American Water Works Association
Pacific Northwest Section

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Reinventing tomorrow.

Ozone Disinfection in Drinking Water Treatment: Back to Basics

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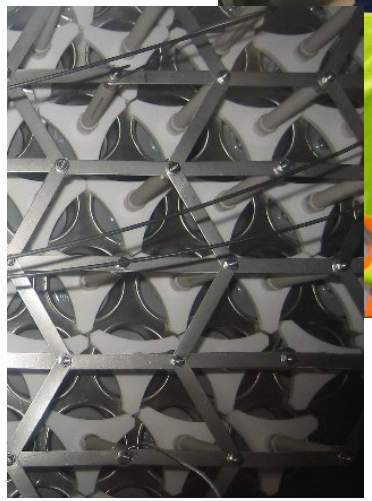
Roadmap

- Regulatory History
- Advantages & Disadvantages
- What is ozone?
- How do we use it?
- How do we make it?
- How do we operate it?
- What's new in Ozone?



Disinfection Technology

- Regulatory Requirements
- Utility Goals
- Enhanced Particulate Removal
- Aesthetics

- Mainstream Disinfection Options
  - Chlorine
  - Ultraviolet (UV)
  - Ozone

Table 1.		
Summary of oxidative power, adapted from Wastewater Engineering: Treatment and Reuse (Metcalf & Eddy, 2003).		
Oxidizer	Electrochemical Oxidation Potential (EOP), V	EOP Relative to Chlorine
Hydroxyl Radical, $HO\cdot$	2.80	2.05
Ozone, O_3	2.08	1.52
Hydrogen Peroxide, H_{2O_2}	1.78	1.30
Hypochlorite, ClO^-	1.49	1.10
Chlorine, Cl_2	1.36	1.00
Chlorine Dioxide, ClO_2	1.27	0.93

Drinking Water Regulation

Federal Drinking Water Regulations

- 1948 – Water Pollution Act
- *1970 – EPA Created*
- **1972 – Clean Water Act**
- **1974 - Safe Drinking Water Act (SDWA)**
- 1977 – Safe Drinking Water Act Amendments
- 1979 – Safe Drinking Water Act Amendments
- 1980 – Safe Drinking Water Act Amendments
- 1985 – National Primary Drinking Water Standards
- **1986 – Safe Drinking Water Act Amendments**
- 1988 – Lead Contamination Control Act
- **1989 – Surface Water Treatment Rule (SWTR)**
- 1989 – Total Coliform Rule (TCR)
- **1996 – Safe Drinking Water Act Amendments**
- **1998 – Interim Enhanced Surface Water Treatment Rule (IESWTR)**
- 1998 – Stage 1 D-DBP Regulation
- 2000 – Radionuclides Rule
- **2001 – Filter Backwash Recycling Rule (FBRR)**
- 2002 – Public Health Security and Bioterrorism Preparedness and Response Act
- **2002 – Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR)**
- **2006 – Stage 2 Disinfectants and Disinfection Byproducts Rule**
- **2006 – Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)**
- 2011 – Reduction of Lead in Drinking Water Act
- 2013 – Community Fire Safety Act
- 2013 – Revised Total Coliform Rule (RTCR)
- 2015 – Drinking Water Protection Act
- 2015 – Grassroots Rural and Small Community Water System Assistance Act
- 2016 – Water Infrastructure Improvements for the Nation Act
- 2018 – America’s Water Infrastructure Act
- 2019 – National Defense Authorization Act for Fiscal Year 2020

Ozone Basics

Ozone Advantages

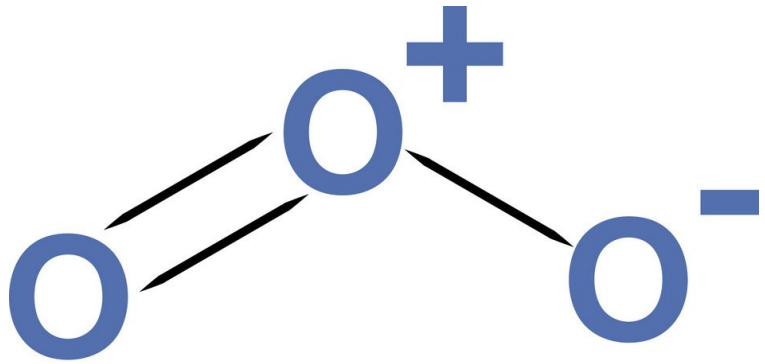
- ✓ High oxidation potential
- ✓ More effective than chlorine at destroying microorganisms
- ✓ Microorganisms cell structures are destroyed, not just DNA “inactivation”
- ✓ Reduced harmful residuals (can reduce organic disinfection byproducts)
- ✓ Shorter contact time
- ✓ Remove taste and odor compounds
- ✓ Raises DO concentration (dissolved oxygen) in effluent

Ozone Disadvantages

- x Ozone is poisonous, highly reactive, and corrosive
  - Expensive equipment
  - Safety risks
- x Complicated equipment and instrumentation
  - Operations and maintenance challenges
- x Requires a lot of electricity
- x Expensive capital investment for new systems
- x Not suitable for all raw water qualities
  - Can introduce ozone specific disinfection byproducts (bromate, NDMA)

