Ozonation and UV Disinfection

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Ozonation & Water Quality

- Used to improve water quality in ultra-intensive recirculating production systems.
  - ✓ Ozone can produce excellent water quality in recirculating systems without resorting to high daily water exchange rates.
  - ✓ Ozone can reduce fish disease problems.

Ozonation: +/-

- Advantages:
  - ✓ rapid reaction rate,
    - dissolved ozone half-life only 0-15 sec (Bullock et al., 1997);
  - ✓ few harmful reaction by-products in freshwater;
  - ✓ oxygen is produced as a reaction end-product.
- Disadvantages:
  - ✓ ozone is dangerous to humans and fish.

Ozone Supports Water Treatment

- directly oxidizes NO_2^- to NO_3^- ;
- helps remove color & dissolved organic matter:
  - ✓breaks non-biodegradable compounds into smaller & more biodegradable compounds;
- helps remove dissolved & fine particulate matter
  - ✓precipitates dissolved organic molecules,
  - ✓micro-flocculates fine particulate matter,
  - ✓improving solids removal by settling, filtration, or flotation.

Ozone Can Reduce Fish Disease

- Ozone is also added to recirculating systems to reduce fish disease, by:
  - ✓ improving water quality and reducing fish stress
  - ✓ disinfecting the water
    - large reductions in micro-organisms are possible, but
      - ozone's rapid reaction with nitrite and organic matter limit C*t;
      - requires much greater ozone doses than required for water quality control;
      - disinfection not commonly achieved in recirculating systems.

Ozonation for Disinfection

- Must maintain a residual concentration (C) for a given time (t), i.e., Chick-Watson Law:

$$\text{microbial reduction} \propto [O_3]_{\text{residual}} \cdot t_{\text{contact}}$$

Ozone Doses for Disinfection

- Must maintain a residual concentration (C) for a given time (t):

	C*t, mg*min/L
✓ ISAV	0.3
✓ Aeromonas salmonicida	1.6
✓ Yersinia ruckeri	0.45-0.6
✓ Flavobacterium sp.	2.8
✓ Flexibacter sp.	1.6
✓ Streptococcus sp.	0.015
✓ Vibrio salmonicidia	0.45-0.6

Maintaining Ozone Residual

- Sometimes difficult to maintain ozone residual for a given contact time due to ozone demand of water.
  - dissolved ozone has a half-life of only 0-15 sec in recirc systems (Bullock et al., 1997);
  - Ozone demand of relatively clean surface water supplies can range from 2-10 mg/L!
  - Ozone demand of recirc water could be 20-100 mg/L (????)!

Ozone Dosing Rate

- Bullock et al. (1997); Summerfelt et al. (1997)
  - ✓ 0.025 kg O_3 per kg feed input
    - improved water quality and microscreen filter performance
    - reduced mortalities associated with Bacterial Gill Disease (BGD)
    - reduced chemical treatments required to control BGD
    - did not reduce bacteria counts by even 1 $\log_{10}$
  - ✓ 0.036-0.039 kg O_3 per kg feed input
    - same type and magnitude of benefits of lower ozone dose
    - much more likely to kill fish

Ozone Dosing Rate

- Brazil (1996) found:
  - 0.025 and 0.045 kg O_3 per kg feed
    - produced best water quality
  - 0.013 kg O_3 per kg feed
    - was all ozone dose necessary to maximize fish growth

Ozone & Water Quality

- Effect of O_3 on culture tank influent water quality:

	TSS (mg/L)	COD (mg/L)	DOC (mg/L)	Color (Pt-Co)
Control	6.3±1.1	44±4	7.1±0.4	17.7±1.2
Ozone trial 1	4.0±0.6	26±2	NA	5.3±0.9
Ozone trial 2	2.9±0.6	26±6	6.3±0.3	2.9±0.4
Ozone trial 3	5.6±0.5	37±2	6.0±0.3	2.1±0.5
Ozone trial 4	3.1±0.3	24±2	5.5±0.2	2.1±0.4

(Summerfelt et al., 1997)

Ozone & Microscreen Filtration

- Solids removal across the microscreen filter:
  - ✓ no ozone 24% of feed fed removed
  - ✓ ozone 33% of feed fed removed
- Total solids production in system was ~40% of feed fed.
- Increased solid removal was probably due to ozone:
  - ✓ precipitating dissolved organic molecules
  - ✓ microflocculating fine particlates

(Summerfelt et al., 1997)

Ozone & Microscreen Filtration

- Microscreen filter improvements with ozone:
  - ✓ TSS removal — increased 33%
  - ✓ wash cycles — reduced 35%
  - ✓ sludge water production — reduced 53%
  - ✓ sludge water settled sludge volume — reduced 77%

(Summerfelt et al., 1997)

Ozone & Solids Removal

- Also improves solids removal via
  - ✓Foam fractionation
    - Sander & Rosenthal (1975)
    - Otte and Rosenthal (1979)
    - Williams et al. (1982)
  - ✓Settling
    - Wilczak et al. (1992)
    - Reuter and Johnson (1995)

Ammonia and Ozone

- In freshwater systems:
  - Ozone does not oxidize significant NH_3 to NO_3 until pH > 9

Ammonia and Ozone

- In saltwater systems (if sufficient bromide is present),
  - ozone will react with bromide to produce hypobromous acid and this will react with ammonia to produce nitrogen gas while producing H^+ that consumes alkalinity

$$O_3 + Br^- + H^+ \rightarrow HOBr + O_2$$

$$3HOBr + 2NH_3 \rightarrow N_2 + 3Br^- + 3H^+ + 3H_2O$$

$$HCO_3^- + \rightarrow CO_2 + H_2O$$

(Haag and Hoigne, 1984)

Nitrite and Ozone

- Ozone stoichiometrically oxidizes nitrite to nitrate.

