

Tests show surfactant-based technology effective in removing PFAS from soil and groundwater

By **George (Bud) Ivey**, **David Holmes**, and **Cecilia MacLeod**

In recent years, several major corporations, including 3M, DuPont, and Chemours (a DuPont spinoff), have reached major settlements with municipal governments and other plaintiffs, agreeing to spend billions of dollars to remove PFAS from their production processes, products and the environment.

A substantial amount of these settlement funds will go towards helping water treatment facilities to remove PFAS from drinking-water supplies. But significant dollars will also have to be spent to remediate PFAS-contaminated soil, bedrock, and groundwater.

The potential markets for PFAS remediation are numerous, ranging from chemical and other product manufacturing to electric power, wastewater treatment, real estate development, retail petroleum, landfill operations, mining, ports and harbors, federal facilities, and more (*Environmental Business Journal*, Vol. XXXII, No. 5/6, 2019). All face significant future liabilities as the regulatory net and public awareness around PFAS grows and tightens. However, remediation contractors can face these future liabilities as well if their PFAS cleanup solutions prove inadequate to the task.

The traditional pump-and-treat solution has been applied to the remediation of PFAS-impacted groundwater, but it is expensive and can take decades to achieve any significant levels of removal.

Additionally, contamination in the more mobile, high-permeability groundwater zone can migrate into immobile, low-permeability subsurface zones, and pump-and-treat is not effective in removing contamination from those low-permeability zones. This can lead to future releases and back-diffusion into the high-permeability zone,

and thereby failure to meet regulatory standards.

Some chemical and biological removal methods are being tested, but satisfactory results have not emerged. Methanol solvent extraction is used in laboratory soil extraction, and some small-scale testing. However, regulators are not likely to look approvingly at injecting many of these impactful chemicals into the ground.

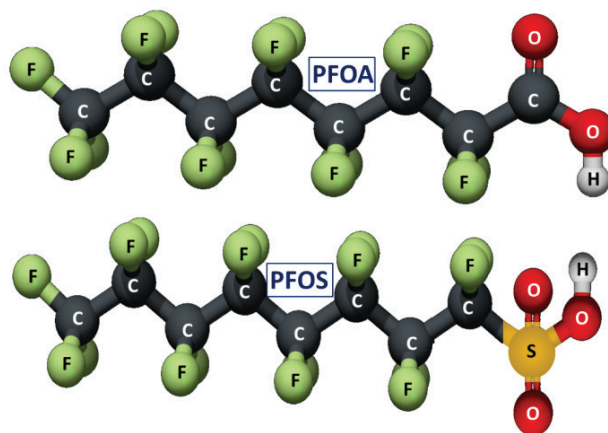
One potential solution, however, has been shown to be effective in recently completed tests. Ivey International Inc. (IVEY) has developed a new formulation from its Ivey-sol[®] enhanced remediation (SER) technology to address PFAS contamination in groundwater, soil, and bedrock regimes.

Tests of the PFAS-SOL[®] formulation conducted in the United Kingdom (UK) in collaboration with the University of Greenwich, with analysis by ALS, have shown significant PFAS mass removal rates. This formulation is non-toxic, biodegradable, and pH neutral. It is based on non-ionic formulations, with a novel additive, that can selectively desorb con-

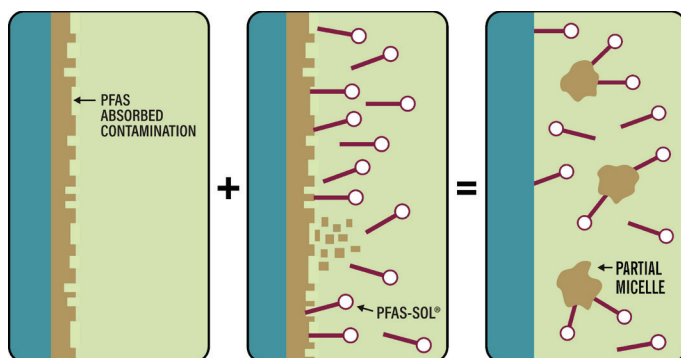
taminants and render sorbed, globular and non-aqueous phase liquids (NAPL) soluble in the aqueous phase. This means it forms a non-emulsified mixture with water and can thus be more easily controlled and removed from impacted soil, fractured bedrock, groundwater, and surface water while maintaining plume control.

The PFAS-SOL surfactant structure consists of a hydrophilic head and a hydrophobic tail. The hydrophobic tail is by design, selectively attracted to the organic functional groupings on target contaminant molecules, while the hydrophilic head is attracted to groundwater.