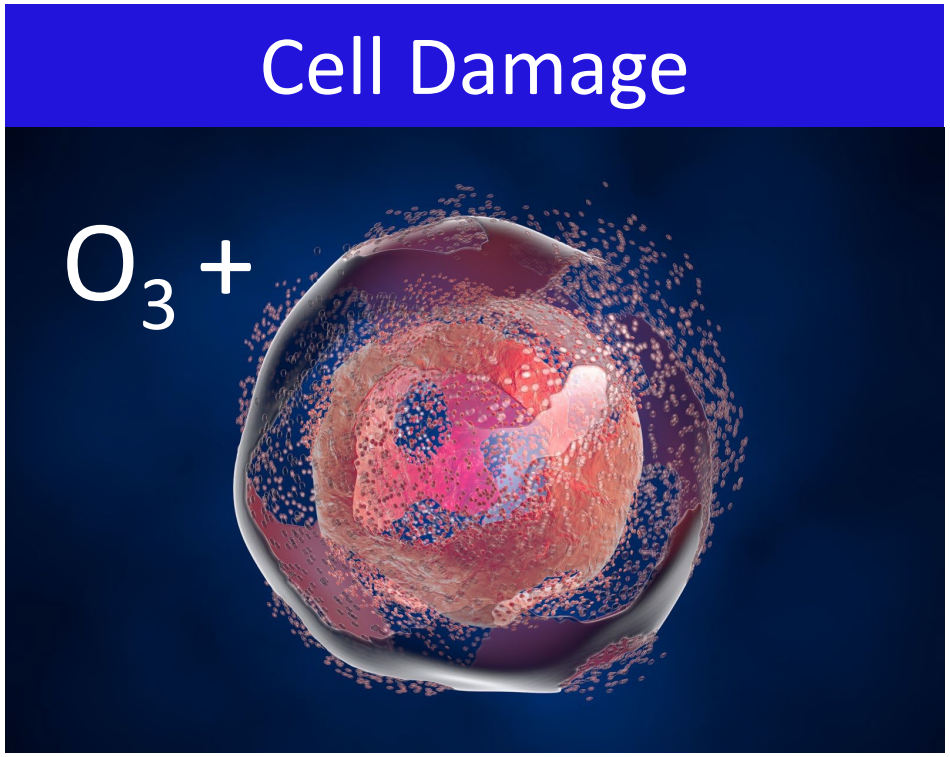
What is Ozone?

- Molecule with Three Oxygen Atoms
- Unstable Gas
- Naturally Occurring
- Smells Like Lightning or Commercial Printers
- Highly Reactive
- Poisonous
- Soluble in Water (Dependent on Temperature)



What can we do with it?

- Chemical Oxidation
  - Stealing e^- or H from molecules
- Biological Oxidation
  - Break cell walls
- Municipal Water and Wastewater Treatment
  - Direct oxidation of cell walls
  - Bacteria
  - Viruses
  - Parasites
  - Algae
- Taste, Odor, and Color
- Volatile Organic Compounds



Where do we use it in treatment?

Method	Treatment Stage
“Pre-Ozone”	Raw Water, Before Clarification or Sedimentation
“Intermediate-Ozone”	Settled Water, After Clarification or Sedimentation but Before Filtration
“Post-Ozone”	Treated Wastewater Effluent, After Clarification and Filtration

Terminology

LOX

Liquid Oxygen (O_2)

Vaporizer

Liquid Oxygen Turns into Oxygen Gas

Generator

Electricity + Dry Oxygen Gas = Ozone

Contactor

Dissolve Ozone Gas in Water

Contact Time

Residual

Dissolved Ozone Concentration in the Water

(mg/L)

Log Removal Value (LRV)

4-Log = 99.99%
3-Log = 99.90%
2-Log = 99.00%
1-Log = 90.00%

Ozone in Water Treatment

How do we make ozone?

- From Liquid Oxygen (LOX)
  - Delivered to Site
  - Ambient Vaporizer Converts Liquid to Gas
- From ambient air

