

EL FUTURO DEL TRATAMIENTO DE AGUA:
AVANCES INNOVADORES EN LA TECNOLOGÍA DE MEMBRANAS CERÁMICAS
THE FUTURE OF WATER TREATMENT:
INNOVATIVE ADVANCES IN CERAMIC MEMBRANE TECHNOLOGY

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INTRODUCTION

Water treatment is a pressing global challenge requiring efficient technologies to remove contaminants and provide clean water. Ceramic membranes are emerging as a promising solution due to their ability to remove heavy metals, pathogens, and other pollutants effectively. This research explores the latest developments in ceramic membranes, focusing on materials, manufacturing techniques, and innovations such as cold sintering, which reduces production costs and enhances membrane performance.

OBJETIVES

1.To develop and optimize ceramic membranes using cold sintering techniques to improve their electrochemical and structural properties.
2.To evaluate the impact of additives with high solubility and ionic conductivity on grain boundary binding and membrane performance.
3.To analyze the environmental and economic feasibility of implementing ceramic membranes in water treatment plants.

Justification

Ceramic membranes stand out for their durability, high selectivity, and resistance to extreme conditions, making them ideal for water treatment applications. Cold sintering presents a groundbreaking method to enhance these properties while reducing energy consumption and production costs. This research contributes to sustainable solutions for global water management by improving pollutant removal efficiency and supporting environmentally responsible technologies.
Visuals: Include diagrams of the cold sintering process, a comparison of conventional vs. cold sintering methods, and performance data of ceramic membranes in removing contaminants.

Experimental Plan

Material Selection

For the manufacture of ceramic membranes by cold sintering, materials based on oxides such as Al2O3, TiO2, SiO2, and ZrO2 will be selected. Additionally, it works with solid electrolyte materials such as LLZO (Li7La3Zr2O12) and LATP (Li1.3Al0.3Ti1.7(PO4)3), known for their high ionic conductivities and potential applications in solid-state batteries.

Cold Sintering Process

•Ceramic Suspension Preparation: Commercial ceramic powders are dispersed in a suitable solvent, usually water or a mixture of organic solvents, to form a homogeneous suspension. Additives with high solubility and ionic conductivity can be added to improve the binding between grain boundaries and increase the density and ionic conductivity of the final material.
•Suspension Compaction: The suspension is compacted in a mold under high pressure (up to several hundred MPa) to form a green body with high initial density.
•Cold Sintering: The compacted green body is subjected to heat treatment at a low temperature (less than 300 °C), while continuous pressure is applied. During this process, the solvent facilitates the dissolution of the sharp edges of the particles, and the subsequent evaporation of the solvent and precipitation of the dissolved species fill the gaps between the particles, achieving high densification.
•Characterization of the Membranes.

Advanced Applications of Ceramic Membranes in Wastewater treatment

To improve the scalability of cold sintering, several key technological innovations are required. First, it is important to maintain stable temperatures and humidity levels within the sintering chambers to prevent defects and ensure the quality of the material . In addition, the sintering mechanisms at the atomic and microstructural levels must be deepened to achieve high densification at low temperatures. Precise control of parameters such as pressure and sintering time is essential to prevent the formation of defects such as blocking layers and pores [1]. Bringing cold sintering to large-scale industrial production requires the design of suitable furnaces and feeding systems, facing challenges of temperature uniformity and low-temperature material handling. In addition, optimization of specific formulations is necessary to enable efficient densification without compromising desired properties.