Based on this modulated structure, these surfactants offer multiple properties that improve the effectiveness of most remediation strategies, predominantly by overcoming the limitations associated with contaminant sorption and low solubility. In addition, they lower the relative surface tension of water and overcome interfacial tension, thereby improving its wetting and associated hydraulic properties across



The PFAS family consists of nearly 15,000 chemicals.



PFAS-SOL can selectively remove PFAS from sorbed soil and bedrock surfaces.

broader soil textures.

PFAS-SOL can selectively remove PFAS from sorbed soil and bedrock surfaces, from globule and/or NAPL phase-partitioned layers, to make them more available for enhance physical, biological, and/or chemical remediation.

For the column tests, one metre by 14 centimetre diameter columns were filled with a mineral sand (a building sand), with 10% activated carbon to act like natural organic carbon absorptive content within the soil. The columns were then slowly saturated with water from the base and drained to a set the volume. They were next spiked with 250 mg each of PFOA and PFOS to mimic a PFAS source zone and then drained and filled, with the effluent sampled to show contaminant recovery in water.

The columns were filled again, one with methanol at a 50% concentration in water, the other with the PFAS-SOL surfactant formation at a 4% concentration. They were then drained, with the increased concentration in the effluent in the PFAS-SOL column showing a large increase in PFAS concentration. The columns were then slowly taken apart to deliver a moisture profile and obtain soil samples to measure retained PFAS.

The results showed significant mass PFAS removal from the PFAS-SOL flushes. Flushes with water alone yielded PFAS recovery of approximately 5 micrograms per liter ($\mu\text{g/L}$), whereas surfactant flushes exhibited improved recovery of up to 30.45 micrograms per liter ($\mu\text{g/L}$). This meant an average improvement in PFAS removal of 240%, with concentration spikes of up to 622%. PFOA recovery averaged 160%, with best results of 185%. PFOS recovery averaged 297%, with best



The two test column tubes were spiked with 250 mg each of PFOA and PFOS to mimic a PFAS source zone.

results of 732%. Total PFAS recovery averaged of 242%, with best results of 622%.

Subsequent tests have shown similarly impressive results, suggesting a bright future for this surfactant-based PFAS remediation compared with other methods that are time-consuming and costly, and don't provide assurances against future back-diffusion risks liability associated with new sportive technologies.

Ivey International Inc. won the 2023 M&A Today Global Awards 'Best Environmental Technology Company' in recognition for their innovative technology developments. ■

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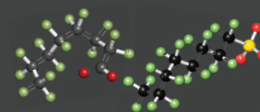
BREAKTHROUGH PFAS REMEDIATION TECHNOLOGY FOR PFAS MASS REMOVAL FROM SOIL, BEDROCK AND GROUNDWATER REGIMES...

PFAS-SOL® Sub CMC Selective Surfactant Desorption Technology

Our testing has shown that PFAS-SOL can reproducibly increase PFAS recovery from soil, and groundwater, several fold (>200% to >700%) when combined with in-situ soil flushing

Our R&D results confirmed the following improved capacity:

- > PFOA Mass recovery of 160% to 185%
- > PFOS Mass recovery of 297% to 732%
- > TOTAL PFAS Mass recovery of 242% to 622%



Improves physical, biological and chemical availability of PFOA and PFAS for remediation



Technology overview and its capacity to resolve Forever Chemicals from the Environment

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Decontaminating fire-fighting equipment to prevent PFAS from entering water supplies

By J. Scott Poynor

Although there is still much to learn, we know that the class of chemicals known as per- and polyfluoroalkyl substances, referred to generally as PFAS, is ubiquitous in the environment and poses risks to human health and the environment. Of utmost concern lately, PFAS in water supplies has become recognized as a special risk, and municipal water systems, or government agencies acting on their behalf, have taken the lead in suing manufacturers to phase out PFAS production and provide the funds for remediation.

Meanwhile, the development of technologies for removing PFAS from the environment is playing catch-up. These environmental endpoints include not only water and soil but surfaces of all kinds of products and equipment that present human exposure risks. Although multiple technology development efforts are underway, there remains a lack of efficient, scalable, cost-effective, and environmentally benign technologies to deal with this broad range of contamination issues.

One promising technology was recently successfully deployed at a petroleum storage facility, which faced PFAS problems associated with its fire-suppression equipment. The facility operator, recognizing the rapidly advancing tide of PFAS-related action, sought to address contamination in certain equipment, in the interest of liability and risk management and out of concern for potential employee exposures.

