DISERTASI

MODIFIKASI HIDROKSI LAPIS GANDA MENGGUNAKAN MAGNETIT BAHAN ALAM SEBAGAI ADSORBEN ZAT WARNA KATIONIK DAN ANIONIK

Diajukan untuk memenuhi salah satu syarat
memperoleh gelar Doktor Pada Program Studi
Doktor Ilmu MIPA Fakultas MIPA
Universitas Sriwijaya

NUR AHMAD

08013682227002

PROGRAM STUDI DOKTOR ILMU MIPA

FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM

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HALAMAN PENGESAHAN

MODIFIKASI HIDROKSI LAPIS GANDA MENGGUNAKAN MAGNETIT BAHAN ALAM SEBAGAI ADSORBEN ZAT WARNA KATIONIK DAN ANIONIK

DISERTASI

Diajukan untuk memenuhi salah satu syarat memperoleh Gelar Doktor Ilmu Matematika dan Ilmu Pengetahuan Alam pada Fakultas Matematika dan Ilmu Pengetahuan Alam Universitas Sriwijaya

Oleh

Nur Ahmad

NIM. 08013682227002

Promotor

Prof. Aldes Lesbani, S.Si., M.Si., Ph.D
NIP. 197408121998021001

Co-Promotor I

Dr. Fitri Suryani Arsyad, S.Si., M.Si
NIP. 197010191995122001

Co-Promotor II

Dr. Idha Royani, S.Si., M.Si
NIP. 197105151999032001

Mengetahui,
Dekan Fakultas Matematika dan Ilmu Pengetahuan Alam

Prof. Hermansyah, S.Si., M.Si., Ph.D
NIP. 197111191997021001

HALAMAN PERSETUJUAN

Karya tulis ilmiah berupa disertasi ini dengan judul 'Modifikasi Hidroksi Lapis Ganda Menggunakan Magnetit Bahan Alam sebagai Adsorben Zat Warna Kationik dan Anionik' telah dipertahankan dihadapan Tim Penguji Karya Tulis Ilmiah Fakultas Matematika dan Ilmu Pengetahuan Alam Program Studi Doktor Ilmu MIPA Universitas Sriwijaya pada Tanggal 22 Januari 2025.

Palembang, Januari 2025
Tim Penguji Karya Tulis Ilmiah berupa Disertasi

Ketua:

1. Prof. Hermansyah, S.Si., M.Si., Ph.D. ( )
   NIP. 197111191997021001

Sekretaris:

2. Prof. Dr. Dedi Rohendi, M.T ( )
   NIP. 196704191993031001

Tim Promotor:

1. Prof. Aldes Lesbani, S.Si., M.Si., Ph.D ( )
   NIP. 197408121998021001
2. Dr. Fitri Suryani Arsyad, S.Si., M.Si ( )
   NIP. 197010191995122001
3. Dr. Idha Royani, S.Si., M.Si ( )
   NIP. 197105151999032001

Tim Penguji:

1. Prof. Drs. Sri Juari Santosa, M.Eng., Ph.D ( )
   NIP. 196501081989031001
2. Prof. Dr.rer.nat. Risfidian Mohadi, S.Si., M.Si ( )
   NIP. 197711272005011003
3. Dr. Assaidah, S.Si., M.Si ( )
   NIP. 198205222006042001

Mengetahui:
Dekan Fakultas Matematika
dan Ilmu Pengetahuan Alam,

Prof. Hermansyah, S.Si., M.Si., Ph.D.
NIP. 197111191997021001

Koordinator Program Studi
Doktor Ilmu MIPA FMIPA,

Prof. Dr. Dedi Rohendi, M.T
NIP. 196704191993031001

HALAMAN PERNYATAAN INTEGRITAS

Yang bertanda tangan di bawah ini:

Nama	:	Nur Ahmad
NIM	:	08013682227002
Judul	:	Modifikasi Hidroksi Lapis Ganda Menggunakan Magnetit Bahan Alam sebagai Adsorben Zat Warna Kationik dan Anionik

menyatakan bahwa disertasi saya merupakan karya sendiri didampingi oleh Tim Promotor dan bukan hasil plagiasi. Apabila ditemukan untur plagiasi dalam disertasi ini, maka saya bersedia menerima sanksi akademik dari Universitas Sriwijaya sesuai ketentuan yang berlaku.