Problems and Variables	Explanation	Applications
Pore Size	Pore size controls how efficiently the membrane can separate particles of different sizes.	Tratamiento de agua potable y residual
Pore Size Distribution	Pore size distribution affects the uniformity and efficiency of filtration across the membrane.	Water purification for industrial use
Surface chemical interactions	Chemical interactions such as adsorption, acid-base interactions, and hydrogen bonding can influence the membrane's ability to retain specific contaminants.	Filtration of contaminated wastewater
Surface modification	Modifying the membrane surface with coatings or chemical functionalization can improve filtration selectivity and efficiency.	Industrial effluent treatment
Mass transport mechanisms	Understanding how contaminants move through pores and the porous matrix is critical to optimizing separation efficiency.	Treatment of water contaminated with heavy metals
Mechanical strength and durability	The strength and durability of the ceramic membrane under different operating conditions determine its long-term service life and performance.	Seawater desalination

Table 1. Matrix of Problems, Variables, and Applications in Filtration Mechanisms and Principles of Operation of Ceramic Membranes in Water Treatment.

Challenges and Future Perspectives in Ceramic Membrane Research and Development

DEMOWARE Project (Netherlands)

Ceramic membrane technology was used for the efficient removal of persistent pollutants such as microplastics and emerging pollutants. Where Ceramic membranes were shown to be highly effective for contaminant removal, with high abrasion resistance and chemical stability, making them suitable for long-term wastewater treatment applications.

Oslo Water treatment plant (Norway)

The Oslo water treatment plant implemented ceramic membranes for drinking water treatment, standing out for its ability to provide an effective barrier against pathogens and organic contaminants. Where the ceramic membranes proved to be robust and capable of operating with high efficiency even under fluctuating water quality conditions, ensuring high-quality drinking water standards in a sustainable manner.

Wastewater Treatment Plant (Barcelona)

The wastewater treatment plant in Barcelona implemented ceramic membranes for the advanced treatment of industrial effluents. These membranes were used for water recovery and the removal of specific contaminants present in industrial wastewater. Where ceramic membrane technology allowed a significant reduction in the pollutant load of treated water, complying with the strictest environmental regulations and facilitating the safe reuse of water in industrial processes.

References

1. He Z, Liu Z, Gu Q, Zhang L, Wang J. Ceramic-based membranes for water and wastewater treatment. Colloids Surf A Physicochem Eng Asp. 2019 Oct;578:123513.
2. Avasarala S, Bose S. 2D nanochannels and huge specific surface area offer unique ways for water remediation and adsorption: assessing the strengths of hexagonal boron nitride in separation technology. Functional Composite Materials. 2023 Apr 24;4(1):5.
3. Li C, Sun W, Lu Z, Ao X, Yang C, Li S. Systematic evaluation of TiO2-GO-modified ceramic membranes for water treatment: Retention properties and fouling mechanisms. Chemical Engineering Journal. 2019 Dec;378:122138.
4. Gitis V, Rothenberg G. Ceramic Membranes: New Opportunities and Practical Applications. Gitis V, Rothenberg G, editors. Wiley; 2016.

