General Atomics Electromagnetic Systems Group

9 October 2023

Destruction of Organic and PFAS Wastes using Supercritical Water Oxidation

Non-Combustion Technologies for the treatment of POPs: Challenges and lessons learned from PCBs and perspectives for PFAS

Presented at the 5th Seminar POPs Columbia

John Follin, GA EMS Director of Strategic Development, Supercritical Water Oxidation

GENERAL ATOMICS ELECTROMAGNETICS

General Atomics

LOCATION: San Diego, California

FOUNDED: 1955

STATUS: Privately held corporation

John Follin
Director
Strategic Development / Business Development
Demilitarization and Chemical Waste Destruction

GA is a recognized world leader in high-technology research, design, and production for industry and government in the U.S. and overseas in four continents with over 15,000 employees

General Atomics Organization

General Atomics
La Jolla, California

Energy
La Jolla, California

- Nuclear Fission
- Inertial Confinement
- Nuclear Fusion

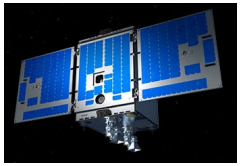


Aeronautics
Poway, California

- Predator
- Grey Eagle
- Ground Services
- Mission Related Activities


Electromagnetics
Rancho Bernardo California

- Electromagnetic Launching
- Lasers
- Satellites
- Railgun
- Radiation Monitoring
- Gulftronics
- Demil / iSCWO / Maglev




Over 30 Years and $250M Invested in iSCWO

1990s-2012
Development & Select US Government Uses

2012-2014
First commercial sale, continued Government use

2015-Present
Commercial and Government sales with aftermarket support

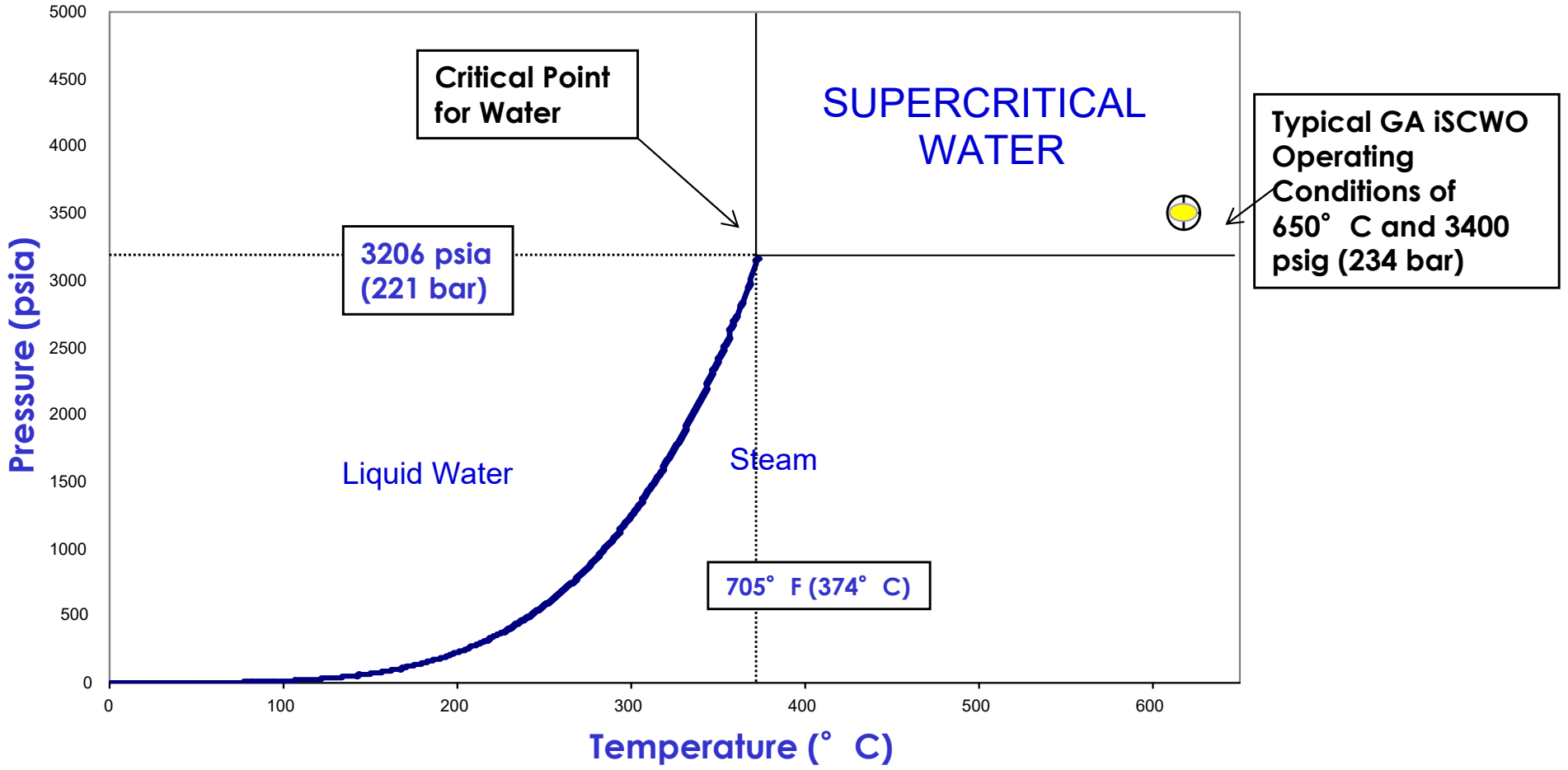
December 2021
iSCWO PFAS Destruction Testing Begins

