Low Electrical Conductivity Glycol Coolants as Alternative to Perfluorinated Fluids for Electronics Cooling Applications

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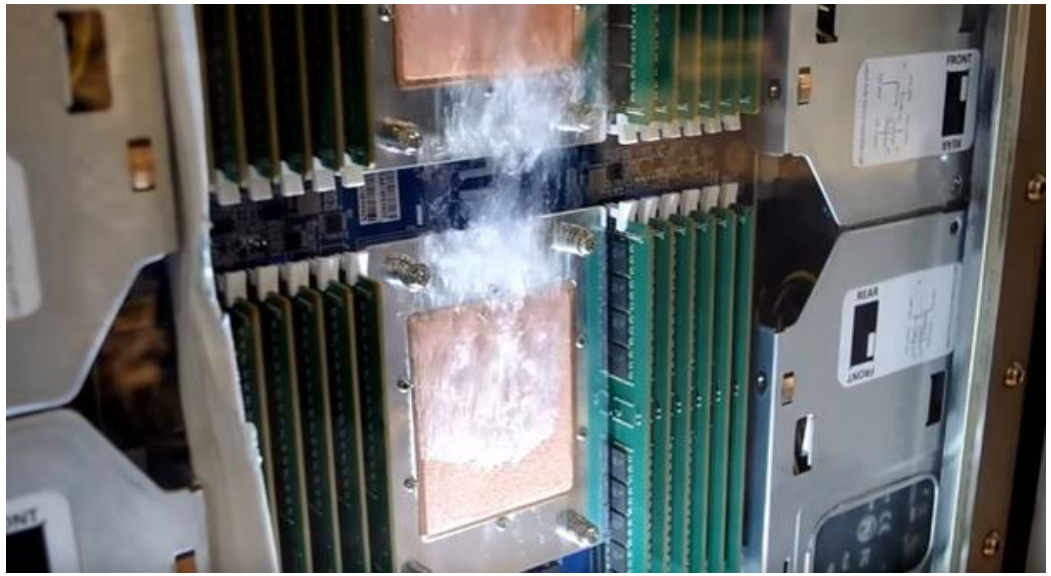
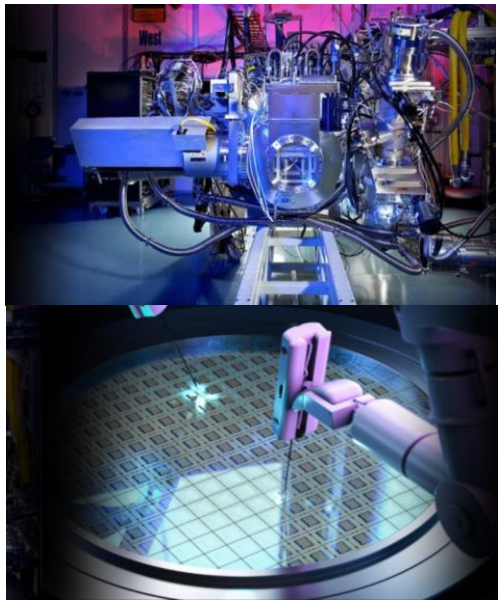
BACKGROUND

Fluorinated Coolants for Electronics Cooling

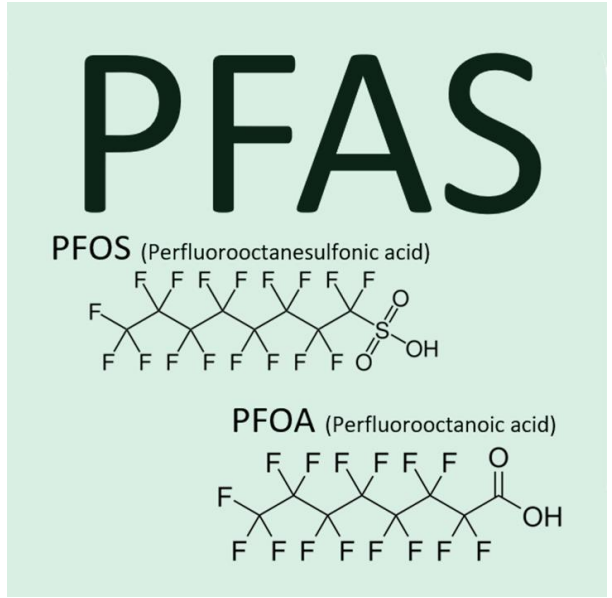
- Gained popularity for cooling electronic components for their direct cooling application.
- Based on Per- and polyfluoroalkyl substances (PFAS/PFOS).
- Long-chain organo-fluoro coolants are non-flammable, dielectric, and thermally stable.
- Linked to “forever chemicals” as they do not breakdown easily and stay in human body.