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Palembang, Januari 2025

Yang membuat pernyataan,

Nur Ahmad

NIM. 08013682227002

HALAMAN PERNYATAAN PERSETUJUAN PUBLIKASI

Yang bertanda tangan di bawah ini:

Nama	:	Nur Ahmad
NIM	:	08013682227002
Judul	:	Modifikasi Hidroksi Lapis Ganda Menggunakan Magnetit Bahan Alam sebagai Adsorben Zat Warna Kationik dan Anionik

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Demikianlah, pernyataan ini saya buat dalam keadaan sadar dan tanpa ada paksaan dari siapapun

Palembang, Januari 2025

Yang membuat pernyataan,

Nur Ahmad

NIM. 08013682227002

RINGKASAN

MODIFIKASI HIDROKSI LAPIS GANDA MENGGUNAKAN MAGNETIT BAHAN ALAM SEBAGAI ADSORBEN ZAT WARNA KATIONIK DAN ANIONIK

Nur Ahmad; dibimbing oleh Promotor Prof. Aldes Lesbani, S.Si., M.Si, Ph.D; Co-Promotor 1 Dr. Fitri Suryani Arsyad, S.Si., M.Si; Co-Promotor 2 Dr. Idha Royani, S.Si., M.Si

Doktor Ilmu MIPA, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Sriwijaya

Kegiatan ekonomi dan industri modern beberapa tahun terakhir yang menghasilkan limbah zat warna diakui sebagai sumber utama pencemaran air yang telah menyebabkan kerusakan lingkungan. Adsorpsi adalah salah satu metode yang tepat menghilangkan zat warna dari limbah karena prosesnya yang sederhana, efektif, efisien, dan biaya murah. Metode adsorpsi membutuhkan adsorben yang sesuai. Adsorben yang efisien dapat disintesis dengan mudah, biaya rendah, dan efisiensi yang tinggi. Penelitian ini menggunakan material hidroksi lapis ganda/layered double hydroxide (LDH) yang dikompositkan dengan magnetit dan material karbon asam humat, *charcoal activated*, dan lignin dipreparasi menggunakan metode kopresipisasi dan metode hidrotermal. Hasil karakterisasi XRD, FTIR, BET, SEM, dan VSM menunjukkan bahwa modifikasi material telah berhasil dilakukan. LDH dan kompositnya digunakan sebagai adsorben zat warna kationik dan anionik (*malachite green, methylene blue, congo red, direct yellow, dan procion red*). LDH dan kompositnya telah berhasil untuk mengadsorpsi zat warna kationik dan anionik. Adsorben yang menunjukkan performa terbaik dan konsisten untuk zat warna kationik dan anionik adalah MgAl-MCA. Hal ini terjadi karena adsorben memiliki lebih banyak gugus fungsi dan pori dari *charcoal activated*. Regenerasi atau penggunaan berulang material hasil modifikasi menunjukkan performa yang baik untuk regenerasi NiAl-MAH dan ZnAl-MAH masing-masing memiliki efisiensi 95,92% dan 97,29% setelah 5 kali siklus regenerasi yang menunjukkan stabilitas yang baik karena telah dikompositkan dengan asam humat untuk memperkuat struktur material. Selain itu, kualitas magnetik material membuat proses adsorpsi menjadi lebih efisien dan mengurangi risiko permukaan material menjadi rusak.

Kata Kunci: LDH, magnetit, asam humat, *charcoal activated*, lignin, zat warna

SUMMARY

MODIFICATION OF LAYERED DOUBLE HYDROXIDE USING MAGNETITE CARBON MATERIAL AS ADSORBENT OF CATIONIC AND ANIONIC DYES

Nur Ahmad; Supervised by Promotor Prof. Aldes Lesbani, S.Si., M.Si, Ph.D; Co-Promotor 1 Dr. Fitri Suryani Arsyad, S.Si., M.Si; Co-Promotor 2 Dr. Idha Royani, S.Si., M.Si

Doctoral Program of Natural Science, Faculty of Mathematics and Natural Science, Sriwijaya University

