UNIVERSITAS DIPONEGORO
The Excellent Research University

UNIT OPERATION LABORATORY
CHEMICAL ENGINEERING
DIPONEGORO UNIVERSITY

Buku Panduan

Laboratorium Operasi Teknik Kimia

Departemen Teknik Kimia
Fakultas Teknik
Universitas Diponegoro

FORMAT PROPOSAL PRAKTIKUM OTK

Halaman Judul

Halaman Pengesahan

Ringkasan (2 paragraf)

Prakata

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Daftar Tabel

Daftar Gambar

Daftar Lampiran

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- 1.2 Rumusan Masalah
- 1.3 Tujuan Praktikum
- 1.4 Manfaat Praktikum

BAB II TINJAUAN PUSTAKA

BAB III METODE PRAKTIKUM

- 3.1 Rancangan Percobaan
  - 3.1.1 Rancangan Praktikum
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- 3.2 Bahan dan Alat yang Digunakan
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  - 3.2.2 Alat
- 3.3 Gambar Rangkaian Alat
- 3.4 Prosedur Praktikum

DAFTAR PUSTAKA

PRACTICUM PROPOSAL FORMAT

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- 1.2 Problem Statement
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- 3.1 Experimental Design
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REFERENCES

FORMAT LAPORAN PRAKTIKUM OTK

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DAFTAR PUSTAKA

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- Laporan Sementara
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PRACTICUM REPORT FORMAT

Title Page
Approval Page
Summary (3 paragraph)
Acknowledgements
Table of Contents
List of Tables
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Appendices
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- Calculation Sheet
- Supporting Data (optional)
- References List
- Assistance Sheet

FORMAT UMUM

PROPOSAL DAN LAPORAN PRAKTIKUM

1. Penomoran Halaman
    - Terletak di kanan bawah.
    - Halaman Pengesahan s.d. Daftar Lampiran: angka Romawi, lowercase, *font* Times New Roman, ukuran 12 pt (i, ii, iii, dst.).
    - Bab I s.d. Daftar Pustaka : angka Arab, *font* Times New Roman, ukuran 12 pt (1, 2, 3, dst.).
    - Lampiran tidak diberi penomoran halaman.
2. Layout Halaman
    - Ukuran kertas F4 (21 x 33 cm).
    - *Font* Times New Roman, ukuran 12 pt.
    - *Alignment justify*.
    - *Margins*: *left* 4 cm; *bottom*, *right*, *top* 3 cm.
    - *Line spacing* 1,5 pt (kecuali bagian Ringkasan); tanpa *spacing before* dan *after*.
    - Judul halaman dari Ringkasan s.d. Lampiran (termasuk judul Bab) diberi 1x enter dengan *line spacing* 1,5 pt sebelum menuju isi halaman.
    - Setiap baris pertama paragraf menjorok 1 cm ke kanan (*first line*).
    - Seluruh penomoran menjorok 1 cm ke kanan (*hanging*).
    - Penulisan persamaan menggunakan *equation*, dilengkapi nomor persamaan.
3. Format Daftar Lampiran

    Hanya tulis lampirannya, tanpa disertai halaman.

COVER

1. Judul “PROPOSAL PRAKTIKUM” untuk Proposal Praktikum dan “LAPORAN PRAKTIKUM” untuk Laporan Praktikum, diketik UPPERCASE, tidak **bold**, *font* Times New Roman, ukuran 18 pt.
2. “UNIT OPERASI TEKNIK KIMIA” diketik UPPERCASE, **bold**, *font* Times New Roman, ukuran 18 pt.
3. “Materi”, “Kelompok”, “Nama Anggota” diketik *font* Times New Roman, ukuran 12 pt.
4. Judul materi praktikum diketik *font* Times New Roman, ukuran 12 pt. Apabila materi berbahasa inggris, *italic*.
5. Nama kelompok diisi dengan format Kelompok-Hari, diketik *font* Times New Roman, ukuran 12 pt.
6. Nama anggota diisi secara sejajar ke bawah, diketik *font* Times New Roman, ukuran 12 pt.
7. “LABORATORIUM UNIT OPERASI TEKNIK KIMIA”, “TEKNIK KIMIA FAKULTAS TEKNIK, “UNIVERSITAS DIPONEGORO, “SEMARANG” diketik UPPERCASE, **bold**, *font* Times New Roman, ukuran 14 pt.

HALAMAN PENGESAHAN

1. Judul “HALAMAN PENGESAHAN (dst.)” diketik UPPERCASE, tidak **bold**, *font* Times New Roman, ukuran 12 pt.
2. Di bawah “HALAMAN PENGESAHAN” diketik “PROPSOAL PRAKTIKUM” untuk Proposal Praktikum dan “LAPORAN PRAKTIKUM” untuk Laporan Praktikum.
3. Materi, Kelompok, dan Anggota diketik urut abjad, *font* Times New Roman, ukuran 12 pt, *alignment left*.
4. Tanggal pada Halaman Pengesahan Proposal Praktikum dikosongkan.
5. Tanggal pada Halaman Pengesahan Laporan Praktikum adalah tanggal ACC Laporan Praktikum dari Dosen Pengampu materi tersebut.
6. Tanggal dan pengesahan Dosen Pengampu diketik *font* Times New Roman, ukuran 12 pt, *alignment left*.
7. Nama Dosen Pengampu atau Asisten Laboratorium (apabila dilimpahkan) diketik <u>underline</u>, **bold**, *font* Times New Roman, ukuran 12 pt.