Coolingzone.com - GIGABYTE demonstrates two-phase immersion cooling for servers



ScotForge | Forgings for Semiconductor Manufacturing

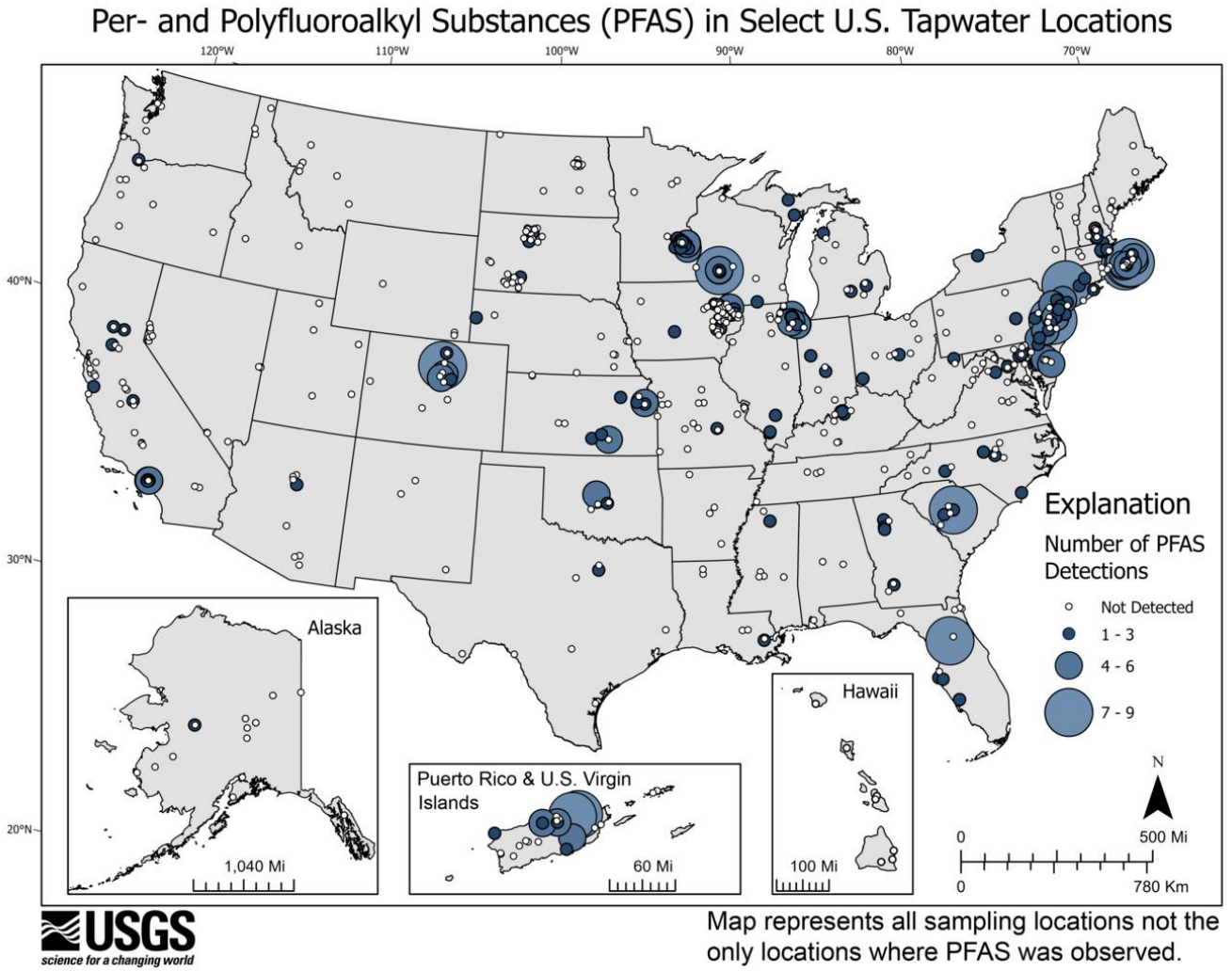


PFAS in Drinking Water- Effects & Treatments- Clearwater Systems

BACKGROUND

Problems with PFAS containing Products

- High levels of PFAS in humans can cause various health issues: [Potential health effects of PFAS chemicals | ATSDR (cdc.gov)]
- Ingestion of food and water is a main route of PFAS exposure: [National Institute of Environmental Health Sciences: Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) (nih.gov)]
- EPA restricting companies from starting or resuming manufacturing of 329 PFAS: [Key EPA Actions to Address PFAS | US EPA]
- Major players discontinuing PFAS based coolants by 2025: [3M to Exit PFAS Manufacturing by the End of 2025 - Dec 20, 2022]



[PFAS in Select U.S. Tapwater Locations | U.S. Geological Survey (usgs.gov)]

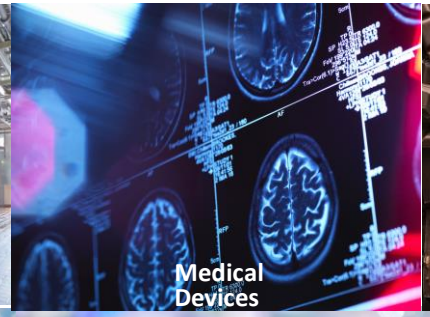
INTRODUCTION

Possible Replacements for Electronic Coolants

Properties	3M Fluroinert Electronic Liquid FC-770	3M Novec 7100	New Fluorinated Coolants (single phase coolant)	Hydrocarbons (single phase synthetic)	55% Glycol Water (Dynalene LC)
Thermal Conductivity	0.063 W m^{-1} $°C^{-1}$	0.069 W m^{-1} $°C^{-1}$	0.115 W*m^{-1}*$°C^{-1}$	0.137 W*m^{-1}*$°C^{-1}$ @ 40°C	0.375 W*m^{-1}*$°C^{-1}$ @ 25°C
Heat Capacity	1038 J kg^{-1} $°C^{-1}$	1183 J kg^{-1} $°C^{-1}$	1087 J*kg^{-1}*$°C^{-1}$ @ 25°C	2212 J*kg^{-1}*$°C^{-1}$ @ 40°C	3167 J*kg^{-1}*$°C^{-1}$ @ 25°C
Viscosity	1.359 cP	0.58 cP	2.45 cP @ 20°C	5.945 cP @ 40°C	3.910 cP @ 22°C
Density	1793 kg/m^3	1510 kg/m^3	1815 kg/m^3 @ 20°C	820 kg/m^3 @ 20°C	1086 kg/m^3 @ 25°C
Boiling Point	95°C	61°C	110°C	>300°C	108°C
Freeze/Pour Point	-127°C	-135°C	-110°C	None	-40.8°C
Flammability	None	None	None	193°C flash	None
Forever Chemical	High	High	?	None	None
Electrical Conductivity	Dielectric	Dielectric	Dielectric	Dielectric	Low
Surface Tension	14.8 dynes/cm^2	13.6 dynes/cm^2	15 dynes/cm^2	25-30 dynes/cm^2	56 dynes/cm^2

APPLICATION

Glycol Water Applications



Why Glycol Water can replace PFAS

- Better Thermal Properties
- Non-Flammable
- Inexpensive
- Low Vapor Pressure and High Surface tension
- Widely available
- Can have low electrical conductivity

