

Advances in Ozone Generation & Injection

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Outline

- Why is ozone used for drinking water treatment?
- Ozone Generation
 - Typical generators
 - Newer technology
- Ozone Injection
 - Diffusers vs. side stream



Use of Ozone in Drinking Water Treatment

- Nearly 300 WTPs in the US
- ~75% are surface water plants with a physical removal process



Applications of Ozone in Drinking Water Treatment

- Oxidation of metals and organics
 - Example: Iron & Manganese



Oxidant name	Chemical formula	pH and rxn rate	Direct oxidation aspects
Permanganate (purchase as potassium or sodium salt)	MnO_4^-	Fast at pH > ~6 (2 to 4 minutes)	<ul style="list-style-type: none"> - Overdose causes pink water - Adds Mn to water - Possible taste & odor benefits - Forms colloidal $\text{MnO}_x(\text{s})$
Chlorine Dioxide	$\text{ClO}_2(\text{aq})$	Fast, little pH impact (1 to 2 minutes)	<ul style="list-style-type: none"> - Generate on-site - Dosing limited by chlorite DBP MCL - Forms colloidal $\text{MnO}_x(\text{s})$
Ozone	$\text{O}_3(\text{aq})$	Fast, little pH impact (1 to few minutes)	<ul style="list-style-type: none"> - Generate on-site - Overdose can create pink water - Hard to yield $\text{Mn}_{\text{diss}} < 20 \mu\text{g/L}$ - Forms colloidal $\text{MnO}_x(\text{s})$
Free Chlorine	$\text{HOCl}, \text{OCl}^-$	Slow until pH > 8 to 9.	<ul style="list-style-type: none"> - Not effective for direct oxidation at pH < 8 – 9 - Very effective for surface oxidation
Oxygen	$\text{O}_2(\text{aq})$	Very slow until pH > 9 – 9.5	- Only significant in high pH softening
Hydrogen Peroxide	H_2O_2	NOT EFFECTIVE for Mn(II) Oxidation	

Source: Brandhuber, P., S. Clark, W. Knocke, and J. Tobiason. (2013) *Guidance for the Treatment of Manganese*. Water Research Foundation. Page 56.



Applications of Ozone in Drinking Water Treatment

- Primary Disinfection
 - Example: CT required for 4-log inactivation of viruses at 10°C, pH=6.0–9.0, mg-min/L
 - Free Chlorine ~ 6.0
 - Chlorine Dioxide ~ 25.1
 - Chloramine ~ 1,491
 - **Ozone ~ 1.00**

