	mgCOD/l	640
Influent TSS	$S_{ti,TSS}$	mgTSS/l	400
Biodegradable COD	S_{bi}	mgCOD/l	499
Total BOD in	FS_{ti}	kgBOD/d	25
Total COD in	FS_{ti}	kgCOD/d	41
BOD/COD ratio	-	-	1.60
Influent NH_4 concentration	N_{ai}	$mgNH_4/l$	40
Influent TKN concentration	N_{ti}	mgN/l	55
Influent FSA fraction	$f_{N'a}$	-	0.73
Influent P concentration	P_{ti}	mgP/l	12
Site pressure / elevation	$p_{a,i}$	psu	14.2
Temperature	T	°C	12
pH	-	-	7.0
H_2CO_3 alkalinity	Alk_i	mg/l as $CaCO_3$	40
Influent ISS	X_{IOi}	mgISS/l	47.8
Reactor volume	$V_{P,chosen}$	gallons	8,242
Sludge age	SRT	d	38
Waste Sludge	FX_t	lb/d	24
Waste Sludge	Q_w	gpd	215
Food to microorganism ratio	F/M_{used}	kgCOD/kgMLSS	0.074
Food to microorganism ratio	F/M_{used}	kgBOD/kgMLSS	0.059
Effluent P	P_{te}	mgP/l	0.5
Effluent BOD	$S_{te,BOD}$	mgBOD/l	<3
Effluent ammonia	N_{ae}	mgN/l	1.2
Effluent nitrate	N_{ne}	mgN/l	0.0
Total effluent N (N_{ne} + N_{te})	N	mgN/l	2.8
Effluent nitrate @ fxdm & opt. recycle rate	N_{ne^*}	mgN/l	6.9
Total effluent N (N_{ne^*} + N_{te})	N*	mgN/l	9.7
Nominal hydraulic retention time	HRT_n	h	11.8
Actual hydraulic retention time	HRT_a	h	1.7

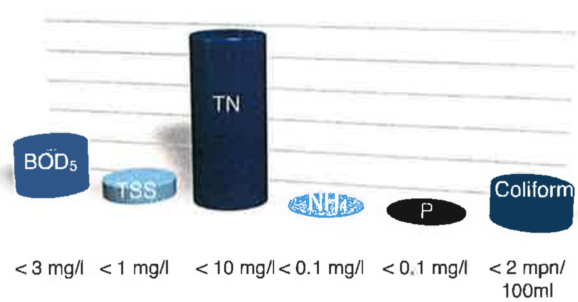
State-of-the-Art Technology

The application of membrane bioreactor (MBR) technology represents the state-of-the-art technology for treating biological wastewater. While conventional treatment processes focus on the degradation of organic contaminants and nutrients such as nitrogen and phosphorous, MBRs also reject turbidity and microorganisms. This generates high-quality reuse water. MBR plants are extremely compact in size due to their high level of biomass and elimination of clarifiers. Further, the modular nature of membrane modules provides for very flexible plant concepts that can "grow", allowing investments to be made only when needed.

MBR Process

Membrane bioreactors combine conventional biological activated sludge processes with membrane filtration. The membranes are directly submerged in the activated sludge. The activated sludge (biomass) is separated from the liquid as it passes through the membranes and is retained in the biological reactor. Conventional sedimentation processes are not required. The small membrane pores retain suspended matter, bacteria, and viruses (pathogens). Membranes are arranged (packaged) in modules for easy installation and maintenance. Aeration devices are located at the bottom of membrane modules. Air bubbles create a cross flow parallel to the membrane surface and generate biomass degradation. The flow across the membranes creates a shear force that limits build-up on the membrane surface.

Achievable Effluent Values with proposed plant



Constants

Parameter	Symbol	Unit	Values
TKN/COD ratio	f_{ns}	mgTKN/mgCOD	0.09
Carbon source addition (Micro C)	B_{MicroC}	lb/d	0
Unbiodegradable particular COD	$f_{S'up}$	-	0.15
Unbiodegradable soluble COD	$f_{S'us}$	-	0.07
Readily bio. org. fraction (RBCOD)	$f_{Sb's}$	-	0.25
VSS/TSS of activated sludge	f_i	mgVSS/mgTSS	0.75
COD/VSS of activated sludge	f_{cv}	kgCOD/kgVSS	1.48
True synthesis fraction	f_s^0	-	0.57
Yield coefficient	Y_{Hv}	mgVSS/mgCOD	0.40
Temperature sensitivity coefficient	Θ_b	-	1.029
Endo. respiration rate (decay)	b_H	gVSS/gVSSd	0.24
Endogenous respiration rate T	b_{HT}	gVSS/gVSSd	0.19
Endogenous residue fraction	f_H	-	0.20
ISS content of OHOs	f_{iOHO}	-	0.15
Yield coefficient	Y_A	mgVSS/mgFSA	0.1
Endogenous respiration rate	b_A	1/d	0.04
Endo. respiration rate - Temp	b_{AT}	1/d	0.032
Temperature sensitivity coefficient	Θ_n	-	1.123
Nitri. pH sensitivity coefficient	K_I	-	1.13
Nitri. pH sensitivity coefficient	K_{max}	-	9.5
Nitri. pH sensitivity coefficient	K_{II}	-	0.3
Max. specific growth rate at 20°C	μ_{Am}	1/d	0.45
Max. spec. growth rate - Temp/pH	μ_{AmTpH}	1/d	0.15
Half saturation coefficient	K_n	mgFSA/l	1
Half saturation coefficient - Temp	K_{nT}	mgFSA/l	0.40
Sludge age calculated	SRT_{calc}	d	40
Unbio. soluble orgN fraction	$f_{N'ous}$	-	0.03
Unbio. particular orgN fraction	f_n	-	0.12
Unbio. particular orgP fraction	f_P	mgP/mgVSS	0.05

$$HRT_n = \frac{V_P}{Q_i} \qquad HRT_a = \frac{HRT_n}{1+m+a} \qquad SRT = \frac{V_P}{Q_w}$$

$$b_{AT} = k_{A20}\left(\theta_b\right)^{(T-20)}$$

$$\mu_{AmTpH} = \mu_{Am20}\left(\theta_n\right)^{(T-20)} K_I \frac{K_{max} - pH}{K_{max} + K_{II} - pH} for\_ph > 7.2$$

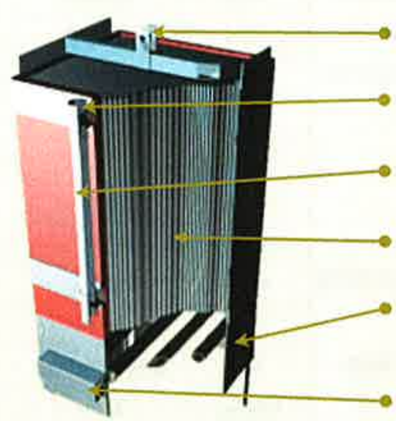
$$\mu_{AmTpH} = \mu_{Am20}\left(\theta_n\right)^{(T-20)} \; [illegible] ^{(pH-7.2)}$$

$$K_{nT} = k_{n20}\left(\theta_n\right)^{(T-20)}$$

$$SRT_{calc} = [illegible]^{(15-T)}$$

MBR Benefits

- Continuous superior effluent quality
- Compact footprint
- Scalable
- Class A reuse water
- Easy operation
- Low maintenance
- Disinfection equipment is reduced or eliminated
- Fully automated operation
- Operation at an average MLSS of 10,000 - 15,000 g/l
- Increased sludge age approves treatment capability
- Lower waste sludge production