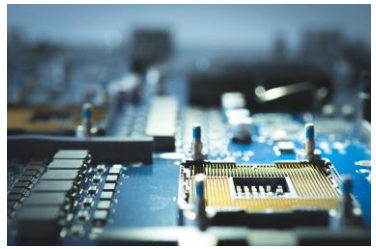
Low Electrical Conductivity Glycol Water

FEV Cooling

https://carboncredits.com/truck-companies-are-shifting-to-hydrogen-fuel-for-long-haul-trips/

BEV Cooling

https://chargedevs.com/newswire/gillig-delivers-first-of-62-battery-electric-buses-to-florida-transit-agency/



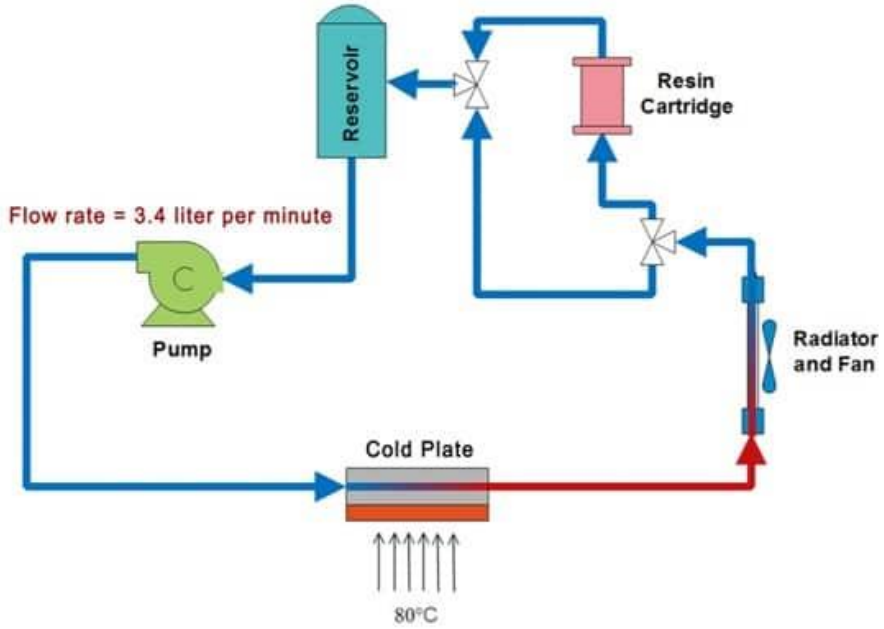
Electronics Cooling

Data Center

Advantages of Low Electrical Conductivity (LC) Glycol Water (< 5 μS/cm)

- Low electrical conductivity coolant limits the chances of thermal events in case of spills and leaks.
- Use of deionizer/ion exchange cartridge in conjunction to maintain low EC < 2 μS/cm.
- Deionizers removes any contaminants, reduces chances of corrosion and degradation and maintains optimum coolant properties.

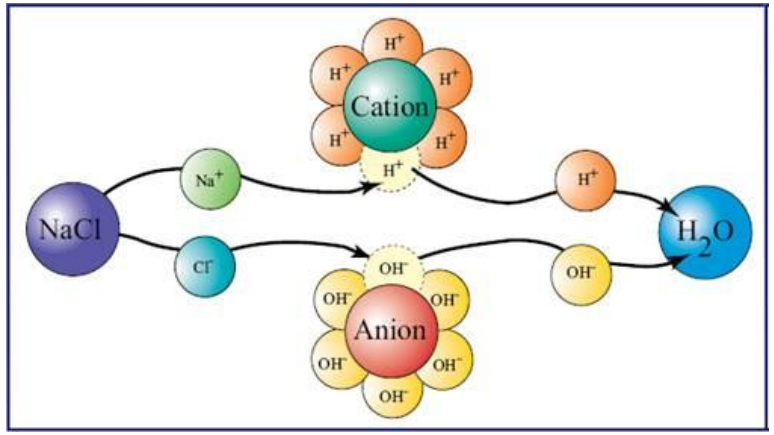
Nikola says coolant leak likely cause of electric semi-truck fire at Phoenix HQ, issues recall (azfamily.com)



Tech Brief - Low Electrical Conductivity Liquid Coolants for Electronics Cooling | Electronics Cooling (electronics-cooling.com)

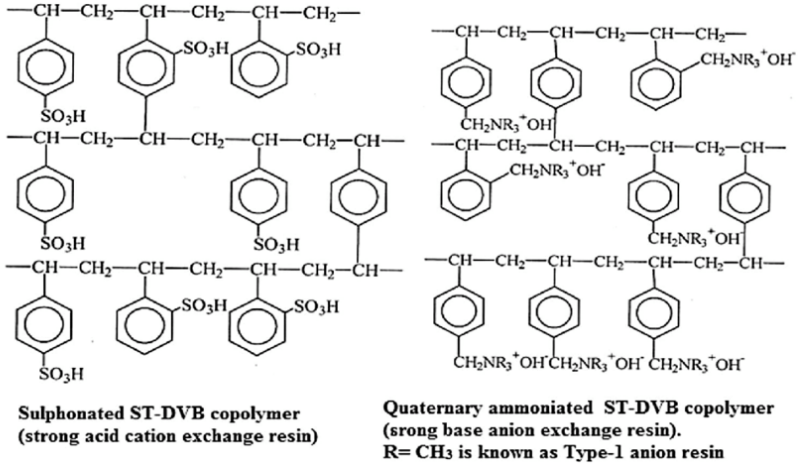
OBJECTIVE

Understand the interaction between glycol/water and ion exchange resin at various temperatures.