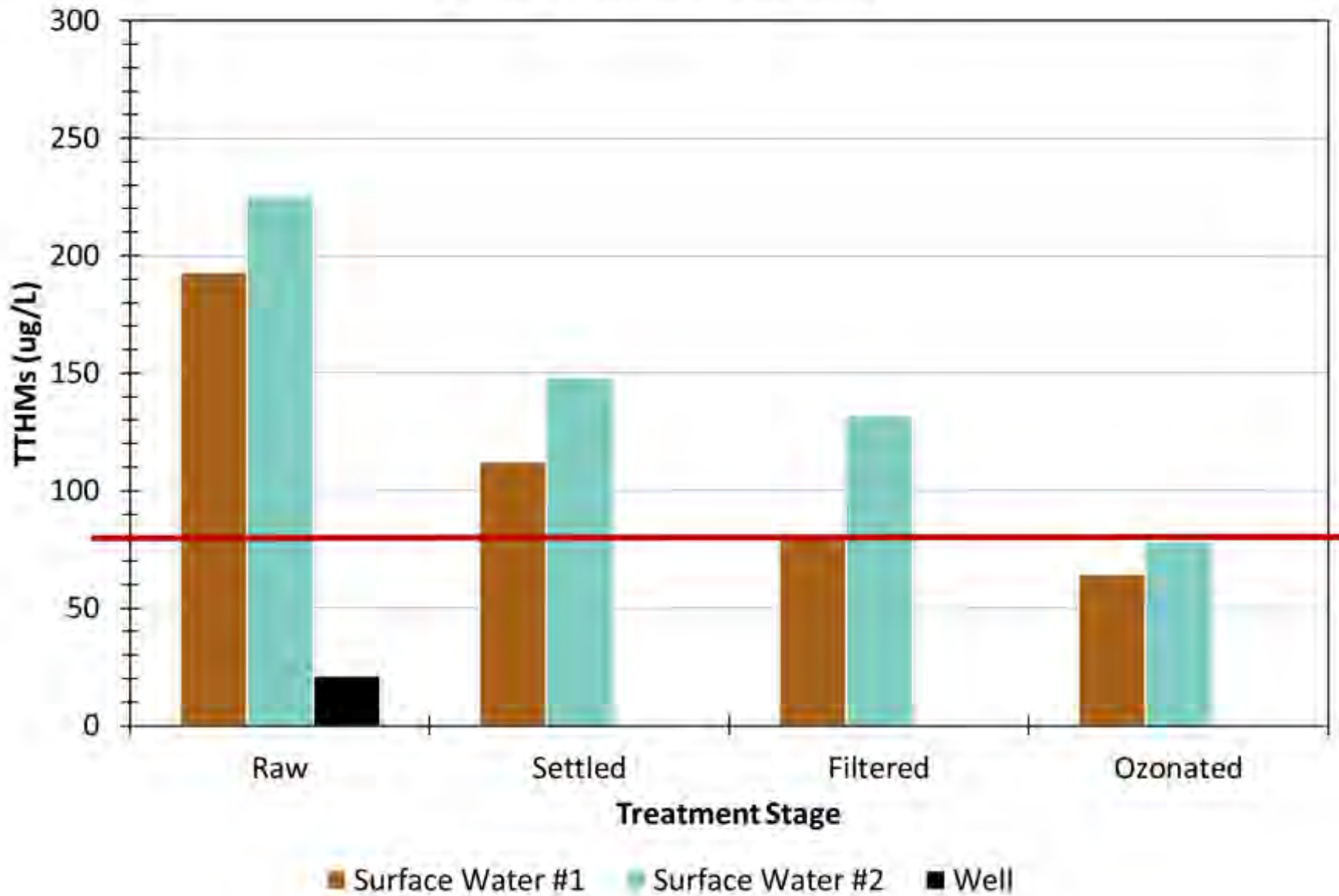


Applications of Ozone in Drinking Water Treatment

- Disinfection By-Product Reduction
 - 19%-60% reduction in trihalomethanes (THMs) in one recent study
 - Bromide -> Bromate concerns



7-Day THMFP Results



Applications of Ozone in Drinking Water Treatment

- Enhanced Filter Performance (Bio-filters)
- Control of Taste & Odor Compounds
 - Hydrogen Sulfide (H_2S)
- Emerging Contaminants
 - Pharmaceutical and Personal Care Products
 - Endocrine-Disrupting Compounds



