

ABSTRAK

Pewarna *malachite green* banyak digunakan dalam industri tekstil dan memiliki sifat toksik, sehingga perlu dihilangkan dari limbah cair melalui proses adsorpsi yang efisien. Penelitian ini bertujuan untuk mengetahui karakteristik fisikokimia dari NMK-M serta parameter kinetika, termodinamika, dan kemampuan adsorpsi NMK-M terhadap MG. Adsorben NMK-M berhasil disintesis dengan menginteraksikan N-metil kitosan dengan $\text{Fe}_3\text{O}_4@\text{Na}_2\text{SiO}_3$ sehingga diperoleh produk berwarna kehitaman. Senyawa NMK-M hasil sintesis kemudian dikarakterisasi dan dilakukan uji adsorpsi terhadap *malachite green*. Analisis FTIR menunjukkan serapan gugus -NH pada 1630 cm^{-1} dan serapan Fe-O pada 567 cm^{-1} yang merupakan karakteristik NMK-M. Analisis XRD menunjukkan adsorben berbentuk spinel kubik. Analisis SEM-EDX menunjukkan NMK-M berbentuk tidak beraturan dan ukurannya bervariasi dengan komposisi Fe>O>C>N>Si>unsur lainnya. Analisis BET menunjukkan NMK-M memiliki struktur mesopori dengan ukuran pori rata-rata 5,68 nm. Analisis VSM menunjukkan NMK-M bersifat superparamagnetik dengan nilai M_s sebesar $\pm 3\text{ emu/g}$. Adsorpsi *malachite green* dengan NMK-M dilakukan pada pH 5 dan waktu optimum 30 menit dengan variasi suhu 20, 30, dan 40 °C. Hasilnya proses adsorpsi sesuai dengan model kinetika orde dua semu dengan nilai energi aktivasi sebesar 31,87 kJ/mol. Data isoterm adsorpsi paling sesuai dengan model Freundlich dengan nilai R^2 maksimal sebesar 0,9888 dibandingkan model Langmuir dengan nilai R^2 maksimal 0,9317 yang menunjukkan karakteristik adsorpsi multilayer pada permukaan heterogen. Berdasarkan pengujian parameter termodinamika adsorpsi terjadi secara spontan dan bersifat eksotermik dengan nilai ΔH° sebesar -4,3048 kJ/mol dan ΔS° sebesar -0,0073 kJ/mol. Nilai ΔG° diperoleh secara berturut-turut -2,1751; -2,1024; dan -2,0298 kJ/mol pada suhu 20, 30, dan 40 °C yang menunjukkan spontanitas berkurang seiring kenaikan suhu. Uji reusability dilakukan hingga lima siklus, dan hasilnya menunjukkan NMK-M masih mempertahankan efisiensi adsorpsi hingga 65% pada siklus ke-5.

Kata kunci: adsorpsi, kinetika, kitosan, *malachite green*, termodinamika

ABSTRACT

Malachite green dye is widely used in the textile industry and has toxic properties, so it needs to be removed from liquid waste through an efficient adsorption process. This study aims to determine the physicochemical characteristics of NMK-M, as well as the adsorption kinetics parameters, thermodynamics, and adsorption capacity of NMK-M toward MG. The NMK-M adsorbent was successfully synthesized by interacting N-methyl chitosan with $\text{Fe}_3\text{O}_4@\text{Na}_2\text{SiO}_3$, resulting in a black-colored product. The synthesized NMK-M compound was then characterized and tested for adsorption of malachite green. FTIR analysis showed absorption of the -NH group at 1630 cm^{-1} and Fe-O absorption at 567 cm^{-1} , which are characteristic of NMK-M. XRD analysis shows that the adsorbent is in the form of cubic spinel. SEM-EDX analysis showed that NMK-M has an irregular shape and varying sizes with a composition of Fe>O>C>N>Si>other elements. BET analysis showed that NMK-M has a mesoporous structure with an average pore size of 5.68 nm . VSM analysis showed that NMK-M is superparamagnetic with an M_s value of $\pm 3\text{ emu/g}$. Malachite green adsorption with NMK-M was conducted at pH 5 and an optimal time of 30 minutes with temperature variations of 20, 30, and $40\text{ }^\circ\text{C}$. The results showed that the adsorption process followed the pseudo-second-order kinetic model with an activation energy of 31.87 kJ/mol . The adsorption isotherm data best fit the Freundlich model with a maximum R^2 value of 0.9888 compared to the Langmuir model with a maximum R^2 value of 0.9317, indicating multilayer adsorption characteristics on a heterogeneous surface. Based on the thermodynamic parameter testing, adsorption occurs spontaneously and is exothermic with a ΔH° value of $-4,3048\text{ kJ/mol}$ and a ΔS° value of $-0,0073\text{ kJ/mol}$. The ΔG° values were obtained sequentially as $-2,1751$; $-2,1024$; and $-2,0298\text{ kJ/mol}$ at temperatures of 20, 30, and 40°C , indicating a decrease in spontaneity with increasing temperature. Reusability testing was conducted up to five cycles, and the results showed that NMK-M maintained adsorption efficiency up to 65% in the fifth cycle.

Keywords: adsorption, chitosan, kinetics, malachite green, thermodynamics