Ion Exchange Mechanism

Mixed Bed Resin



Resin Structure (10.1007/s10967-014-3906-3)

Typical Applications

Water Demineralization

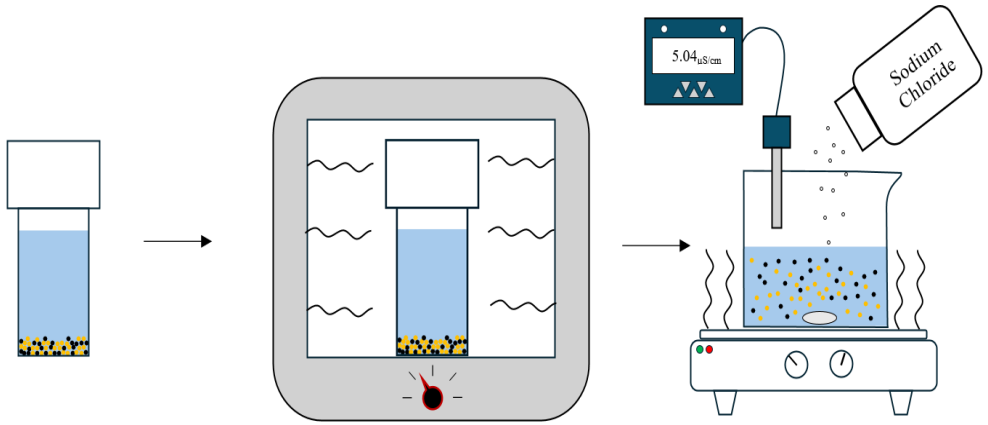
Contamination Removal

LC Applications

Deionizing Cartridges for LC

EXPERIMENTAL

I. Ion Exchange Resin Capacity in LC-EG 50% and UPW

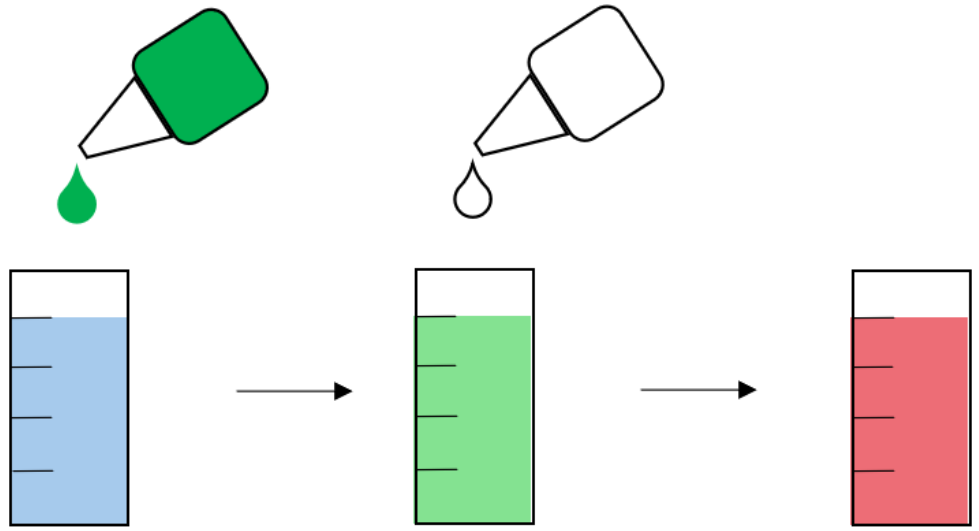


Ion exchange resin added to LC-EG 50% or UPW.

Incubation at -25°C, 20°C, 50°C, 70°C, 93°C, and 100°C for 1, 2, 4, 6, 8, and 12 weeks.

Sodium chloride added to solution while stirring at incubation temperature until conductivity does not drop below 5µS/cm