	NO2-N Influent (mg/L)	***NO2-N Uptake Rate (kg/day)***
Control	**0.28±0.01**	**0.76±0.02**
Ozone trial 1	**0.13±0.01**	**0.65±0.02**
Ozone trial 2	**0.15±0.01**	**0.51±0.02**
Ozone trial 3	**0.11±0.01**	**0.47±0.02**
Ozone trial 4	**0.10±0.01**	**0.41±0.02**

(unpublished data from same experiment as Summerfelt et al., 1997)

Nitrite and Ozone

- Ozone oxidized nitrite to nitrate:
  - ✓reduced nitrite concentration in water
  - ✓reduced nitrite loading on biofilter
  - ✓caused population of nitratifiers to decrease
  - ✓reduced total nitrite removal capacity of biofilter

Nitrite and Ozone

- If ozonation is interrupted:
  - ✓ biofilter cannot remove all nitrite produced
  - ✓ rapid nitrite accumulation occurs
  - ✓ fish health is compromised
  - ✓ several weeks may be required for biofilter to adapt to additional nitrite loading

Ozone Generation

- Energy sources used to generate ozone:
  - ✓High voltage corona discharge
  - ✓UV light at wavelengths < 200 nm
    - Requires 6-30 times more energy than corona discharge systems
  - ✓Cheminuclear sources
  - ✓Electrolytic processes

Ozone Generation

- Corona discharge energy dissociates O_2 into oxygen radicals and produces O_3:

$$O_2 + \text{energy} \rightarrow O + O$$

$$O + O_2 \rightarrow O_3$$

- Ozone is produced when oxygen gas is exposed to electric current arcing between two parallel electrode surfaces.

Ozone Generation

- Must be generated onsite.
- Ozone generation requires 2-3 times less energy using enriched oxygen gas rather than air.
- Most economical ozone generation method takes advantage of the oxygen feed gas already required to increase carry capacity.

Ozone Generation

- Ozone generation:
  - ✓ operating costs:
    - corona discharge generator (~10 KW per kg O_3 generated)
    - increases cost of oxygen by 17-35% (Wade et al., 1996)
  - ✓ capital costs:
    - ozone generators cost more than onsite oxygen generators
    - large economies of scale for large facilities

Ozone Generation

- Air cooled ozone generator

(Target Marine Hatchery)

Ozone Generation

- Water cooled ozone generator.

(Freshwater Institute)

Ozone Generation

- Safety interlocs shut-off generators in case of problems.

(Freshwater Institute)

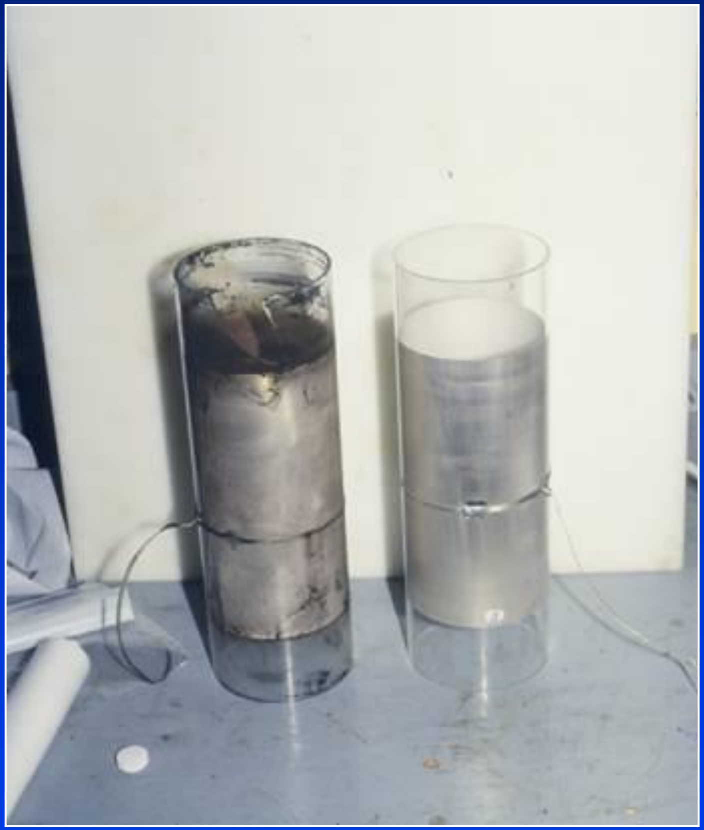
Ozone Generator Fires

- Before Fire….
- After Fire….

(USFWS Fish Technology Center, Bozeman, MT)

Ozone Generation

- If it becomes necessary, cleaning dielectrics can be a hassle.



(Freshwater Institute)

Ozone Gas Transport

- Use stainless steel, teflon, viton, or kynar.

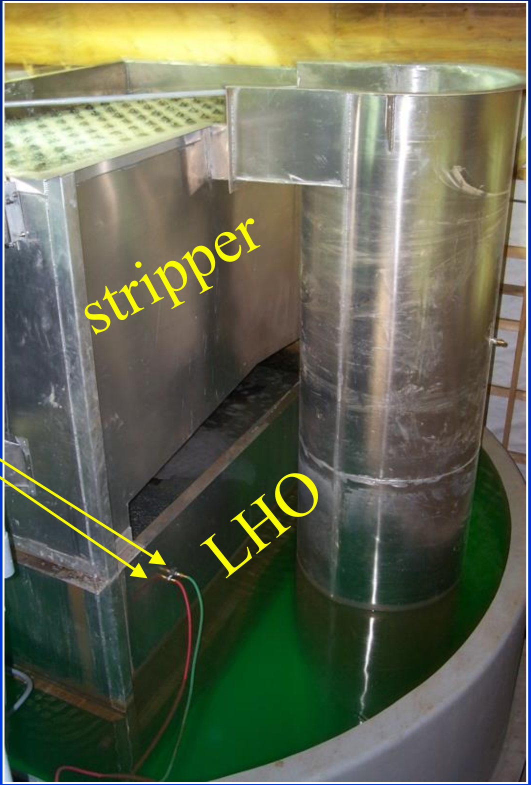
(Freshwater Institute)

(Target Marine Hatchery)

Ozone Gas Transport

- Use stainless steel, teflon, viton, or kynar.