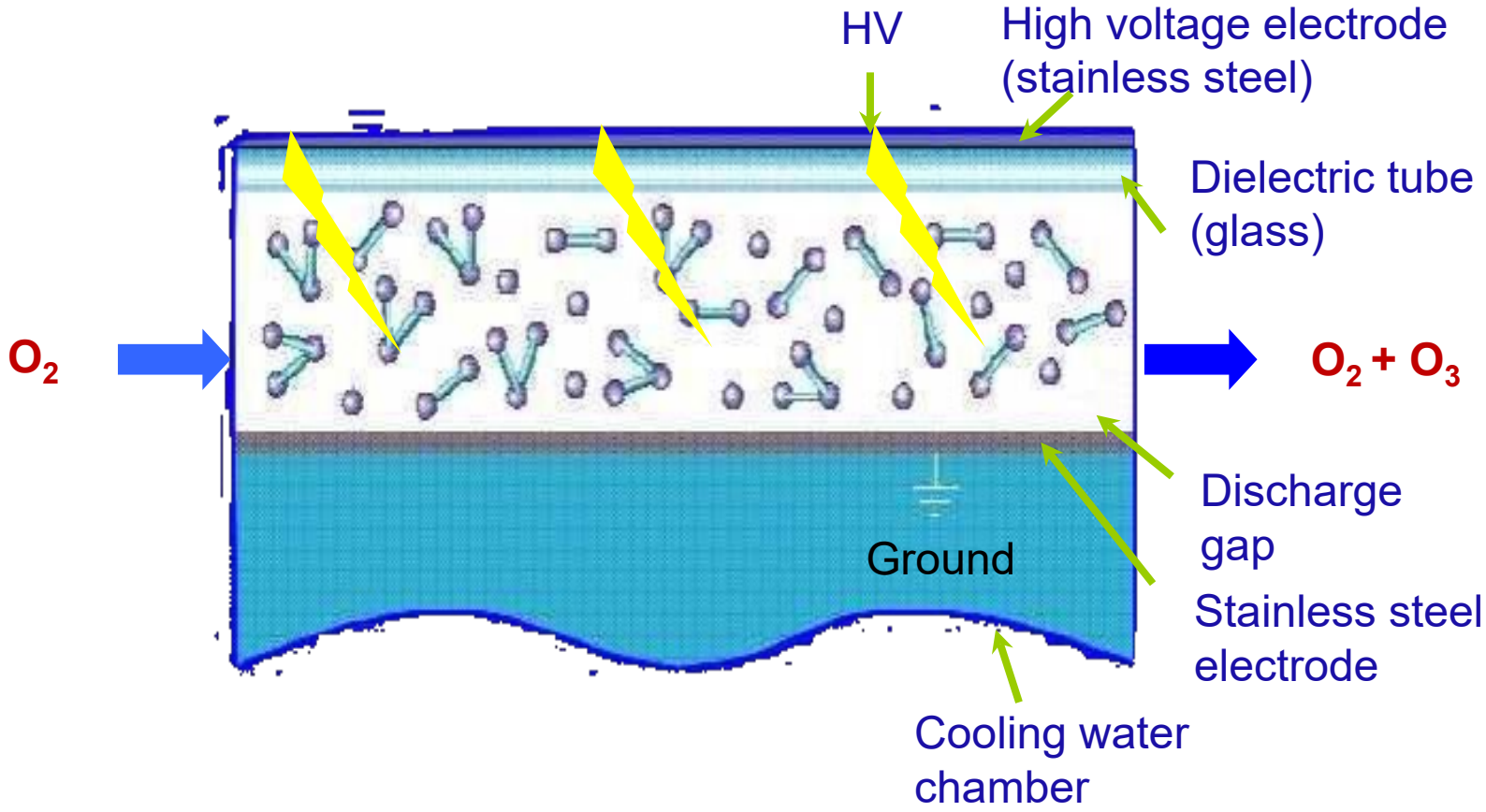
- Heat Exchanger

How do we make ozone?

- Dry Oxygen Gas + Nitrogen Gas
- Ozone Generator (Corona Discharge Method)
- How is ozone made in nature?

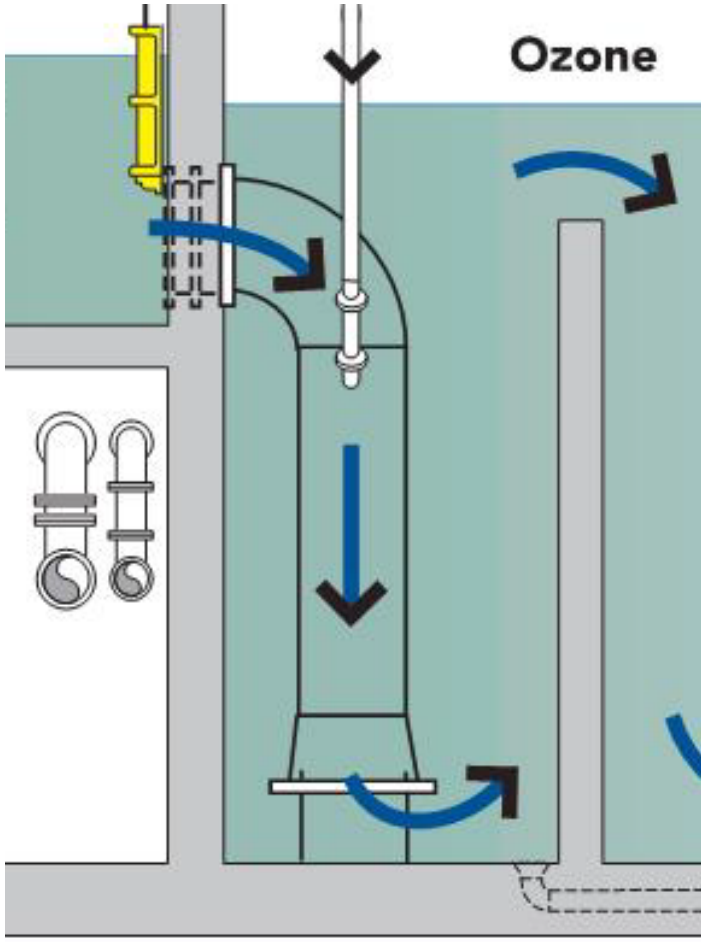
How do we make ozone?

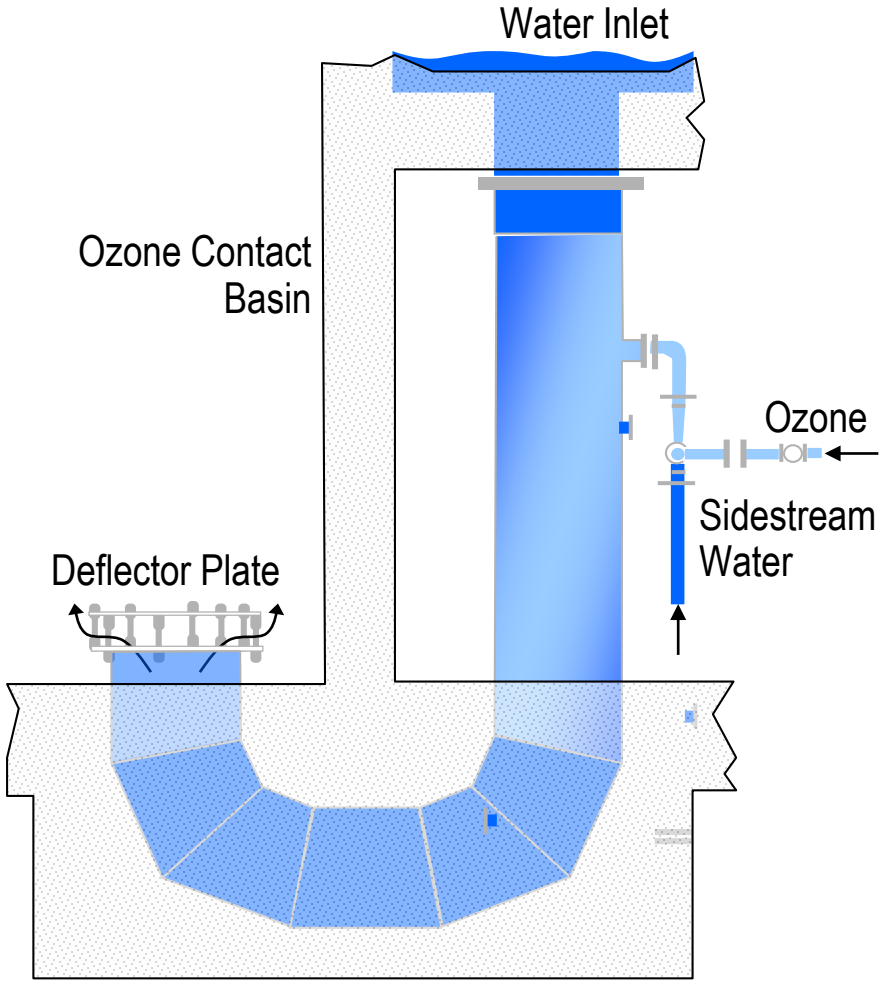
Ozone is produced when dry OXYGEN-rich gas passes through an electrical field, where a high frequency electrical current causes a “split” in the oxygen molecules.
This unstable state will cause some “split” molecules to re-combine with “non-split” oxygen molecules to create the triatomic molecule called OZONE.