II. Effect of Thermal Degradation on Resin (Amine Titration)



Addition of indicator to analyte

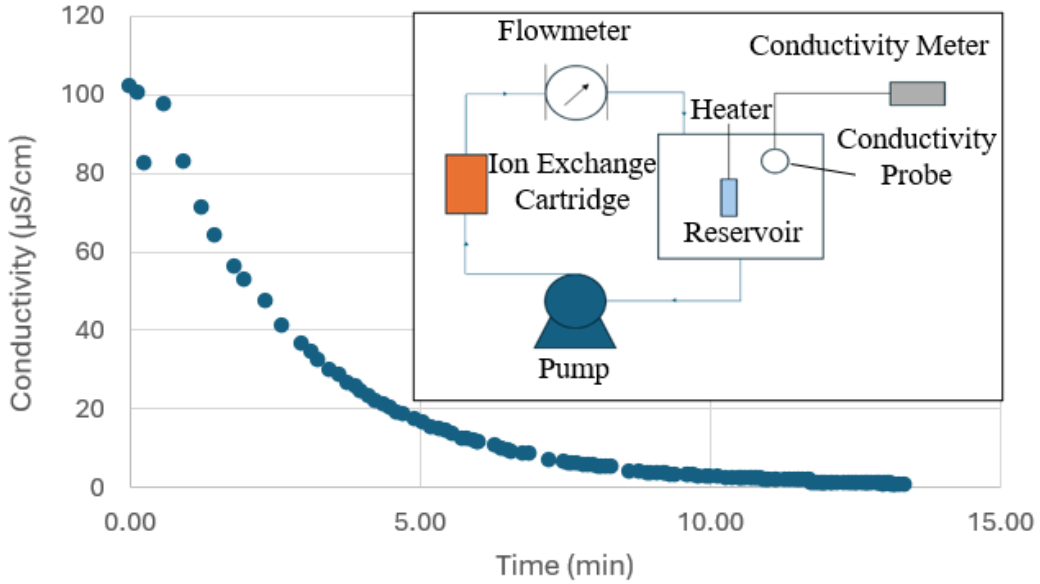
Addition of titrant

Neutralization

Role of Deionizing Cartridge

Experimental Studies

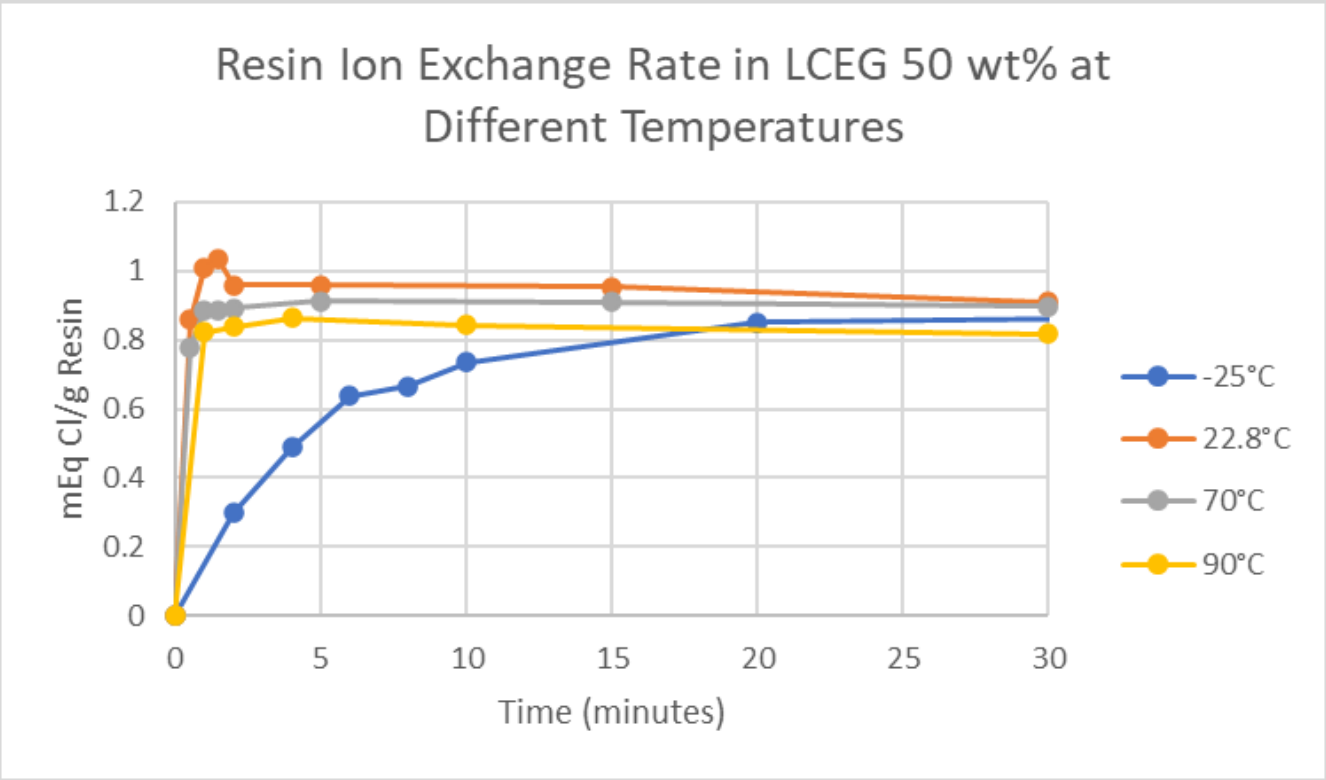
Electrical conductivity (EC) was measured versus time for 40L Dynalene LC-EG 50 wt% circulated through an IC-093-08H mixed bed resin deionizing cartridge at 85°C and 15LPM.



1. EC decreased <5 µS/cm under 10 mins from 100 µS/cm.
2. EC further dropped to < 1 µS/cm under 15 mins.

RESULTS

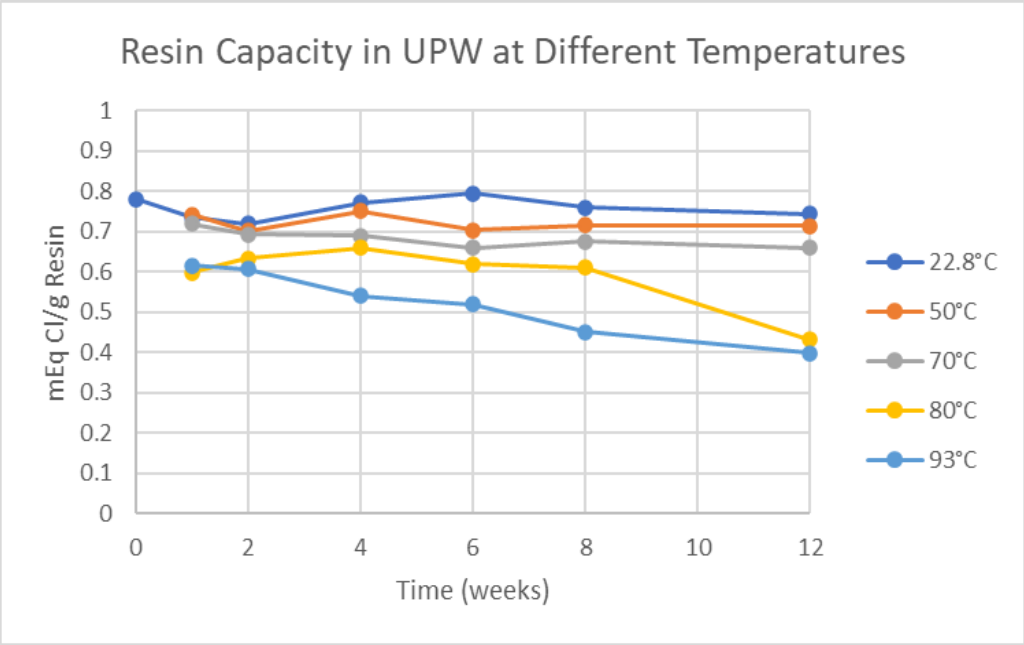
Resin capacity versus time for Dynalene LC-EG 50 wt%

