EXTENDED ABSTRACT

PDMS based Soft Structures for Continuous Mass Transfer and Visible Light Induced Photocatalytic Reaction Operations, and Batch Pervaporation Applications

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Abstract

In present work, the possible ways of using a silicone elastomer, poly-di-methyl-siloxane (PDMS) have been explored by fabricating membranes for batch pervaporation and thermal energy storage application and coiled flow inverter for continuous mass transfer and visible light induced photocatalytic reaction operation. PDMS is a transparent, non-toxic, insulating and viscoelastic silicon-based organic polymer with hydrophobic surface. We have used Sylgard 184 as our PDMS material that comes with a cross-linking agent. At room temperature it is in liquid state and when mixed with cross linking agent, it starts curing and after sufficient period of time and heating it becomes completely cured and retains softness. This property of softness and transparency of PDMS urged us to utilize it in various structures such as membranes, and coiled flow inverter (CFI) in their neat and corresponding 'particle impregnated' forms. Utilizing these soft structures, applications of pervaporation, thermal energy storage, mass transfer and photocatalysis have been performed. The work has been summarized in four chapters as described below.

Chapter 1 presents pervaporation of ethanol from ethanol-water mixture (ratio 1:1 by volume). In this work two novel methods have been used, one for preparing silicon oxycarbide (SiOC) particles from PDMS foam and the other for impregnating the PDMS films with these particles. The SiOC particles prepared by heat treatment of PDMS foam show large specific surface areas (192 m^2/g). The impregnation of the membranes is achieved by exposing the swollen PDMS membranes to the suspension of the SiOC particles in diisopropylamine leading to impregnation of the membranes up to a depth of 100 μm from one side and making that side more hydrophilic. The impregnated membranes also show much larger pore-size as suggested by capillary flow prorometry data. Pervaporation performance of the impregnated membranes for separation of ethanol-water mixtures by presence of SiOC particles inside the PDMS membrane matrix improves the ethanol transport across the membrane as particles adsorb water molecules forming a water rich region inside the membrane, which thereby affords a liquid phase diffusion as compared to neat PDMS membrane which offers only solid-state diffusion.

Chapter 2 presents the study of liquid-liquid extraction and mass transfer of acetic acid from the mixture of acetic acid and toluene (ratio 1:9 by volume) and water using PDMS-CFI, a millifluidic device. Initially a monolithic PDMS block of cylindrical shape with internally helical channel was fabricated. The inner channel of CFI with mean coil diameter of 11.8 mm has been made by a PVA filament of diameter 2.85 mm and length 313.5 mm. Then cylindrical PDMS block was divided into four equal segments, arranged at 90 degrees, and

interconnected using silicone tubes to fabricate the desired Coiled Flow Inverter (CFI). The unique flow dynamics of the CFI significantly improves the extraction and mass transfer evaluated at different flow rates. Superior mass transfer is achieved with increasing water flow rate as compared to toluene-acetic acid mixture flow rate.

Chapter 3 presents the photocatalytic degradation of methylene blue (MB) dye from wastewater using the same PDMS-CFI, utilized in mass transfer of acetic acid (chapter 2), when impregnated with plasma treated zinc titanate ($ZnTiO_3$) particle suspension and worked as a continuous flow photocatalytic reactor. By observation, it was noticed that plasma treatment improves particle dispersion, therefore a uniform and better homogeneous suspension of $ZnTiO_3$ particles with concentration of 1g/L was prepared using nitrogen gas plasma. The inner channel swelled by tetrahydrofuran (THF) solvent, was contacted with the prepared plasma treated $ZnTiO_3$ particle dispersion to make the particle impregnation. The impregnation of $ZnTiO_3$ particles within the PDMS-CFI provides a novel approach to harnessing photocatalysis for pollutant removal. MB dye is a prevalent pollutant in wastewater, posing environmental and health risks due to its toxic nature. Primarily, owing to the property of optical transparency of PDMS, it has been possible to increase the efficacy of visible light activity and perform photocatalysis. Additionally, the advantage of using CFI here is to make a continuous production process of dye mitigation out of water. Under visible light irradiation, $ZnTiO_3$ nanoparticles catalyze the degradation of MB dye molecules through the generation of reactive oxygen species, leading to the transformation of the dye into non-toxic byproducts. The intricate flow patterns within the CFI facilitate efficient mixing and mass transfer, ensuring enhanced contact between the photocatalyst and the dye solution. The decolorization rate of 18.6% for MB is obtained using this setup. The $ZnTiO_3$-impregnated CFI exhibits robust performance and durability, making it a promising technology for wastewater treatment applications.

Chapter 4 presents thermal energy storage (TES) and its retrieval. TES is a technology in which thermal energy (either heat or cold) is stored through a storage medium and used later when needed. In this work, PDMS membrane is incorporated with stearic acid (SA), a phase change material (PCM). PCMs are being used for energy storage and thermal abatement in a wide range of applications.

The varying quantities of SA ranging from 5.7wt% to 23.3wt% of PDMS mixed with 2 ml and 4 ml THF content were used to prepare various composite membranes by doctor blading method. Differential scanning calorimetry analysis of various SA incorporated membranes shows higher specific enthalpy at higher SA weight% and saturates beyond nearly 20wt% SA. A comparison of thermal analysis using temperature versus time behavior of 23.3wt% SA membrane and pure SA was done and observed that the composite membrane had a longer cooling time compared to that of pure stearic acid due to the insulating properties of PDMS and a shorter latent heat storage time because of the reduced amount of stearic acid, however the PDMS matrix affected the overall heat release behavior.

Chapter 5 presents the conclusion with a summary of findings and future research directions.