Biological Mass Balance

Parameter	Symbol	Unit	Values
Influent biodegradable COD mass	FS_{bi}	kgCOD/d	32
Influent particular unbio. COD mass	FX_{Ivi}	kgVSS/d	4
Influent particular inorg. COD mass	FX_{IOi}	kgISS/d	3
Sludge age	SRT	d	38
Mixed liquor suspended solids	X_t	mgTSS/l	13,750
Active organism mass	MX_{BHv}	kgVSS	59
Endogenous residue mass	MX_{EHv}	kgVSS	85
Unbiodegradable particular mass	MX_{Iv}	kgVSS	157
Volatile suspended solids mass	MX_V	kgVSS	301
Inorganic suspended solid mass	MX_{IO}	kgISS	124
Total suspended solids mass	MX_t	kgTSS	425
Active fraction - VSS	f_{avOHO}	-	0.195
Active fraction - TSS	f_{at}	-	0.15
Mass/Sludge TSS wasted	FX_t	KgTSS/d	11
Mass/Sludge VSS wasted	FX_V	kgVSS/d	8
Effluent COD	S_{te}	mgCOD/l	44.8
COD mass out (effluent and waste)	FS_{te}	kgCOD/d	2.8
Mass/Sludge COD wasted	FX_{COD}	kgCOD/d	12
Reactor volume	V_P	gallons	8,170
Reactor volume	V_P	m^3	31
Food to microorganism ratio	F/M	$kgFS_{bi}$/kgMLSS	0.075
Food to microorganism ratio	F/M	kgBOD/kgMLSS	0.060

$$FS_{bi} = Q_i S_{ti}(1 - f_{S'us} - f_{S'up}) + B_{MicroC} \qquad FX_{Ivi} = \frac{FS_{ti} f_{S'up}}{f_{cv}}$$

$$FX_{IOi} = Q_i X_{IOi}$$

$$MX_{BHv} = FS_{bi} \frac{Y_{Hv} SRT}{(1 + b_H SRT)} \qquad MX_{EHv} = f_H b_H MX_{BHv} SRT$$

$$MX_{Iv} = FX_{Ivi} SRT \qquad MX_v = MX_{BHv} + MX_{Ev} + MX_{Iv}$$

$$MX_{IO} = FX_{IOi} SRT + f_{iOHO} MX_{BHv} \qquad MX_t = MX_v + MX_{IO}$$

$$f_{avOHO} = \frac{MX_{BHv}}{MX_v} \qquad f_{at} = f_i f_{av} \qquad f_i = \frac{MX_v}{MX_t}$$

$$FX_t = \frac{MX_t}{SRT} \qquad FX_v = FX_t f_i$$

$$S_{te} = S_{le} = f_{S'us} S_{ti} \qquad FS_{te} = S_{te} Q_{ti}$$

$$FX_{COD} = \frac{MX_v f_{cv}}{SRT}$$

$$V_P = \frac{MX_t}{X_t} \qquad F/M = \frac{FS_{ti}}{V_P X_t}$$

Biological Oxygen Demand

Parameter	Symbol	Unit	Values
Mass carbonaceous oxygen demand	FO_C	kgO_2/d	26
Carbonaceous oxygen utilization rate	O_c	kgO_2/d	0.85
Nitrification oxygen demand	FO_n	kgO_2/d	11
Total oxygen demand	FO_t	kgO_2/d	37
Oxygen recovered by denitrification	FO_d	kgO_2/d	7
Net total oxygen demand (AOR)	FO_{td}	kgO_2/d	30
Oxygen saturation @ operating temp.	c_s	mg/l	10.9
Desired oxygen level	c_x	mg/l	1.5
Transfer coefficient	α	-	0.4
Diffuser water depth	DWD	feet	7.3
Oxygen transfer efficiency	OTE	%	1.5
Standard total oxygen demand (SOR)	SOR	kgO_2/d	96
Required air flow	Q_{air}	scfm	78
Oxygen requir. per volume & depth	OS	$gO_2/(Nm^3 * m_D)$	12
Required air flow, alternative	$Q_{air,alter.}$	scfm	88

$$FO_C = FS_{bi}\left[\left(1 - f_{cv} Y_{Hv}\right) + \left(1 - f_H\right) b_H \frac{Y_{Hv} f_{CV} SRT}{\left(1 + b_H SRT\right)}\right]$$

$$O_C = \frac{FO_C}{V_P} \qquad FO_n = 4.57 FN_{ne}$$

$$FO_t = FO_C + FO_n \qquad FO_d = 2.87\left(N_C - N_{ne}\right) Q_i$$

$$c_s = e^{-0.0209T}$$

$$SOR = \frac{1}{\alpha} \frac{c_s}{c_s\left(\frac{p_{a,1}}{p_{atm}}\right) - c_x} AOR(FO_{td})$$

$$Q_{air} = SOR\left(\frac{RT}{6.66 p_{a,1} OTE \cdot D}\right) \qquad Q_{air,alter.} = \frac{SOR}{D \frac{OS}{1000}}$$

Tank/Basin Inside Dimensions

Parameter	Length [ft]	Width [ft]	Diameter [ft]	Height [ft]	Liquid level [ft]	Volume [cf]	Volume [gallons]
Anoxic I	7.0	0.0	9.0	0.0	0.0	531	3,970
Anoxic II	0.0	0.0	0.0	0.0	0.0	0	0
Aerobic	0.0	0.0	0.0	0.0	0.0	0	0
Membrane	10.0	0.0	9.0	0.0	0.0	604	4,518
Sludge	8.0	0.0	9.0	0.0	0.0	591	4,422
EQ (Pump Station)	0.0	0.0	0.0	0.0	0.0	0	0

Membrane Module Layout

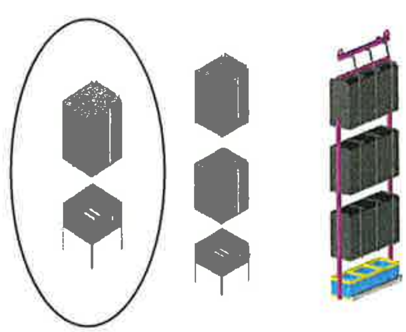
Parameter	Symbol	Unit	Values
Permeate on cycle	T_o	minute	8
Permeate off cycle (relaxation)	T_s	minute	2
Effective membrane module surface	$A_{m,eff}$	m^2	70
Effective membrane module surface	$A_{m,eff}$	ft^2	753
Total number of membrane modules	N_M	-	3
Total membrane module surface	A_{total}	m^2	210
Total membrane module surface	A_{total}	ft^2	2,260
Nominal average flux	$Q_{ave,n}$	lmh	15.8
Nominal monthly max. average flux	$Q_{ave,n,max,mo}$	lmh	19.7
Nominal peak flux (including duty cycles)	$Q_{peak,n}$	lmh	31.5
Nominal average flux	$Q_{ave,n}$	gfd	9.3
Nominal monthly max. average flux	$Q_{ave,n,max,mo}$	gfd	11.6
Nominal peak flux (including duty cycles)	$Q_{peak,n}$	gfd	18.6
Total membrane module displacement vol.	$V_{modules}$	ft^3	33
Total membrane module displacement vol.	$V_{modules}$	gallons	247
Aeration modules	A#	-	3
Membrane module aeration requirement	Q_{am}	acfm	29
Total membrane modules aeration requirement	$Q_{am.total}$	acfm	88
Membrane diffuser water depth	DWD_m	feet	7.3
Oxygen requirement per volume & depth	OS	$gO_2/(Nm_3*m_D)$	12
Standard oxygen rate, membrane aeration	SOR_m	lbO_2/d	210
Standard oxygen rate, membrane aeration	SOR_m	kgO_2/d	96