How do we get it in the water?

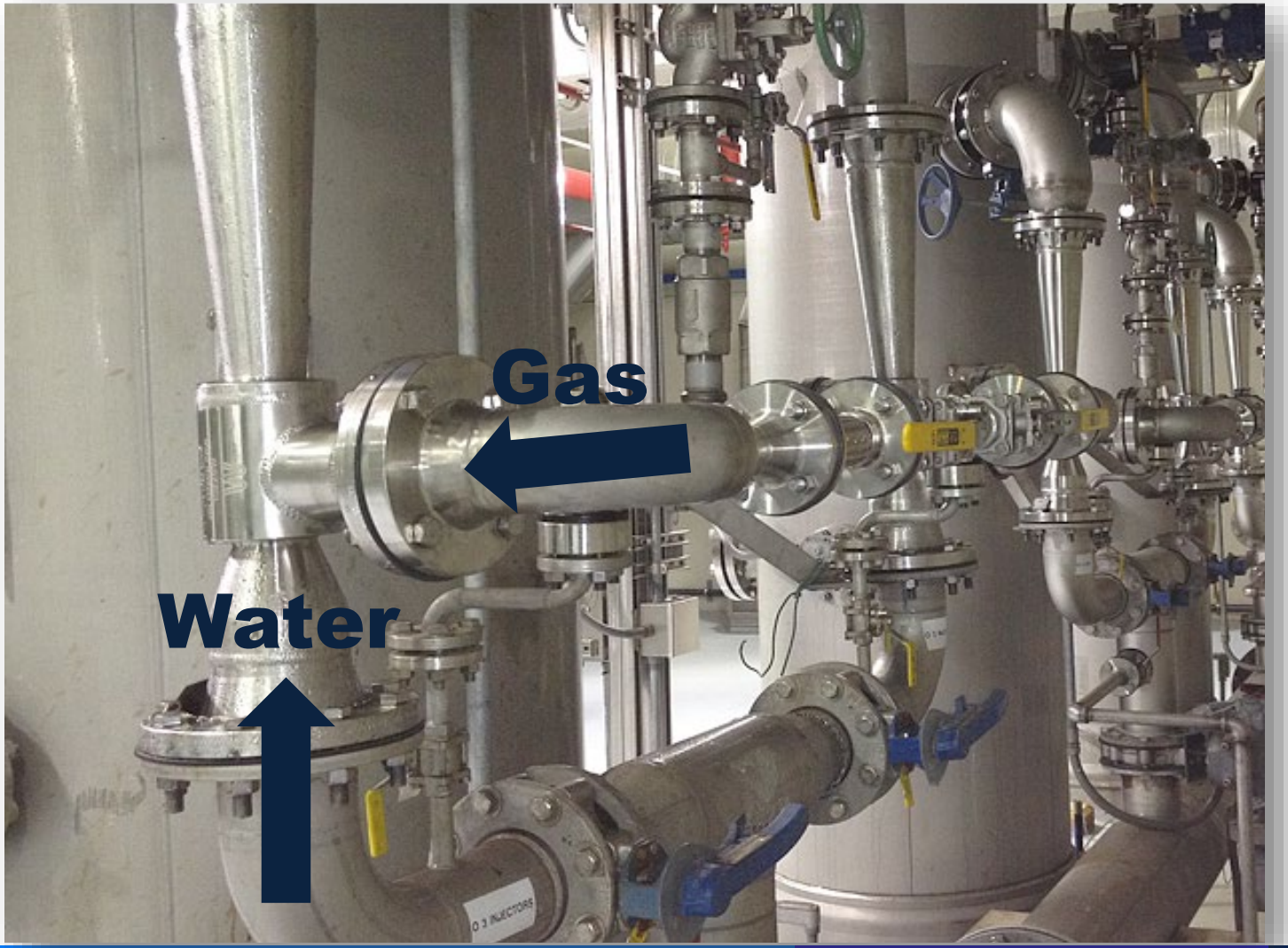
- Bubble Diffusers
- Sidestream injection
  - Downflow Tube
  - J-Tube
- Inline injection mixers