September 2022
EPA Evaluation Complete - Verifies 99.99% Destruction of PFAS

iSCWO has been out of the lab and in the field since 2012. No R&D

Now – Systems sales for organic and PFAS Waste Destruction

What is Supercritical Water?

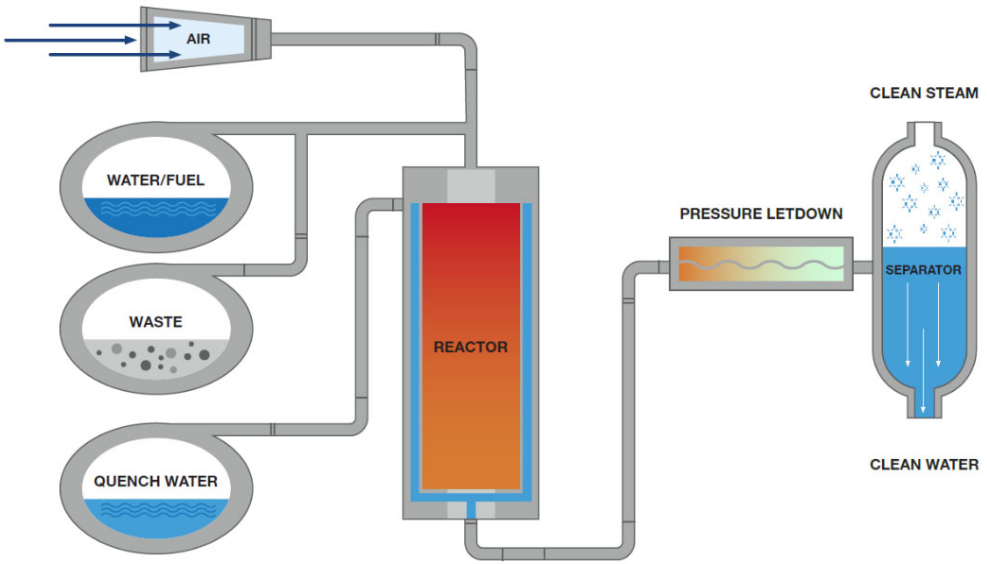


Supercritical water is water that is heated and pressurized above its thermodynamic critical point of 374°C and 221 bar