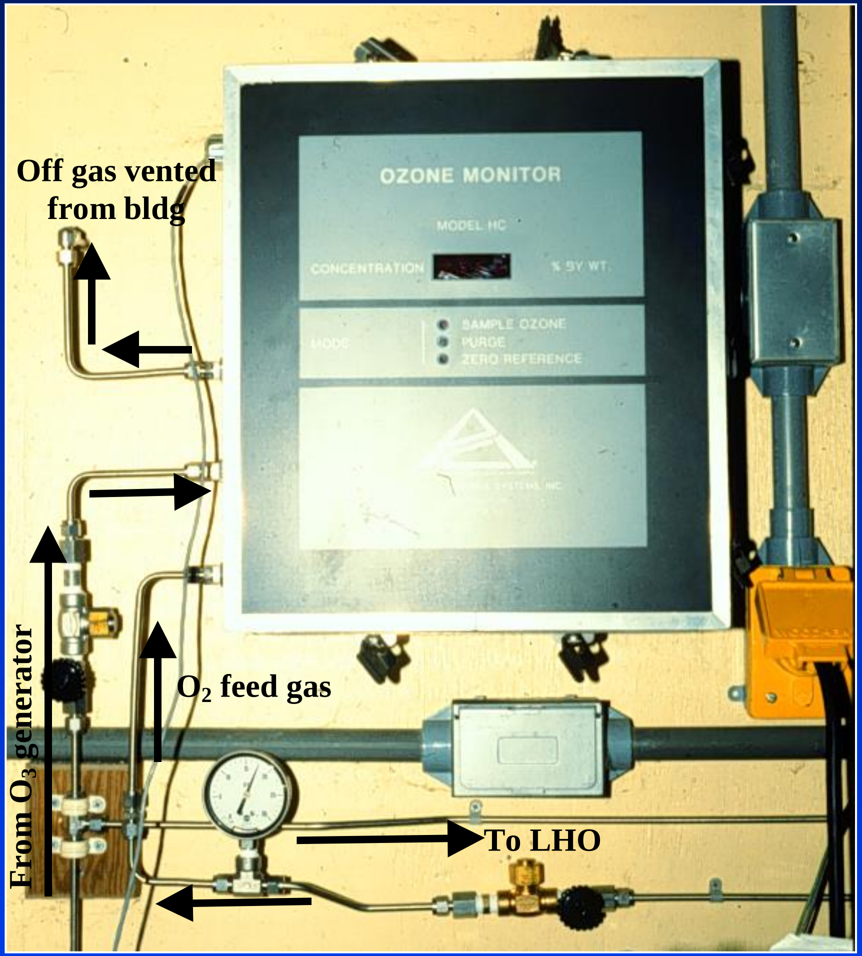
O_2 & O_3
gas supplies



(Freshwater Institute)

(Nutreco's Big Tree Creek Hatchery)

Ozone Monitoring in Gas Phase



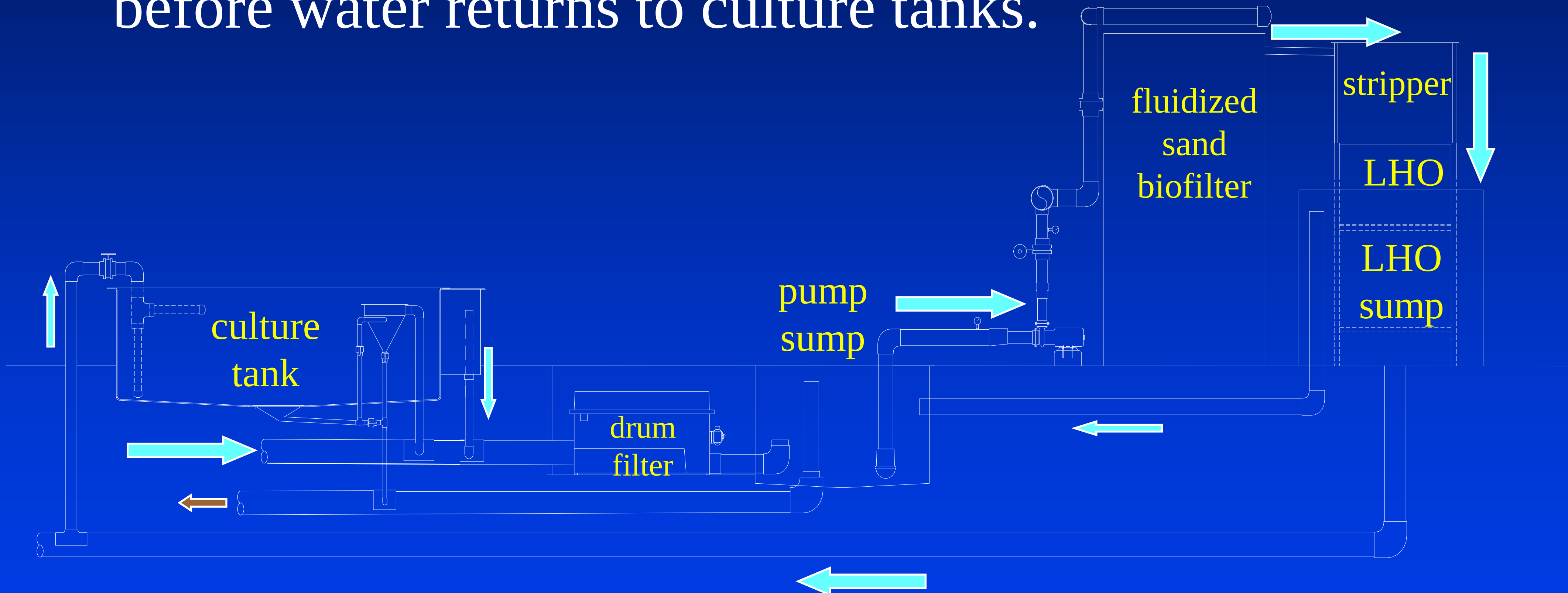
(Freshwater Institute)

Ozone Transfer

- When adding ozone to a recirculating system, suggest taking advantage of the oxygen gas stream and oxygen transfer unit already used to increase the system's carrying capacity.

Ozone Transfer in Recirc Systems

- Ozone is often added in LHO just before water returns to culture tanks.



(courtesy of PRAqua Technologies)

Ozone Transfer in Recirc Systems

- Ozone added within LHO at WV Aqua LLC (Man, WV)

(system designed by PRAqua Tech.)