J-Tube with Injectors

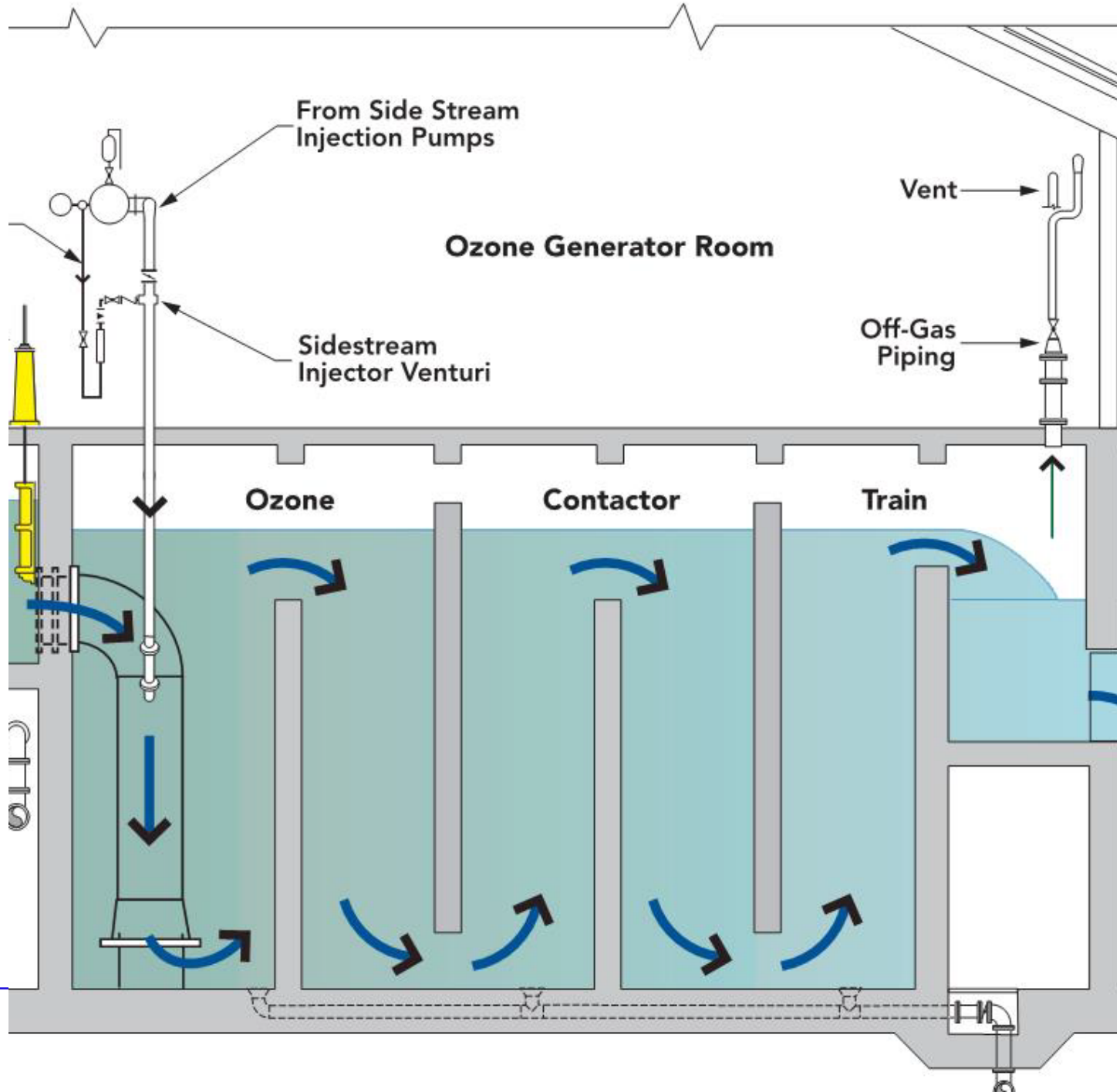
Sidestream injection



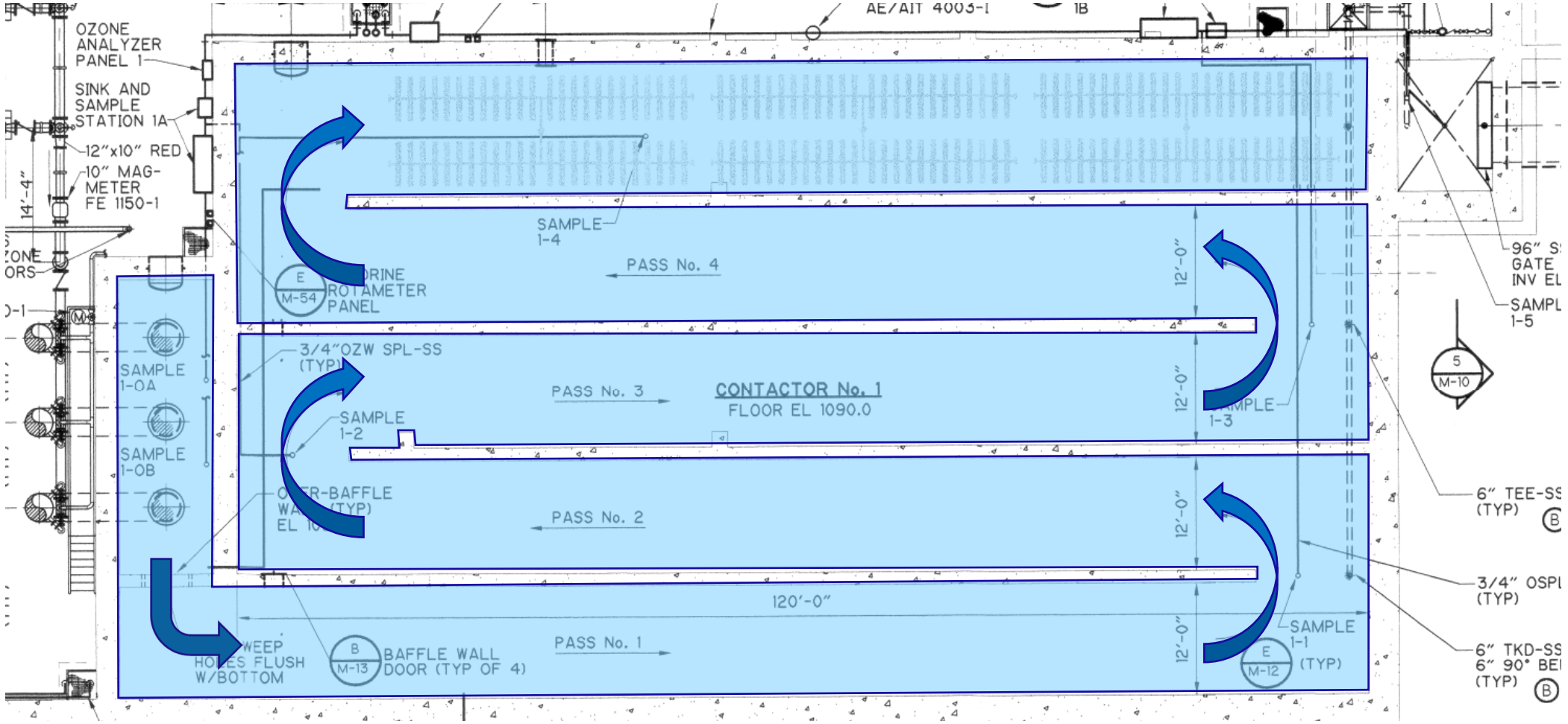
It’s in the water, now what?