We operate at 650°C and 234 Bar to ensure complete oxidation of wastes

Breaking the PFAS Contamination Cycle for Good

iSCWO Process



- Perfect for onsite waste destruction
- Cost competitive with other onsite destruction technologies
- No post-treatment required
- No high emissions to deal with
- No hazardous by-products to store, transport, or dispose of
- Waste stream testing at GA

Unique reactor technology provides great reliability and continuous destruction throughput

High Heat
650° C

High Pressure
4,000 psi

Greater Than 99.99%
Destruction Efficiency

GENERAL ATOMICS
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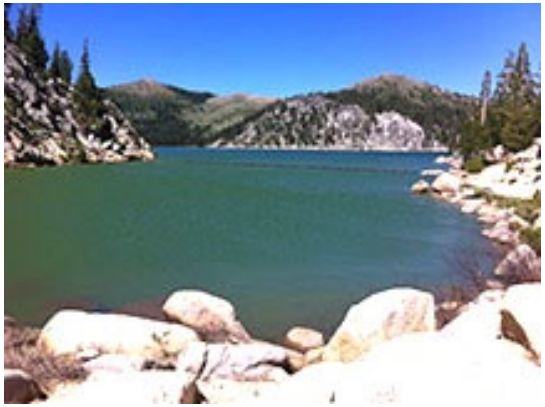
Why are our Customers Interested in iSCWO?

Rarely is there any motivation by waste generators or waste consolidators to implement new technologies that enhance the environment (e.g., the right thing to do)

The issues that generate interest in onsite waste treatment process such as iSCWO are:

- **Can't ship the waste (legal or transportation issues)**
- **Can't treat the waste after shipment (environmental or process issues)**
- **Shipping and/or treatment costs very high (and will get higher)**
- **Fines have or will be assessed by EPA (state or federal)**
- **Threats of incarceration due to known violations**
- **Lawsuits against continued waste generation or onsite waste storage**
- **Companies that don't have the expertise to dispose of the waste**

iSCWO Release Streams Meet Environmental Requirements

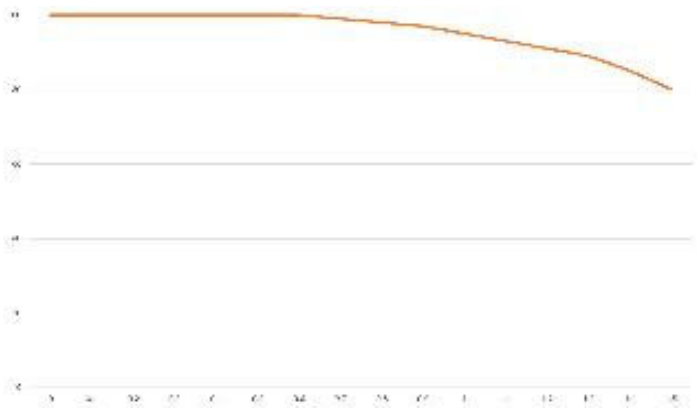


Waste Feed	Gas Release	Liquid Release
Hydro Carbon	O_2 CO_2 Nitrogen Water vapor Organic free	Organic-free water Neutral pH
Halogens		Some salts (depending on chemical feed)
Metals		Metallic oxides particles (depending on chemical feed)
-ites, -ates O_2 O_3		Molecular oxygen can reduce the amount of cfm needed by air compressor

All Liquid Releases Designed for Discharge Directly to a Public Owned Treatment Works (POTW)