RINGKASAN

1. Pada Proposal Praktikum, ringkasan terdiri dari 2 paragraf: paragraf 1 untuk Bab I dan II, paragraf 2 untuk Bab III.
2. Pada Laporan Praktikum, ringkasan terdiri dari 3 paragraf: paragraf 3 untuk Bab IV dan V.
3. *Line spacing* 1 pt khusus untuk isi ringkasan.
4. Maksimal 1 halaman.

PRAKATA

1. Kata-kata dibuat oleh masing-masing praktikan.
2. Seminimalnya memuat ucapan terima kasih untuk
    a. Dosen Penanggung Jawab Laboratorium OTK
    b. Dosen Pengampu Materi
    c. Laboran
    d. Koordinator Asisten Laboratorium OTK
    e. Asisten Pengampu Materi (2 orang)
    f. Teman-teman Angkatan
3. Sesuaikan penulisan “Proposal Praktikum” atau “Laporan Praktikum”.
4. Tidak perlu diberi tanda tangan.
5. Keterangan waktu cukup ditulis: kota, bulan, dan tahun.
6. Keterangan waktu dan penyusun diketik *alignment left* di bagian kanan bawah.
7. Maksimal 1 halaman.

DAFTAR ISI

1. Daftar Isi dibuat menggunakan fitur *Table of Contents*, pastikan setiap judul Bab dan Subbab terdata dalam *heading*.
2. Nomor Halaman Judul s.d. Daftar Lampiran menggunakan angka romawi.
3. Nomor halaman Bab I s.d. Daftar Pustaka menggunakan angka latin.
4. Lampiran tidak menggunakan nomor halaman.
5. Judul Bab diketik UPPERCASE dan **bold**.
6. Judul Subbab diketik Capitalize Each Word, kecuali konjungsi.
7. Penomoran Subbab sejajar dengan nomor Bab.

8. Penomoran Sub-subbab sejajar dengan kata pertama judul Subbab.

DAFTAR TABEL DAN GAMBAR

1. Daftar Gambar dan Tabel berisi keterangan secara berurutan dari seluruh gambar dan tabel dalam Proposal atau Laporan Praktikum.
2. Daftar Gambar dan Tabel dibuat menggunakan fitur *Table of Figures*, pastikan setiap keterangan gambar dan tabel terdata pada *style* masing-masing.
3. Keterangan tabel dan gambar diketik kapital hanya pada huruf pertama kata pertama dalam keterangan.
4. Sitasi pada keterangan tabel dan gambar tidak dicantumkan.

DAFTAR LAMPIRAN

1. Daftar Lampiran berisi Laporan Sementara, Lembar Perhitungan, Data Pendukung (opsional tergantung materi), Referensi, dan Lembar Asistensi.
2. Isi Daftar Lampiran diketik UPPERCASE, tidak **bold**, *alignment left*, *font* Times New Roman, ukuran 12 pt.
3. Halaman pada keterangan lampiran tidak ditulis.

BAB IV HASIL DAN PEMBAHASAN

1. Penulisan Subbab

   Contoh:

   4.1 Subbab Poin Pertama

   4.1.1 Sub-subbab Poin Pertama

   4.1.2 Sub-subbab Poin Kedua

   4.2 Subbab Poin Kedua

   dan seterusnya.

   - Judul Subbab ditulis Capitalize Each Word (kecuali konjungsi), **bold**, *font* Times New Roman, ukuran 12 pts.
   - Tingkat penomoran maksimal hingga Sub-subbab.
   - Penomoran Subbab dan Sub-subbab menjorok 1 cm ke kanan (*hanging*).

- Setiap isi Subbab dalam Bab IV disusun dalam bentuk paragraf dengan ketentuan:
  - Paragraf 1: berisi kalimat pembuka sebagai pendahuluan sebelum melampirkan hasil dan pembahasan.
  - Lampiran Tabel atau Gambar dari hasil praktikum.
  - Paragraf 2: berisi penjelasan deskriptif dari lampiran Tabel atau Gambar.
  - Paragraf 3: berisi teori yang mendukung dan menjelaskan fenomena yang terjadi.
  - Paragraf 4: berisi kesimpulan pembahasan dan alasan penyimpangan secara teoritis apabila hasil tidak sesuai dengan teori.