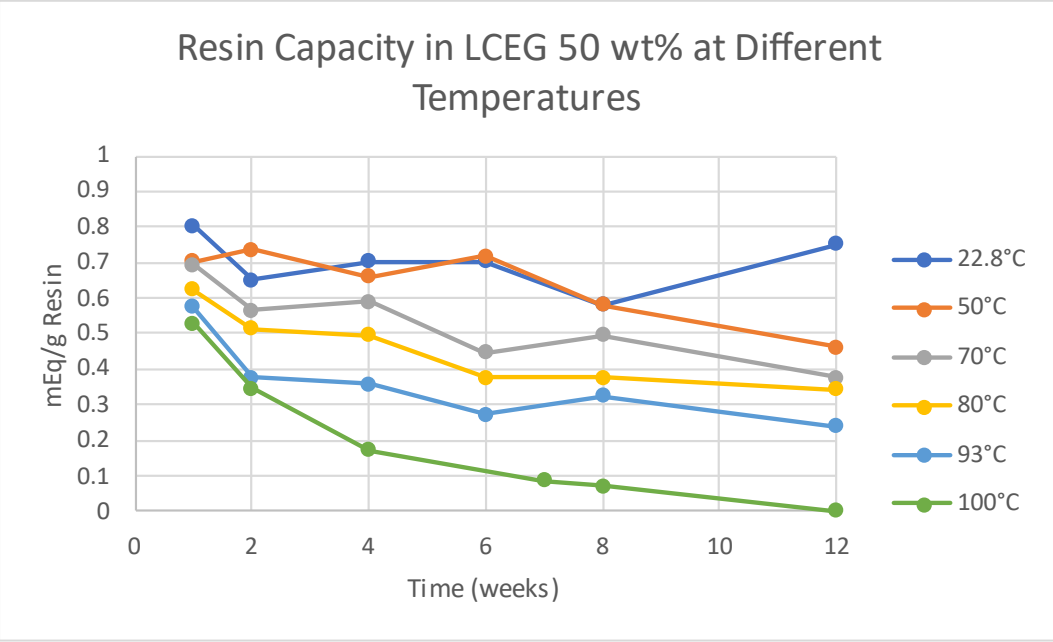


1. Ion exchange rate increased from -25°C to room temperature.
2. Ion exchange capacity dropped slightly from room temperature to 90°C.

RESULTS

Resin capacity over 12 weeks at different temperature

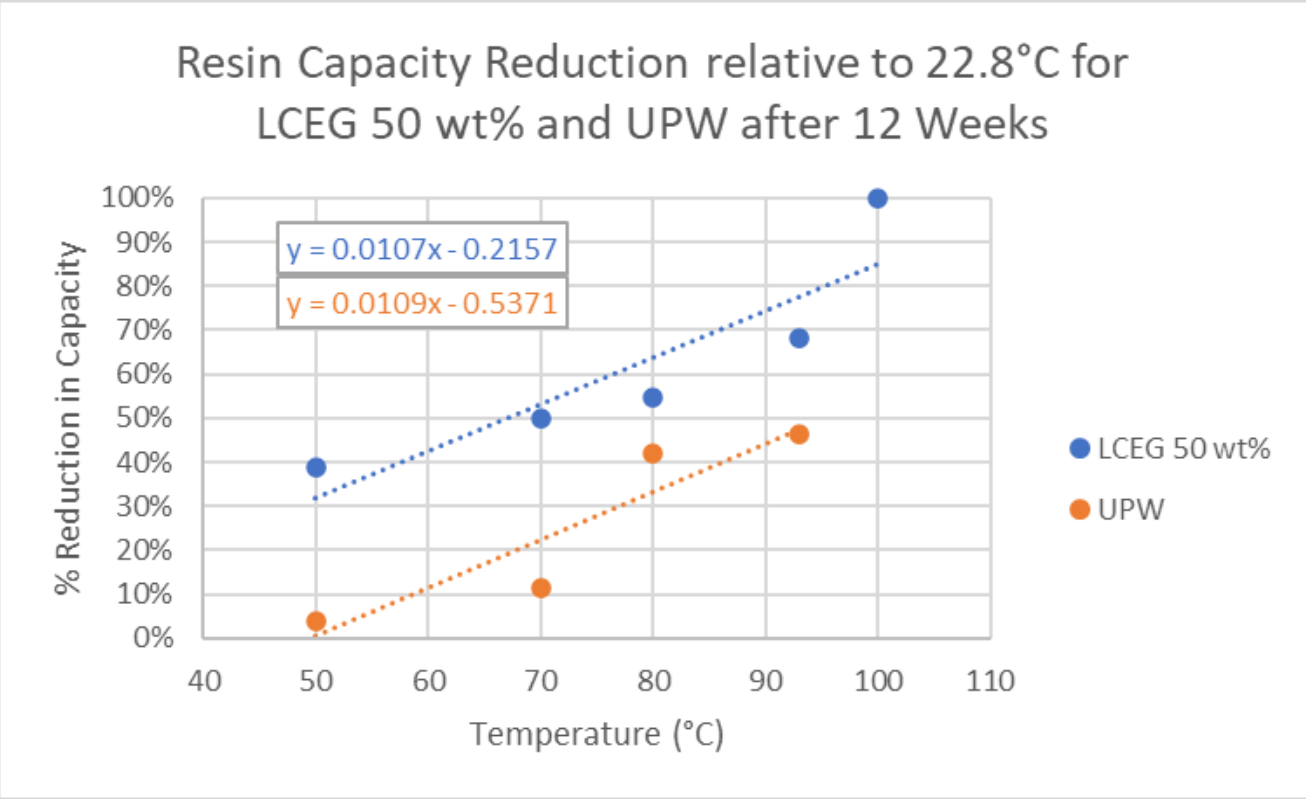




1. UPW resin exhibited after 12 weeks, 5.1% decrease in capacity at 22.8°C and 47% at 93°C.
2. LC-EG 50 wt% resin experienced after 12 weeks, a 6.3% decrease in capacity at 22.8°C and 68% at 93°C.