The equipment in question consisted of a fire-fighting system, including piping that stored aqueous film-forming foam (AFFF), a fire-fighting liquid that contains PFAS compounds.

Replacing the PFAS-contaminated equipment was not viable, due to cost considerations and, even more, to the time required for procurement and installation



The facility operator agreed to GST's recommendation that PFAS-SOL be deployed to reduce the concentrations of PFAS residues on the fire-fighting system piping and equipment surfaces.

of new equipment. Fire-fighting systems at petroleum storage facilities are required to be operational essentially full-time, so removing the residual PFAS from the existing equipment was deemed the preferred option.

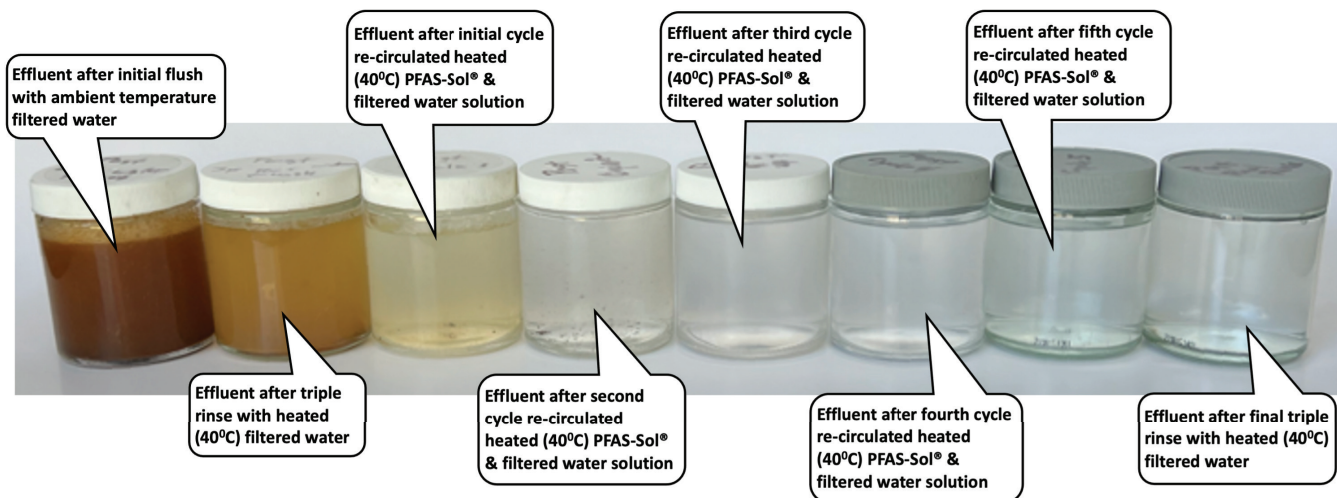
Following removal of the AFFF from the system, residual concentrations of PFAS were detected on the equipment surfaces. The facility operator performed a thorough, high-pressure flushing of the system using filtered municipal potable water, but that action left a PFAS concentration of 342,643 ng/100 cm² on the equipment's interior surface, a level deemed significant and falling short of the facility operator's decontamination goals.

The facility operator then engaged Geologic Science and Technology Group (GST), an environmental consulting firm with which the operator had fre-

quently worked in the past, to undertake the equipment decontamination project. The objective of the project was to reduce residual concentrations of detected PFAS constituents to the maximum extent possible using currently available technology.

In initial discussions with the facility operator, GST reviewed the known available options for removing PFAS from surfaces. Flushing with an alcohol-based solvent (ethanol or methanol) has historically worked better than flushing with water, but it is known to leave PFAS concentrations in residue of about 10%, which was substantial and considered to be too high.

GST then presented a surfactant-based solution that had shown the potential to achieve substantially improved removal rates compared with alcohol-based solvents. PFAS-SOL[®] is a patent-pending,



The remediation project then proceeded with a series of five flush cycles using combinations of PFAS-SOL and filtered municipal potable water.

non-ionic surfactant developed by British Columbia based Ivey International Inc. (IVEY) that is pH neutral, non-caustic, non-corrosive, non-toxic, and biodegradable.

In extensive bench-scale testing, PFAS-SOL® has demonstrated the capacity to desorb PFOA and PFOS, which are associated with AFFF, from a broad range of impacted surfaces, including metal, plastic, glass, ceramics, and composites. The technology has also been tested for more than 157 chemical impurities, with some at parts-per-quadrillion (ppq) levels, including the compounds contained in the removed AFFF.