Ozone Transfer

- O_2 & O_3 transfer within low head oxygenators (LHOs)

O_2 & O_3
gas supplies

(Nutreco's Big Tree Creek Hatchery;
designed by PRAqua Technologies)

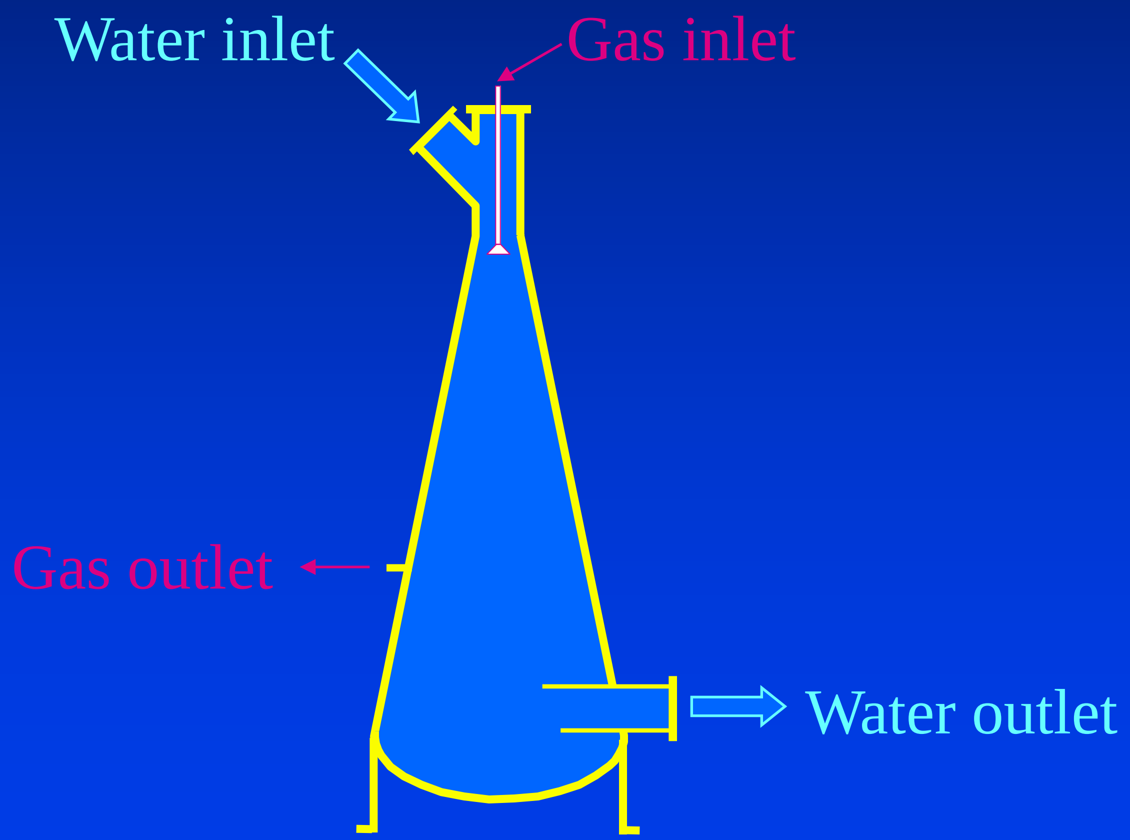
Ozone Transfer

- O_2 & O_3 transfer within low head oxygenators (LHOs)
  - ✓ Ozone transfer efficiency can approach 100% in a good oxygen transfer unit, because:
    - Ozone is 13 times more soluble than oxygen (Henry's Law);
    - Gas residence time in LHO can be up to 45 min;
    - Nitrite & TOC rapidly react with ozone.

(Summerfelt & Hochheimer, 1997)

Ozone Transfer

- Gas transfer within oxygen cones
  - ✓ also called downflow bubble contactors



Ozone Transfer

- Gas transfer within oxygen cones
  - ✓ also called downflow bubble Contactors

(Fingerlakes Aquaculture LLC)

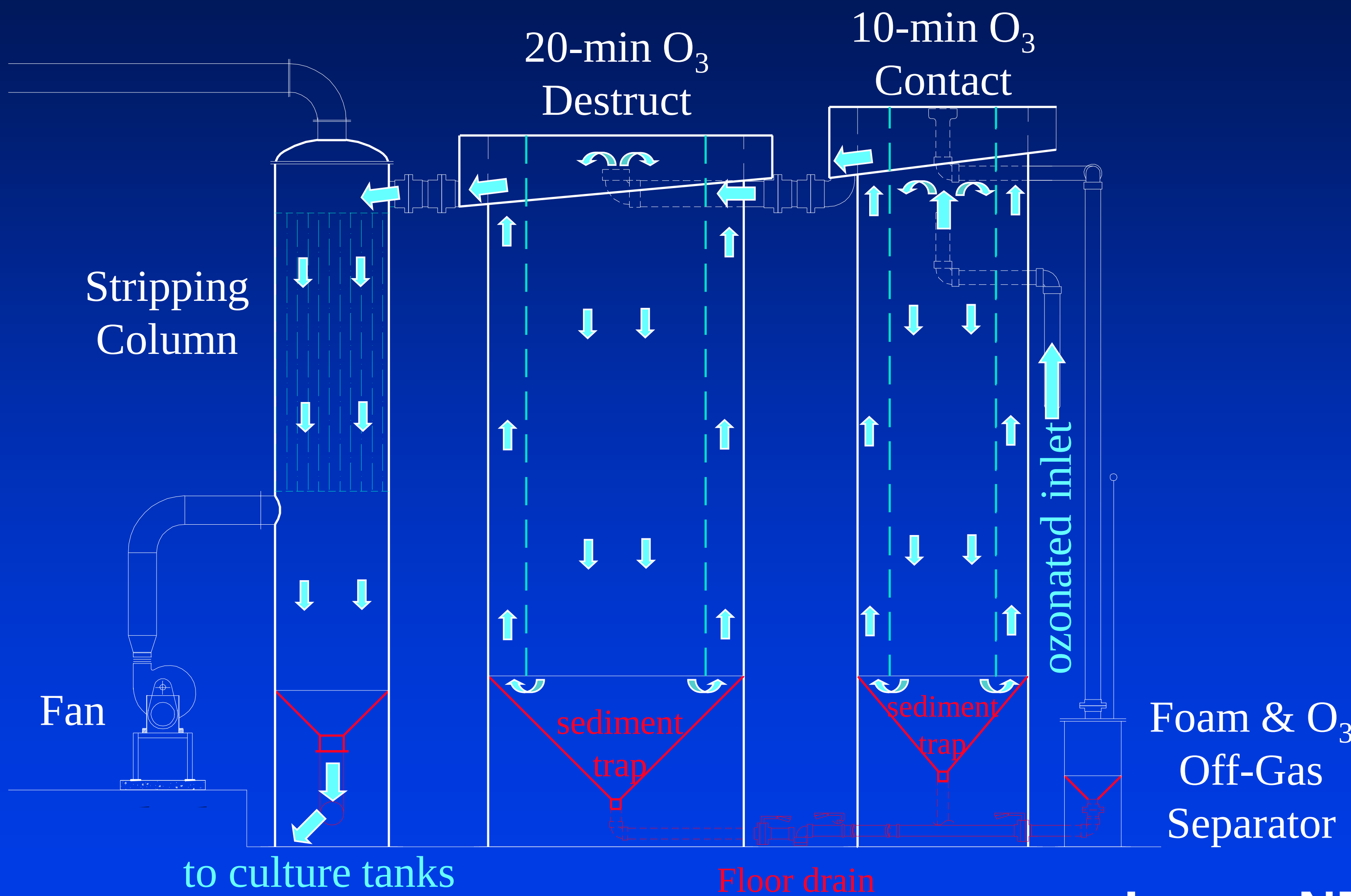
(Target Marine)