RESULTS

Resin capacity loss relative to 22.8°C



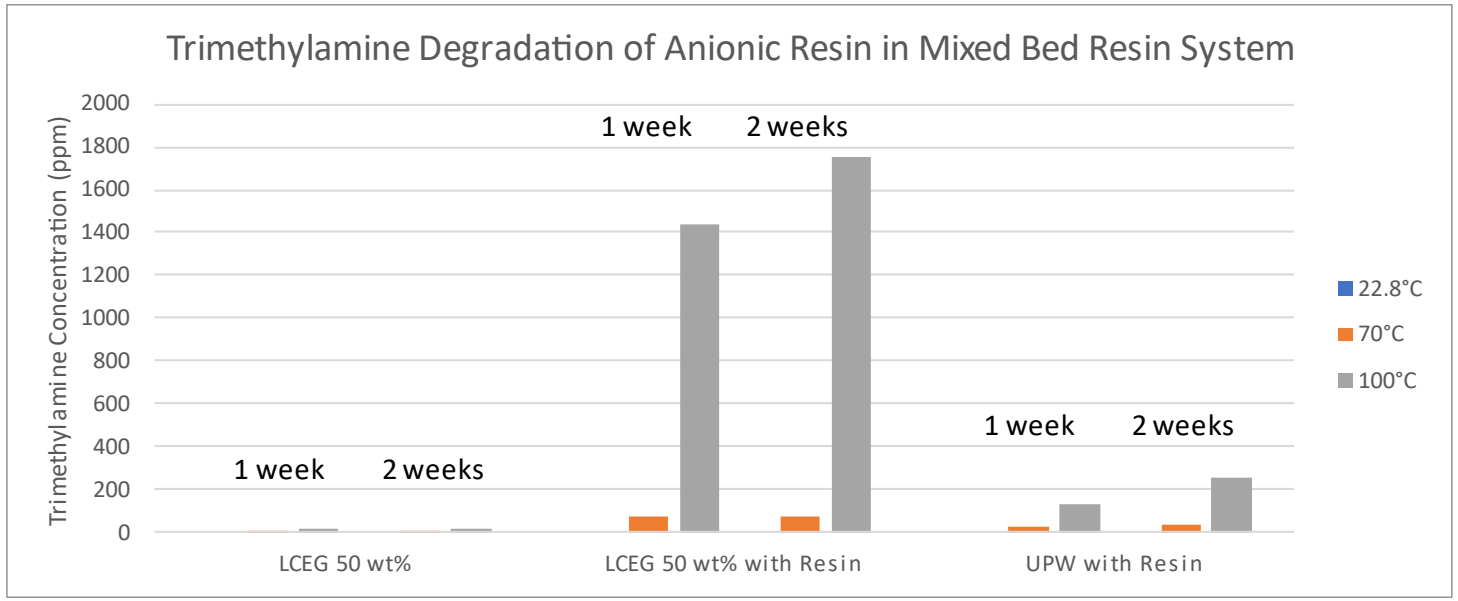
Time (weeks)	Recovered Capacity
1	0.00%
2	8.83%
4	6.38%
6	5.74%
8	3.62%
12	0.00%

1. On average resin capacity loss relative to 22.8°C in UPW was twice as great in LC-EG 50 wt%.
2. Rate of reduction of ion exchange with temperature is similar for both the fluid.

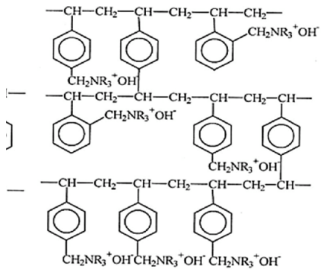
Recovered Capacity for Resin Cooled from 100°C to 22.8°C relative to Resin at 100°C, expressed as a Percentage of Original Capacity.

RESULTS

High Temperature Anionic Resin Breakdown



Trimethylamine degradation data shows elevated TMA levels in samples containing LCEG 50 wt% and resin, at 100°C.



Quaternary ammoniated ST-DVB copolymer (srong base anion exchange resin). R= CH_3 is known as Type-1 anion resin

