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Validation of Foam Fractionation as an Effective Treatment Technology

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Introduction

During 2015-2016, OPEC Systems Pty Ltd was engaged by a key government client to conduct a detailed laboratory study to evaluate the performance of several techniques to treat PFAS impacted water. The study included common ISCO, ISCR experiments, fungal treatment, high energy sonication and foam fractionation. Foam fractionation produced the most significant reduction in PFAS concentrations with exceptional rates of removal which offered practical application. The study concluded with a small-scale field trial in NSW. Continued research and development through 2016-2018 has resulted in the following achievements:

1. Continued development of Downhole Foam Fractionation (DFF),
2. Surface Active Foam Fractionation (SAFF),
3. Field Implementation (full-scale 3yr ex-situ WTP 2018),
4. In-situ Soil Liquifractionation (ARC grant, 2018) value AUD *$900,000*.

Surface Activation Foam Fractionation

AIR in – PFAS out

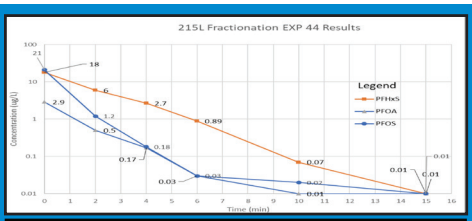
PFAS removal from water, soil and concrete

Minimises waste and environmental impact

Scalable, modular and proven

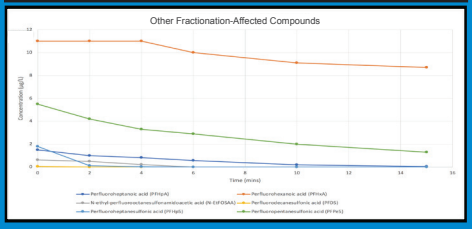
Australian innovation, international application

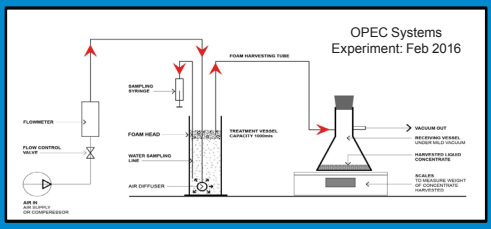
Bench and Pilot Scale Results



AIR In – PFAS Out

- Removes priority PFAS below Aust. DWG's,
- Exceptional waste management outcomes,
- Zero water consumption,
- Conserves polishing resins (used to remove non-regulated/ short chain PFAS compounds),
- Various WTP sizes and configurations,
- Patent pending.





Conclusion

Foam Fractionation was found to provide superior performance as a remediation treatment that could be deployed as either the core or stand-alone component of a Water Treatment Plant (WTP) to rapidly remove bulk priority PFAS compounds from environmental, drinking waters and solid media wash-waters for recycling and/ or disposal. ISCO, ISCR, and sonication experiments were found to be ineffective or non-conclusive. Fungal experiments significantly reduced PFAS concentrations, but the process was not understood and produced a waste product.

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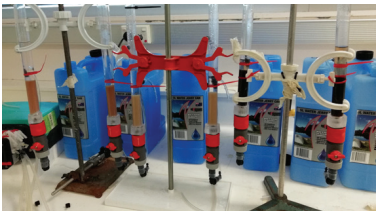
In-House Design and Validation Laboratory

Purpose: optimisation of the selected remediation treatment process using site specific waters (including soils where wash-waters require PFAS removal). Experiments consider site feed concentrations, native water chemistry from site likely to cause fouling and/ or suppression of the remedial mechanism, quality control and scaling up of the engineering design to meet project objectives.

The in-house laboratory tasks are provided by competent and qualified OPEC Systems staff, including a senior chemist, chemical engineer, civil engineer and hydrogeologist. Analytical testing is sub-contracted to NATA accredited laboratories as required.

Bench and pilot-scale testing (depicted in photos below) conducted in OPEC Systems premises provide the experimental conditions to generate results presented in documented experiments (refer to Experiment 44: Post Cover Page graphs).



OPEC History

For over 25 years OPEC Systems has been designing, supplying, installing and maintaining engineering solutions for Australian industry and government.

