Sintesis Adsorben Magnetik Berbasis Abu Layang Batubara untuk Adsorpsi *Methylene Blue* dan Ion Pb(II)

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INTISARI

Pemanfaatan abu layang batubara sebagai bahan baku alternatif dalam rekayasa material adsorben semakin mendapat perhatian, terutama melalui berbagai upaya modifikasi struktur dan komposisinya. Penelitian ini mengkaji modifikasi abu layang batubara melalui aktivasi, pengkayaan SiO_2, magnetisasi dan imobilisasi ditizon serta karakterisasinya. Aktivasi dan pengkayaan SiO_2 menghasilkan adsorben non-magnetik (FAA_NaOH, FAA_HCl, FAA_HAc, SiO_2_HCl dan SiO_2_HAc). Magnetisasi kemudian dilakukan sehingga diperoleh adsorben magnetik (Fe_3O_4/FAA_NaOH, Fe_3O_4/FAA_HCl, Fe_3O_4/FAA_HAc, Fe_3O_4/SiO_2_HCl dan Fe_3O_4/SiO_2_HAc). Modifikasi lanjutan yaitu imobilisasi ditizon dilakukan pada adsorben magnetik sehingga dihasilkan adsorben magnetik terimobilisasi ditizon (Fe_3O_4/FAA_NaOH/Dtz dan Fe_3O_4/SiO_2_HAc/Dtz). Adsorben yang diperoleh dikarakterisasi menggunakan XRF, SEM-EDX, FTIR, XRD, TGA, dan BET. Adsorben magnetik digunakan untuk adsorpsi zat warna methylene blue (MB), dan adsorben magnetik terimobilisasi ditizon digunakan untuk adsorpsi Pb(II). Parameter adsorpsi yang dikaji meliputi pH, massa adsorben, waktu interaksi, konsentrasi awal dan suhu. Variasi suhu digunakan untuk menentukan parameter termodinamika ($\Delta G°$, $\Delta H°$, dan $\Delta S°$) serta energi aktivasi adsorpsi (Ea). Selain itu, desorpsi sekuensial dengan berbagai pelarut dilakukan untuk mengetahui jenis interaksi yang terjadi selama proses adsorpsi Pb(II).

Hasil karakterisasi menunjukkan keberhasilan modifikasi abu layang batubara melalui aktivasi, pengkayaan SiO_2, magnetisasi, dan imobilisasi ditizon. Adsorpsi zat warna MB menggunakan adsorben magnetik dan non-magnetik mencapai kondisi optimum pada pH 8 dengan dosis adsorben 1,5 mg/mL dan waktu kontak 75 menit. Sedangkan adsorpsi ion logam Pb(II) menggunakan adsorben magnetik terimobilisasi ditizon mencapai kondisi optimum pada pH 5 dengan dosis adsorben 2,0 mg/mL untuk Fe_3O_4/FAA_NaOH/Dtz dan 2,5 mg/mL untuk Fe_3O_4/SiO_2_HAc/Dtz, serta waktu kontak 90 menit. Adsorpsi MB dan Pb(II) mengikuti model kinetika orde dua semu dan isoterm Langmuir, dengan proses adsorpsi bersifat spontan dan endotermik. Berdasarkan kajian desorpsi sekuensial Pb(II), interaksi dominan pada adsorben magnetik adalah interaksi elektrostatik dan ikatan hidrogen, sedangkan pada adsorben magnetik terimobilisasi ditizon didominasi oleh ikatan hidrogen dan kompleksasi. Hasil penelitian ini diharapkan dapat mendukung pengembangan adsorben efektif untuk remediasi lingkungan dan rekayasa material.

Kata kunci: abu layang, adsorben magnetit, adsorpsi, *methylene blue*, Pb(II).

Synthesis of Magnetic Adsorbent from Coal Fly Ash for Adsorption of Methylene Blue and Pb(II) Ion

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ABSTRACT

The utilization of coal fly ash as an alternative raw material in adsorbent engineering has received increasing attention, particularly through modification of its structure and composition. This study investigated the modification of coal fly ash through activation, SiO_2 enrichment, magnetization, and dithizone immobilization, and characterized the resulting materials. Activation and SiO_2 enrichment produced non-magnetic adsorbents (FAA_NaOH, FAA_HCl, FAA_HAc, SiO_2_HCl and SiO_2_HAc). Subsequent magnetization resulted in magnetic adsorbents (Fe_3O_4/FAA_NaOH, Fe_3O_4/FAA_HCl, Fe_3O_4/FAA_HAc, Fe_3O_4/SiO_2_HCl and Fe_3O_4/SiO_2_HAc). Further modification by dithizone immobilization was carried out on the magnetic adsorbents, yielding dithizone-immobilized magnetic adsorbents (Fe_3O_4/FAA_NaOH/Dtz and Fe_3O_4/SiO_2_HAc/Dtz). The adsorbents were characterized using XRF, SEM-EDX, FTIR, XRD, TGA, and BET. Magnetic adsorbents were applied for the adsorption of methylene blue (MB), whereas dithizone-immobilized adsorbents were used for Pb(II). The adsorption parameters investigated included pH, adsorbent dosage, contact time, initial concentration, and temperature. Temperature variation was employed to determine thermodynamic parameters ($\Delta G°$, $\Delta H°$, and $\Delta S°$) as well as activation energy (Ea). Additionally, sequential desorption using various solvents was conducted to identify the types of interactions during Pb(II) adsorption.

The characterization confirmed successful modification of coal fly ash through activation, SiO_2 enrichment, magnetization, and dithizone immobilization. The adsorption of MB using both magnetic and non-magnetic adsorbents reached its optimum conditions at a pH of 8, with a dosage of 1.5 mg/mL and a contact time of 75 minutes. Meanwhile, adsorption of Pb(II) using dithizone-immobilized magnetic adsorbents reached optimum conditions at pH 5 with an adsorbent dosage of 2.0 mg/mL for Fe_3O_4/FAA_NaOH/Dtz and 2.5 mg/mL for Fe_3O_4/SiO_2_HAc/Dtz, and a contact time of 90 minutes. The adsorption of both MB and Pb(II) followed the pseudo-second-order kinetic model and the Langmuir isotherm, indicating a spontaneous and endothermic process. Based on the sequential desorption of Pb(II), the dominant interactions in magnetic adsorbents were electrostatic and hydrogen bonding, whereas in dithizone-immobilized adsorbents, they were hydrogen bonding and complexation. These findings were expected to support the development of effective adsorbents for environmental remediation and material engineering.

Keywords: fly ash, magnetite adsorbent, adsorption, methylene blue, Pb(II).