- Contact Basins, aka “Contactors”
- In-Pipeline
- Over-Under Baffle Design
- Serpentine Baffle Design

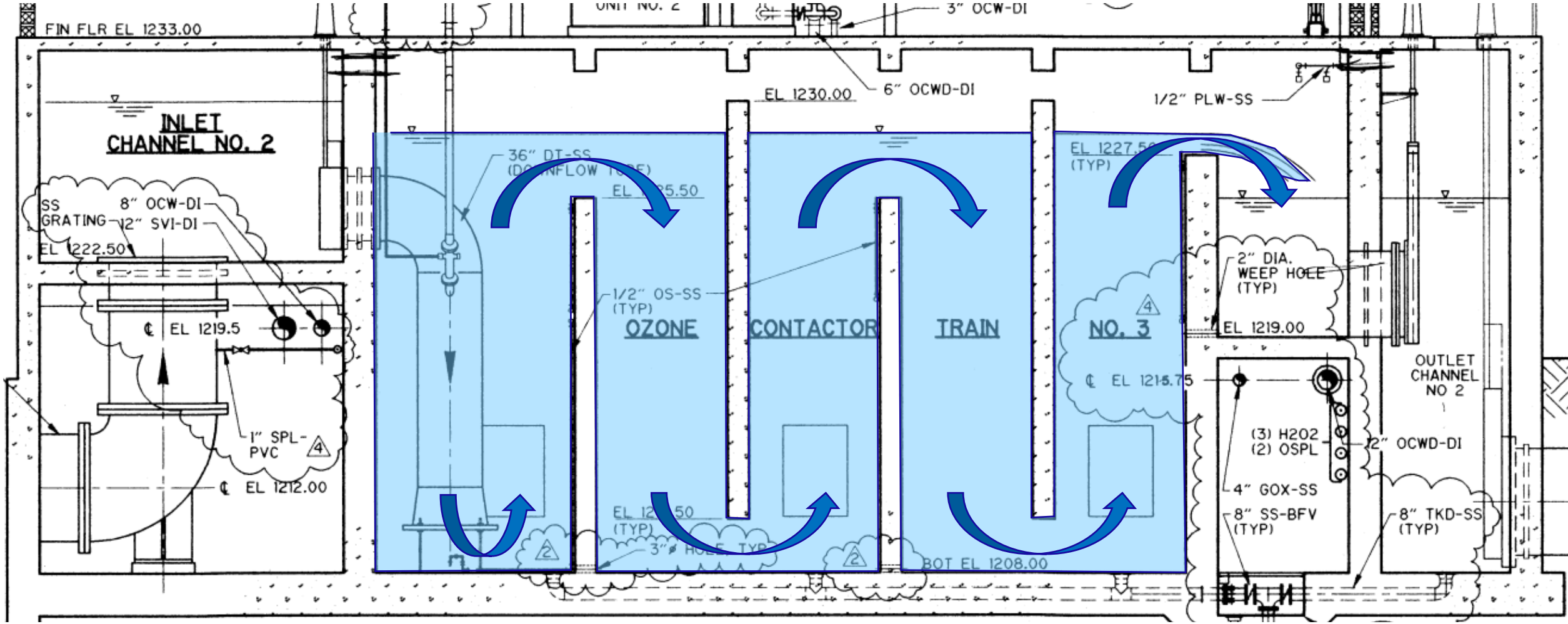
- Retention time and Baffle Factor impact CT and required ozone dosages



Serpentine Contact Basin Arrangement



Over-Under Baffle Arrangement



Off-Gas System

- Leftover Undissolved Ozone Gas
- Vacuum
- Thermal-Catalytic Destruct unit
- Ozone Broken Up back to Oxygen
- Blower to Vent to Outside