Over the past three years our scientists have pioneered a range of innovative ex-situ and in-situ technologies for removing PFAS, including new research through scientific collaboration and in-house pilot testing to validate our solutions.

Comparison Results

RESULTS SUMMARY: ISCO, ISCR, Sonication Investigations

Results/Lessons Learned. The chemical experiments indicated that chemical transformation of regulated PFAS compounds in Australia by **ISCO** was unlikely, and by **ISCR** was inconclusive. No transformation was observed from **sonication** experiments. **Foam fractionation** detailed experimental data indicated that PFAS compounds possessing a chain length of (≥C6) were highly amenable to separation from source water.

Test	Description	Initial PFOS, ug/L	Final PFOS, ug/L	Removal	Initial PFOA, ug/L	Final PFOA, ug/L	Removal
OX1	Persulfate + Heat	580	490	16%	46	31	33%
OX2	Persulfate + Heat + High pH	570	470	11%	43	33	23%
OX3	Permanganate + Heat + Acid + HA	400	270	33%	40	14	65%
OX7	Persulfate + Permanganate	530	530	NA	45	41	9%
OX8	Permanganate + HA	540	540	NA	45	36	20%
OX4	Permonosulfate + Heat	560	410	27%	45	35	22%
OX9	Permonosulfate + Cobalt	550	550	NA	45	39	13%
OX10	ZVI + Peroxide	550	35	94%	45	13	71%
OX11	Persulfate + Heat + Acid + HA	540	540	NA	45	9	80%
OX12	Permonosulfate + Heat + HA	690	630	9%	45	39	13%
OX13	Persulfate + Permanganate + Heat + HA	550	450	18%	43	39	9%
OX14	Permonosulfate + Heat + HA + Cobalt	610	620	NA	45	18	60%
RED1	ZVI + HA	550	37	93%	45	19	58%
RED2	Iron Oxide + HA	620	620	NA	43	43	NA
RED3	ZVZ	630	580	8%	42	40	5%
RED4	ZVZ + HA	580	86	85%	45	42	7%
RED5	ZVI + HA	531	28	95%	56	37	34%
OX12	ZVI + HA	556	47	92%	47	30	36%
OX11	ZVI + Peroxide + HA	556	77	86%	47	30	36%
SONO1	Cup Horn	550	600	NA	44	44	0%
SONO2	Cup Horn + H2O2 + ZVI	640	690	NA	37	36	3%
Interim Drinking Water Criteria (pre-Oct 2016 criteria)			0.2			0.4	

Notes
OX = Experimental Conditions to mimic In Situ Chemical Oxidation (ISCO)
RED = Experimental Conditions to mimic In Situ Chemical Reduction (ISCR)
SONO = Sonication Experiment
HA = Humic Acid
ZVI = Zero Valent Iron
ZVZ = Zero Valent Zinc