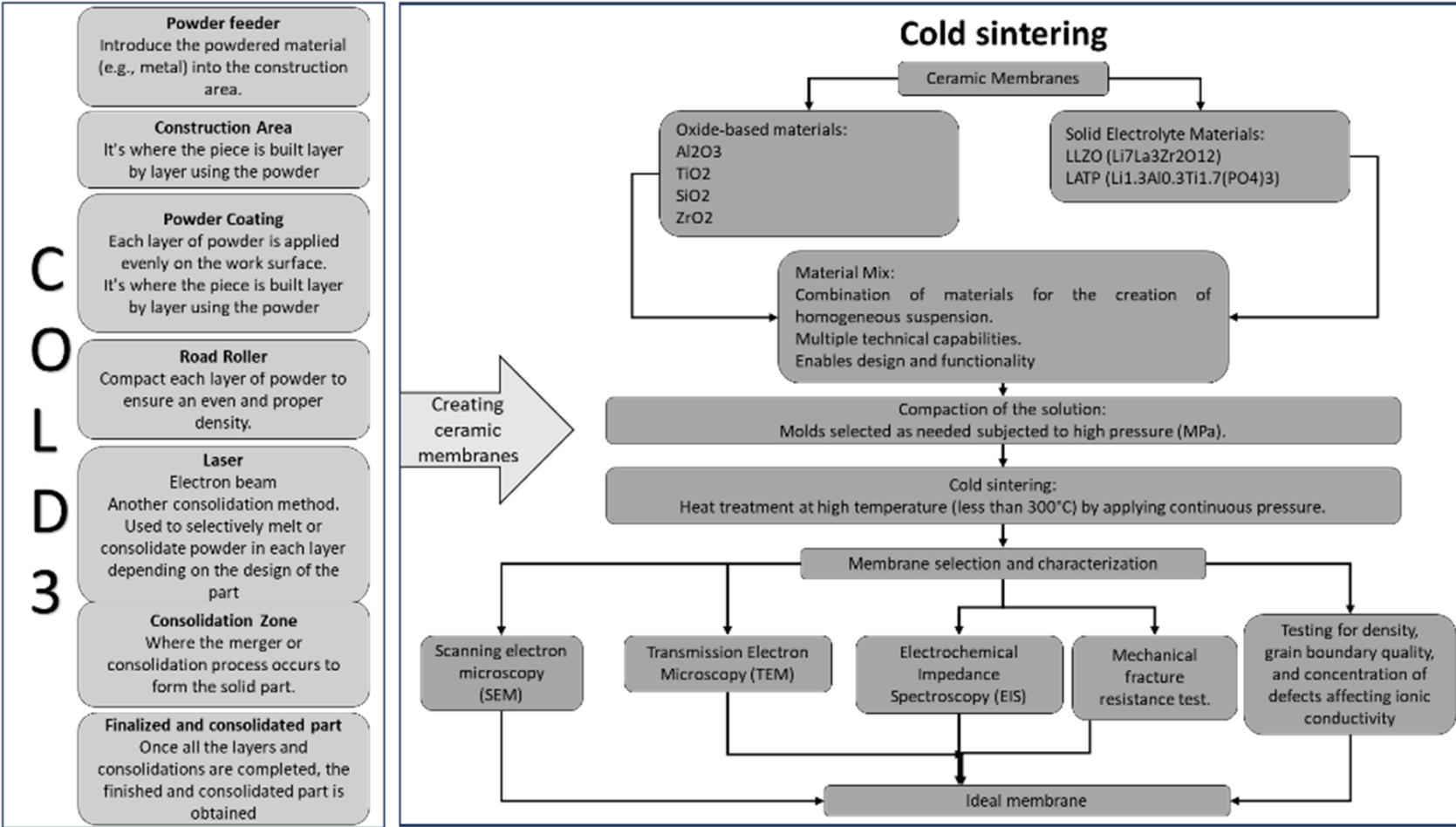


Image 1. Methodology for the creation of cold sintering of ceramic membranes.

Challenges and Future Perspectives in Ceramic Membrane Research and Development

The main technological challenges in the implementation of cold sintering include:

•Temperature and Humidity Control: Maintaining stable temperatures and humidity levels within sintering chambers is important to avoid defects and ensure material quality. Temperature and humidity control systems must be accurate and reliable.
•Densification at Low Temperatures: Achieving high densification of materials at much lower temperatures than conventional sintering is a key technical challenge. This requires a deep understanding of the mechanisms of sintering at the atomic and microstructural levels.
•Defect Minimization: Low-temperature sintering must prevent the formation of blocking layers, pores, and other defects common in high-temperature sintering. This involves precise control of the process parameters.
•Industrial Scalability: Bringing cold sintering from laboratory scale to large-scale industrial production presents engineering challenges related to the design of furnaces, powder feeding systems, and automated processes.
•Integration with Applications: Integrating cold sintering efficiently into applications such as water treatment and energy storage requires optimizing the ionic conductivity and structural stability of materials.
•In summary, the main technical challenges include the precise control of processing conditions, the understanding of the fundamental mechanisms of low-temperature sintering, and the scalability of the process for industrial implementation.