The facility operator agreed to GST's recommendation that PFAS-SOL® be deployed to reduce the concentrations of PFAS residues on the fire-fighting system piping and equipment surfaces. The equipment decontamination project was undertaken in early March 2024, with a series of sequential phases.

Tanks for blending the surfactant with municipal potable water were staged by the pipe fittings on the portion of the fire-fighting system to be decontaminated, both upstream and downstream to create a closed-loop system.

The emptied piping system was initially flushed with filtered potable water at an ambient temperature (approximately 19°C) and then flushed three times with filtered potable water heated to 40°C. Following this flushing and wipe sampling at the discharge point, laboratory analysis detected a total of 12 PFAS ana-

SUMMARY OF PFAS COMPOUNDS DETECTED ON INTERIOR SURFACE OF FIREFIGHTING PIPING SYSTEM AFTER AFFF REMOVAL

DETECTED PFAS			AFTER SYSTEM AFFF PURGE & WATER RINSE	AFTER HEATED PFAS-SOL® WASH and HEATED WATER RINSE	
Type	Compound	CAS	Pre-Decon	Post-Decon	% Reduction
Acids	Perfluorobutanoic acid (PFBA)	375-22-4	365.0 ng	<0.288 ng U	> 99.96055%
	Perfluoropentanoic acid (PFPeA)	2706-90-3	336.0 ng	<0.0424 ng U	> 99.99369%
	Perfluorohexanoic acid (PFHxA)	307-24-4	2,800.0 ng	<0.0245 ng U	> 99.99956%
	Perfluoroheptanoic acid (PFHpA)	375-85-9	311.0 ng	<0.0497 ng U	> 99.99201%
	Perfluorooctanoic acid (PFOA)	335-67-1	1,260.0 ng	<0.0312 ng U	> 99.99876%
	Perfluorononanoic acid (PFNA)	375-95-1	108.0 ng J	<0.0156 ng U	> 99.99278%
	Perfluorodecanoic acid (PFDA)	335-76-2	472.0 ng	<0.0330 ng U	> 99.99650%
	Perfluoroundecanoic acid (PFUnDA)	2058-94-8	39.9 ng J	<0.0296 ng U	> 99.96291%
	Perfluorododecanoic acid (PFDoA)	307-55-1	151.0 ng	<0.0349 ng U	> 99.98844%
Sulfonate	Perfluorooctanesulfonic acid (PFOS)	1763-23-1	<10 ng U	0.0209 ng J	> 99.58200%
	6:2 Fluorotelomer sulfonic acid (6:2 FTS)	27619-97-2	284,000.0 ng	0.0629 ng	99.99998%
	8:2 Fluorotelomer sulfonic acid (8:2 FTS)	39108-34-4	82,800.0 ng	<0.0190 ng U	> 99.99999%
Sum of detected PFAS			372,643 ng	0.0838 ng	99.99998%

NOTE: 1. A surrogate value = 1/2 of the reporting level was used for non-detects in calculating percent reduction. 2. J = laboratory estimated value. 3. U = not detected. 4. Laboratory analysis was performed by Enthalpy Analytical Ultra Trace Testing Laboratory in Wilmington, North Carolina using a modified EPA method 1633 by adding laboratory grade PFAS standards labeled with Carbon 13 (C13) isotope, allowing lowered reporting levels and minimizing re-extraction for high concentration samples.

lytes on the piping interior surface. These analytes consisted of nine acid compounds and three sulfonate compounds.

The remediation project then proceeded with a series of five flush cycles using combinations of PFAS-SOL® and filtered municipal potable water. In each cycle, the surfactant-water solution was heated to 40°C and recirculated for one to 1.5 hours by redundant pumps at high velocity under increased pressure. Following each cycle, the piping system was purged with filtered potable water heated to 40°C to remove all traces of the solution before applying it again in the next cycle. One final triple rinse followed cycle five.

A wipe sample was collected at the discharge point over a 100 cm² area of piping and compared with a baseline wipe sam-

ple that had been collected prior to the initial flush. The decontamination process reduced residual PFAS contamination on the equipment surfaces by an additional 99.99998%, to 0.0838 ng/100 cm², beyond what the AFFF removal and potable water flushing were able to achieve.

Another significant outcome was the fact that decontamination with the PFAS-SOL® surfactant-water solution significantly reduced residues of the longer- and shorter-chain PFAS compounds, such as C4 through C12, and not just the C8 chains that have garnered much of the attention for decontamination. ■

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