+ heat = DVB-Polystyrene polymer +TMA

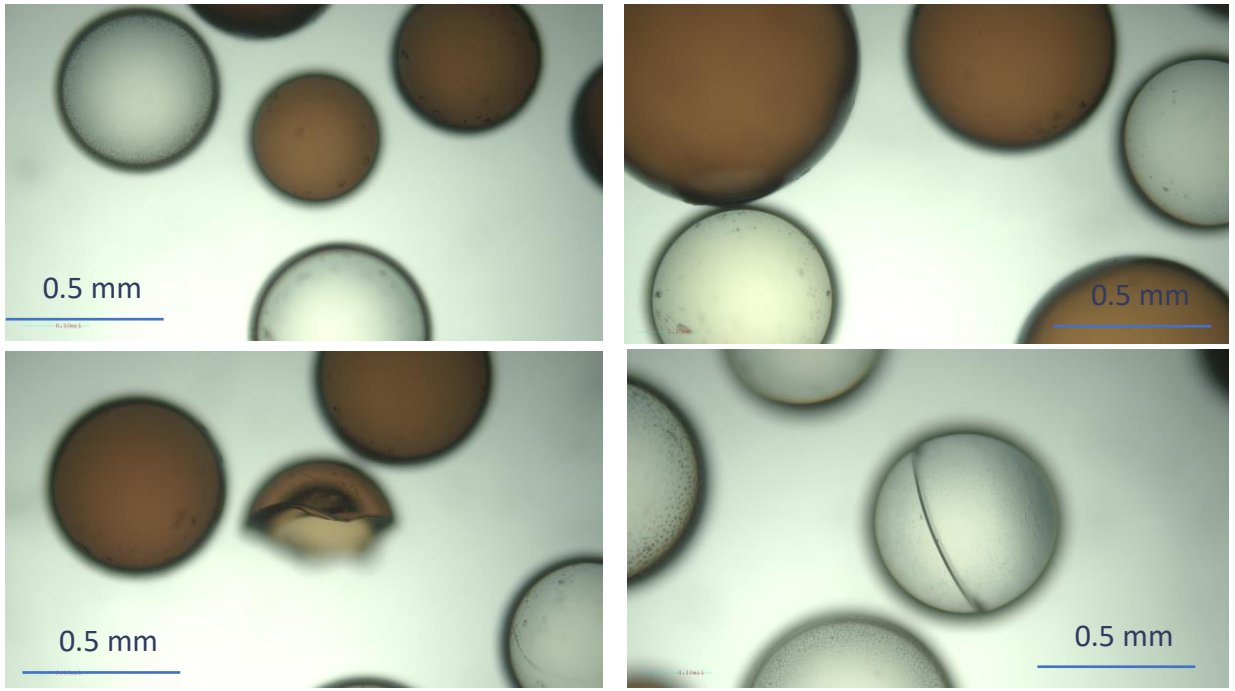
CONCLUSIONS

Summary

- Mixed bed deionizing cartridges keep conductivity levels below 5 µS/cm in an LC glycol-water solution, a threshold adhered to in multiple industries.
- Mixed bed resin has a continuous usage temperature range from -25°C to 93°C in LC coolants.
- Ion exchange occurs faster from 22.8°C to 70°C.
- Loss of resin capacity in glycol-water > 70°C, can be caused by the formation of acidic breakdown products of the glycol and resin shrinking.
- Anionic resin degradation is greater (2.5 times) for resin in LCEG 50 wt% compared to resin in UPW.

Ongoing & Future Work

- Long term compatibility (almost complete).
- Understanding interaction of LC coolant and resin under high pressure and low temperature under flow.
- Micrography of the mixed bed resin to understand the physical integrity of the resin particles.



Mixed Bed Resin exposed to different conditions

ACKNOWLEDEMENTS

Thank you to the Dynalene Team

Jennifer Pearage

Dewanshu Verma

Michael Irelan

Questions?

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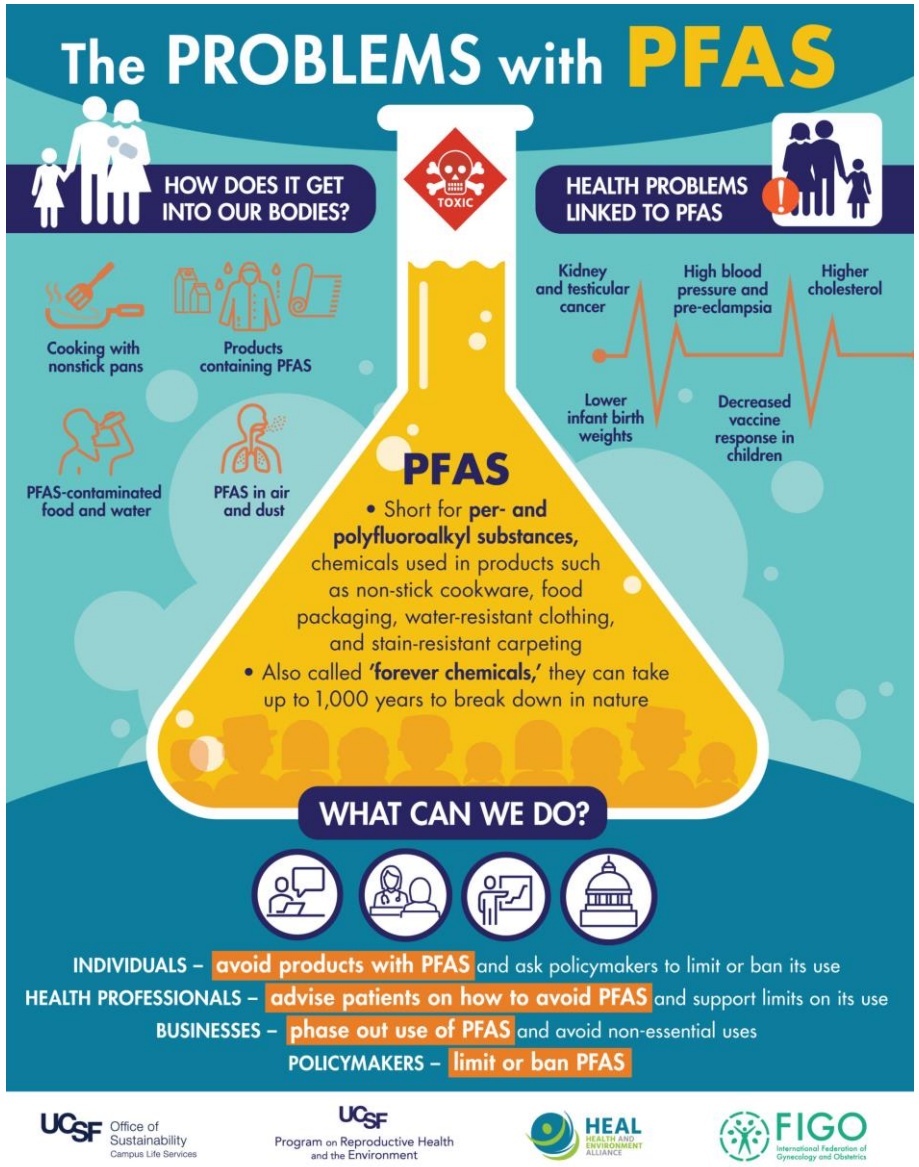
Measurement of Ion Exchange Capacity

Sodium chloride was added in small additions and the solution's conductivity was monitored with a threshold of 5 μS/cm. Using the total amount of chloride removed by the resin, the resin capacity in milli-equivalence (mEq) Cl was calculated:

$$mEq\ Cl = \frac{mg_{Cl} \times Valence}{AW}$$

where mg Cl is the total amount of chloride added in mg and AW is the atomic weight of chloride.



Health and Environment Alliance | How PFAS chemicals affect women, pregnancy and human development: Health actors call for urgent action to phase them out (env-health.org)