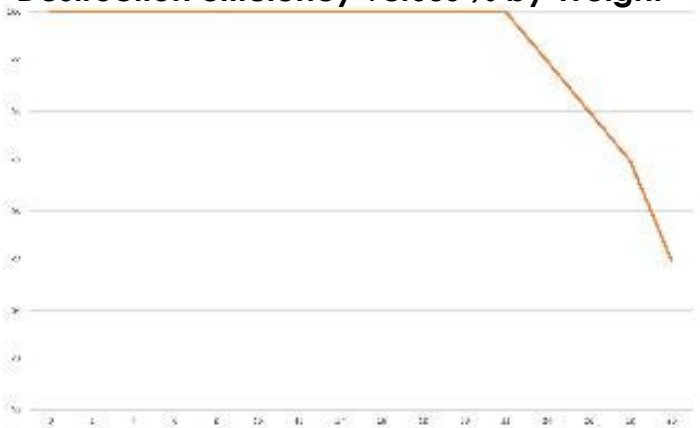
iSCWO Operational Conditions

Destruction efficiency versus Particle Size



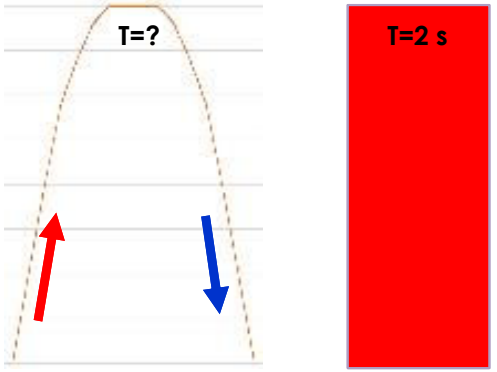
Zero to 0.5mm to larger size particle

Destruction efficiency versus % by Weight



Zero to 20% to high % by weight

Static Versus Continuous Flow Tests



- Static test conditions encounter reformation issues due to varying temp and pressure
- GA's continuous 3gpm tests are at operating temperature and pressure

System Operations

- **Autogenic conditions 2200 BTU/lbm (5117 KJ/kg or 1223 kcal/kg or 320 g/L COD)**
- **Maximum design rate of a 3gpm iSCWO system with a liquid waste feed at autogenic conditions is 36,000 lbs per day or 16.4 metric tons/day**
- **Most waste slurry applications range between 20,000 lbs to 30,000 lbs per day (9.1 MT/day to 13.7 MT/day)**
- **Pumping viscosity ranges from 0.3 to 8000 mPa-s or Centipoise (CP)**

ABOVE DEPENDS ON MATERIAL, CONCENTRATION, and HEAT CONTENT

Scalable, Compact Footprint for Easy On-site Installation

Transportable iSCWO system

Fixed iSCWO system

- Available as fixed or transportable units for convenient on-site waste destruction without the need for additional infrastructure.
- Single or multiple iSCWO systems operating in parallel can be configured to support unique installation, waste, and throughput requirements.

iSCWO in Industrial Environments

iSCWO destroys the following:

- PFAS and other fluorinated organic compounds
- Fire retardant materials
- Expired or obsolete pesticides, fertilizers, and fungicides
- Contaminated water (wastewater cleanup)
- Polychlorinated biphenyls (PCBs)
- Organic cleaning solutions and antifreeze
- Energetic Materials (explosives or propellants)
- Petroleum, oils, lubricants and/or petrochemical waste
- Sewage sludge/animal waste products
- Pharmaceutical waste
- Plastic waste
- Expired or obsolete paints
- Expired or obsolete pesticides
- Materials not suitable for normal transportation or disposal

iSCWO destroys 200+ types of hazardous and non-hazardous waste

iSCWO destroys PFAS with co-contaminants simultaneously with equal efficiency

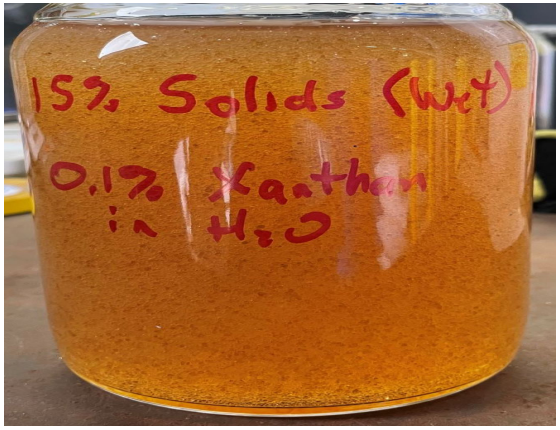
Micronized Feed for Slurry Feeding into iSCWO

