ABSTRACT

Pollution caused by synthetic dye waste, such as crystal violet (CV), has become an environmental concern due to its toxicity and resistance to degradation. Adsorption and photocatalysis using biopolymer-based membranes modified with photocatalytic materials offer an effective alternative for addressing such contamination. Titanium dioxide (TiO_2) is a promising photocatalyst; however, its photocatalytic activity is primarily limited to ultraviolet light. Therefore, nitrogen doping of TiO_2 (N-TiO_2) is employed to enhance its activity under visible light irradiation. The incorporation of N-TiO_2 into membranes based on chitosan (CS), carrageenan (CARR), and polyvinyl alcohol (PVA) is expected to improve their adsorption–photocatalytic performance for the degradation of crystal violet dye. This study aimed to synthesize N-TiO_2 and N-TiO_2-immobilized PVA-blended carrageenan-modified chitosan membranes and to evaluate their effectiveness in degrading CV dye. The study involved the synthesis of nitrogen-doped titanium dioxide (N-TiO_2) via the sol–gel method, followed by characterization using FTIR, XRD, and UV–DRS. Chitosan (CS) and modified chitosan membranes were synthesized, including chitosan/carrageenan (CS/CARR), chitosan/carrageenan/N-TiO_2 (CS/CARR/N-TiO_2), chitosan/carrageenan/PVA (CS/CARR/PVA), and chitosan/carrageenan/PVA/N-TiO_2 membranes with N-TiO_2 mass variations of 0.1 g (CS/CARR/PVA/N-TiO_2 1), 0.2 g (CS/CARR/PVA/N-TiO_2 2), and 0.3 g (CS/CARR/PVA/N-TiO_2 3). The membranes were characterized through weight and thickness measurements, swelling degree, water uptake, porosity, contact angle, FTIR, and SEM–EDX analyses. Pure chitosan and modified chitosan membranes were subsequently applied in adsorption–photocatalytic processes for the degradation of CV solutions. The results demonstrated that N-TiO_2 was successfully synthesized as a white powder with a yield of 83.59%. FTIR characterization revealed characteristic Ti–N and Ti–O–Ti absorption bands, indicating the successful incorporation of nitrogen into the TiO_2 structure. Nitrogen doping reduced the band gap energy to 3.09 eV. XRD analysis confirmed that N-TiO_2 exhibited the anatase crystalline phase. The CS/CARR/PVA/N-TiO_2 membranes were also successfully synthesized, as evidenced by the appearance of characteristic N–O and Ti–N absorption bands in the FTIR spectra, relatively uniform membrane morphology observed by SEM, and the presence of Ti, O, and N elements confirmed by EDX analysis. Based on the adsorption–photocatalytic tests using crystal violet solutions, the CS/CARR/PVA/N-TiO_2 2 membrane exhibited the optimal performance, achieving a degradation efficiency of 82.89%. Reusability tests showed a decrease in degradation efficiency with each successive cycle, indicating a decline in membrane activity after repeated use.

Keywords: *chitosan, membrane, N-Ti0$_2$, crystal violet, adsorption-photocatalysis*