In recent years, modern economic and industrial activities that generate dye effluents are recognized as a major source of water pollution that has caused environmental damage. Adsorption is one of the appropriate methods of removing dyestuff from effluents due to its simple, effective, efficient, and low-cost process. Adsorption methods require suitable adsorbents. Efficient adsorbents can be synthesized easily, with low-cost, and high efficiency. This study used layered double hydroxide (LDH) material composited with magnetite and carbon materials of humic acid, activated charcoal, and lignin prepared using coprecipitation and hydrothermal methods. The results of XRD, FTIR, BET, SEM, and VSM characterization showed successful material modification. LDH and its composites were used as adsorbents for cationic and anionic dyes (malachite green, methylene blue, congo red, direct yellow, and procion red). The adsorbent that showed the best and consistent performance for both cationic and anionic dyes was MgAl-MCA. This is because the adsorbent has more functional groups and pores than charcoal activated. Regeneration materials showed good performance for the regeneration of NiAl-MAH and ZnAl-MAH with 95.92% and 97.29% efficiency respectively after 5 regeneration cycles which showed good stability as they have been composited with humic acid to strengthen the material structure. In addition, the magnetic quality of the material makes the adsorption process more efficient and reduces the risk of the material surface being damaged.

Keywords: LDH, magnetite, humic acid, charcoal activated, lignin, dyes

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BAB I
PENDAHULUAN

1.1 Latar Belakang

Kegiatan ekonomi dan industri modern beberapa tahun terakhir diakui sebagai sumber utama pencemaran air yang telah menyebabkan kerusakan lingkungan. Industri tekstil, karet, plastik, kertas, kayu, obat-obatan, makanan, dan kosmetik menggunakan zat warna untuk mewarnai berbagai produk tersebut dan mengkonsumsi banyak air (X. Li et al., 2022; You et al., 2022). Akibatnya, kegiatan tersebut menghasilkan sejumlah besar air limbah zat warna. Ada sekitar 100.000 zat warna komersial yang berbeda, dan lebih dari 700.000 ton diproduksi setiap tahun di seluruh dunia (González-López et al., 2021; Yi Liu et al., 2022). Diperkirakan sekitar 10-15% dari pewarna ini dilepaskan ke lingkungan dalam bentuk limbah berwarna (Heo et al., 2022). Oleh karena itu, zat warna dapat dianggap sebagai salah satu polutan terpenting yang mengancam kehidupan manusia dan lingkungan.

Zat warna yang digunakan dalam industri dapat dikategorikan dalam banyak cara, misalnya dari warna, struktur kimia, dan aplikasinya (Shi et al., 2022). Dalam penelitian ini, zat warna diklasifikasikan menjadi tiga jenis, yaitu zat warna kationik, anionik, dan netral, berdasarkan muatannya ketika dilarutkan. Secara harfiah, zat warna kationik dan anionik masing-masing bermuatan positif dan negatif, sedangkan zat warna netral ada sebagai molekul netral (Mittal, 2021). Zat warna menyebabkan masalah lingkungan karena kontribusinya terhadap beban organik yang tinggi, toksisitas dan kontaminasi oleh warna, mengurangi penetrasi cahaya dan fotosintesis yang mempengaruhi kehidupan akuatik (Kamath Miyar et al., 2021). Selain itu, sebagian besar pewarna bersifat toksik atau mutagenik dan karsinogenik yang dapat menyebabkan gangguan pada sistem imun dan reproduksi bahkan menyebabkan gagal ginjal (Banerjee et al., 2016; Sun et al., 2022). Oleh karena itu, menghilangkan zat warna dari limbah sangat penting dilakukan.

Ada berbagai teknologi menghilangkan zat warna dari limbah, seperti filtrasi membran, pertukaran ion, presipitasi kimia, elektrokoagulasi, dan adsorpsi (Habibi et al., 2022; Lv et al., 2022; Signorelli et al., 2021; Vedula and Yadav, 2022).

