Oxidation-Filtration Systems Based on Catalytic Membranes: A Systematic Review

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This study addresses challenges in membrane separation by introducing a review about catalytic membranes, that degrades contaminants using hydroxyl radicals, offering simultaneous physical separation and chemical oxidation. Achieved through catalyst incorporation, these membranes exhibit dual functionality: filtration and catalysis. This systematic review, following PRISMA guidelines, focuses on catalytic membrane-based oxidation-filtration articles from 2013 to 2023. Eligible criteria include English-language, peer-reviewed articles. The discussion emphasizes reduced equipment cost, lower energy consumption, and higher efficiency. This review consolidates knowledge and identifies future research directions for catalytic membrane oxidation systems, serving as a valuable resource for researchers and practitioners.

Introduction

The membrane separation process, although efficient and scalable, faces challenges with highly contaminated matrices due to fouling [1]. Catalytic membranes are proposed to overcome this, which use hydroxyl radicals to degrade organic contaminants directly, enabling both physical separation and chemical oxidation simultaneously. These membranes transform filtration processes, overcoming issues like fouling and pollutant degradation, resulting in cost reduction and higher efficiency [2].

This study addresses catalytic membranes made of materials, characterized as inorganic membranes and organic ones, which exhibit dual function - filtration and catalysis. It provides a systematic review of oxidation-filtration systems, discussing materials, principles, applications, advantages, future challenges, and research directions.

Material and Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was used for the systematic literature search. The electronic databases utilized were: Science Direct and Scopus. Additionally, the references of the obtained articles were also investigated to select other articles. The terms used in the search were: catalytic membrane; membrane separation; advanced oxidation technologies: oxidation-filtration; hybrid processes. Boolean operators "AND" were used in various combinations with the provided words. The information extracted from each included literature (using a standard data extraction form) consisted of the following items: (a) The name of the author, journal, title and year of publication; (b) Membrane fabrication method; (c) Membrane type; (d) Catalyst; (e) Catalyst Activator; (f) Membrane separation; (g) Application.

Results and Discussion

The bibliographic research carried out identified 660 results, of which 103 were selected using inclusion and exclusion criteria and constituted the analysis set for this review. These criteria were established based on the defined keywords and the search restriction for the period from 2013 to 2023. The PRISMA flowchart analysis is shown in Figure 1.

The bibliographic survey revealed that currently three main approaches are being studied for catalytic membrane oxidation-filtration systems: Applications of Polymeric Catalytic Membranes (approximately 30% of the research), Catalyst Preparation Methods (approximately 50% of the research), and Coating Techniques for Catalytic Membranes (approximately 20% of the research). These percentages provide a more precise characterization of the identified results in the review.

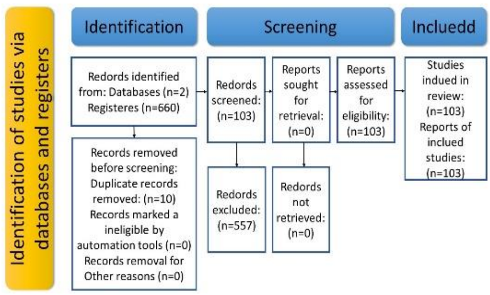

Figure 1. Identification PRISMA flow diagram of studies via databases and registers.

Therefore, this summary highlights the essential elements addressed in each study, emphasizing their importance for the advancement of research and development of catalytic membranes, providing a comprehensive view of the materials, methods, and challenges involved. The results of this review have shown that catalytic membrane materials can be polymeric, ceramic, or metallic, or a combination thereof. The choice of matrix material should consider cost, application, suitability for the separation process, and adherence to the catalyst. The selection of the catalyst should take into account cost, selectivity, stability, and adhesion to the membrane matrix [3].

Polymeric catalytic membranes offer simplicity in fabrication, robustness, and high efficiency in particle removal. This versatility has been utilized in various reaction/separation coupling applications, such as biosynthesis and photocatalysis, among others [4]. They are commonly made of polyvinylidene fluoride (PVDF), polyethersulfone (PES), and polysulfone (PSf), but recent research primarily focuses on PVDF due to its thermal stability, mechanical strength, and chemical resistance.[5]. On the other side, the materials used for the preparation of the inorganic membrane matrix are ceramics, zeolites, and metals. Alumina (Al2O3), silicon carbide (SiC), and zirconia (ZrO2) are the ceramics commonly used to fabricate catalytic inorganic membranes. [6,7] Catalysts can be developed to obtain the active catalytic surface mainly by: depositing a laminar film of catalytic substance on the membrane and/or pores, depositing catalytic substance nanoparticles into the porous structure, and forming constrictions in the porous structure through chemical vapor deposition.[8]. Metallic catalytic membranes are presented as single-phase metal membranes or alloy, and their use is encouraged because they exhibit the highest selectivity among other materials. However, they are still affected by a relatively high cost compared to polymeric and ceramic membranes. Nevertheless, they are promising materials for some catalytic processes where extremely high selectivity is required, such as ammonia synthesis and fuel cell provision.[8]

According to the literature, there are some preparation methods route of a single catalyst. Briefly, the preparation methods include the precipitation, impregnation, precipitation-impregnation, sol-gel and chemical deposition methods [9].

The physical coating approach mainly consists of the techniques: physical vapor deposition, dip coating, spin coating, casting, filtration, layer by layer assembly. Otherwise, the chemical coating process is made by: copling agents, sol-gel reaction, chemical vapor deposition, surface grafting, in situ growth [6].

The profitability of a catalytic membrane coating asserts not only effectiveness but also economic enhancement. After insertion into the membrane surface, unfortunately, many catalysts suffer from disadvantages in their own activities and, in some cases, are discarded due to several key limitations such as low catalyst loading, hindered catalyst access, poisoning, and catalyst deactivation. Therefore, further development of innovative insertion techniques should be pursued to ensure adequate economic viability in catalytic membranes.

Conclusions

In conclusion, the selected articles on catalytic membranes involve careful consideration of matrix materials, catalyst preparation methods, and coating techniques. Each choice is influenced by factors such as cost and the desired application. However, studies also indicate that, despite advances, there are challenges to be overcome, such as reducing the catalyst load, difficulty in accessing the catalyst after insertion into the membrane, and problems such as catalyst inactivation. Therefore, continued research and the development of new insertion techniques are essential to ensure the economic viability of these membranes in catalytic applications.

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Feel free to contact the organizing comittee for any further information.

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