Ozone (O₃) Production in Nature

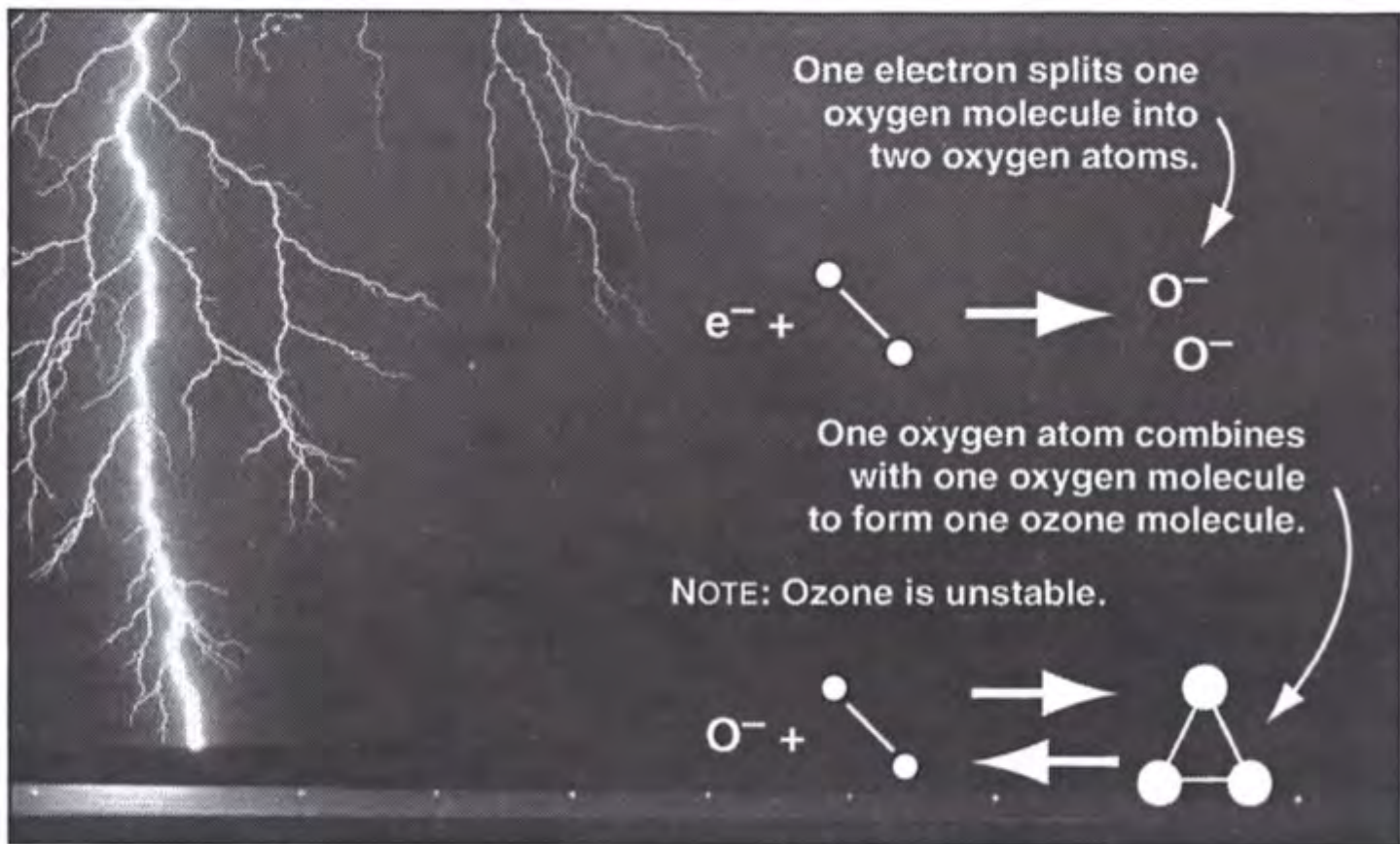
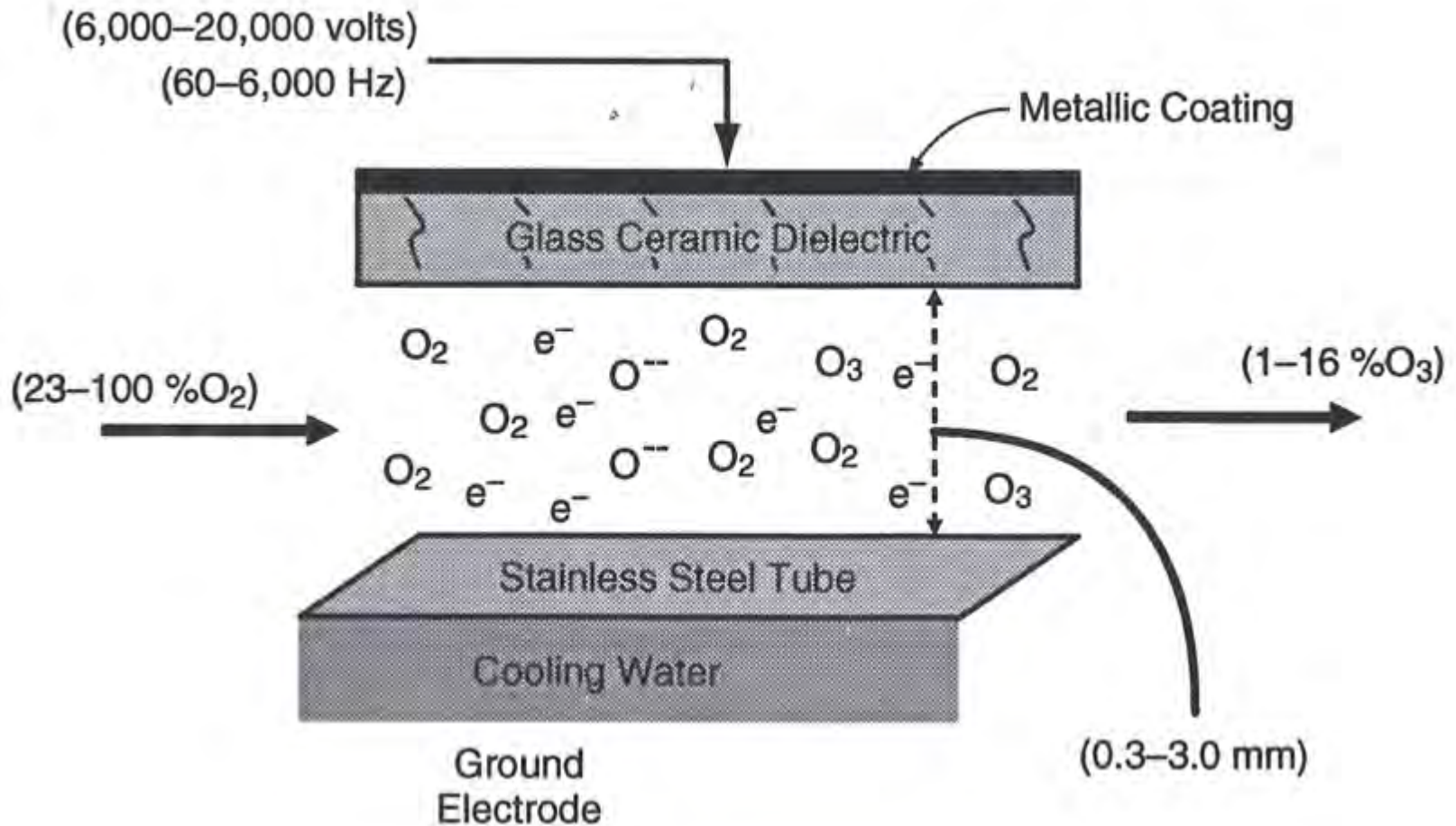


Figure 1-1 Electrical energy splits oxygen molecules to form ozone

Source: Rakness, Kerwin L. (2005) *Ozone in Drinking Water Treatment: Process Design, Operation, and Optimization*. AWWA. Page 3.



Industrial Ozone (O_3) Production



Source: Rakness, Kerwin L. (2005) *Ozone in Drinking Water Treatment: Process Design, Operation, and Optimization*. AWWA. Page 3.



Traditional Vessel/Tube Generators



Traditional Vessel/Tube Generators



After cleaning the Generator with the water brush, a clean rag, damp with water is pushed through the Tube. If the rag exits the tube soiled, then the rag is repositioned on the cleaning stem and passed through the Tube until the Tube is clean. When the rag remains clean or with a minor brown discoloration, a dry rag is passed through the Tube, followed by a rag slightly damp with alcohol, followed by a clean dry rag. A light brown coating may persist on the rags during these last three passes with rags. This is normal.