Namun, biaya tinggi dan kurang efektif dari beberapa teknologi tersebut adalah batasan utama untuk aplikasi. Adsorpsi cocok dilakukan karena prosesnya yang sederhana, efektif, efisien, dan biaya murah. Metode adsorpsi membutuhkan adsorben yang sesuai (H. Li et al., 2022). Adsorben yang baik dapat disintesis dengan mudah, biaya rendah, dan efisiensi yang tinggi. Beberapa adsorben yang telah dilaporkan untuk menghilangkan zat warna dalam air limbah, diantaranya kaolin, oksida logam, ekstrak tumbuhan, bentonit, dan layered double hydroxide (LDH) (Angerasa et al., 2021; Arab et al., 2022; Esmaili et al., 2022; Ghibate et al., 2021; Wang et al., 2021).

Salah satu adsorben yang berpotensi digunakan adalah layered double hydroxide. Layered double hydroxide (LDH), atau hidroksi lapis ganda, dapat disintesis dengan mudah, biaya rendah dan tingkat efisiensinya yang tinggi (Palapa et al., 2021b). Struktur LDH terdiri dari lapisan hidroksida bermuatan positif yang dihasilkan dari campuran atom divalent (M^{2+}) dan atom trivalent (M^{3+}) (Chouaybi et al., 2022; Van Everbroeck et al., 2022). LDH sangat menarik karena luas permukaannya yang besar, distribusi homogen dari berbagai komponen dasar (Karim et al., 2022). Keunikan lain dari hidroksi lapis ganda yaitu mampu merekonstruksi struktur aslinya setelah kontak dengan air dan sumber anion yang dikenal dengan ‘memory effect’ (Fang et al., 2021). Karena sifatnya yang unik, LDH banyak digunakan sebagai adsorben yang menjanjikan dalam remediasi air.

LDH murni memiliki beberapa keterbatasan, seperti regenerasi yang sulit dan kurangnya gugus fungsional (Normah et al., 2021). Untuk mengatasi keterbatasan ini, LDH telah dimodifikasi dengan berbagai senyawa seperti bahan karbon, oksida logam dan polimer untuk meningkatkan kemampuan adsorpsinya (Khorshidi et al., 2022). Beberapa penelitian telah dilakukan untuk menyelidiki kemampuan LDH dan kompositnya untuk adsorpsi limbah seperti penelitian yang dilakukan oleh Luo et al. (2023) yang memodifikasi NiFe-LDH dengan biochar yang meningkatkan kapasitas adsorpsi *reactive red 120*. Brahma dan Saikia (2022) memodifikasi MgAl-LDH dengan ZnO_2 untuk meningkatkan adsorpsi *congo red*. Sementara itu, Lesbani et al. (2021) memodifikasi NiAl-LDH dengan biochar berhasil meningkatkan kapasitas adsorpsi *methylene blue* dan memiliki kemampuan regenerasi yang lebih baik dari LDH murni. Pengembangan material LDH yang dimodifikasi dengan berbagai senyawa untuk adsorpsi zat warna masih terus dilakukan. Komposit baru seperti asam humat, *charcoal activated*, dan lignin dapat digunakan untuk memodifikasi material LDH.

Asam humat adalah polimer organik besar dengan struktur acak dengan gugus keasaman total, gugus fungsi karboksilat, dan gugus fungsi fenolik (Niu et al., 2021; Shao et al., 2022). Asam humat tersebar luas, tidak hanya di tanah tetapi juga ditemukan di air (Pramono et al., 2022; Tadini et al., 2022). Selain itu, asam humat telah dilaporkan sebagai penukar ion, respon antibodi, pengurangan kapasitas, dan adsorben (Akaichi et al., 2022; Sharafabad et al., 2022). Asam humat telah digunakan sebagai adsorben logam berat (Pb(II) dan Cd(II)), amonia, nitrogen organik, zat warna kristal violet, dan zat warna *malachite green* (el Gaayda et al., 2022; C. Li et al., 2022; Lu et al., 2019; Wan et al., 2022; Y. Zhang et al., 2020). Asam humat memiliki luas permukaan yang besar dengan aktivitas permukaan yang tinggi, sehingga dapat digunakan sebagai adsorben (Shao et al., 2022).