Ozone Transfer

- Gas transfer within aspirator-type venturi injectors.

(Mazzei injectors made from Kynar for ozone resistance)

Ozone Contacting



Lamar NFH (PA)

Methods to Remove Dissolved Ozone

- Provide extended contact time & let ozone react away;
- Aerate to strip ozone into air;
  - ✓ G:L of 10:1 to 20:1
- Expose to high intensity UV light:
  - ✓ wavelength of 250-260 nm;
  - ✓ 60-120 $mW\text{-}s/cm^2$ to remove 0.5 mg/.
- React with hydrogen peroxide;
- Pass through an activated carbon bed or biofilter.

UV Disinfection

- DNA is denatured by UV electromagnetic radiation at wavelengths of 100-400 nm,
  - ✓ kills or inactivates microorganisms,
  - ✓ 255-265 nm are most effective destroying DNA & RNA and are most lethal wavelengths,
  - ✓ 280 nm wavelength denatures proteins and enzymes

- The quantity of energy transmitted at a wavelength of 254 nm is the standard used to estimate UV inactivation potential.

UV Dose

- Achieving UV disinfection requires maintaining a minimum UV dose:

$$\text{UV dose} = (\text{UV intensity}) \cdot (\text{exposure time})$$

$$= (\text{mW}/\text{cm}^2) \cdot (\text{sec})$$

$$= \text{mW} \cdot \text{sec}/\text{cm}^2$$

- 10-30 second contact times are typical (White, 1992).

UV Dose

- Actual UV dose applied to water flow depends on:
  - ✓ Water flowrate (Q) and operating volume within UV vessel;
  - ✓ Lamp intensity (including losses at quartz sleeve);
  - ✓ UV transmittance of water (% Transm.).

$$\text{UV dose} = (\text{UV intensity}) \cdot (\text{exposure time}) \cdot (\text{transmittance factor})$$

$$\cong (\text{UV intensity}) \cdot \left(\frac{V_{\text{vessel}}}{Q}\right) \cdot a \cdot \exp^{(b \cdot \%\text{Transm})}$$

$$= \#\ \text{mW} \cdot \text{sec/cm}^2$$

UV Doses Required for Disinfection

- Dose to inactivate 99.9% of BACTERIA from Wedemeyer (1996) and Liltved (2001):

	$mW\text{-}sec/cm^2$
✓ *Aeromonas salmonicida*	4
✓ *Aeromonas hydrophila*	5
✓ *Vibrio anguillarum*	4
✓ *Yersinia ruckeri*	3
✓ *Pseudomonas fluorescens*	5

UV Doses Required for Disinfection

- Dose to inactivate 99.9% of VIRUSES from Wedemeyer (1996) and Liltved (2001):

	$mW\text{-}sec/cm^2$
✓ *ISA*	4-10*
✓ *IHN*	1-3
✓ *IPN*	100-200
✓ *Channel catfish virus*	2
✓ *Herpesvirus salmonis*	2
✓ *White spot syndrome baculovirus*	900*

*loss of infectivity

UV Doses Required for Disinfection

- Wedemeyer (1996):

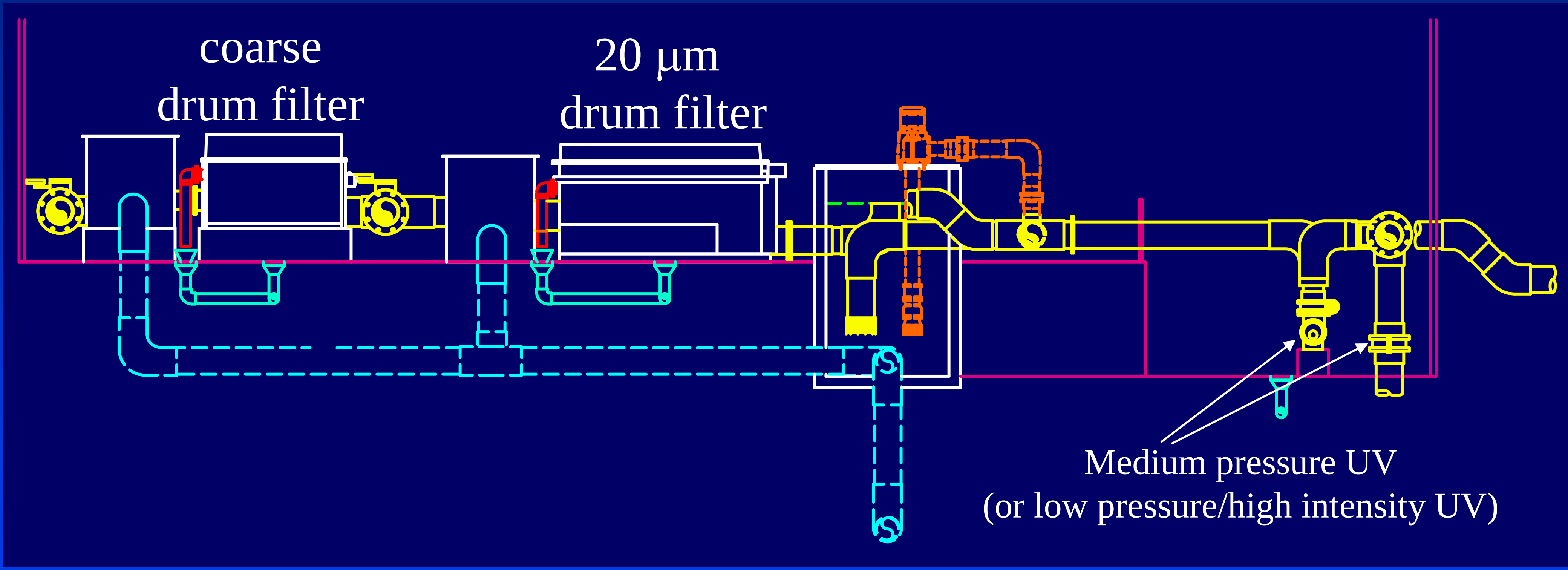
	mW-sec/cm^2
✓ Dose to inhibit growth of *Saprolignia*	230
✓ Dose to decrease infectivity of *myxobolus cerebralis*	28
✓ Recommended dose for recirculated water	30
✓ Recommended dose for hatchery wastewater	30

