Fungsionalisasi Material Magnetik Alam Terlapis Silika dengan Organosilan untuk Adsorpsi Kloramfenikol dan Siprofloksasin

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INTISARI

Dua senyawa antiobiotik, yaitu kloramfenikol (CAP) dan siprofloksasin (CIP), banyak digunakan dalam akuakultur, namun penggunaan yang berlebihan menimbulkan resistensi bakteri dan residu baik pada ikan maupun lingkungan. Upaya penghilangan antibiotik tersebut dengan adsorben magnetik yang efektif, mudah dipisahkan dan dapat digunakan kembali perlu dilakukan. Untuk itu, penelitian ini bertujuan mensintesis material magnetik terlapis silika terfungsionalisasi gugus hidrofobik organosilan untuk mengadsorpsi CAP dan CIP.

Tahapan penelitian yang dilakukan meliputi isolasi material magnetik alam (MMA), ekstraksi silika (SiO_2) dari pasir, dan fungsionalisasi MMA terlapis SiO_2 dengan gugus hidrofobik organosilan (MMA@SiO_2/organosilan). Perbandingan jumlah mol organosilan terhadap berat 1 g MMA@SiO_2 divariasi, sedangkan organosilan yang dikaji meliputi metiltrimetoksisilan (MTMS, C1), oktiltrimetoksisilan (OTMS, C8), heksadesiltrimetoksisilan (HDTMS, C16), dan trimetoksi[3-(fenilamino)propil]silan (TMPS, FA). Materials yang dihasilkan dikarakterisasi dengan FTIR, XRF, XRD, SEM-EDX, VSM, BET. Adsorpsi CAP dan CIP dilakukan dalam sistem *batch* dengan kondisi (pH, waktu dan konsentrasi) yang divariasi. Kandungan CAP dan CIP dalam larutan sebelum dan setelah adsorpsi dianalisis dengan spektroskopi UV/Vis. Karakteristik adsorpsi CAP dan CIP meliputi kinetika, isoterm dan termodinamika adsorpsi dievaluasi.

Hasil penelitian menunjukkan bahwa karakterisasi dengan FTIR, XRF, XRD, SEM-EDX *mapping*, VSM, dan BET pada keempat jenis adsorben MMA@SiO_2/C1, MMA@SiO_2/C8, MMA@SiO_2/C16, dan MMA@SiO_2/FA mengkonfirmasi keberhasilan sintesis. Semakin panjang rantai atom karbon dan semakin besar jumlah mmol organosilan yang ditambahkan, semakin tinggi sifat hidrofobisitas material hasil sintesis. Kapasitas adsorpsi CAP dan CIP menurun seiring dengan bertambahnya panjang rantai atom karbon. Urutan kapasitas adsorpsi CAP adalah MMA@SiO_2/C1(3) (58,46 mg/g) > MMA@SiO_2/C8(3) (56,44 mg/g) > MMA@SiO_2/C16(3) (39,13 mg/g), sedangkan kapasitas adsorpsi CIP adalah MMA@SiO_2/C1(3) (106,81 mg/g) > MMA@SiO_2/C8(3) (87,93 mg/g) > MMA@SiO_2/C16(3) (59,54 mg/g). Kapasitas adsorpsi CAP dan CIP pada MMA@SiO_2/FA(3) masing-masing sebesar 87,31 mg/g dan 161,17 mg/g, lebih tinggi dibandingkan dengan modifikasi gugus alifatik. Material magnetik alam yang difungsionalisasi dengan organosilan menunjukkan potensinya untuk adsorpsi dan desorpsi antibiotik.

Kata kunci: Material magnetik alam, silika, organosilan, kloramfenikol, siproflokasin

Functionalization of Natural Magnetic Materials Coated With Organosilan Silica for the Adsorption of Chloramphenicol and Ciprofloxacin

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ABSTRACT

Two antibiotics compounds, namely chloramphenicol (CAP) and ciprofloxacin (CIP), are widely used in aquaculture; however, their excessive use leads to bacterial resistance and the accumulation of residues in both fish and the surrounding environment. Therefore, efforts to remove these antibiotics using an effective magnetic adsorbent that is easily separable and reusable are necessary. This study aimed to synthesize silica-coated magnetic materials functionalized with hydrophobic organosilane groups for the adsorption of CAP and CIP.

The research stages included the isolation of natural magnetic material (MMA), silica (SiO_2) extraction from sand, and functionalization of silica-coated MMA with hydrophobic organosilanes. The molar ratios of organosilanes per 1 g of MMA@SiO_2 were varied, and the organosilanes examined were methyltrimethoxysilane (MTMS, C1), octyltrimethoxysilane (OTMS, C8), hexadecyltrimethoxysilane (HDTMS, C16), and trimethoxy[3-(phenylamino)propyl]silane (TMPS, FA). The resulting materials were characterized using FTIR, XRF, XRD, SEM–EDX, VSM, and BET analyses. Adsorption of CAP and CIP was carried out in a batch system under varied pH, contact time, and initial concentration. The concentrations of CAP and CIP before and after adsorption were determined using UV–Vis spectroscopy, and adsorption characteristics including kinetics, isotherms, and thermodynamics—were evaluated.

The results showed that FTIR, XRF, XRD, SEM–EDX mapping, VSM, and BET confirmed the successful synthesis of the four adsorbents MMA@SiO_2/C1, MMA@SiO_2/C8, MMA@SiO_2/C16, and MMA@SiO_2/FA. Increasing the alkyl-chain length and organosilane loading enhanced the hydrophobicity of the synthesized materials. The adsorption capacities of CAP and CIP decreased with increasing alkyl-chain length. For CAP, the adsorption capacities followed the order MMA@SiO_2/C1(3) (58.46 mg/g) > MMA@SiO_2/C8(3) (56.44 mg/g) > MMA@SiO_2/C16(3) (39.13 mg/g), while for CIP they followed MMA@SiO_2/C1(3) (106.81 mg/g) > MMA@SiO_2/C8(3) (87.93 mg/g) > MMA@SiO_2/C16(3) (59.54 mg/g). The adsorption capacities of CAP and CIP on MMA@SiO_2/FA(3) are 87.31 mg/g and 161.17 mg/g, respectively, which are higher than those obtained with aliphatic group modification. Overall, natural magnetic materials functionalized with organosilanes demonstrate promising potential for the adsorption and desorption of antibiotic contaminants.

Keywords: Natural magnetic materials, silica, organosilanes, chloramphenicol, ciprofloxacin