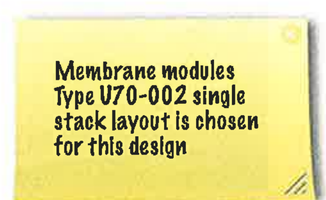
Tank Volumes

Parameter	Unit	Values
Total tank volume	gallons	8,242
Unaerated tank percentage	%	48%
Membrane modules volume	gallons	247
F/M_{used}	kgCOD/kgMLSS	0.074
F/M_{used}	kgBOD/kgMLSS	0.059

Weir Design

Parameter	Unit	Values
Level over weir	inches	1.0
Weir length	ft	2.0
Velocity	fps	0.94





Air Piping & Blower Design

Parameter	Symbol	Unit	Membrane	Aerobic	Sludge
Minimum air flow for membrane modules	$Q_{A,re}$	acfm	88	78	18
Chosen air flow for membrane modules - actual	$Q_{A,\ chosen}$	acfm	100	0	26
Chosen air flow for membrane modules - inlet	$Q_{A,chosen}$	scfm	111	0	28
Chosen air flow for membrane modules - piping	$Q_{A,chosen}$	acfm	82	0	21
Pipe pressure	p_b	psi	5.0	0.0	5.0
Pipe losses	H	psi	0.30	0.00	0.13
Equivalent length in pipe looses	L_p	feet	850	0	750
Internal pipe diameter	d_l	inches	3.3	2.3	2.3
Standard temperature	T_1	K	293	293	293
Pipe temperature	T_2	K	319	293	319
Constant	f	-	0.02	0.13	0.03
Air velocity	v	fps	23.6	0.0	12.6
Atmospheric pressure	$p_{a,l}$	psi	14.2	14.2	14.2
Absolute pressure	p_2	psi	19.2	14.2	19.2
Pressure due to tank liquid level	$p_{DWD,m}$	psi	3.2	3.2	3.7
Pressure due to aeration device	p_{DWD}	psi	1.0	0.9	0.5
Pressure due to pipe losses	$p_{DWD,S}$	psi	0.3	0.0	0.1
Total pipe losses	p_t	psi	4.4	4.1	4.3

Equivalent for fitting losses

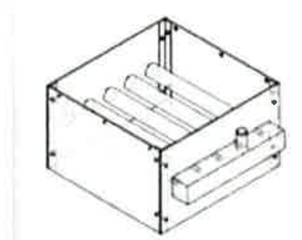
	Membrane piping			Aeration Piping			Sludge Piping		
	k	Quantity	Subtotal	k	Quantity	Subtotal	k	Quantity	Subtotal
Ball valve	0.10	0	0.00	0.10	0	0.00	0.10	0	0.00
Swing check	2.50	1	2.50	2.50	1	2.50	2.50	1	2.50
Butterfly valve	0.50	2	1.00	0.50	2	1.00	0.50	2	1.00
45° Elbow	0.35	0	0.00	0.35	0	0.00	0.35	0	0.00
90° Elbow	0.25	4	1.00	0.25	4	1.00	0.25	4	1.00
Tee through	0.60	2	1.20	0.60	2	1.20	0.60	2	1.20
Tee branch	1.80	1	1.80	1.80	1	1.80	1.80	1	1.80
Exit	1.00	0	0.00	1.00	0	0.00	1.00	0	0.00
	750		7.50	625		7.50	625		7.50

$$H = 9.82 \cdot 10^{-8} \frac{\left(f \cdot L_p T_2 Q_{A,chosen}\right)}{\left(p_2 d_i\right)^5}$$

$$f = \frac{0.029 d_i^{0.027}}{Q_{A,chosen}^{0.148}}$$

$$T_2 = T_1 \left(\frac{p_2}{p_{a,1}}\right)^{0.283}$$

Generally, rotary lobe blowers are used for double and triple membrane stacked modules, side channel blowers for single stack layout



Aeration module type B70-002 for membrane module type U70-002

Nitrogen Removal

Parameter	Symbol	Unit	Values
Factor of safety	S_f	-	1.25
Influent unbio. soluble organic N	N_{ousi}	mgN/l	1.65
Influent unbio. particular org. N	N_{oupi}	mgN/l	7.8
Influent biodegradable organic N	N_{obi}	mgN/l	13.4
Effluent unbio. soluble organic N	N_{ouse}	mgN/l	1.65
NH4 concentration avail. for nitri.	N_{an}	mgN/l	38.4
Effluent ammonia	N_{ae}	mgN/l	1.2
Effluent TKN	N_{te}	mgN/l	2.8
N concentration into sludge prod.	N_s	mgN/l	14.9
Nitrification capacity	N_c	mgN/l	37.3
Mass nitrifiers	MX_A	kgVSS	4
Mass nitrogen into sludge prod.	FN_S	kgN/d	1
Mass of nitrate generated per day	1	kgN/d	2
Temperature sensitivity coefficient	Θ_{nk1}	-	1.2
Temperature sensitivity coefficient	Θ_{nk2}	-	1.08
Temperature sensitivity coefficient	Θ_{nk3}	-	1.029
Denitrification rates at 20°C	k_1	-	0.7
Denitrification rates at 20°C	k_2	-	0.101
Denitrification rates at 20°C	k_3	-	0.072
Denitrification rates	k_{1T}	-	0.163
Denitrification rates	k_{2T}	-	0.055
Denitrification rates	k_{3T}	-	0.057
Denitrification potential RBCOD	$D_{p1RBCOD}$	$mgNO_3$-N/l	17.6
Denitrification potential SBCOD	$D_{p1SBCOD}$	$mgNO_3$-N/l	24.2
Denitrification potential RBCOD	$D_{p3RBCOD}$	$mgNO_3$-N/l	0.0
Denitrification potential SBCOD	$D_{p3SBCOD}$	$mgNO_3$-N/l	0.0
Minimum sludge age for nitri.	SRT_m	d	22
Permissible unaer. sludge mass fraction	f_{xm}	-	0.52
Design unaerated sludge mass fraction	f_{xt}	-	0.48
Minimum primary anoxic mass fraction	f_{x1min}	-	0.12
Primary anoxic mass fraction	f_{x1}	-	0.48
Secondary anoxic mass fraction	f_{x2}	-	0
Denitrification potential primary tank	D_{p1}	mgN/l	41.9
Denitrification potential secondary tank	D_{p2}	mgN/l	0.0
Denitrification potential due to recycle rate @ ($f_{xm} = f_{xdm}$)	$D_{p'}$	mgN/l	31.9
DO in a recycle	O_a	mgO_2/l	0
DO in m recycle	O_m	mgO_2/l	0
Underflow/membrane recycle ratio	m	-	6
Recycle ratio	a	-	0
Effluent nitrate	N_{ne}	mgN/l	0.0
Effluent nitrate @ f_{xdm} & recycle rate	$N_{ne'}$	mgN/l	6.9

$$N_{ousi} = N_{ouse} = f_{N'a} N_{ti} \qquad N_{oupi} = \frac{f_n f_{S'up} S_{ti}}{f_{cv}}$$

$$N_{obi} = N_{ti}\left(1 - f_{N'a} - f_{N'ous}\right) \qquad N_{an} = N_{ti} - N_S - N_{ousi}$$

$$N_{ae} = \frac{K_{nT}\left(b_{AT} + \frac{1}{SRT}\right)}{\mu_{AmTpH}\left(1 - f_{xt}\right) - \left(b_{AT} + \frac{1}{SRT}\right)}$$

$$N_{te} = N_{ae} + N_{ouse} \qquad N_S = \frac{f_n MX_v}{Q_i SRT}$$

$$N_C = N_{ti} - N_S - N_{te} \qquad MX_A = \frac{FN_{ne} Y_A SRT}{\left(1 + b_{AT} SRT\right)}$$