UV Doses Required for Disinfection

- Prefiltration through 50 μm screens can improve bacterial inactivation with UV by 3.0 $\log_{10}$ units.
  - Liltved and Cripps (1999)

Filtration & UV Disinfection

- Pittsford NFH Surface Water Disinfection



Types of UV Lamps

Mercury Lamps:

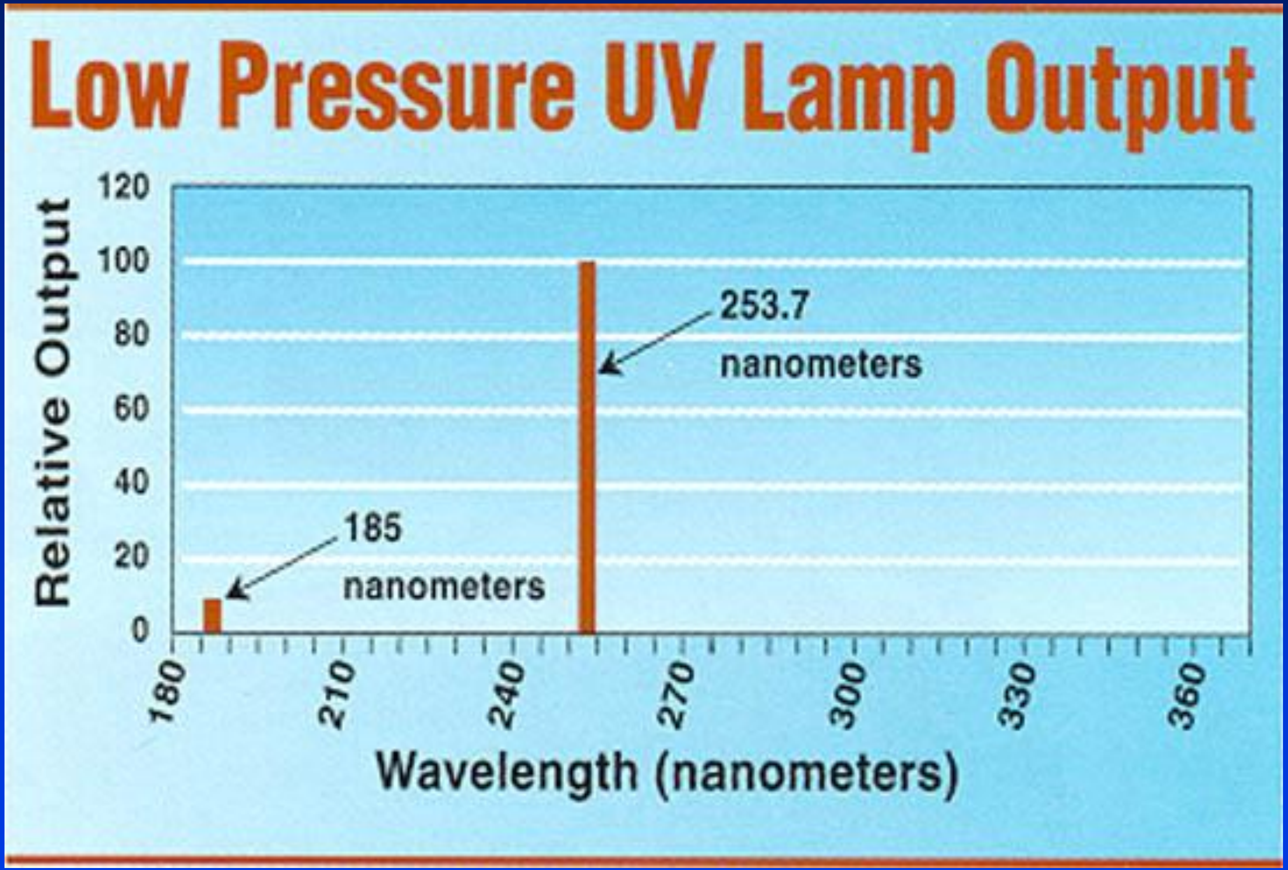
- Low pressure, low intensity (old technology)
- Low pressure, high intensity (newest technology)
- Medium pressure, high intensity (new technology)

UV Systems Compared

- A. Kolch. 1999. *Pollution Engineering*. pp: 34-36.