Source: Ozonia North America, LLC. (2010) *Ozone System Equipment Operation & Maintenance Manual*.
Revision A. New Great Pond Water Treatment Plant. "Ozone Generator Cleaning Procedure."

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Recent Generator Advances for Small Systems

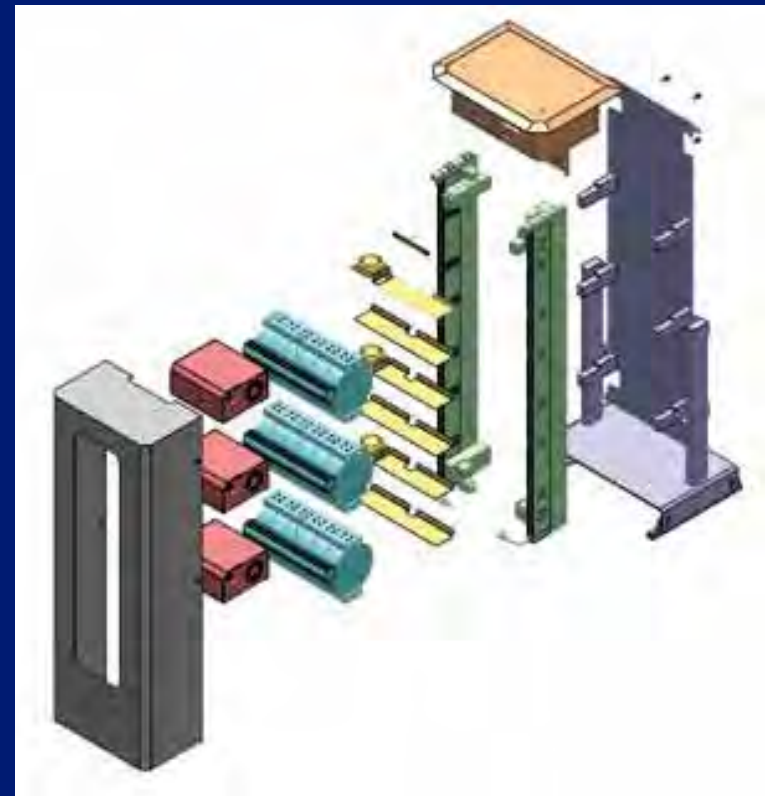
- Single Cabinet
 - Power Supply
 - Generator Modules
 - Controls
- Examples
 - ~100 ppd
 - ~3'x3' footprint



Sources: Pinnacle Ozone Solutions, LLC and Primozone Production AB



Inside the Cabinets Modular Components



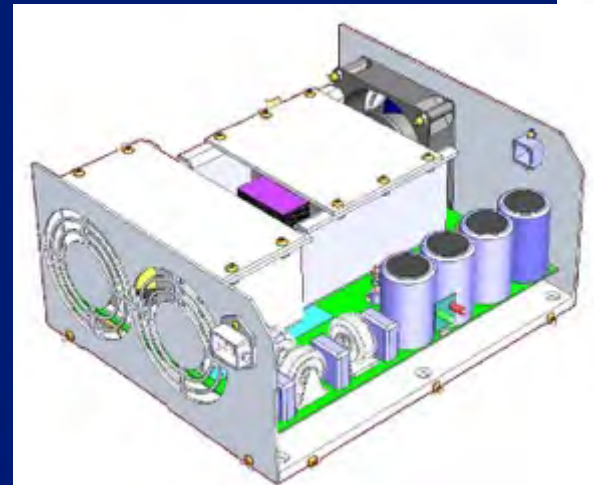
Sources: Pinnacle Ozone Solutions, LLC and Primozone Production AB

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Ozone Modules & Power Supply Units (PSUs)

- Integrated PSU vs. Separate PSU



Sources: Pinnacle Ozone Solutions, LLC and
Primozone Production AB

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Nagog Pond Water Supply

- Low turbidity (<1 NTU)
- Low alkalinity (5 to 10 mg/L CaCO₃)
- Moderate pH (6.0 to 7.0)
- Low levels of iron (Fe < ~0.2)
- Seasonally variable manganese levels (Mn 0.1 to 0.3 mg/L)
- Seasonally variable levels of NOM (TOC: 2.5 to 5.5 mg/L)
- Susceptible to algal blooms