$$FN_S = Q_i N_S \qquad FN_{ne} = Q_i N_{ne}$$

$$K_{jT} = k_j \theta^{(T-20)}$$

$$D_{p1RBCOD} = \frac{f_{Sb's} S_{bi}\left(1 - f_{cv} Y_{Hv}\right)}{2.86} \qquad D_{p1SBCOD} = \frac{K_{2T} f_{x1} MX_{BH}}{Q_i}$$

$$D_{p3SBCOD} = \frac{K_{3T} f_{x3} MX_{BH}}{Q_i}$$

$$SRT_m = \frac{1}{\mu_{AmTpH}\left(1 - f_{xt}\right) - b_{AT}} \qquad f_{xm} = \frac{1 - S_f\left(b_{AT} + \frac{1}{SRT}\right)}{\mu_{AmTpH}}$$

$$f_{x1min} = \frac{f_{Sb's} S_{bi}\left(1 - f_{cv} Y_{Hv}\right)\left(1 + b_{HT} SRT\right)}{2.86 K_{1T} Y_{Hv} SRT}$$

$$f_{xt} = f_{x1} + f_{x2}$$

$$D_{p1} = D_{p1RBCOD} + D_{p1SBCOD}$$

$$D_{p3} = D_{p3RBCOD} + D_{p3SBCOD}$$

$$N_{ne} = N_{ai} - N_{ae} + \frac{aO_a}{2.86} + \frac{sO_S}{2.86} - D_{p1} - D_{p2}$$

$$N = N_{te} - N_{ne}$$

Alkalinity

Parameter	Symbol	Values	Parameter
Alkalinity Nitrification as CaCO3 (consumed)	Alk_{Nitri}	mg/l as $CaCO_3$	1
Alkalinity Denitrification as CaCO3 (recovered)	$Alk_{Denitri}$	mg/l as $CaCO_3$	0
Alkalinity ef	Alk_e	mg/l as $CaCO_3$	50
Alkalinity inf	Alk_i	mg/l as $CaCO_3$	40
Alkalinity Alum (consumed)	Alk_{Alum}	mg/l as $CaCO_3$	0
Alkalinity Total	Alk_{total}	mg/l as $CaCO_3$	-11
Alkalinity Added	Alk_{added}	mg/l as $CaCO_3$	61
Alkalinity Added	$XAlk_{added}$	lb/d	8.5
Density caustic solution (50%)	-	lb/gal	12.8
Alkalinity recovered	$Alk_{recovered}$	$lbCaCO_3/lb$	0.4
Caustic needed	-	lb/d	3.4
Caustic needed	-	gpd	0.3

$$Alk_{Nitri} = Q_i\left(N_{ne} + N_{ae}\right)7.14$$

$$Alk_{Denitri} = Q_i N_{ne} 3.57$$

$$Alk_{Alum} = Q_i 7.14 S_{Alum} 0.45$$

$$Alk_{total} = Alk_i - Alk_e - Alk_{Denitri} + Alk_{Nitri} - Alk_{Alum}$$

Phosphorous Removal

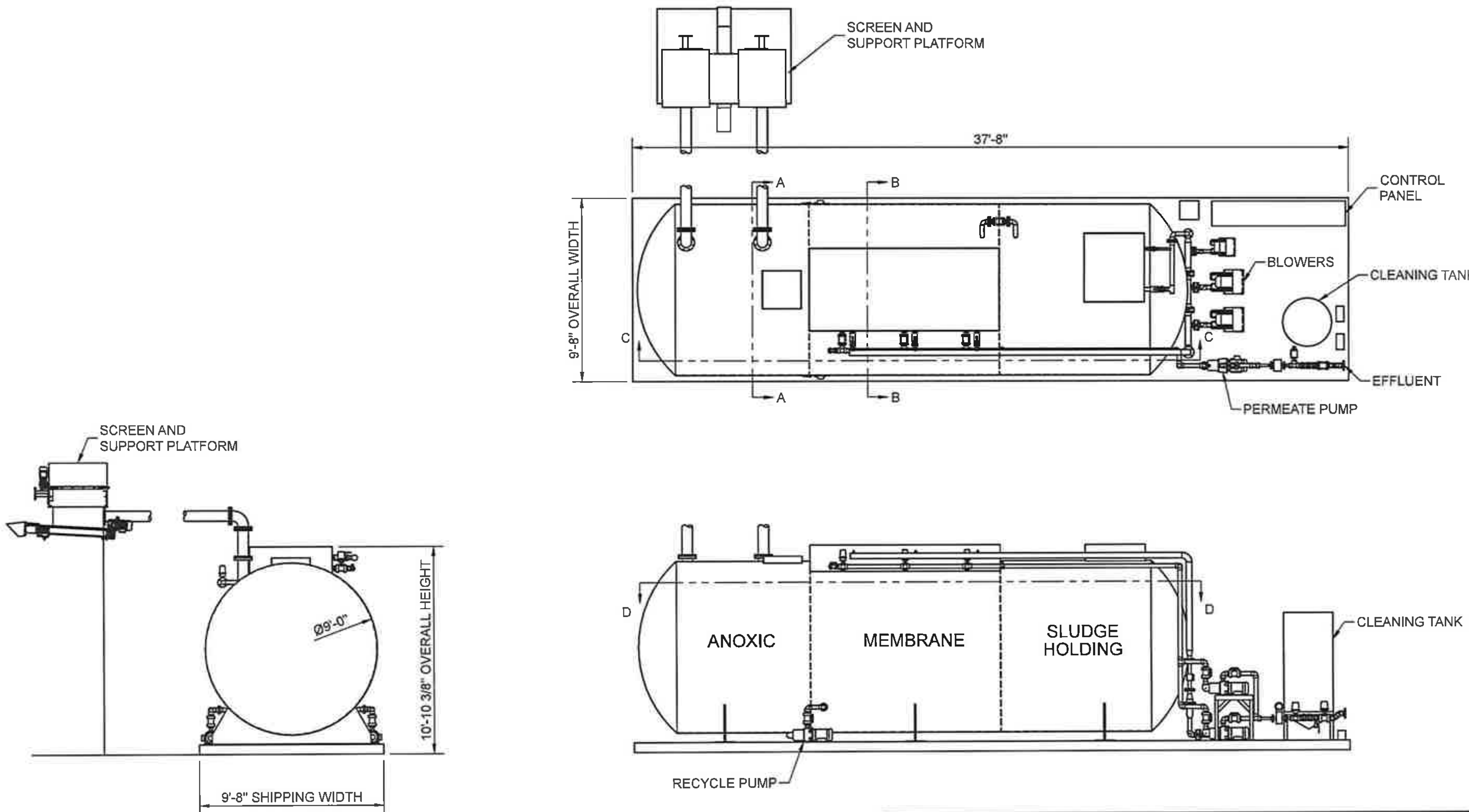
Parameter	Symbol	Values	Parameter
Influent P	P_{ti}	mgP/l	12.0
Effluent P	P_{te}	mgP/l	0.5
P into sludge production	P_s	mgP/l	6.2
P used for biological process	P_{bio}	mgP/l	7.5
P precipitated	P_{prec}	mgP/l	0.0
Precipitation chemical	B_{Alum}	lb/d	0.0
Precipitation chemical	Solution	gal/d	0.0
Density Alum	$z_{AL^{3+}}$	lb_{AL}/lb_{prec}	0.0997
Density Iron	$z_{FE^{3+}}$	lb_{FE}/lb_{prec}	0.0766
Alum efficiency	-	g/kg	40
Chemical precipitation sludge	-	lb/d	0.0

