Enzymatic degradation of PFAS

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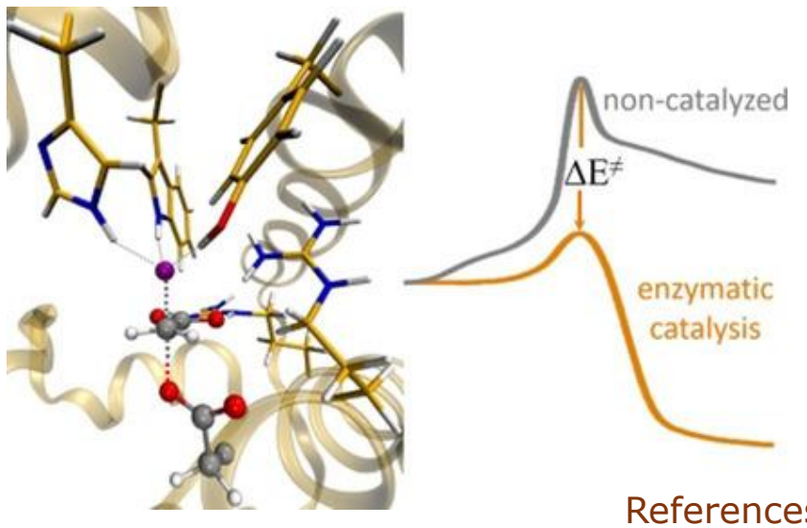
Why enzymes?

PFAS (Per- and Polyfluoroalkyl Substances) are highly persistent due to their strong carbon-fluorine bonds. Widely used in industrial and consumer products, PFAS cause environmental contamination and significant health risks. Degradation of PFAS using enzymes offers a potential strategy to break down PFAS under mild conditions, using natural catalysts. This may greatly reduce the energy costs for PFAS mineralization compared to e.g. incineration.

Direct enzymatic C-F bond cleavage

Fluoroacetate dehalogenase (FAcD) is one of the few *known* enzymes capable of directly cleaving C–F bonds, but its activity is limited to simple monofluorinated compounds and does not extend to PFAS.[1-2]



Source: Miranda-Rojas *et al.* (2018). DOI:10.1002/cctc.201701517

Engineering specialized enzymes

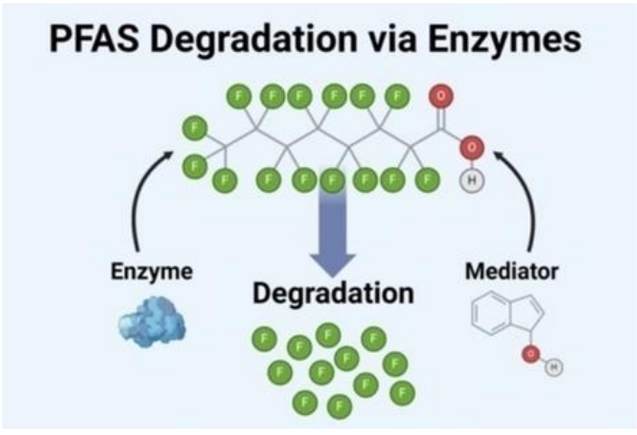
Even though the C-F bond is very strong, various defluorinase enzymes exist. Wackett recently proposed that it is not the bond strength, but rather the toxicity of the defluorinase reaction product (the fluorine anion) that causes the inexistence of bacteria or other microorganisms that can degrade PFAS in a natural environment.[3] Research is focusing on engineering specialized enzymes to tackle these pollutants.[4] Screening for new enzymes could be much more effective if the enzymes are expressed intracellularly into fluorine-resistant microorganisms, so that the enzyme is not lost after a single defluorination reaction has been performed.

Laccases

Laccase enzymes are found in fungi, bacteria, and plants. They have been found to be able to degrade PFAS indirectly by generating reactive radicals with the help of mediator molecules. These radicals initiate PFAS breakdown, including decarboxylation and functional group cleavage. Experimental studies report up to 59% PFOS degradation and 31% defluorination over 162 days, with enhanced results in the presence of metal ions like Cu^{2+} and Mg^{2+}. Laccases operate effectively in marine environments due to their salt tolerance and ability to function without external peroxide sources.[1,5]

Outlook

Challenges remain, including inconsistent reproducibility, incomplete degradation, and the formation of persistent by-products such as fully fluorinated alkenes. Research is currently limited to a narrow subset of PFAS compounds, primarily PFOA and PFOS.[1] Laboratory results often do not reflect real-world conditions, and degradation times are impractically long. Future research should focus on understanding degradation mechanisms, improving laccase efficiency, and expanding studies to diverse PFAS compounds in environmental settings. Despite current limitations, laccase-based systems or fluorine-resistant microorganisms hold potential for sustainable PFAS remediation.



Source: Harris et al, 2024 [1]

References

[1] Harris et al, 2024, Enzymatic Degradation of PFAS: Current Status and Ongoing Challenges. ChemSusChem, 18(2), e202401122.
[2] Kamachi et al, 2009, The Catalytic Mechanism of Fluoroacetate Dehalogenase: A Computational Exploration of Biological Dehalogenation. Chemistry – A European Journal, 15(30), 7394–7403.
[3] Wackett, 2025. Confronting PFAS persistence: enzymes catalyzing C–F bond cleavage. Trends in Biochemical Sciences, 50(1), 71-83.
[4] Walker et al, 2014, Natural and engineered biosynthesis of fluorinated natural products. Chem. Soc. Rev., 43(18), 6527–6536.
[5] Luo et al, 2018, Perfluorooctanesulfonate Degrades in a Laccase-Mediator System. Environmental Science and Technology, 52(18), 10617–10626.

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