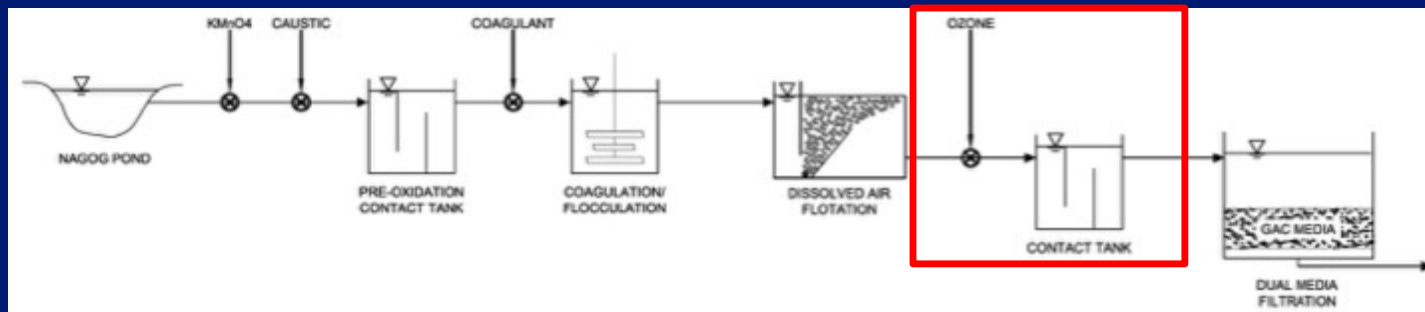
Nagog Pond Treatment

- Existing – Filtration Waiver
 - Ozone & UV
 - Chlorine, pH adjustment, corrosion control



Nagog Pond Treatment

- Proposed – Filtration Plant
 - Pre-oxidation with KMnO_4
 - Coagulation/Flocculation
 - Dissolved Air Flotation (DAF) clarification
 - **Intermediate Ozonation**
 - Biologically Activated Carbon (BAC) filters



Pilot System

- February 2014
- 3.8 ppd Capacity
- Dual-Zone O₃ Streams
- WTP Connections
 - Electrical
 - Compressed Air



Full Scale Pilot Summer 2014 & 2015

- 30-32 ppd
- Generally Reliable



Photos courtesy of Pinnacle Ozone Solutions, LLC

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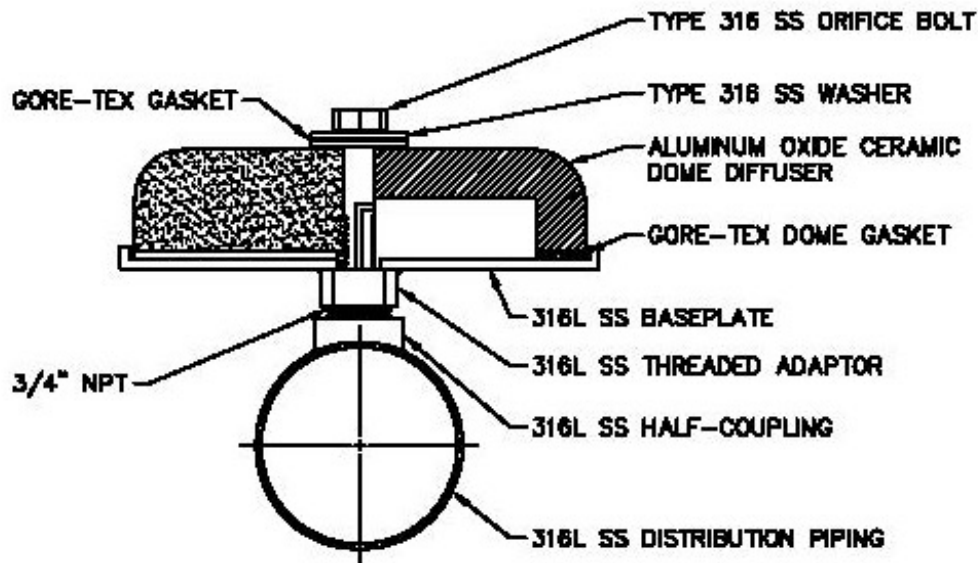
Cabinet Generation Systems

- Advantages
 - Simpler maintenance
 - Footprint
 - Potentially cheaper for small systems
 - O₃ Concentration/Turndown
- Disadvantages
 - Newer technology – fewer installs
 - >90% Oxygen

Sources: Pinnacle Ozone Solutions, LLC and Primozone Production AB



Classic Ozone Injection Diffusers

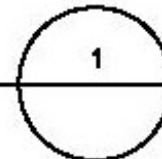


NOTES:

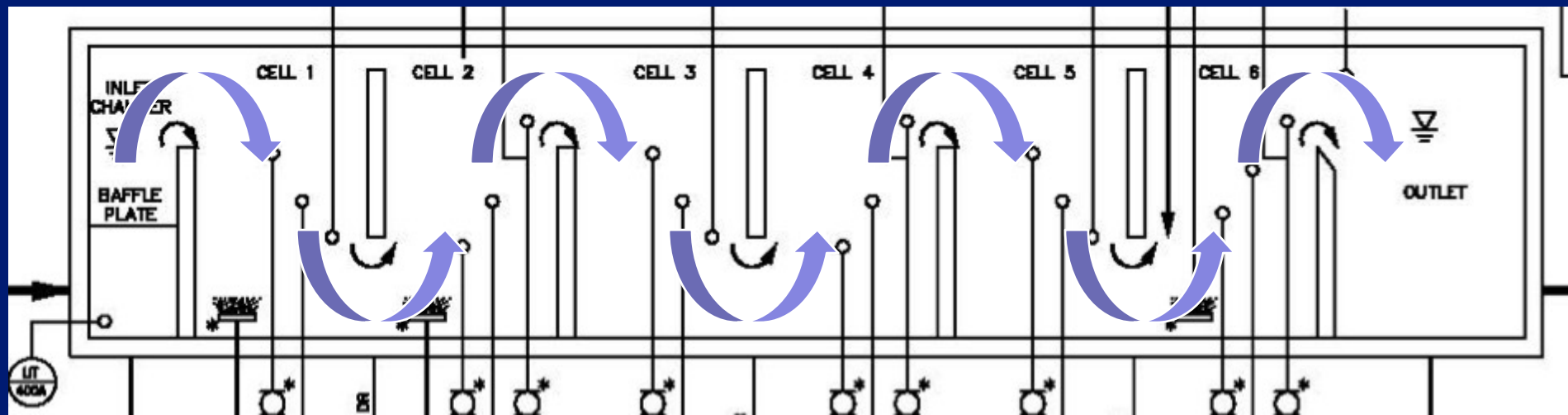
1. ALL GASKETING MATERIAL IS GORE-TEX.
2. DOME DIFFUSER IS 7.0" DIA. x 1.5" HIGH.
3. DOME DIFFUSER IS MODEL AF-30.
4. ORIFICE IS 13/64" DIAMETER.