Charcoal activated telah terbukti menjadi bahan yang efisien dan mudah diproduksi (Shen et al., 2018). Dengan membakar biomassa, seperti bambu, biji kopi, tempurung kelapa, dan tebu, hingga suhu sekitar 700℃ tanpa oksigen (pirolisis), *charcoal activated* dapat dibuat (Thotagamuge et al., 2021). *Charcoal activated* adalah adsorben yang paling mudah beradaptasi karena berbagai sifat fisik dan kimianya, yang mencakup luas permukaan yang besar dengan struktur berpori, kapasitas adsorpsi yang luar biasa, dan komposisi kimia permukaan yang dapat dimodifikasi (Ekka et al., 2022; Nayak et al., 2020). Oleh karena itu, LDH dimodifikasi dengan *charcoal activated*.

Lignin adalah polimer aromatik alami yang menyumbang 30% dari total karbon di bumi (Heo et al., 2022). Lignin memiliki berbagai gugus aktif, seperti karboksil, fenolik, hidroksil, dan metoksi (Jiang et al., 2022). Oleh karena itu, lignin merupakan bahan baku yang ideal untuk membuat adsorben yang murah dan ramah lingkungan (Dai et al., 2022). Komposit LDH-Lignin merupakan salah satu adsorben terbaik untuk adsorpsi zat warna. LDH-Lignin telah digunakan untuk komposit karet (Xiao et al., 2013), busa poliuretan fleksibel (Gómez-Fernández et al., 2018), dan adsorpsi logam berat (H. Chen et al., 2022).

Keterbatasan lain dari LDH murni maupun LDH yang telah dimodifikasi dengan senyawa karbon, oksida logam, dan polimer yaitu pemisahannya dari media berair membutuhkan waktu yang lama. Untuk mengatasi keterbatasan ini, LDH dimodifikasi dengan material magnetit untuk membantu memisahkan LDH dari zat warna setelah proses adsorpsi (Esmaeilian and O'Shea, 2022). LDH yang memiliki sifat magnetit dapat dipisahkan dengan mudah menggunakan magnet eksternal yang memungkinkan untuk penggunaan berulang dari material tersebut (Taher et al., 2021a).

Pada penelitian ini, dipreparasi komposit berbasis LDH dengan metode kopresipitasi. LDH (MgAl, NiAl dan ZnAl) dimodifikasi dengan material berbasis karbon untuk membentuk komposit LDH-x (x = asam humat, *charcoal activated*, lignin). Setelah itu, komposit LDH ditambahkan material magnetit dengan metode hidrotermal. Keberhasilan proses preparasi komposit berbasis LDH diketahui melalui karakterisasi menggunakan analisis XRD untuk mengetahui struktur dan kristalinitas, identifikasi kemagnetan menggunakan VSM, identifikasi gugus fungsional dengan spektrofotometer FTIR, analisis luas permukaan dengan metoda BET, dan analisis morfologi permukaan dengan analisis SEM. Selanjutnya komposit hasil preparasi digunakan sebagai adsorben limbah zat warna kationik dan anionik (*malachite green, methylene blue, congo red, direct yellow, dan procion red*). Faktor-faktor yang menentukan proses adsorpsi dipelajari melalui pH, pHpzc, variasi waktu, variasi konsentrasi dan temperatur, regenerasi material. Kinetika, isoterm, dan termodinamika adsorpsi juga dipelajari untuk mengetahui kecenderungan proses adsorpsi yang dilakukan.

1.2 Rumusan Masalah

Layered double hydroxide (LDH) merupakan mineral lempung terdiri dari laminasi bermuatan positif dan anion interlayer bermuatan negatif, yang dihubungkan oleh ikatan non-kovalen. Pengembangan material LDH untuk adsorpsi zat warna yang mencemari lingkungan perlu dilakukan. LDH murni memiliki beberapa keterbatasan, seperti regenerasi yang sulit dan dan kurangnya gugus fungsional. Untuk mengatasi keterbatasan ini, LDH dimodifikasi dengan asam humat, *charcoal activated*, dan lignin untuk meningkatkan surface area dari material sehingga meningkatkan kapasitas adsorpsi zat warna. Preparasi komposit

LDH melalui metode kopresipitasi. Selain itu, pemisahan LDH dari larutan berair diatasi dengan menambahkan material magnetit ke LDH, sehingga pemisahannya lebih mudah dan meningkatkan penggunaan material secara berulang.