$$P_{bio} = 0.015 \cdot S_{ti,COD}\left(1 - f_{S'up} - f_{S'us}\right)$$

$$P_S = \frac{f_p N_S}{f_n}$$

$$B_{Alum} = P_{prec} 1.2 \frac{Q_i}{z}$$

$$P_{prec} = P_{ti} - P_{te} - P_S - P_{bio}$$



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REVISED	TMP	DATE	4/22/11
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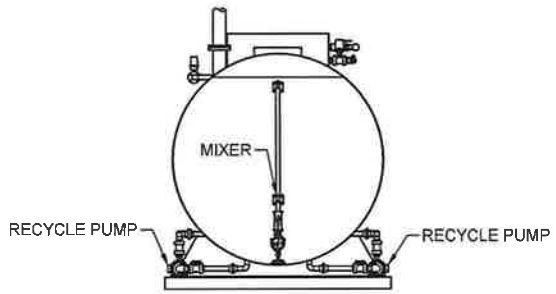
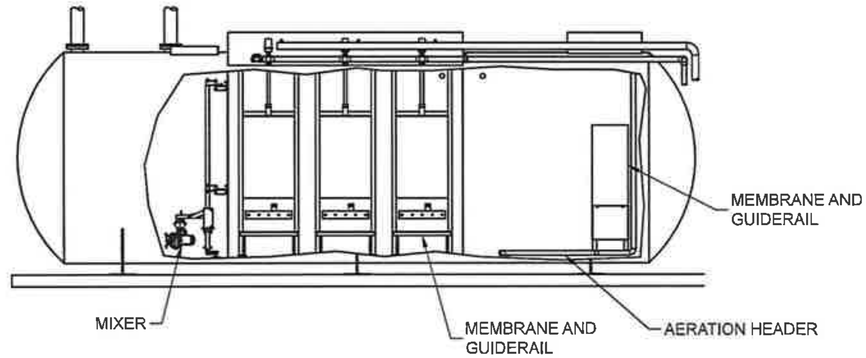
DWG NO.	BP-196-1	REV	1



SECTION A-A



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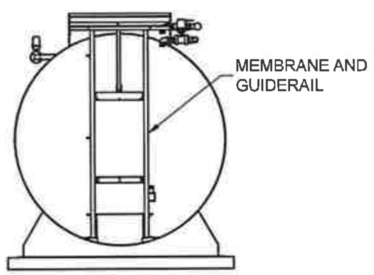

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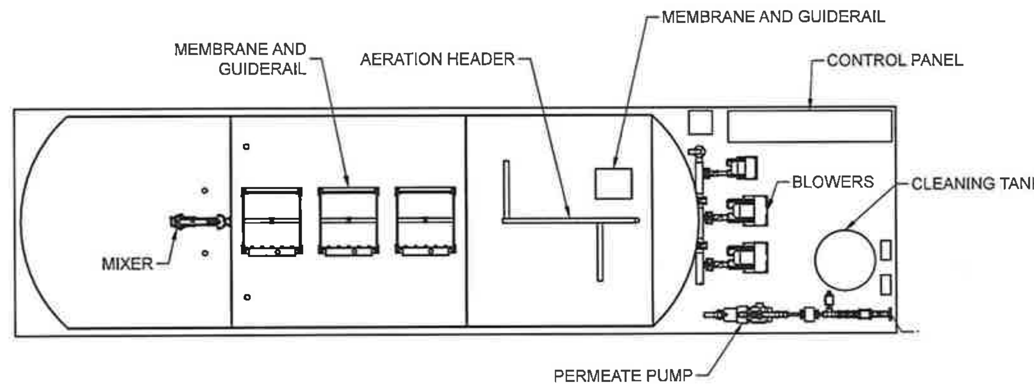

SECTION D-D

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	REVISED TMP	DATE 4/22/11	
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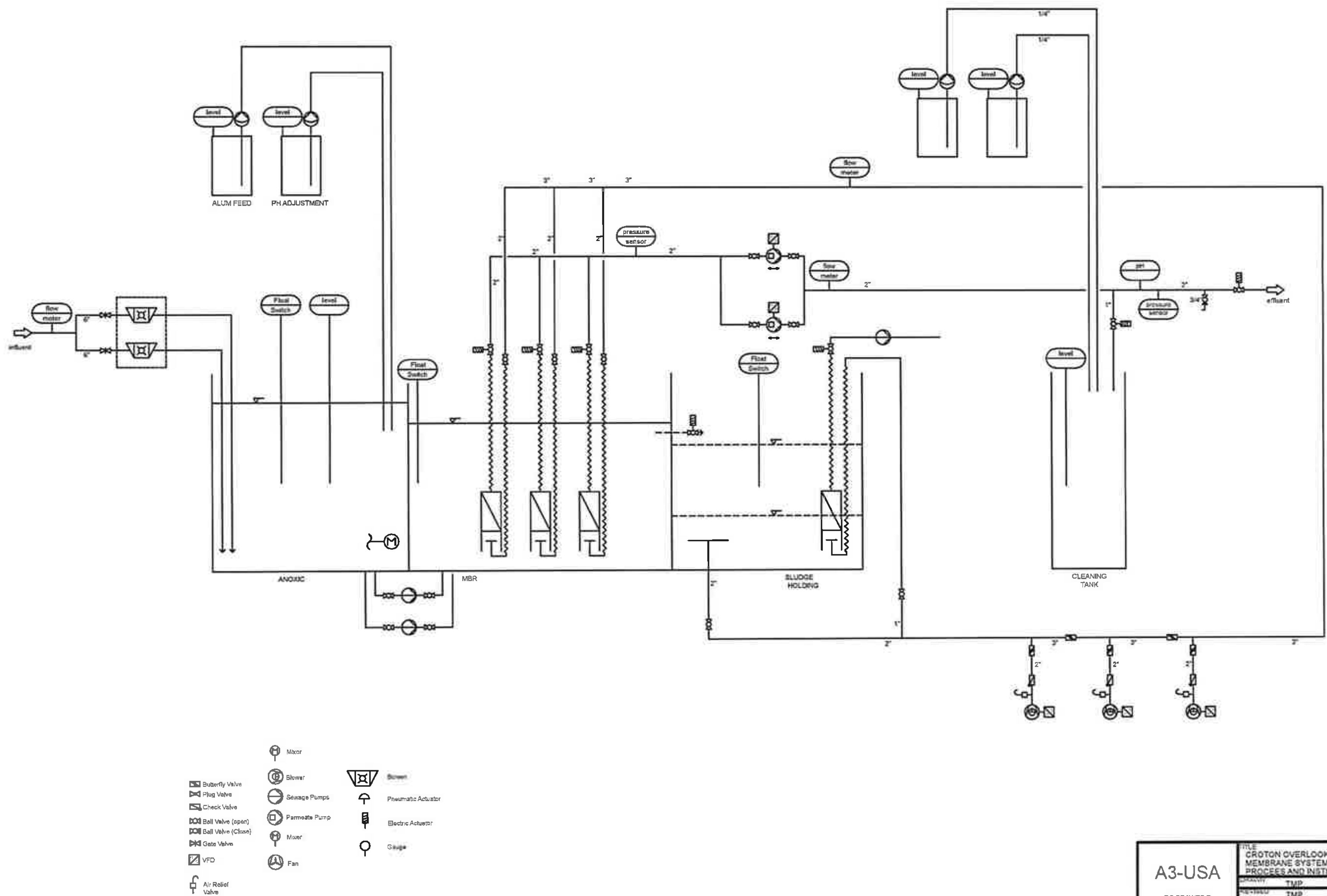