Wood

Carbon

Mining Ore

Plastics/Rubber



Resin Beads

Slurry

Multiple Options for iSCWO Waste Feed

- **Liquid feed**
  - Generated by in-line process or liquids stored onsite
  - Pumped directly into the iSCWO system

- **Slurry Feed**
  - Powdered solids (e.g., pesticides or pharmaceuticals) in water
  - Ground-up solids (resins or GAC) in water solution
  - Size-reduced solids pumped directly into the iSCWO system

- **Reverse Osmosis (RO)**
  - Large Amounts of Contaminated Water
  - RO waste stream (stew) is pumped into the iSCWO system

- **Thermal Desorption (TD)**
  - Contaminated Soil Cleanup (e.g., PCB)
  - TD waste stream (scum) is pumped into the iSCWO system

- **Gaseous Diffusion (GD)**
  - Contaminated Hardened Material
  - GD waste stream is condensed and pumped into iSCWO

GA iSCWO Demonstration System – No R&D

iSCWO System used for different chemical waste treatment tests

Dedicated iSCWO Test Facility that customers can observe tests

No R&D – Just confirmatory tests for both process and environmental regulatory permits

System arrangement allows for easy tests with data analysis

Some Slurry Organic Destruction Process Results*

Material	Matrix	Feed Concentration	Throughput (gallon/min)	Quantity processed (gallons)	Destruction Efficiency
Mining ore with gold	Slurry	10% solids	1.1	420	99%
Plastics	Slurry	10% solids	1.1	950	99%
Food waste	Slurry	10% solids	1.1	550	99%
Ground resin beads	Liquid	15% solids	2.2	1060	99.9%
Whole resin beads	Slurry	10% solids	1.5	120	99.9%
Tear Gas	Slurry	10% Solids	1.6	425	99.99%
Leachate from Landfill	Liquid	Thick material	2.2	20	99.999%
Biosolids	Slurry	10% solids	2	730	Test in Oct

*Note – the feed concentration, rates, and quantities were defined by the customer

Whole Resin Beads – Effluent

Some Halogenated Organic Destruction Process Results*

Material	Matrix	Feed Concentration	Throughput (gallon/min)	Quantity processed (gallons)	Destruction Efficiency
CCl_4 / CS_2	Liquid	100%	0.052	107	99.999%
Tear Gas	Slurry	10% solids	1.6	425	99.99%
1,4-Dioxane	Liquid	0.4%	1.6	107	99.9%
Bromine-Polymer Wash	Liquid	1%	1.1	140	99.99%