1.3 Hipotesis

Difraksi sinar-X (XRD) digunakan untuk mengkarakterisasi ukuran kristal, struktur kristal, dan komposisi LDH dan kompositnya (Ahmed and Mohamed, 2023). Analisis ini didasarkan pada perekaman intensitas hamburan sinar-X sebagai fungsi sudut. Pola XRD LDH menunjukkan puncak tajam 2θ pada 9-11° yang sesuai dengan jarak antara bidang basal yang berurutan; namun, puncak lain yang relatif lemah 2θ pada 59-61° (Ahmad et al., 2022a). MgAl yang disiapkan melalui metode kopresipitasi menunjukkan pola XRD yang mengandung puncak (003), (006), (015), (018), dan (110). Puncak (003) dan (110) masing-masing terletak di 11,39° dan 61,42° (Kim et al., 2022). Hasil XRD dari ZnAl LDH muncul pada puncak (003), (006), (012) dan (110), menunjukkan kristalinitas tinggi dari LDH. Puncak (003) dan (110) masing-masing terletak di 9,995° dan 60,552° (Rashed et al., 2022). Selanjutnya, pola XRD NiAl 11,50°, 23,38°, 35,18°, 39,61°, 47,01°, 61,36◦, dan 62,67°, sesuai dengan (003), (006), (012), (015), (018), (110), (113) yang merupakan karakteristik untuk NiAl-LDH yang disiapkan. Puncak khas untuk material berbasis karbon (asam humat, *charcoal activated*, lignin) 2θ berada pada 20-25° (dos Santos et al., 2021). Penggabungan magnetit memberikan puncak baru pada 2θ dari 30,0° (220), 35,5° (311), 43,0° (400), 53,5° (422), 56,8° (511), 62,5° (440), yang menunjukkan tingginya kristalinitas komposit baru yang menggabungkan magnetit (Stoicescu et al., 2022).

Hipotesis 1. *Material LDH (MgAl, NiAl, ZnAl) yang disintesis menunjukkan adanya sudut difraksi 2θ pada 9-11° dan 59-61°. Komposit magnetit-LDH (MgAl, NiAl, ZnAl)-x (x = asam humat, charcoal activated, lignin) memiliki puncak khas 2θ dari prekursornya.*

Spektrofotometer FTIR adalah analisis yang efisien untuk menguji gugus fungsi LDH dan kompositnya. Analisis ini dapat digunakan untuk mengkonfirmasi keberadaan gugus fungsi dari LDH berupa anion terinterkalasi pada interlayer, dan jenis ikatan yang terbentuk oleh anion. Pertama, puncak luas sekitar 3100-3600 cm^{-1} dan 1600-1800 cm^{-1} diberikan untuk berbagai jenis vibrasi dari O-H, seperti molekul air interlayer, gugus hidroksil, dan air yang diserap (Gautam et al., 2022). Kedua, puncak pada 1350–1380 cm^{-1} anion interlayer CO_3^{2-} atau NO_3^- (Ahmad et al., 2022b). ketiga, puncak yang terletak sekitar 400-800 cm^{-1} ditetapkan vibrasi ikatan logam M-O maupun M-O-M (Machrouhi et al., 2022; Sriram et al., 2020). Berbagai penelitian menggunakan analisis FTIR untuk mengkonfirmasi keberhasilan preparasi komposit LDHs. Modifikasi MgAl dengan CA menghasilkan vibrasi baru pada puncak 1097 cm^{-1} yang merupakan ikatan C-O dari karbon aktif (Khalil et al., 2022). Sementara itu, preparasi NiAl-Kitosan muncul puncak baru pada 1150 cm^{-1} dan 1050 cm^{-1} untuk C-O dan C-O-C dari kitosan (Khan et al., 2021).