CERAMIC DOME DIFFUSER DETAIL

SCALE: N.T.S.



Contactor

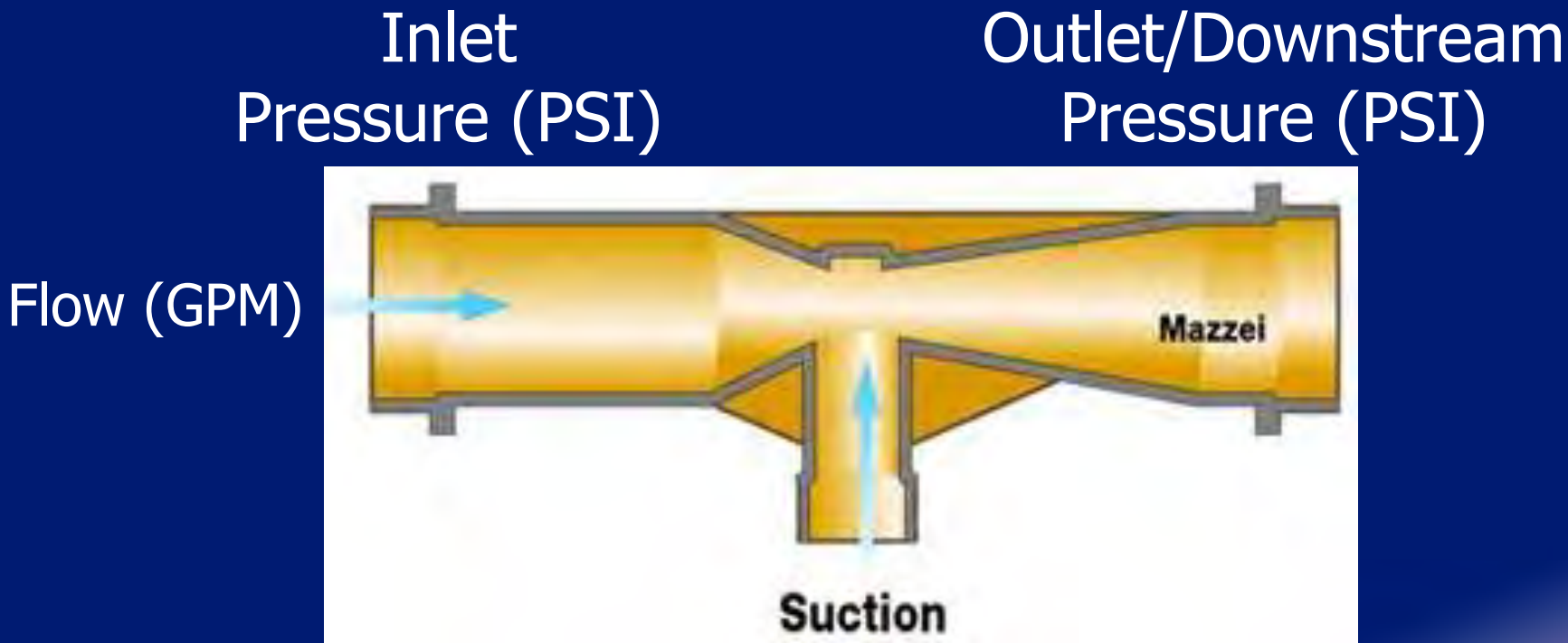


Ozone Injection Industry Trends

- 0-2 wt. % O_3 -> Ceramic Diffusers
- 5-6 wt. % O_3 -> Disk Diffusers
- 10-12 wt. % O_3 -> Venturi Injectors
 - "...Between 75 and 90% of new ozone system projects and about one-half of ozone system retrofit projects include Venturi-type injectors..."