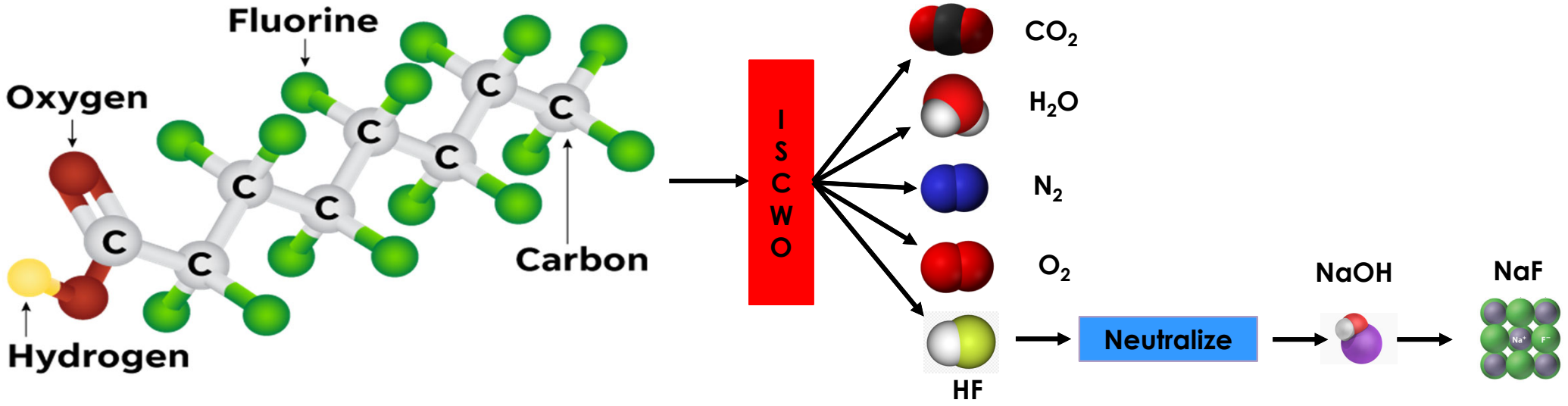
*Note – the feed concentration, rates, and quantities were defined by the customer

Some Organic Destruction Process Results*

Material	Matrix	Feed Concentration	Throughput (gallon/min)	Quantity processed (gallons)	Destruction Efficiency
Energetics Waste (NH_4NO_3)	Liquid	25%	2.5	1,060	99.99%
Organics containing NaI and CsCL	Slurry	10%	1.2	950	99%
EDTA with hydrazine	Liquid	15%	3.9	1,075	99.99%
Corrosive Solvent Waste	Liquid	15%	2.2	400	99.9%
Cresylate	Thick Liquid	20%	1 – ntrlzd 0.5 – nt ntrlzd	215	99.99%
PBX-9502 (explosives)	Slurry	20%	2	3,000	99.99%

*Note – the feed concentration, rates, and quantities were defined by the customer

PFAS iSCWO Test Analysis



- **With a typical feed of PFAS, iSCWO breaks the PFAS into**
  - Carbon which combines with oxygen to make CO_2
  - Fluorine which is stripped off of the PFAS molecule and combines with hydrogen to make HF
  - Oxygen which combines with carbon, be consumed by the fuel and generates H_2O and/or CO_2, or emitted as excess oxygen

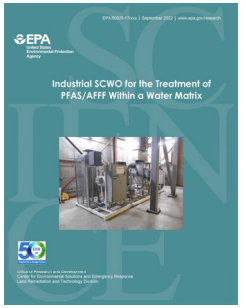
- **Immediately at the reactor exit, the hot liquid will be quenched with sodium hydroxide (a base) which neutralizes the HF (an acid) to make a salt which is sodium fluoride (NaF).**

PFAS Test Results

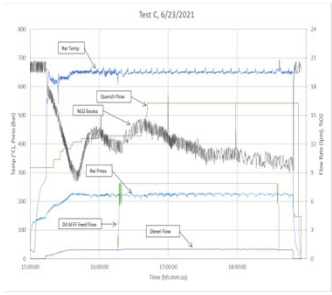
Destruction of PFAS efficiency: >99.99% for multiple tests

Materials Tested for DRE Calculations Include:

- Aqueous Fire Fighting Foam (AFFF)
- 6:2 fluorotelomer sulfonic acid (6:2 FTS)
- Perfluorooctanesulfonic acid (PFOS)
- Integrated Derived Waste (IDW)



Published Reports



Recorded Data

Test	Total Processed	Dilution of Waste	PFAS Feed	Source of Material	Destruction Efficiency
Test 1 AFFF	253 gal	1000x	~30 ppm	Lightwater	99.9996%
Test 2 AFFF	252 gal	1000x	~30 ppm	Lightwater	99.9996%
6:2 FTS	350 gal	0x	210 ppb	Fire pit wash	99.9929%
PFOS	350 gal	0x	1700 ppt	IDW	Non-detect
Test 1 AFFF	310 gal	159x	~194 ppm	Aer-O-Water	~99.999%
Test 2 AFFF	302 gal	152x	~199 ppm	Aer-O-Water	~99.999%
Test 3 AFFF	310 gal	34x	~974 ppm	Aer-O-Water	~99.999%

