PFAS detection using electrochemistry in microfluidic devices

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Nature du financement demandé : Stage de ~~L3, M1,~~ M2, ~~mobilité sortante, Professeur Invité~~, Autres (préciser)
Période : (dates du stage ou de la venue du Professeur Invité) à partir de mars 2025

Résumé : (200 mots)
The objective of this project is to develop a microfluidic platform that will allow the detection and analysis of **per- and polyfluoroalkyl substances** (**PFAS**) in environmental samples. The innovative approach proposed here is to combine cutting edge technologies (i) microfluidic and (ii) electrochemistry at immiscible interfaces. The detection of such substances is a new research axis at Institut des Nanotechnologies de Lyon (INL) and I would like to participate through this novel approach. Moreover, this axis has been recently identified by MITI CNRS as a new research challenge and a call has been launched in June 2024

Sujet développé :

Context: PFAS are manufactured chemical substances that contain the specific perfluoroalkyl chain (C_nF_{2n+1}) and polar/ionizable end groups. These substances are widely used in various industrial applications such as firefighting foams, food packaging, cookware, cosmetics and paints. Therefore, they have economical relevance worldwide that results in their widespread use and their release into the environment. It was uncovered that human exposure to PFAS is of high concern as these substances are connected with multiple toxicological issues such as cancer, diabetes, fertility and cardiovascular diseases (Jane L, 2022) (Bartell SM, 2021). Hence, the sensitive detection of these substances is a major concern worldwide. The most widely used analytical technique is liquid chromatography-tandem mass spectrometry combined with solid phase extraction. It was approved by the Environmental Protection Agency of the USA for 29 PFAS (Rosenblum L., 2019). However, it is unsuited for on-site analyses and requires highly-skilled users. Alternative analytical approaches are currently under investigation.
Project: Here, I propose to use an electrochemical approach to detect PFAS with ionizable properties (PFOA: perfluorooctanoic acid, PFOS: perfluorooctane sulfonic acid for example). Direct oxidation or reduction of such substances is not feasible due to their chemical stability, so indirect detection is required. My strategy is to investigate a seldomly used approach based on **electrochemistry at interfaces between two immiscible electrolyte solutions** (**ITIES**). In this approach, the electrical polarization between two immiscible solutions drives the transfer of non-redox species from one phase to another, resulting in an electrical signal proportional to the concentration of the non-redox species. Few publications have demonstrated the capacity of this approach to detect PFAS at ng/L limit of detection (Lamichhane HB, 2023) (Islan GJ, 2022) (Viada BN, 2020), which is compatible with PFAS concentration found in drinking water. The **novelty of this project is to combine this electrochemical detection with microfluidic technology**. Microfluidic is a powerful approach to develop analytical platforms that can be both sensitive due to miniaturization and automated thanks to integration. I believe that this combination will circumvent some of the limitations of the current approaches.
Methodology. This project will be divided in 4 Workpackages and the preliminary experiments will be carried out with the help of master students. She/He will be dedicated to the electrochemical

experiments with flowing µITIES (WP2 & WP3). Even if all the WP are presented here, some of the objectives are out of the scope of this call.

WP 1: Investigation of the electrochemical transfer of ionizable PFAS at static macro-scale ITIES

Here the objectives are to obtain an experimental set-up adapted to carry out electrochemistry at static ITIES and also optimize chemical experimental conditions. The electrochemical response of ionizable PFAS will be evaluated as a function of the organic phase and salt chosen (1,2-dichloroethane for example). The possibility to solidify this phase (using a plasticizer such as o-nitrophenyl octyl ether) in the perspective of sensor development and/or to replace this phase by a "green" organic phase (oils) will need to be investigated as well.

WP 2: Investigation of the electrochemical transfer of ionizable PFAS at static micro-scale ITIES

In order to enhance sensitivity, the miniaturization of the interfaces is crucial. We will therefore investigate the electrochemical response of such static micro-ITIES. The formation of stable micro-ITIES is obtained by contacting the 2 immiscible phases through membranes containing micro-pores. The geometry of micropores will be optimized by using finite element numerical modelisation (electrochemistry module of COMSOL Multiphysics) and the optimized geometries will be experimentally evaluated in terms of limit of detection.

WP 3: Investigation of the formation of flowing ITIES in microfluidic environment

The main objective here will be to design microfluidic environments that will permit to stabilize ITIES in flowing conditions. This is extremely challenging and two approaches will be tested

(i) formation of stable ITIES by optimizing various physical parameters that can influence such interfaces in flowing conditions. We will therefore evaluate the impact of geometrical shapes and dimensions of the microchannels, but also channel surface properties (interface energy) and flow rate conditions on the interface shape. As reported in literature and as we observed in preliminary experiments, various shapes can be obtained (laminar parallel flow, droplet flow, …).

(ii) Formation of stable ITIES by solidifying the organic phase. Plasticizer studied in WP1 will be used to solidify the organic phase. This will require to effectively control the interface formation and solidification will be monitored thanks to microscopic observation.

WP 4: electrochemical detection of PFAS in microfluidic environment

In this WP, we will investigate the detection of ionizable PFAS in microfluidic environment. After optimization of stabilization conditions (WP3), we will equip such microchannels with Pt or Au electrodes in order to polarize flowing ITIES. We will investigate the electrochemical response depending on various physical and chemical conditions (flow rates, organic phase, channel dimensions, …). Moreover, one objective here is also to design a microfluidic architecture in order to carry out automatic quantification.

References

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