ABSTRACT

Congo Red is an azo dye commonly found in textile industrial wastewater. It is toxic and difficult to degrade. One effective method for treating this pollutant is photocatalysis using semiconductor materials. Zirconium dioxide (ZrO_2) has great potential as a photocatalyst due to its high chemical and thermal stability. Pure ZrO_2 generally has a wide band gap of approximately 4–5 eV, while the characteristics of ZrO_2-based materials extracted from zircon sand may differ due to the presence of various oxide impurities. Nevertheless, material modification is still required to enhance its photocatalytic activity. Cu doping can alter the electronic properties of the material, improve electron–hole pair separation, and broaden light absorption. Therefore, this study aimed to synthesize and characterize Cu-doped ZrO_2-based materials derived from zircon sand and to evaluate their adsorption and photocatalytic activities toward Congo Red dye.

The study investigated four samples: ZrO_2, ZrO_2–Cu 1.2%, ZrO_2–Cu 2.4%, and ZrO_2–Cu 3.6%. The synthesis process involved precursor preparation from zircon sand, gel formation, and calcination. The materials were characterized using X-ray Fluorescence (XRF) to determine elemental composition, Scanning Electron Microscopy–Energy Dispersive X-ray Spectroscopy (SEM-EDX) to analyze surface morphology and elemental composition, Ultraviolet–Visible Diffuse Reflectance Spectroscopy (UV-DRS) to determine optical properties and band gap energy, X-ray Diffraction (XRD) to identify crystal structure and phase, Thermogravimetric Analysis (TGA) to evaluate thermal stability and mass changes, and Surface Area Analysis (SAA) to determine surface area and pore characteristics. In addition, Ultraviolet–Visible Spectroscopy (UV–Vis) was used to determine the concentration of Congo Red. The photocatalytic degradation efficiency was evaluated using UV–Vis spectrophotometry through two experimental variables: irradiation time (0, 30, 60, 180, and 240 min) and initial Congo Red concentration (10, 20, 30, 40, and 50 ppm).

XRF analysis showed that the zircon sand-derived material contained SiO_2, MgO, Al_2O_3, Fe_2O_3, TiO_2, HfO_2, and CeO_2. SEM-EDX analysis revealed a non-uniform surface morphology. XRD results indicated that the material was amorphous. UV-DRS analysis showed that the band gap energy of the undoped zircon sand-derived ZrO_2 was 2.80 eV and decreased to 1.27 eV after Cu doping. TGA results indicated changes in thermal stability, while SAA analysis revealed mesoporous characteristics. The photocatalytic performance demonstrated that longer irradiation time increased the degradation efficiency of Congo Red, whereas increasing the dye concentration reduced the degradation efficiency. The ZrO_2–Cu 2.4% sample exhibited the highest photocatalytic activity, achieving a degradation efficiency of 98.75% for 10 ppm Congo Red after 3 h of irradiation. However, increasing the Cu dopant concentration to 3.6% resulted in a decrease in photocatalytic activity.

Keywords: ZrO_2; Cu doping; zircon sand; photocatalysis; Congo Red.