Targeted PFAS Summary with Fluoride Concentration Analysis

PFAS average DRE > 99.99%
Test C (highest influent conc.) DRE > 99.999%

Test	Influent Sum of Targeted PFAS (ppt)	Effluent Sum of Targeted PFAS (ppt)	%DRE Targeted PFAS	Influent Fluoride‡ (ppm)	Effluent Fluoride‡ (ppm)	Theoretical fluoride from targeted PFAS* (ppm)	Theoretical PFAS from Fluoride* (ppm)
A	3,128,300	51.56	99.9984	0.81	173.61	1.86	289.35
B	3,294,600	82.03	99.9975	0.78	235.29	1.96	392.16
C	13,640,000	30.32	**99.9998**	1.5	482.21	8.07	803.68
Average DRE:			**99.9985**				

- **Targeted 21 PFAS in AFFF waste feed**
- **DRE does not fully reflect iSCWO's capabilities**
  - Non-detect PFAS amounts default to method limits
  - PFAS present in San Diego tap water used to quench liquid effluent

PFAS remaining - PFBA, 6:2 FTS, and sulfonates (C4-8) - undetermined whether from water or system

Effluent values include dilution factor of about 1.5 due to higher liquid flow from separator (~12 Lpm out vs ~8 Lpm in)

Effluent values from 120 minutes sampled

* Assumes 60% Fluorine content in associated targeted PFAS
‡ ~0.8 ppm fluoride typical in SD tap water

Air emissions from the iSCWO system would be considered *clean*

VOCs detected are *not* fluorinated

Most SCWO system and incinerator gas emissions have not been tested for PFAS release – GA's iSCWO has

Ongoing iSCWO Test Programs for CY 2023

- US Army Engineer Research and Development Center (ERDC) Army Corps of Engineers (ACE) PFAS and AFFF Tests
  - Two-year project
  - PFAS destruction tests at GA
  - Deploy a system at a Government site for PFAS destruction

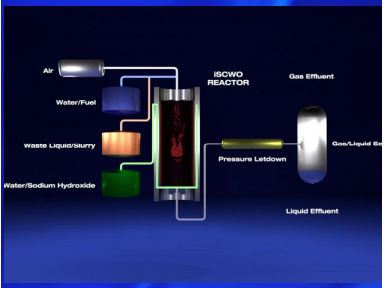
- Defense Innovation Unit for PFAS and AFF Destruction
  - Two-year project
  - Deploy a system at a Clean Earth facility

- Navy GAC project

- Air Force RO project

- Incentive energetics destruction project

Conclusions



- Simple to operate, automated and maintain
- iSCWO is an excellent waste destruction process suitable for ***onsite*** treatment of organic wastes at an affordable cost
- iSCWO is fully capable of destroying a wide range of pumpable hazardous waste including AFFF / PFAS to strict environmental standards
  - Pure PFAS streams / diluted PFAS streams
  - Leachates
  - Biosolids
  - Soils after proper preparation
  - GAC, resin and filtration medias
- Mobility for multi-site waste destruction – System easy to setup
- iSCWO systems use air rather than liquid oxygen which makes the processing site easier to permit and eliminates a number of safety issues related to LOX systems
- No pollution abatement system necessary to meet environmental regulations
- GA has 35 years experience with SCWO systems – no R&D
- GA provides testing capability – know before you buy

Contact Information

Thank you very much for your time!

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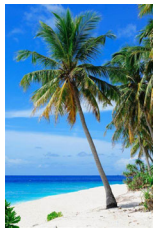

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