

ABSTRAK

Proses produksi tekstil menghasilkan banyak limbah salah satunya adalah limbah zat warna metilen biru, yang merupakan senyawa organik yang sukar terurai, dan toksik. Berbagai metode digunakan untuk mengolah limbah mengandung zat warna, adsorpsi adalah salah satu metode yang digunakan. Penelitian ini bertujuan untuk mengetahui karakteristik, kinetika, dan termodinamika adsorpsi metilen biru (MB) oleh $\text{Fe}_3\text{O}_4@\text{SiO}_2\text{-CS}$. Sintesis $\text{Fe}_3\text{O}_4@\text{SiO}_2\text{-CS}$ berhasil dilakukan dengan persen rendemen 33,11% dengan sampel berupa padatan yang berwarna hitam. Karakterisasi material dilakukan menggunakan FTIR, XRD, SEM-EDX, TEM, BET, dan VSM. Hasil FTIR menunjukkan adanya gugus $-\text{OH}$, $-\text{NH}$, Si-O-Si , dan Fe-O yang menandakan keberhasilan sintesis. Analisis XRD memperlihatkan puncak difraksi khas magnetit silika dengan struktur kubik, sedangkan SEM-EDX menunjukkan morfologi partikel tidak beraturan dengan distribusi unsur Fe, Si, O, dan C yang merata. Hasil TEM memperlihatkan partikel berbentuk bulat dengan struktur *core-shell* dan ukuran rata-rata sekitar 39 nm. Analisis BET menunjukkan penurunan luas permukaan spesifik setelah modifikasi kitosan, sedangkan VSM mengonfirmasi sifat superparamagnetik. Kinetika adsorpsi mengikuti PSO dengan nilai energi aktivasi 27,06 kJ/mol dengan isotherm Freundlich. Analisis termodinamika menunjukkan bahwa proses adsorpsi bersifat spontan dan endotermik, dengan peningkatan suhu menyebabkan kenaikan kapasitas adsorpsi. Nilai energi bebas Gibbs (ΔG°) bernilai negatif, sedangkan entalpi (ΔH°) dan entropi (ΔS°) bernilai positif, yang menandakan bahwa proses adsorpsi terjadi secara fisik. Uji *Reusability* dilakukan 4 kali pengulangan dengan rentang persen 92-60%.

Kata kunci: adsorpsi, $\text{Fe}_3\text{O}_4@\text{SiO}_2$, kitosan, metilen biru, termodinamika

ABSTRACT

The textile production process generates a lot of waste, one of which is methylene blue dye waste, which is an organic compound that is difficult to decompose and toxic. Various methods are used to treat dye-containing waste, and adsorption is one of the methods used. This study aims to determine the characteristics, kinetics, and thermodynamics of methylene blue (MB) adsorption by $\text{Fe}_3\text{O}_4@\text{SiO}_2\text{-CS}$. The synthesis of $\text{Fe}_3\text{O}_4@\text{SiO}_2\text{-CS}$ was successfully carried out with a yield of 33.11% with a black solid sample. Material characterization was performed using FTIR, XRD, SEM-EDX, TEM, BET, and VSM. The FTIR results showed the presence of $-\text{OH}$, $-\text{NH}$, Si-O-Si , and Fe-O groups, indicating successful synthesis. XRD analysis showed characteristic diffraction peaks of silica magnetite with a cubic structure, while SEM-EDX showed irregular particle morphology with an even distribution of Fe, Si, O, and C elements. TEM results showed spherical particles with a core-shell structure and an average size of approximately 39 nm. BET analysis showed a decrease in specific surface area after chitosan modification, while VSM confirmed superparamagnetic properties. Adsorption kinetics followed PSO with an activation energy value of 27,06 kJ/mol with Freundlich isotherm. Thermodynamic analysis showed that the adsorption process was spontaneous and endothermic, with an increase in temperature causing an increase in adsorption capacity. The Gibbs free energy (ΔG°) value was negative, while the enthalpy (ΔH°) and entropy (ΔS°) values were positive, indicating that the adsorption process occurred physically. The reusability test was performed 4 times with a range of 92-60%.

Keywords: adsorption, $\text{Fe}_3\text{O}_4@\text{SiO}_2$, chitosan, methylene blue, thermodynamics