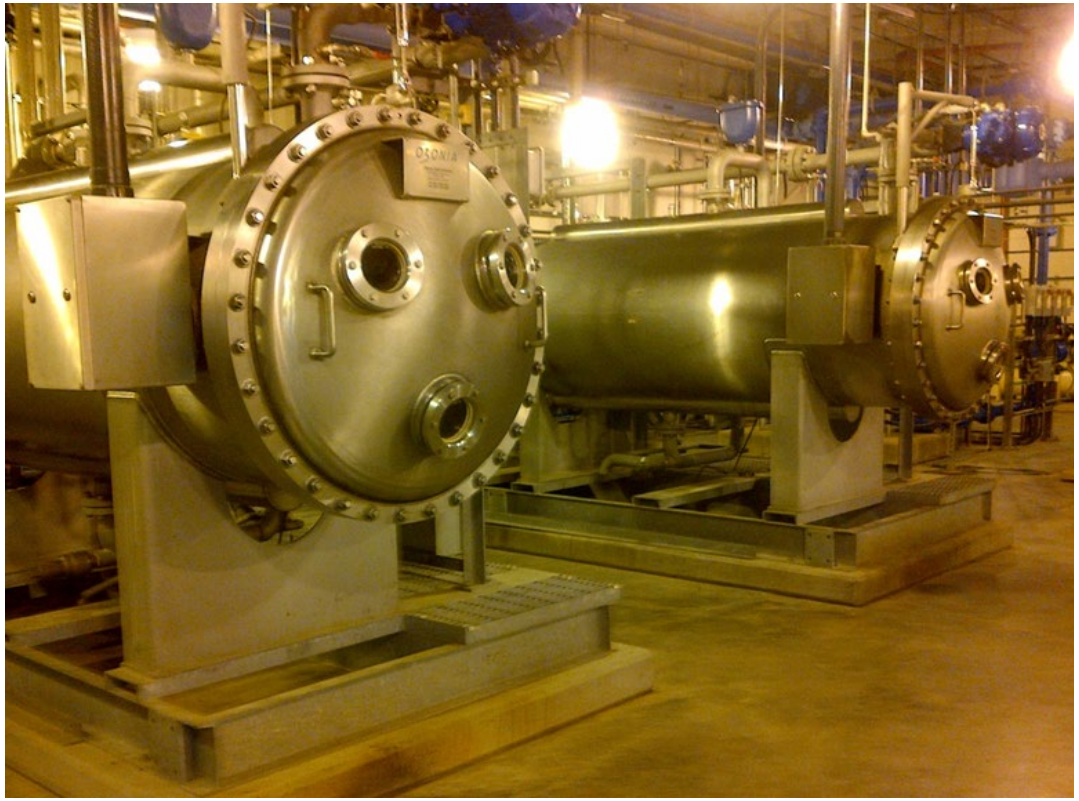
Process Design

- CT Calculation
- Known or Measured:
  - Temperature
  - Flowrate
  - Contact Time
  - Residual Ozone

$$CT = \int [O_3]\, dt = \int [O_3]_0 e^{-kt}\, dt$$

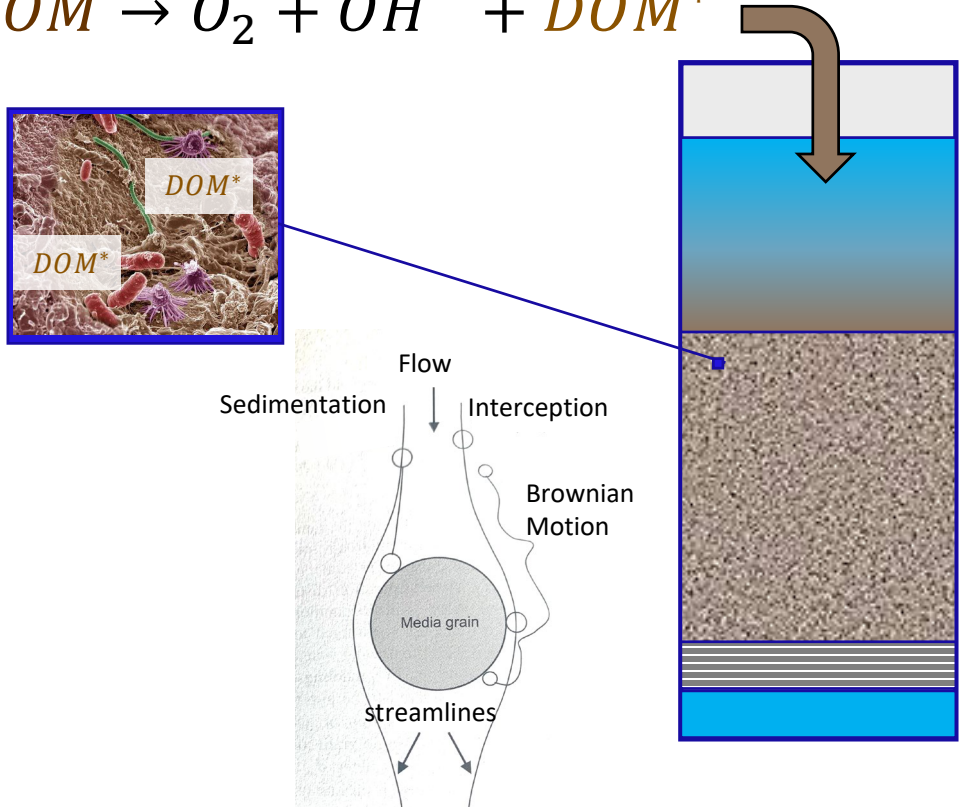
$$CT = \frac{[O_3]_0}{k \times e^{kt} - 1}$$

