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Comparative Performance Analysis of Unprocessed Quartz and Commercial Ceramic Membranes Coated with Hydrophilic Nanoparticles for Oil-Water Separation and Industrial Wastewater Reuse

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Abstract:

Industrial wastewater often contains emulsified oils, making efficient separation crucial for water reuse. While commercial ceramic membranes are widely used for oil-water separation, their high cost necessitates the exploration of affordable alternatives such as quartz-based membranes. This study evaluates and compares the surface morphology, wettability, and separation efficiency of three quartz-based membranes—unprocessed raw quartz, chemically washed quartz (treated with descaling chemicals), and hydrophilic nanoparticle-coated quartz—against a commercial ceramic membrane. The objective is to determine membrane performance for oil-water separation and assess their potential application in industrial wastewater treatment and sustainability.

Methodology and Theoretical Orientation: Surface characterization was conducted using Scanning Electron Microscopy (SEM) to examine morphology, nanoparticle distribution, and surface aggregation. Wettability was evaluated through contact angle measurements, where lower angles indicated greater hydrophilicity. Oil-water separation experiments were performed using a custom-built filtration system with synthetic oily wastewater at an initial oil concentration ranging from 200 to 500 mg/L. Membrane performance was analyzed based on permeate flux (L/m²h), oil rejection efficiency (%), and residual oil concentration in the filtrate. Additionally, Total Organic Carbon (TOC) and Chemical Oxygen Demand (COD) analyses were conducted to assess water quality improvement.

Findings: The results showed that unprocessed quartz membranes exhibited a contact angle of 98° ± 3°, indicating low hydrophilicity, with an oil rejection rate of 67% and a permeate flux of 30 L/m²h. Chemically washed quartz membranes demonstrated improved hydrophilicity, with a contact angle of 72° ± 4°, achieving 79% oil rejection and a permeate flux of 42 L/m²h. Notably, nanoparticle-coated quartz membranes exhibited a contact angle of 28° ± 2°, comparable to commercial ceramic membranes (32° ± 2°), signifying enhanced wettability. The nanoparticle-coated quartz membrane achieved 96% oil rejection with a permeate flux of 64 L/m²h, outperforming both untreated quartz and chemically washed membranes, and closely matching the 94% oil rejection and 61 L/m²h flux of commercial ceramic membranes. The residual oil content in the filtrate was significantly lower in the nanoparticle-coated quartz membrane (11 mg/L) compared to unprocessed (140 mg/L) and chemically washed quartz (62 mg/L), indicating its superior separation capability.

Conclusion & Significance: The study concludes that nanoparticle-coated quartz membranes can serve as cost-effective alternatives to commercial ceramic membranes for oil-water separation in industrial wastewater treatment. Their high hydrophilicity, reduced fouling tendencies, and improved oil rejection rates make them viable for enhanced water recovery applications, contributing to sustainable wastewater management and environmental conservation. By reducing operational costs while maintaining separation efficiency, the adoption of quartz-based membranes could offer a practical and scalable solution for industries facing water scarcity challenges.

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Biography

Ms. Nthabiseng J. Ramanamane is a distinguished lecturer and researcher at the University of South Africa (UNISA), specializing in material sciences and membrane technology for sustainable water recovery. She serves as the Study Leader and Chairperson of the Quartz Membranes Research Group and Deputy Chair of Teaching and Learning in CSET. Currently pursuing her PhD in Engineering at UNISA, her research focuses on quartz-based oil-water filtration membranes to address global water scarcity challenges. She holds an MEng (Cum Laude) from the Vaal University of Technology and a BTech (Cum Laude) from UNISA. With seven peer-reviewed publications, multiple research grants from NRF (BAAP), ISP, and pending TIA-UNISA funding, her work bridges scientific innovation and real-world applications.

About Research Topic

Water scarcity and industrial wastewater pollution are significant global challenges, requiring innovative and cost-effective treatment solutions. Membrane technology has proven to be an efficient method for oil-water separation, but high-cost commercial ceramic membranes limit widespread application in resource-constrained industries. This research explores the potential of unprocessed quartz membranes as a low-cost, high-performance alternative for industrial wastewater treatment and reuse. The study investigates the comparative performance of unprocessed raw quartz, chemically treated quartz (washed with descaling chemicals), and hydrophilic nanoparticle-coated quartz membranes against commercial ceramic membranes. The research focuses on surface morphology, wettability, and separation efficiency, providing scientific insights into their practical applications in wastewater management. By employing Scanning Electron Microscopy (SEM), oil rejection analysis, and water quality assessments, the study evaluates hydrophilicity, nanoparticle distribution, membrane fouling behavior, and overall separation performance. The goal is to validate whether quartz-based membranes, particularly those coated with hydrophilic nanoparticles, can match or outperform commercial ceramic membranes in oil-water separation and water recovery efficiency. This study contributes to sustainable water reuse solutions, industrial wastewater management, and environmental conservation efforts by demonstrating the feasibility of cost-effective membrane alternatives for oil-water separation. The findings could facilitate the commercialization and large-scale adoption of quartz-based membranes, promoting their use in various industrial applications where water treatment is crucial for environmental sustainability.

About Institution:

The University of South Africa (UNISA), located in Florida, South Africa, is the largest open distance learning (ODeL) institution in Africa and a key driver of research, innovation, and technological advancement. As part of the College of Science, Engineering, and Technology (CSET), the Department of Mechanical Engineering, Bioresources, and Biomedical Engineering is dedicated to cutting-edge research in materials science, fluid mechanics, and sustainable engineering solutions. UNISA is inspired by its vision to become "the African university shaping futures in the service of humanity." This vision defines its mission and commitment to serving every country on the African continent and the broader global community while transcending language and cultural barriers. The institution fosters multidisciplinary collaborations with national and international research institutions, industry stakeholders, and government bodies, ensuring that its research contributes to scientific advancements and real-world applications. With a strong faculty of researchers, academics, PhD candidates, and industry partners, UNISA remains a pioneering institution in membrane technology, environmental sustainability, and industrial wastewater treatment.

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