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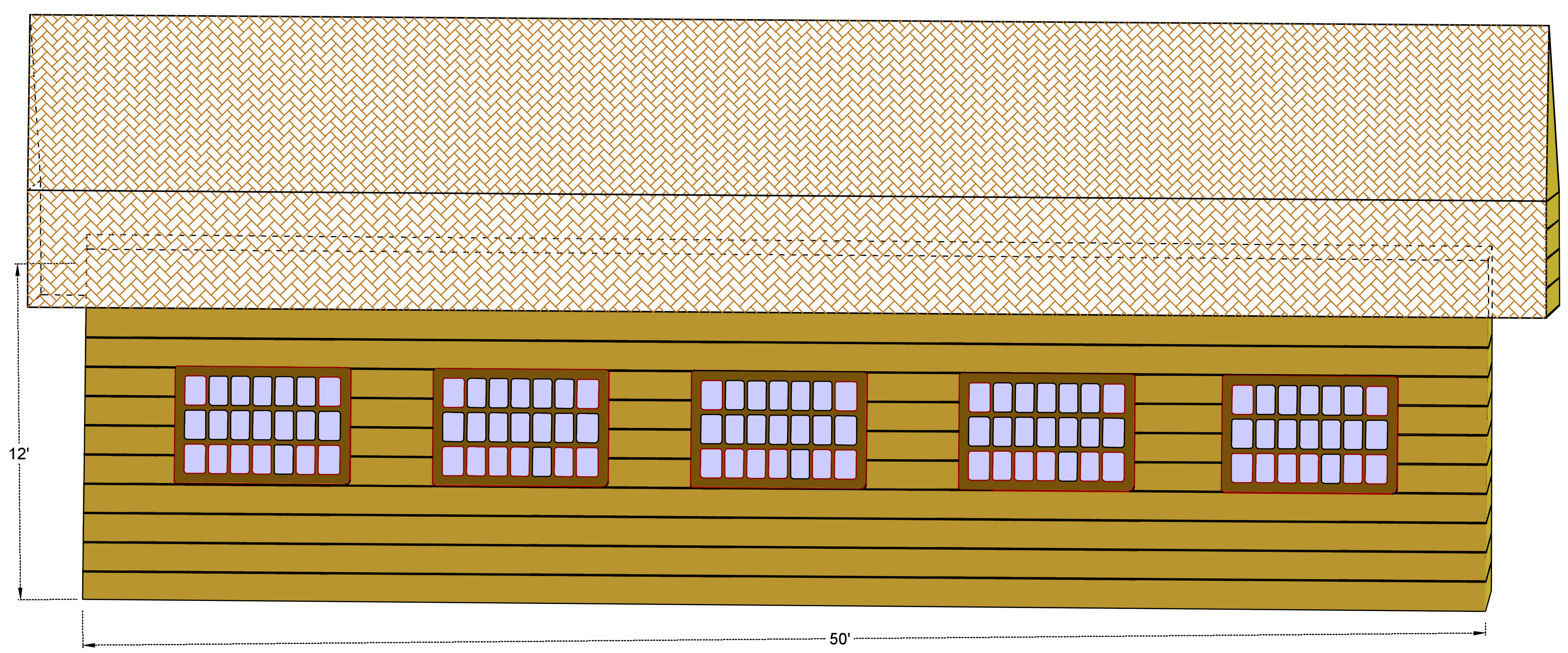
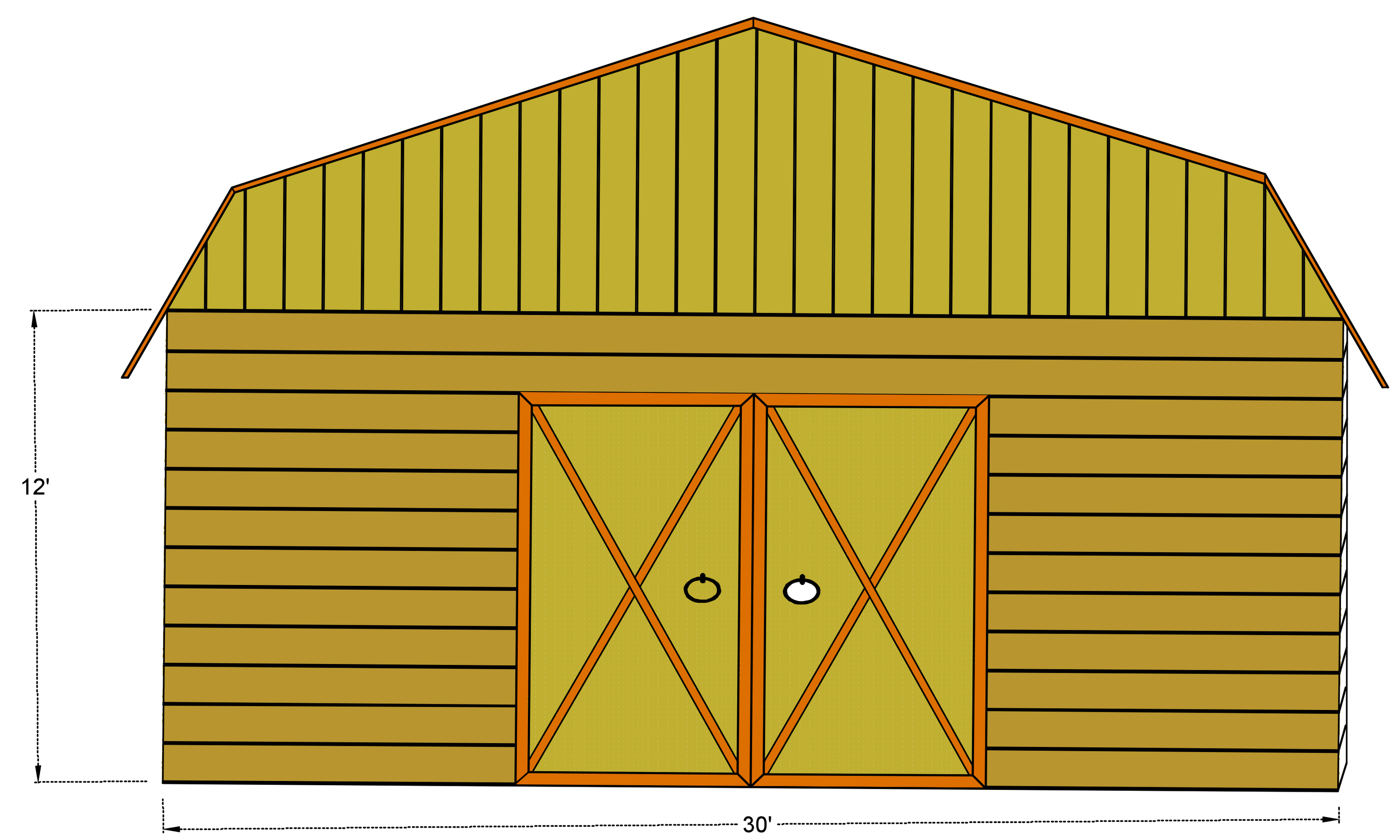
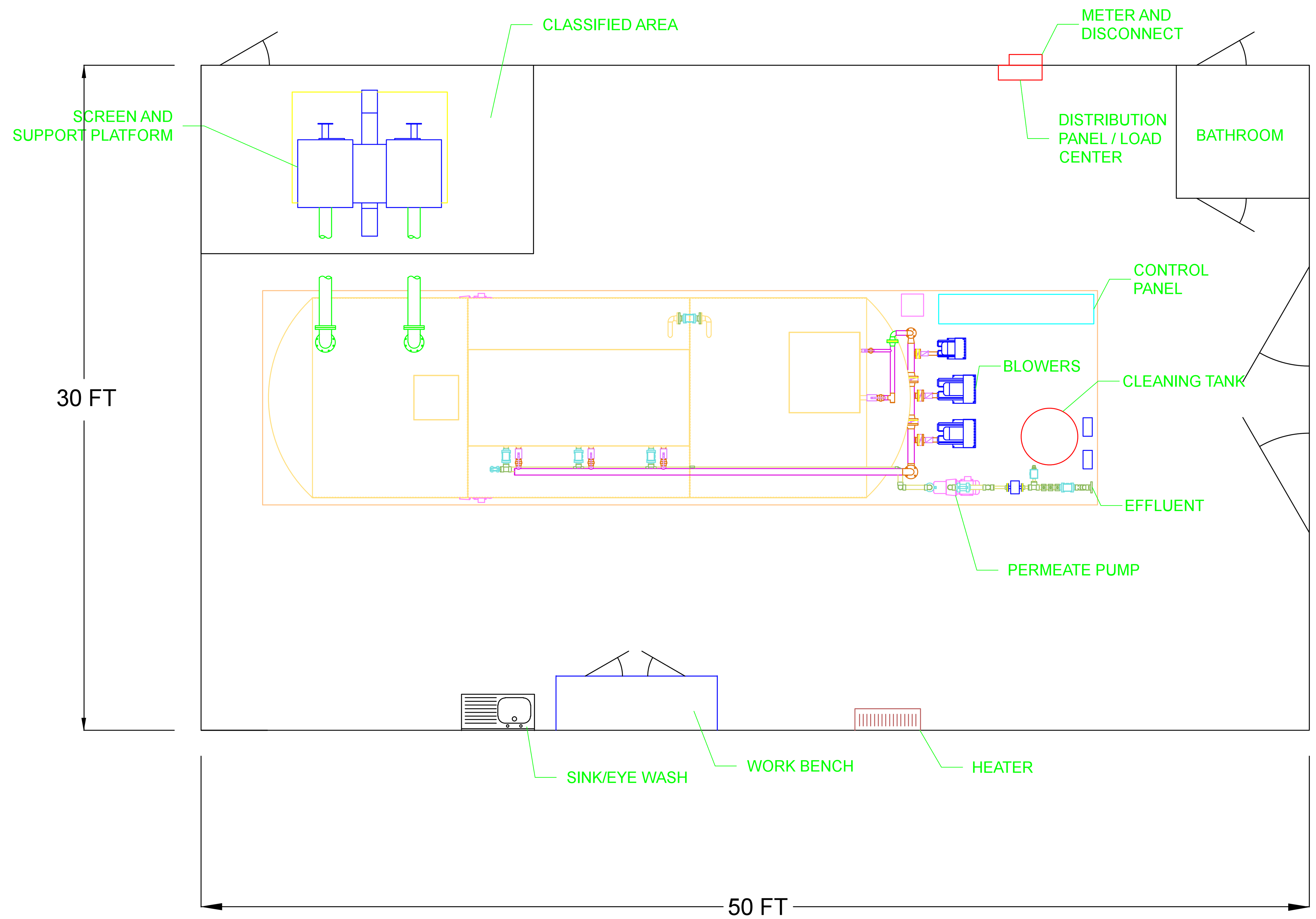
2