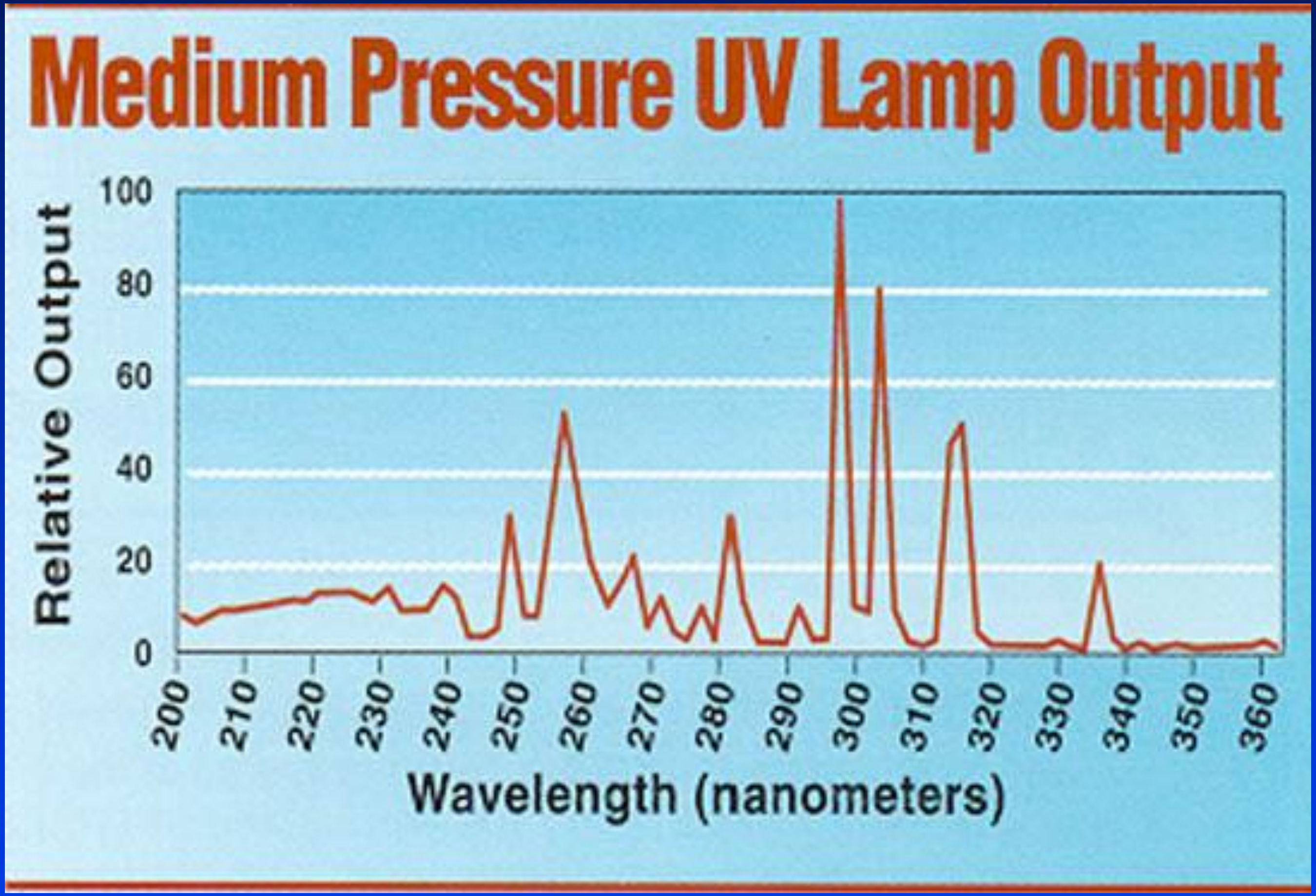
	Low/Low	Low/High	Medium/High
Lamp power	**15-70 W**	**120-260 W**	**4000 W**
Efficiency	**40%**	**35-40%**	**10-15%**
Lamp output @ 254 nm	**0.1-0.2 W/cm**	**0.5-1.0 W/cm**	**3 W/cm UVC tot**
Lamp temperature	**39ºC**	**100ºC**	**600ºC**
Lamps needed for 0.8 m^3/s flow	**~100**	**~30**	**~5**
Total power cons	**7.5 kW**	**7.8 kW**	**20 kW**

Low-Pressure UV Output



(courtesy of Trojan Technologies)

Medium-Pressure UV Output



(courtesy of Trojan Technologies)

Medium-Pressure UV

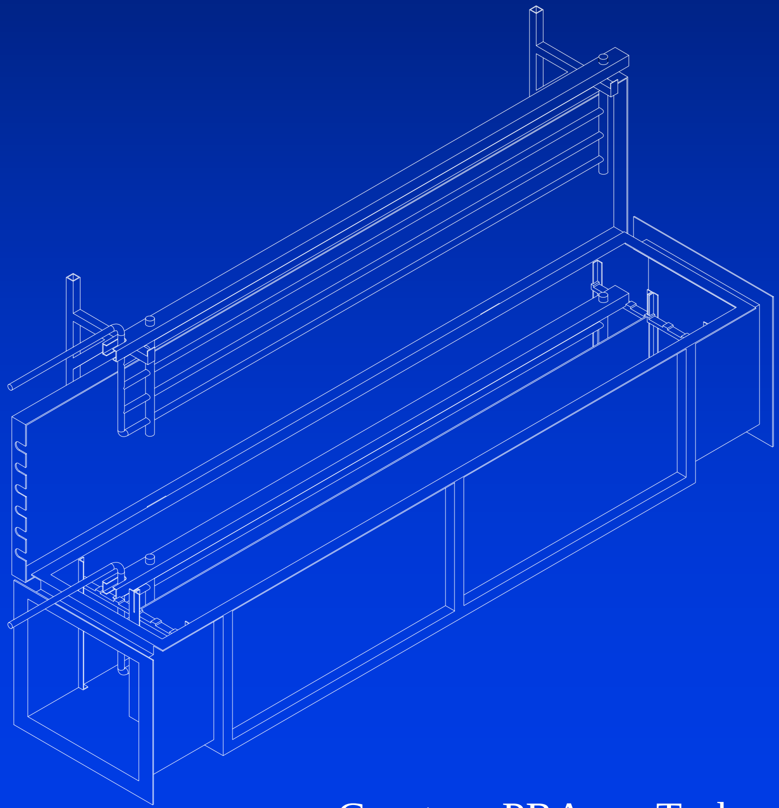
- In addition to disinfection, medium-pressure UV can:
  - ✓ photo-oxidize organic carbon at 185 nm wavelengths,
    - produces hydroxy radicals (HO-) to break apart organic molecules
  - ✓ convert nitrate into nitrite if special quartz sleeve filtering is not applied.

