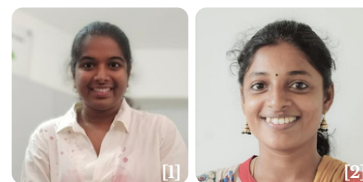


Revitalizing Spent Solvents: A Sustainable Path to Waste Reduction

KID: 20260209



Solvent extraction techniques are widely adopted to separate and recover valuable materials. Over time, however, the solvents used in these processes begin to degrade, creating a mixture of useful organic compounds and unwanted by-products. Managing these spent solvents is an important challenge, as the accumulation of degradation products can reduce process efficiency and increase waste generation. One of the key solvents used in the extraction processes are organophosphates. Various degradation products formed during the extraction process can interfere with solvent performance by altering extraction behavior, promoting undesirable interactions with metal ions, and reducing the solvent's ability to be reused efficiently. Traditional methods for treating spent solvents often involve extensive washing procedures or destructive treatment techniques. Although these approaches help remove contaminants, they may also result in the loss of valuable solvent components, reducing the overall sustainability of the process. To address this issue, our work explores an innovative Size and Other Properties - Based Selection and Exclusion Based Membrane Separation.

In this approach, the degradation products are first selectively bound to a suitable agent. The resulting compounds are then removed using membrane-based separation technology, allowing the valuable solvent fraction to be retained and recovered. By targeting only the undesirable components, this method aims to maximize solvent reuse while minimizing waste. The proposed strategy offers a promising pathway towards more sustainable extraction strategy. By improving solvent recovery and reducing the generation of secondary waste, it contributes to both environmental protection and resource conservation. As industries continue to seek cleaner and more efficient technologies, such innovative separation methods could play a key role in shaping the future of spent solvent waste management.

When Chemistry Meets Membrane Technology

The spent solvent investigated in this study is composed mainly of organophosphates and a diluent, along with smaller amounts of degradation products. Although present in relatively low concentrations, these degradation products have a significant impact on solvent performance and therefore need to be removed efficiently. The proposed treatment method follows a simple but innovative sequence:

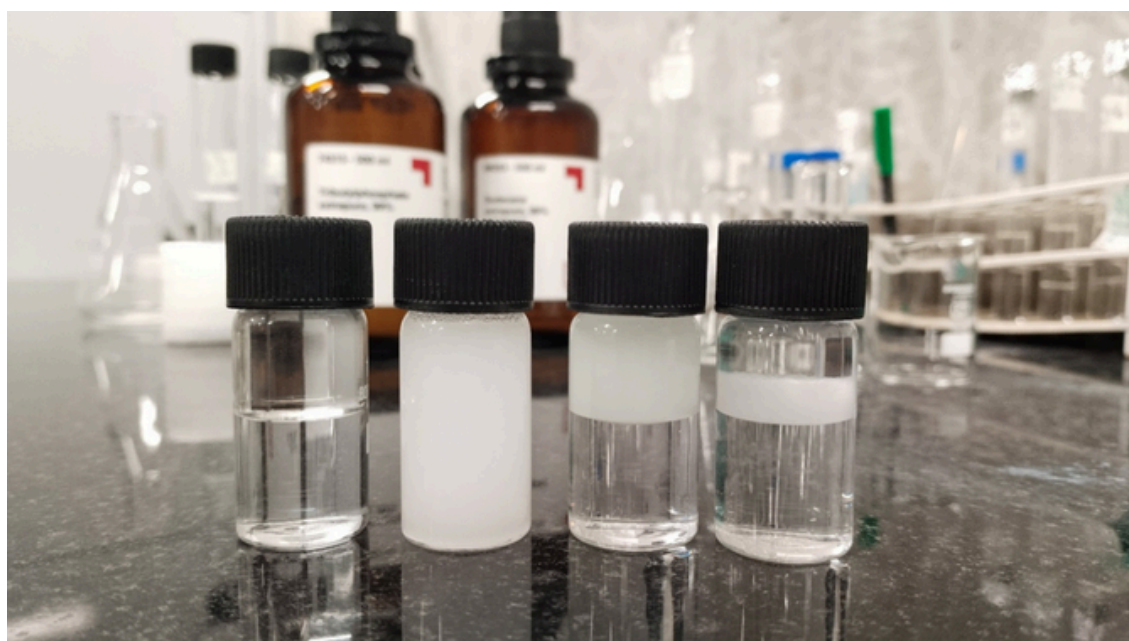


Figure 1. Size and Other Properties Based Selection and Membrane Separation

Membrane Materials and Filtration Approaches

The success of the proposed method is critically dependent on the selection of suitable membrane materials and filtration mechanisms. Because this approach integrates size and other properties-based selection and separation, membrane selection must consider not only pore size but also chemical resistance, solvent compatibility, hydrophilicity, surface properties, fouling resistance, and interactions with degradation by-products. Both polymeric and ceramic membranes represent promising candidates for this application. Polymeric membranes such as polyethersulfone (PES), polysulfone (PSF), polyvinylidene fluoride (PVDF), and polytetrafluoroethylene (PTFE) offer advantages including low cost, ease of fabrication, and tunable pore structures. However, their long-term stability and resistance to swelling in solvent systems require careful evaluation. In contrast, ceramic membranes based on alumina (Al_2O_3), zirconia (ZrO_2), titania (TiO_2), silica (SiO_2), and silicon carbide (SiC) provide superior chemical, thermal, and mechanical stability and are therefore attractive for operation in aggressive solvent environments. In particular, Al_2O_3 -supported ZrO_2 or TiO_2 selective layers offer a robust membrane architecture with controllable surface chemistry and excellent opportunities for surface functionalization. Further enhancement may be achieved through the development of functionalized, hybrid, and mixed-matrix membranes incorporating hydroxyl-, amine-, phosphonate-, or other ligand-containing groups, as well as inorganic nanoparticles such as ZrO_2 , TiO_2 , Al_2O_3 , and SiO_2 . From a process perspective, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and organic solvent nanofiltration (OSN) are potential separation platforms. Consequently, MF and UF are proposed as the primary laboratory-scale technologies for initial membrane screening and process optimization.

Reactor Development

The performance and scalability of the proposed separation process will also depend on the design of an appropriate reactor configuration. Initial membrane screening studies can be performed using a stirred dead-end flat-sheet membrane cell, where the feed solution is continuously mixed and pressure-driven permeation is used to evaluate membrane flux, pollutant rejection, and solvent recovery. This configuration is simple, requires relatively small feed volumes, and allows rapid comparison of different membrane materials and operating conditions. For long-term performance assessment and scale-up investigations, cross-flow flat-sheet membrane reactors or batch-recirculation systems consisting of a feed reservoir, circulation pump, membrane module, and retentate return loop can be constructed. Such systems will enable detailed evaluation of concentration polarization, membrane fouling, flux decline, operational stability, solvent recovery efficiency, and repeated-use performance. The outcomes of these studies will provide critical engineering data required for the development of a practical and scalable membrane separation process for selective pollutant removal and efficient solvent recovery.

Towards a More Sustainable Future in Spent Solvent Management

As the demand for cleaner and more efficient industrial processes continues to grow, the need for sustainable solvent management has become increasingly important in various sectors. Spent solvents not only contain unwanted degradation products but also retain valuable components that can be recovered and reused. Developing technologies that can selectively remove contaminants while preserving useful materials is therefore essential for improving both economic efficiency and environmental sustainability. The approach explored in this work combines the strengths of chemistry and membrane technology to address this challenge. By selectively binding degradation products and separating them from the solvent stream, the process aims to recover a larger fraction of reusable solvent while reducing the amount of material that must be treated as waste. Unlike conventional treatment methods, which may result in the loss of valuable solvent components, this strategy focuses on retaining resources and maximizing their useful lifetime. An additional advantage of this method is its potential to reduce the generation of secondary waste. Minimizing waste production is a key objective in modern industrial operations, as it lowers disposal requirements and supports environmentally responsible practices. The ability to regenerate and recycle solvents can also contribute to more cost-effective process operations and improved resource management. Beyond its immediate application in the extraction processes, the concept highlights how innovative separation technologies can be used to solve complex industrial challenges. Although further investigation and optimization are required, the preliminary concept offers an encouraging pathway toward next-generation solvent recovery systems. As advances in materials science, membrane engineering, and chemical separation continue to emerge, such technologies could play an important role in enhancing process efficiency, reducing environmental impact, and supporting the long-term sustainability of various industries. Ultimately, transforming spent solvents from a waste management challenge into a recoverable resource represents a significant step toward a more circular and sustainable future.

[1] Ms Anjana Jayakumar

Research Scholar, Department of Civil Engineering

[2] Dr Ambika S

Assistant Professor, Department of Civil Engineering