Croton Overlook







AGE ORIENTED COMMUNITY

Westchester Co., New York – Town Of Yorktown

WASTEWATER TREATMENT

PREPARED BY: George Calandriello

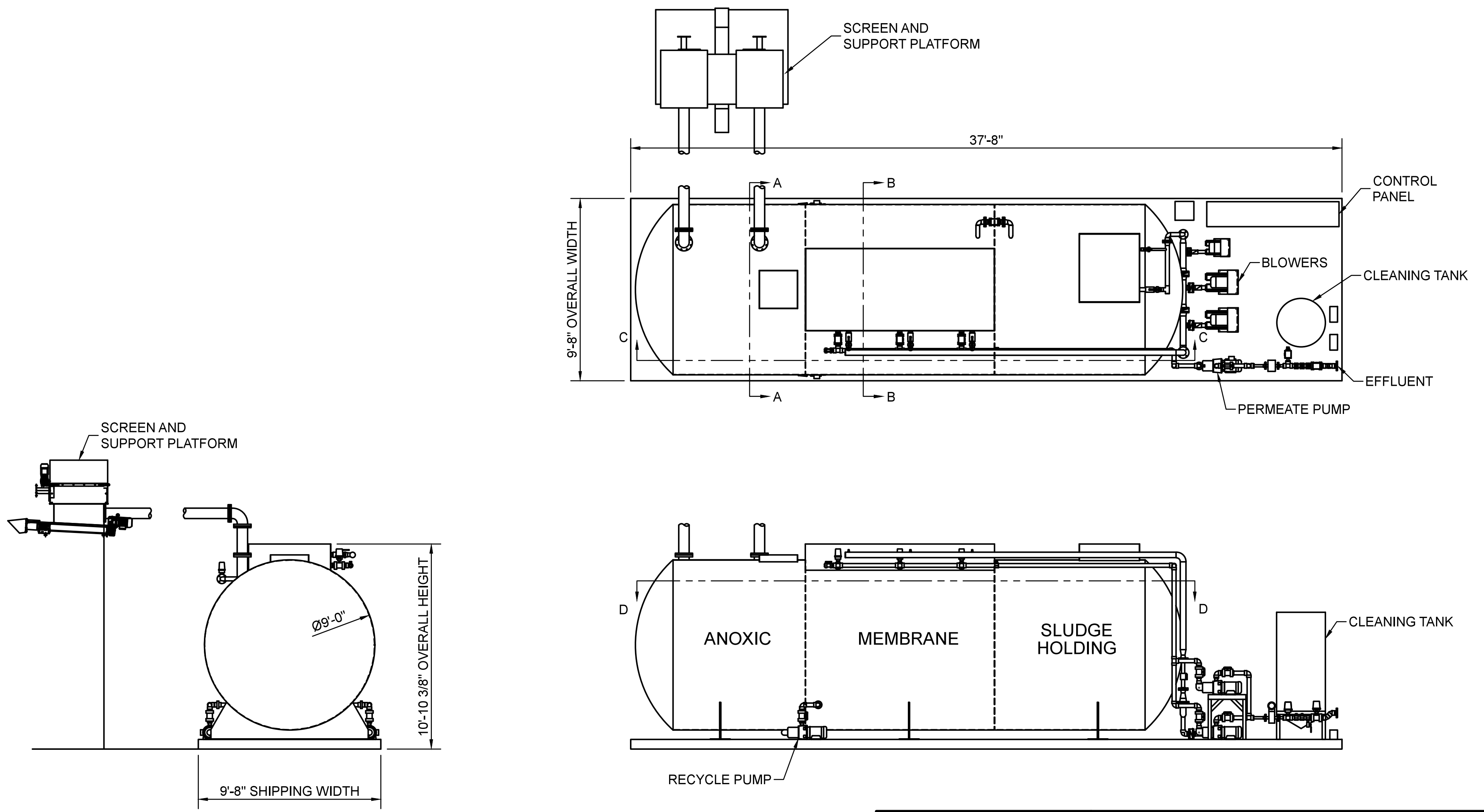
SCALE: 1" = 100'

WT-1

DATE: 6-29-2011

Revisions:

No.	Date	Comments:



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	REVISED TMP	DATE 4/22/11		
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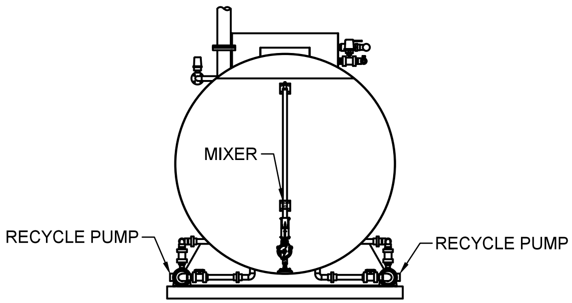