Vessel Design

- Pressurized "*Tube-and-Shell*" design
  - Selected when water pressure needs to be conserved in a pipeline
  - Ttypically operates at > 0.2-1 m of water headloss
- Non-pressurized "*Open Channel*" Design
  - Selected in situations with little available water head

Horizontal Channel UV Filter

- Freshwater Institute's Grow-out System



Courtesy PRAqua Technologies (BC)

Horizontal Channel UV Filter

- Courtesy of Trojan Technologies, Inc.

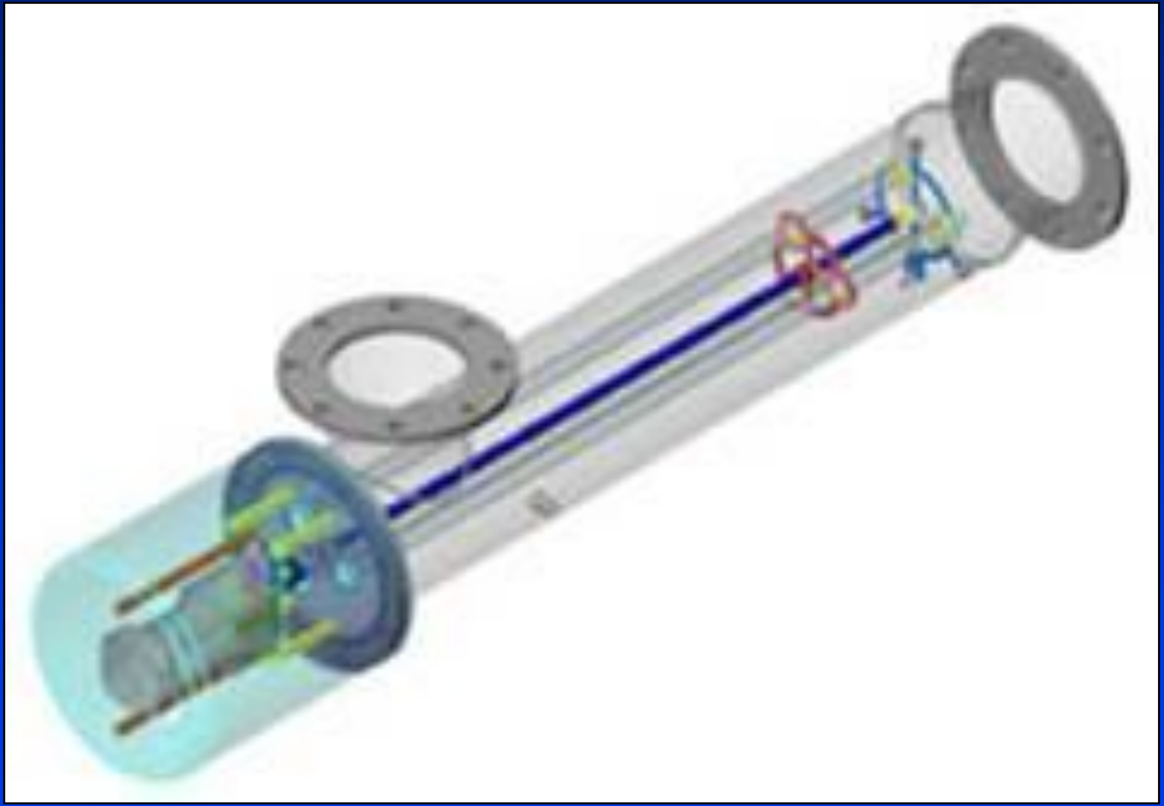
Vertical Channel UV Filters

- Three salmon smolt systems (~3000 gpm/system) at Nutreco's Big Tree Creek Hatchery (BC)

(system designed by PRAqua Technologies)

Medium-Pressure UV Unit

- Tube-and-shell design



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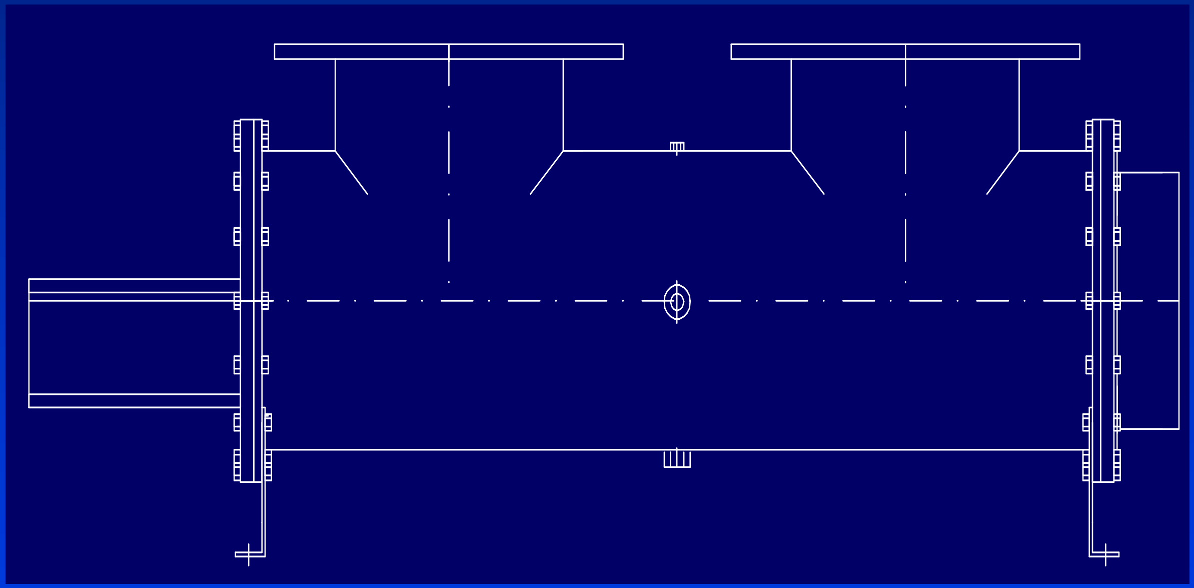
Medium-Pressure UV Unit

- Tube-and-shell design.



(courtesy of Ozonia)

Ozone Followed by UV Filtration

- Freshwater Institute's Grow-out System.

Ozone Followed by UV Filtration

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