Side Stream Injection General Information



Ozone Gas (SCFH)

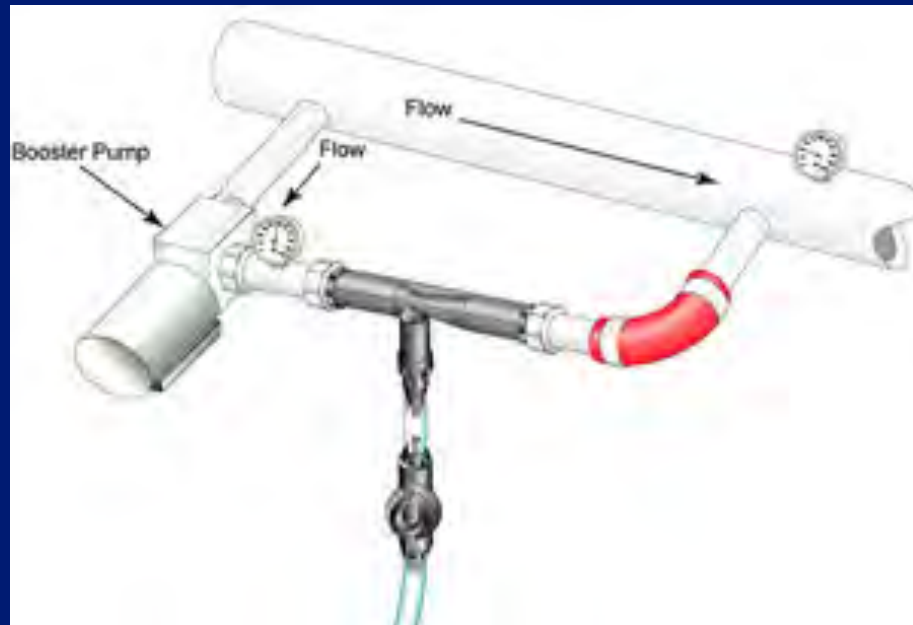
Source: Mazzei Injector Company, LLC

A partnership for engineering solutions.