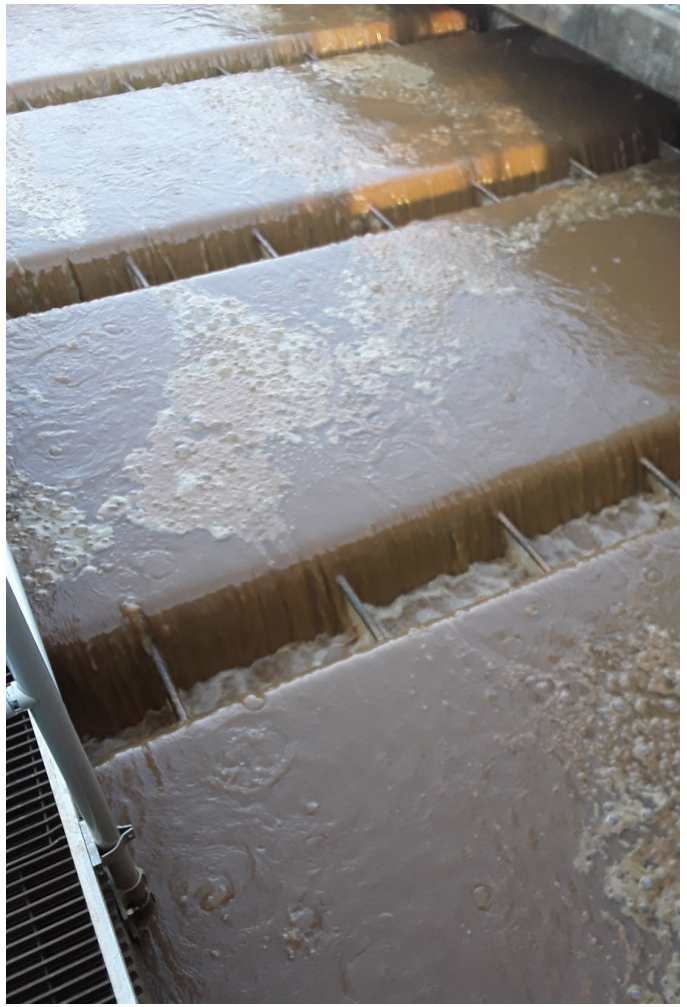
- Adjust Ozone Dosage to target LRV



Biofiltration or Biologically Active Filtration (BAF)

- Improved organics removal
- Increased filtration rates
- Need to mature filters to build community
- $O_3 + DOM \rightarrow O_2 + OH^- + DOM^*$

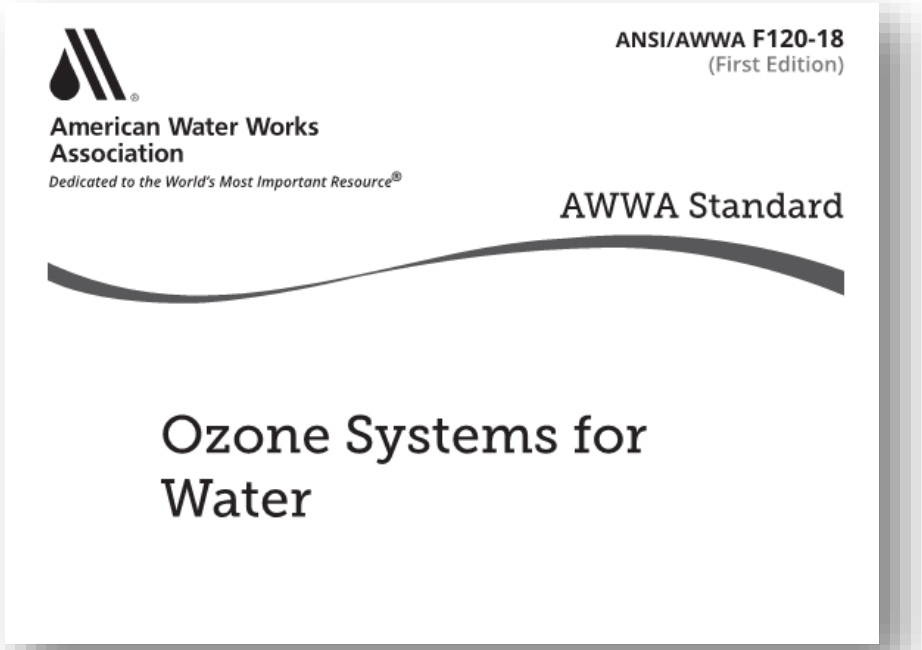




What's New in Ozone?

- AWWA Standard New in 2018
  - F-120 "Ozone Systems for Water"
- Computational Fluid Dynamics (CFD)

- More efficient reactors



Source: AWWA

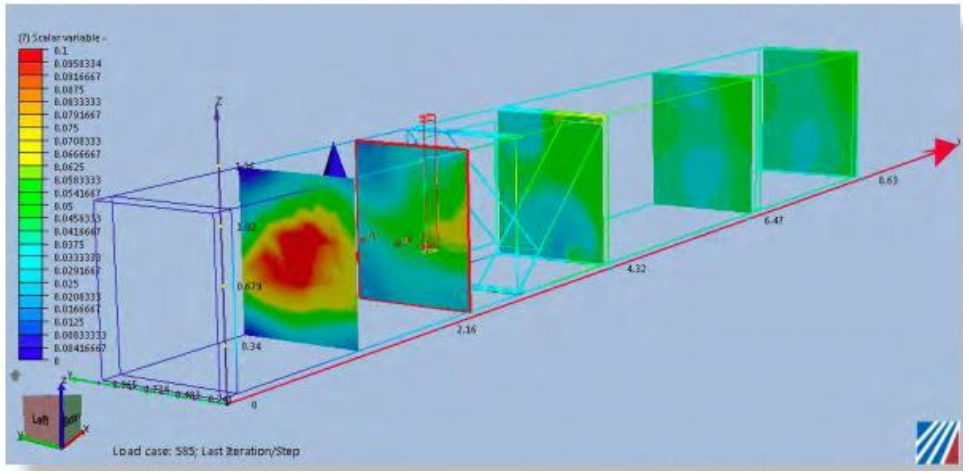


Image Source: Mazzei Injector Company, LLC

What we haven’t covered

- Safety
- Capital and Life-Cycle Costs
- Unregulated Contaminants
- Limiting bromate and NDMA byproduct formation

Questions?

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