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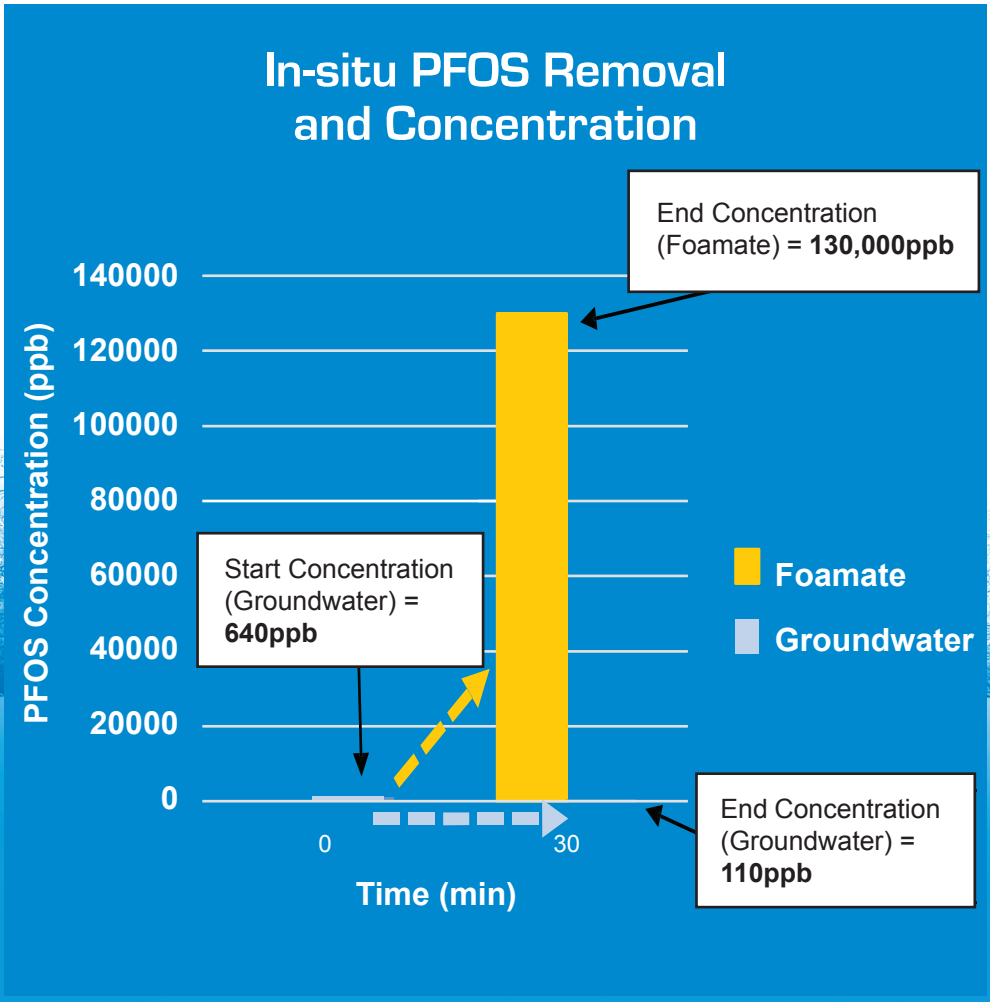
Limited Field Trial

July 2016: In-situ Foam Fractionation testing conducted on-site at an Australian government site in NSW. Summary of results (below).

Limited Field Trial Results



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Unfinished Business – Fungal Experiments

Results/Lessons Learned. The apparent reduction of PFAS by **fungal treatment** was likely due to adsorption to biomass, however the experimental budget and time was exhausted before this line of investigation could be concluded.

Ongoing investigations could include, but not be limited to the following: evaluation of Australian province (local native) species of fungi to be used as an ex-situ polishing remediation treatment of soil pore water following bulk remediation activities. Such investigations may involve a collaboration with NSW and/ or QLD DPI's to identify endemic Australian fungi exhibiting the capacity to survive/ biodegrade low-level concentrations of PFAS analytes into less harmful substances. Short-listed fungi species could then be evaluated in the laboratory and those species proven to accelerate PFAS degradation should be further examined to identify the biochemical pathways and chemistry of the final breakdown products.

Final stage would be to identify a commercial grower with appropriate licences to culture the species of fungi, or make a blend of several fungi to take the laboratory bench-scale trial to a pilot field trial.

Fungi as a Tool for the Degradation of PFAS

SUMMARY of RESULTS for FUNGAL TREATMENT

Test	Testing Time, Days	Initial PFOS, ug/L	Final PFOS, ug/L	Reduction	Initial PFOA, ug/L	Final PFOA, ug/L	Reduction
P1	19	590	47	92%	68	18	74%
P2	19	590	36	94%	68	4.3	94%
P1A	15	590	61	90%	68	15	78%
P1B	2	590	61	90%	68	12	82%
P2A	15	590	21	96%	68	3.3	95%

The above results show a significant reduction in PFOS and PFOA concentrations in impacted groundwater after only two days of contact with fungi. The mechanism associated with the removal of these compounds from solution needs to be further understood. Should it be proven that the fungi are associated with degradation of these PFAS compounds then they could be incorporated into a remediation solution. However, there are significant challenges with such an approach, the primary being maintaining any fungal based "bio-reactor" in a healthy and functioning state.

Biography – Steve Phillips

Steve Phillips has been working in the contaminated land and associated industries for over 25 years. He has a BSc (Hons) 1st Class in Hydrogeology from UNSW and says one of his favourite activities is finding awesome solutions to client challenges. On weekends Steve runs one of Australia's most popular artist blacksmith studios in Footscray, Melbourne.

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