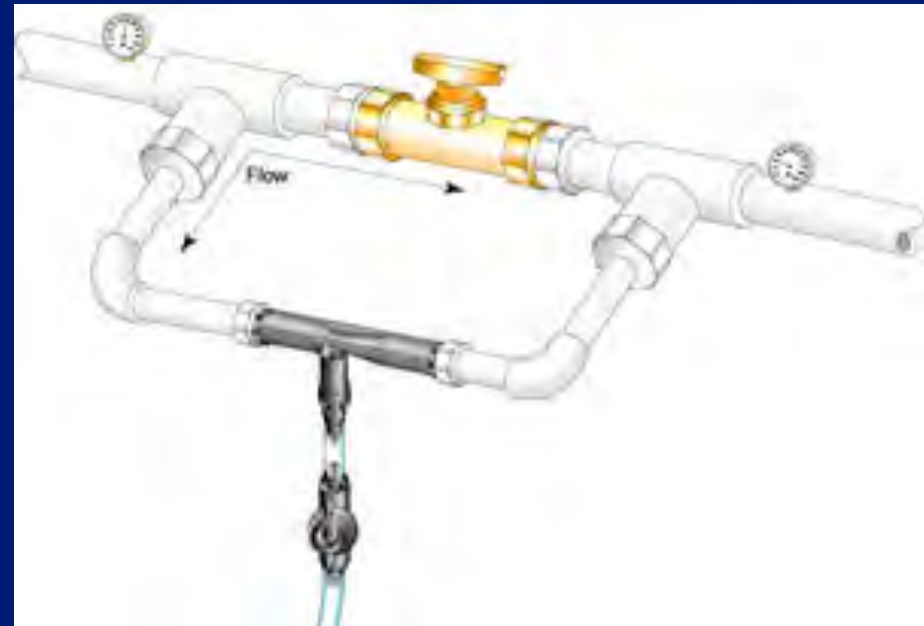


Side Stream Injection General Information

With Booster Pump



With Pressure Reducer

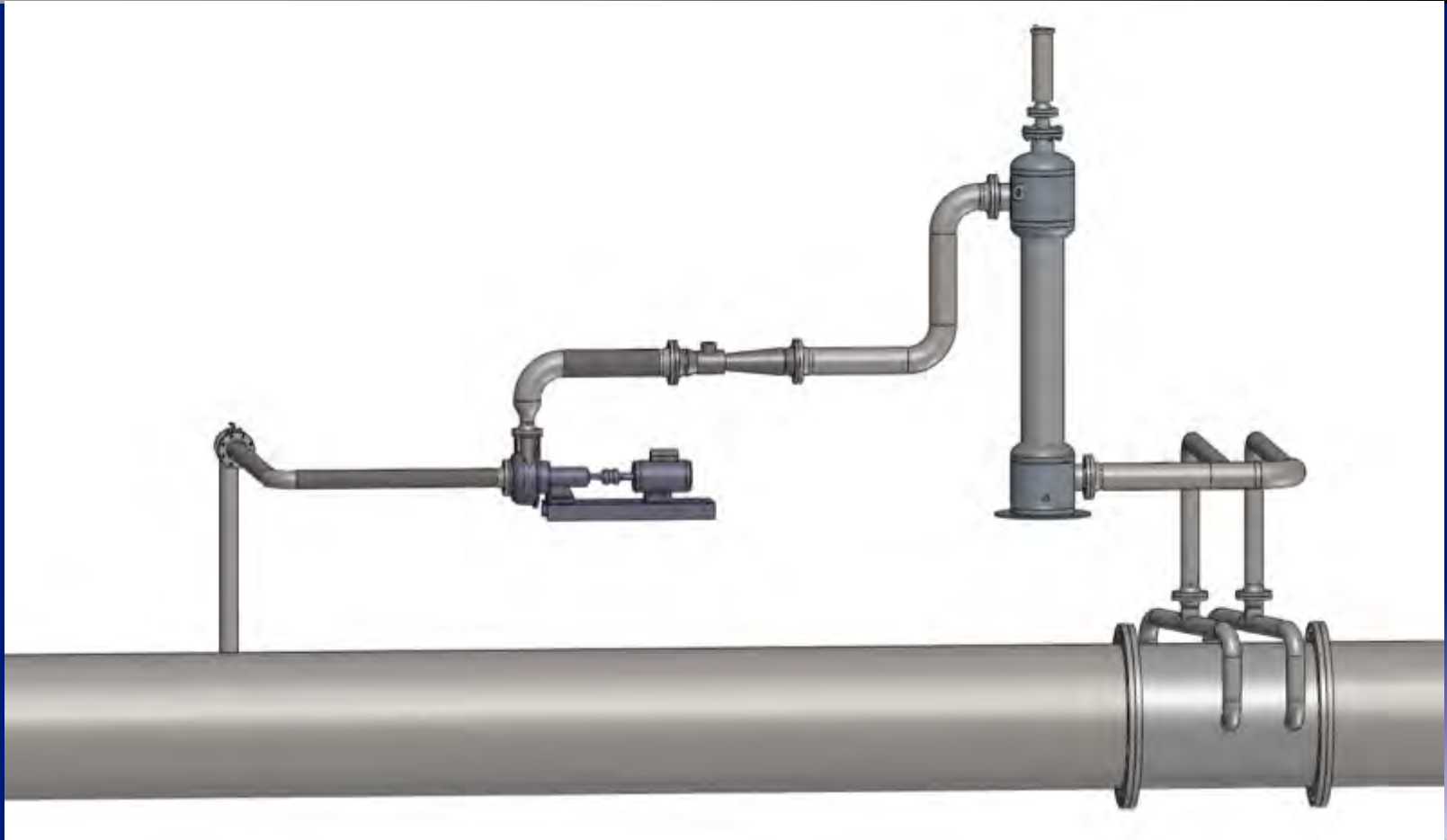


Source: Mazzei Injector Company, LLC

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Side Stream Injection Example Installation



Source: Mazzei Injector Company, LLC

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Side Stream Injection Design Considerations

- Pressures and flows at injector
- Factors that affect mass transfer efficiency (MTE):
 - Ozone concentration
 - Gas/liquid ratio
 - Dose
 - Process flow pressure

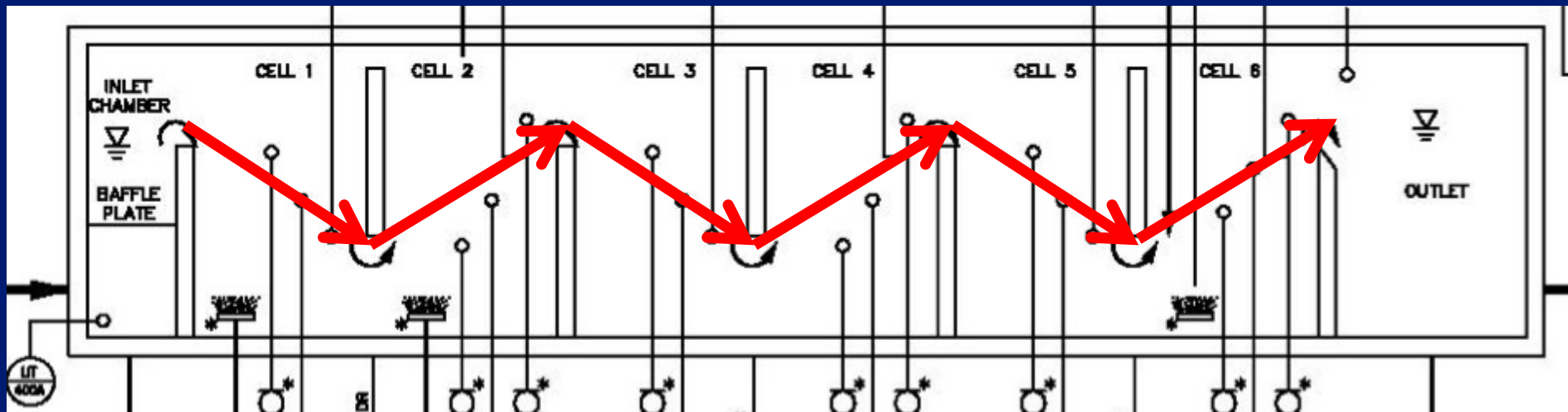


Side Stream Injection

- Advantages
 - Maintenance/Access
 - Very high mass transfer efficiency in some applications (efficient)
 - More contactor design flexibility



Baffling Factor



Side Stream Injection

- Disadvantages
 - Lots of stainless piping & fittings
 - Energy – Pressure reducing valve or pump



Summary

- Many applications for ozone in drinking water treatment
- Cabinet-based generators
- Side stream venturi injection



Questions?

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