Hipotesis 2. *Material modifikasi magnetit-LDH (MgAl, NiAl, ZnAl)-x (x = asam humat, charcoal activated, lignin) memiliki spektra FTIR khas dari prekursornya. Spektra FTIR khas dari prekursor komposit adalah puncak 3100-3600 cm^{-1}, 1600-1800 cm^{-1}, 1350–1380 cm^{-1}, 1150–1050 cm^{-1}, dan 400-800 cm^{-1}.*

Analisis Brunauer–Emmett–Teller (BET) telah diterapkan pada adsorben berbasis LDH untuk memperkirakan distribusi ukuran pori, luas permukaan spesifik, dan volume pori. Luas permukaan CuAl mengalami peningkatan dari 46,279 m^2/g menjadi 200,90 m^2/g setelah dikompositkan dengan biochar (Wijaya et al., 2021). Dalam studi lain, ZnAl termodifikasi hydrochar memberikan luas permukaan 29,87 m^2/g, lebih besar dari prekursornya (Juleanti et al., 2022). Penelitian lebih lanjut menunjukkan bahwa nilai luas permukaan MgFe meningkat setelah dikompositkan dengan biochar dari 64,54 m^2/g menjadi 209,70 m^2/g (Ding et al., 2023).

Hipotesis 3. *Komposit magnetit-LDH (MgAl, NiAl, ZnAl)-x (x = asam humat, charcoal activated, lignin) memiliki luas permukaan yang lebih besar dibandingkan LDH.*

Upaya peningkatan luas permukaan LDH diharapkan dapat meningkatkan kapasitas adsorpsi terhadap zat warna kationik maupun anionik. Kemampuan LDH yang telah dimodifikasi mempunyai luas permukaan yang lebih besar dan gugus fungsional yang lebih banyak. Pada penelitian sebelumnya, ZnAl yang telah dikompositkan dengan hydrochar meningkatkan kapasitas adsorpsi fenol dari 48,077 mg/g menjadi 90,090 mg/g (Badaruddin et al., 2022). Modifikasi CaAl dengan biochar berhasil dilakukan dan meningkatkan kapasitas adsorpsi *malachite green* dari 51,020 mg/g menjadi 71,429 mg/g (Mohadi et al., 2021). Sementara itu, MgAl dan hasil modifikasinya MgAl/$Cu(NO_3)_2.6H_2O$ mempunyai kapasitas adsorpsi masing-masing 68,996 mg/g dan 104,167 mg/g pada pH basa (Badri et al., 2021). pH larutan secara langsung mempengaruhi muatan permukaan adsorben dan derajat ionisasi molekul adsorbat. Oleh karena itu, dalam proses adsorpsi yang melibatkan muatan permukaan adsorben, pH larutan akan sangat berpengaruh terhadap kinerja adsorpsi.

Hipotesis 4. *Komposit magnetit-LDH (MgAl, NiAl, ZnAl)-x (x = asam humat, charcoal activated, lignin) meningkatkan kapasitas adsorpsi zat warna kationik dan anionik (malachite green, methylene blue, congo red, direct yellow, dan procion red) dibanding menggunakan LDH murni.*

LDH memiliki beberapa keterbatasan, seperti regenerasi yang sulit, kurangnya gugus fungsional, dan pemisahannya dari media berair membutuhkan waktu yang lama. Untuk mengatasi keterbatasan ini, LDH telah dimodifikasi dengan berbagai senyawa seperti bahan karbon, oksida logam dan polimer untuk meningkatkan kemampuan adsorpsinya. Selain itu, LDH dimodifikasi dengan material magnetit membantu memisahkan LDH dari zat warna setelah proses adsorpsi. LDH yang memiliki sifat magnetit dapat dipisahkan dengan mudah menggunakan magnet eksternal yang memungkinkan untuk penggunaan berulang dari material tersebut. Lesbani et al. (2021) memodifikasi NiAl-LDH dengan biochar berhasil meningkatkan kapasitas adsorpsi *methylene blue* dan memiliki kemampuan regenerasi yang lebih baik dari LDH murni. Modifikasi LDH dengan kitosan masih dapat mengadsorpsi ion Cl 68% pada siklus kelima regenerasi (Wu et al., 2017). Sementara itu, magnetit membuat proses adsorpsi menjadi lebih efisien dan mengurangi resiko rusaknya permukaan material (Kalidason and Kuroiwa, 2022).