Cold sintering offers several significant benefits:

•Cost Reduction: By operating at much lower temperatures than conventional sintering, energy and operating costs are greatly reduced. In addition, cold sintering can eliminate the need for expensive high-temperature equipment, reducing capital investment.
•Improved Efficiency: The ability to achieve high densification at low temperatures can improve the ionic conductivity and structural stability of membranes, critical to their performance in water treatment and energy storage applications.
•Minimization of Defects: Low-temperature sintering can prevent the formation of blocking layers and other defects associated with high-temperature sintering, improving the overall quality of the material .
•Environmental Sustainability: By reducing energy consumption and minimizing the generation of toxic byproducts, cold sintering is a more sustainable and environmentally friendly technology.

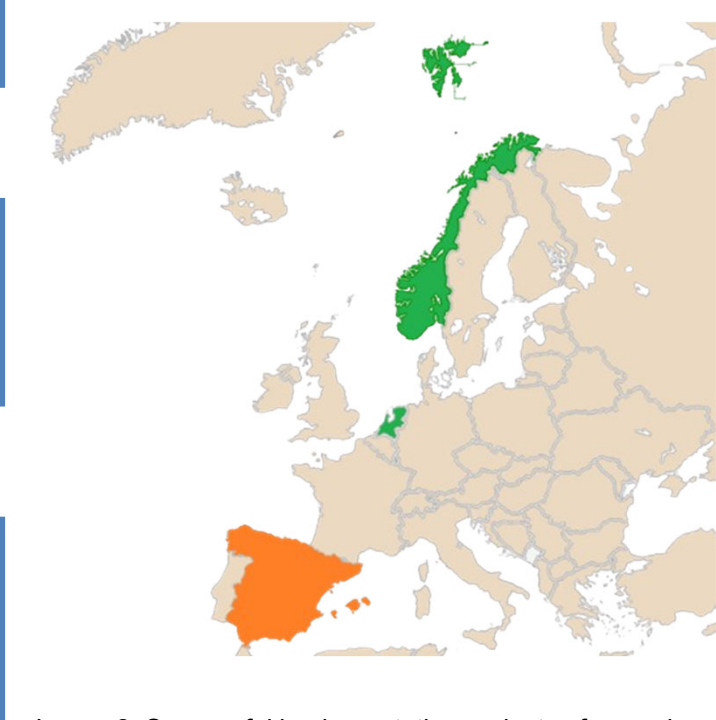


Image 2. Successful implementation projects of ceramic membranes in water treatment projects..

CONCLUSIONS

•Efficiency and Selectivity: Ceramic membranes play a key role in water treatment by efficiently removing contaminants, with factors such as pore size, surface modifications, and mechanical durability being critical to their performance.

•Cold Sintering Advantage: Cold sintering improves the sustainability of ceramic membranes by allowing production at lower temperatures, reducing energy consumption, operating costs, and minimizing environmental impact. This method also enhances the durability and efficiency of membranes.

•Technological Barriers: Key challenges include controlling parameters like temperature and humidity during manufacturing, minimizing structural defects, and scaling production for industrial applications. Overcoming these will further optimize membrane performance.

•Case Studies: European projects, such as DEMOWARE in the Netherlands and LIFE REMEMBRANE in Spain, highlight successful implementation, showing significant improvements in filtration efficiency and environmental impact reduction.
•Environmental Sustainability: Cold sintering reduces the carbon footprint, minimizes toxic waste, and offers environmentally friendly manufacturing processes. It also contributes to water quality improvement and the safe reuse of treated wastewater, which is crucial in water-scarce regions.

•Global Impact: Cold sintering holds promise for ensuring sustainable and safe water supplies, particularly in areas affected by water stress, and can help address emerging challenges posed by climate change. Its application can support water conservation, improve public health, and foster resilience in vulnerable communities.