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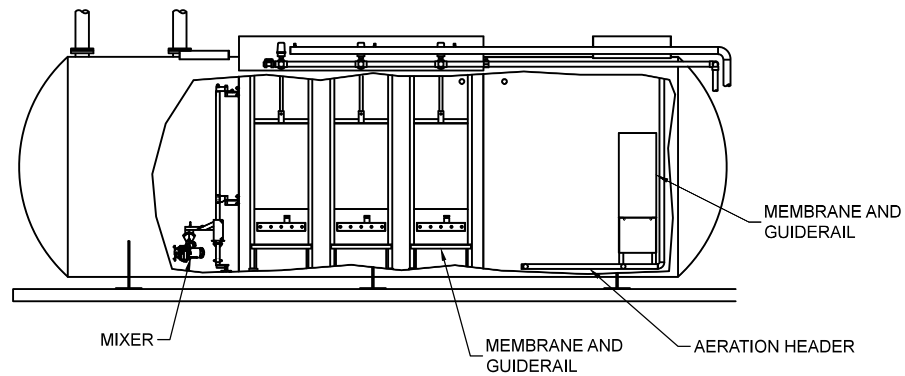

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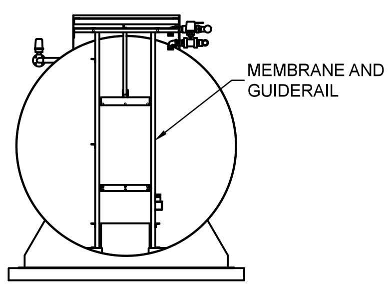

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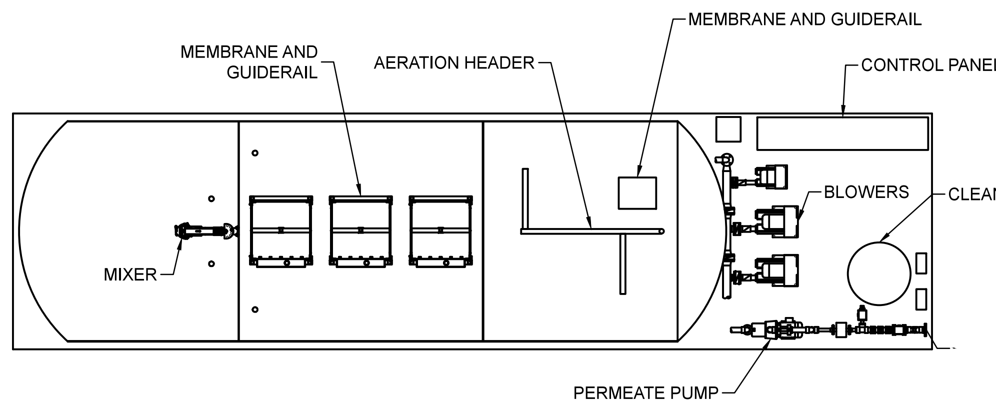


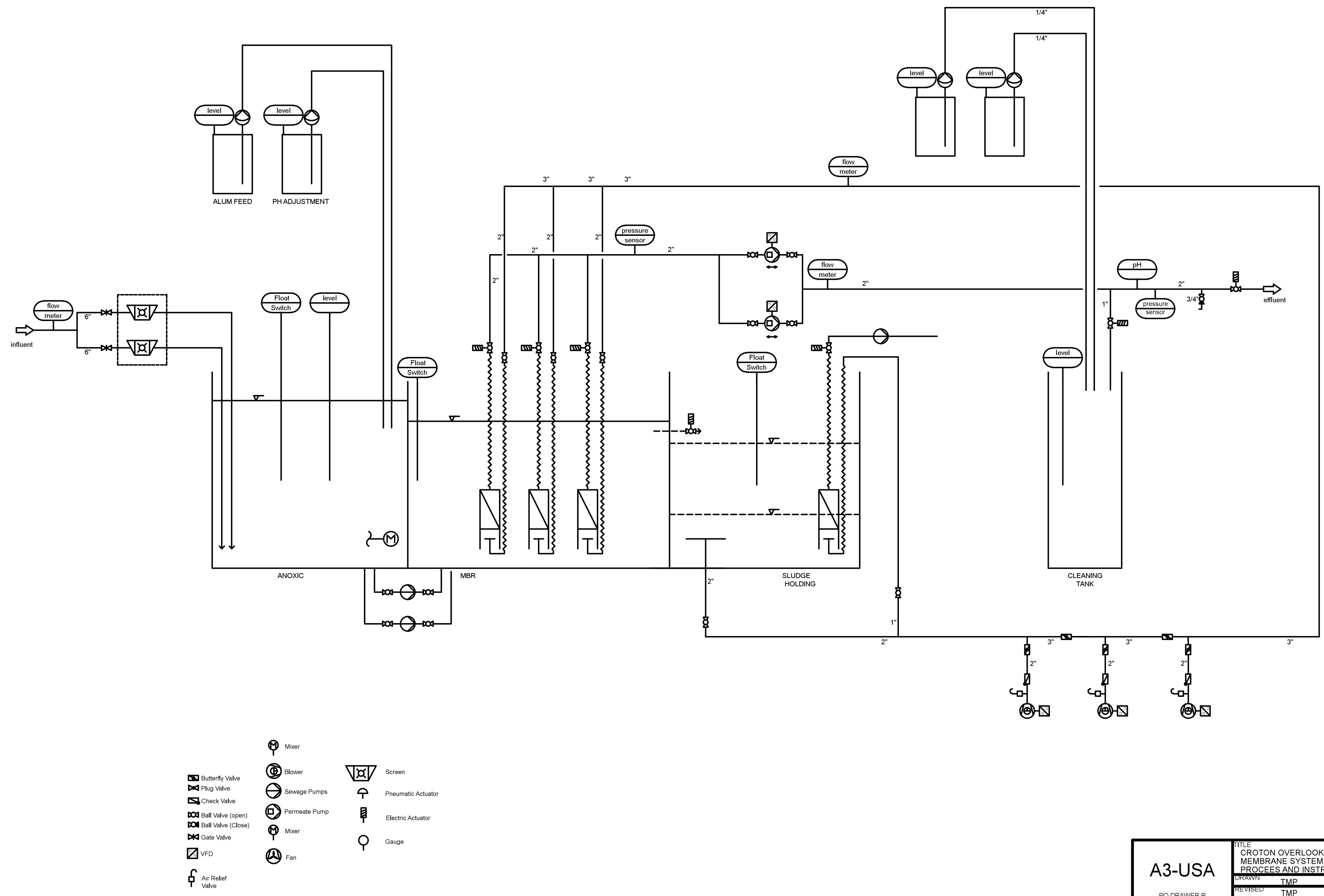
SECTION D-D

A3-USA

PO DRAWER R
IRWIN, PA 15642
724-871-7170

TITLE
CROTON OVERLOOK
MEMBRANE SYSTEM
SECTION VIEWS

DRAWN	TMP	DATE	1/31/11
REVISED	TMP	DATE	4/22/11
SCALE	3/16" = 1'-0"	SIZE	B
DWG NO.	BP-196-2	REV	1



A3-USA

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TITLE	CROTON OVERLOOK MEMBRANE SYSTEM PROCEES AND INSTRUMENTATION DIAGRAM		
DRAWN	TMP	DATE	1/31/11
REVISED	TMP	DATE	4/27/11
SCALE	NOT TO SCALE	SIZE	D
DWG NO.	BP-196-3	REV	1