Hipotesis 5. *Material modifikasi magnetit-LDH (MgAl, NiAl, ZnAl)-x (x = asam humat, charcoal activated, lignin) memiliki kemampuan regenerasi adsorben yang lebih baik pada zat warna kationik dan anionik (malachite green, methylene blue, congo red, direct yellow, dan procion red) dibanding menggunakan LDH murni.*

1.4 Tujuan Penelitian

Tujuan penelitian yang ingin dicapai yakni:

1. Keberhasilan preparasi layered double hydroxide (LDH) menjadi magnetit-LDH-x (x = asam humat, *charcoal activated*, lignin) dan karakterisasinya menggunakan X-ray difraktometer (XRD), Spektrofotometer Fourier Transform Infra-Red (FTIR), Brunauer-Emmett-Teller (BET), Scanning Electron Microscopy (SEM), dan Vibrating Sample Magnetometer (VSM).
2. Penggunaan LDH dan hasil modifikasinya sebagai adsorben zat warna kationik dan anionik (*malachite green, methylene blue, congo red, direct yellow*, dan *procion red*) melalui penentuan parameter kinetika dan parameter termodinamika yang diamati pada kondisi pH pzc pada beberapa variasi waktu, temperatur dan konsentrasi adsorpsi.
3. Penggunaan berulang LDH hasil modifikasi pada proses adsorpsi.

1.5 Manfaat Penelitian

Manfaat penelitian ini adalah sebagai berikut :

1. Memberikan informasi tentang pemanfaatan asam humat, *charcoal activated*, dan lignin untuk memodifikasi LDH.
2. Memberikan informasi tentang modifikasi LDH melalui proses magnetisasi menjadi magnetit-LDH-x (x = asam humat, *charcoal activated*, lignin). Magnetisasi memudahkan pemisahan adsorben setelah digunakan mengadsorpsi zat warna.
3. Memberikan informasi tentang kemampuan LDH dan modifikasinya dalam proses adsorpsi adsorben zat warna kationik dan anionik (*malachite green, methylene blue, congo red, direct yellow*, dan *procion red*) dan penggunaannya secara berulang.

1.6 Kebaruan Riset

Adsorpsi adalah salah satu teknologi menghilangkan zat warna dari limbah karena prosesnya yang sederhana, efektif, efisien, dan biaya murah. Metode adsorpsi membutuhkan adsorben yang sesuai. Adsorben yang efisien dapat disintesis dengan mudah, biaya rendah, dan efisiensi yang tinggi. Salah satu adsorben yang berpotensi digunakan adalah layered double hydroxide. Layered double hydroxide (LDH), atau hidroksi lapis ganda, dapat dibuat dengan mudah, biaya rendah dan tingkat efisiensinya yang tinggi ditandai dengan kapasitas adsorpsi yang tingi. Peneliti telah banyak menggunakan LDH untuk adsorpsi zat warna maupun logam berat. Namun, LDH murni memiliki beberapa kekurangan, seperti regenerasi yang sulit, kurangnya gugus fungsional, dan pemisahannya dari media berair membutuhkan waktu yang lama. Untuk mengatasi kekurangan ini, LDH dimodifikasi dengan berbagai senyawa seperti material karbon, seperti kitosan, biochar, selulosa, dan grafit sudah pernah dilakukan.

Penelitian ini menggunakan material karbon asam humat, *charcoal activated*, dan lignin untuk membuat struktur LDH lebih stabil sehingga meningkatkan kemampuan adsorpsi dan dapat dipakai berulang. Selain itu, LDH dimodifikasi dengan material magnetit untuk membantu memisahkan LDH dari zat warna setelah proses adsorpsi. LDH yang memiliki sifat magnetit dapat dipisahkan dengan mudah menggunakan magnet eksternal yang memungkinkan untuk penggunaan berulang dari material tersebut. Sehingga penelitian ini merupakan penelitian pertama yang memodifikasi LDH dengan asam humat, *charcoal activated*, dan lignin kemudian ditambahkan material magnetit. Adapun komposit yang dipreparasi adalah magnetit-LDH-x (x = asam humat, *charcoal activated*, lignin). LDH dan hasil modifikasinya digunakan sebagai adsorben zat warna kationik dan anionik (*malachite green, methylene blue, congo red, direct yellow, dan procion red*).

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