2. Tabel dan Gambar
   - Tabel dan gambar *alignment center* terhadap paragraf.
   - Gambar tidak perlu menggunakan *outline*.
   - Komponen pada gambar yang berupa grafik atau diagram diatur berwarna hitam, tanpa *grid* horizontal dan vertikal, *tick mark outside*, menampilkan *axis title*, font Times New Roman, ukuran 12 pt.
   - Tabel harus memiliki judul kolom.
   - Garis pembatas tabel hanya pada garis horizontal bagian atas dan bawah baris judul kolom, serta bagian bawah baris terakhir tabel.
   - Tabel diatur *line spacing* 1,5 pt, tanpa *spacing before* dan *after*, *cell margin* 0,05 cm segala sisi.
   - Angka dalam tabel *alignment center*.
   - Keterangan tabel dan gambar:
     - Kapital hanya pada huruf pertama kata pertama.
     - *Alignment center* terhadap tabel atau gambar terkait.
     - Diakhiri tanpa tanda titik.
     - Terdiri dari 3 bagian: keterangan Tabel atau Gambar, nomor Bab, dan nomor tabel atau gambar.
       Contoh: Tabel 2.1 Hubungan arus dan tegangan
     - Keterangan tabel berada pada baris sebelum tabel dicantumkan, sedangkan keterangan gambar berada pada baris setelah gambar dicantumkan.

- Bagi tabel atau gambar yang diambil dari suatu referensi, sitasinya diletakkan di akhir keterangan tabel atau gambar terkait.

3. Penulisan Sitasi
    - Sitasi dicantumkan di akhir kalimat yang disitasi dari sumber.
    - Referensi yang disitasi wajib tercantum dalam Daftar Pustaka.
    - Apabila penulis hanya 1 orang, maka sitasi diketik dengan ketentuan (Nama terakhir, tahun). Contoh: (Aryaputra, 2024).
    - Apabila penulis berjumlah 2 orang, maka sitasi diketik dengan ketentuan (Nama terakhir 1 & Nama terakhir 2, tahun). Contoh: (Wijaya & Ghoffaru, 2024).
    - Apabila penulis berjumlah lebih dari 2 orang, maka sitasi diketik dengan ketentuan (Nama terakhir 1 *et al*., tahun). Contoh: (Fortunata *et al*., 2024).
4. Penulisan Persamaan
    - Diketik dengan *equation*, *alignment center* terhadap paragraf, *font* Cambria Math, ukuran 12 pt, dilengkapi dengan keterangan nomor persamaan *alignment right*.
    - Keterangan nomor persamaan teriri dari 2 bagian: bagian pertama menunjukkan nomor Bab, bagian kedua menunjukkan urutan persamaan dalam Bab terkait.

      Contoh:

$$\theta = \frac{\gamma \cdot \alpha \cdot w}{2 \cdot \Delta P \cdot g_c \cdot A^2} V^2 + \frac{\gamma \cdot R_m}{\Delta P \cdot g_c \cdot A} V \tag{2.6}$$

BAB V PENUTUP

1. Kesimpulan terdiri dari poin rangkuman hasil yang didapatkan dari keberjalanan praktikum, disesuaikan terhadap tujuan praktikum atau Subbab pada Bab IV.
2. Saran terdiri dari poin masukan terhadap keberjalanan praktikum, dapat berupa saran teknis maupun nonteknis.

DAFTAR PUSTAKA

1. Daftar Pustaka mengacu pada *APA Style 7th Edition*.
2. Daftar Pustaka diketik menjorok 1 cm ke kanan (*hanging*) dengan *alignment justify*.
3. Tidak diperkankan mengambil referensi dari skripsi, tesis, laporan, maupun *website*.
4. Penulisan nama penulis diawali dengan nama terakhir, diikuti tanda koma dan insial dengan titik.

   Contoh:

   van den Bosch, G.

   Staudohar, P. D.
5. Format Penulisan:
   - Buku, satu penulis, edisi ke-3

     Nama terakhir, inisial. (tahun publikasi). *Judul buku* (Edisi ed.). Penerbit.

     Levenspiel, O. (1997). *Chemical Reaction Engineering*. (3rd ed.). Wiley.
   - Buku, dua penulis, edisi revisi

     Nama terakhir, inisial., & Nama terakhir, inisial. (tahun). *Judul buku* (Rev. ed.). Penerbit.

     Davis, M. E., & Davis, R. J. (2002). *Fundamentals of Chemical Reaction Engineering* (Rev. ed.). McGraw-Hill.
   - Buku, tiga penulis atau lebih, tanpa edisi

     Nama terakhir, inisial., Nama terakhir, inisial., & Nama terakhir, inisial. (tahun). Judul buku. Penerbit.

     Bird, B. R., Stewart, W. E., & Lightfoot, E. N. (2006). *Transport Phenomena*. Wiley.
   - Buku, organisasi, tanpa edisi

     Organisasi. (tahun). Judul buku. Penerbit.

     Coronavirus Organization. (2021). *Coronavirus*. Pearson.
   - *Journal article*, DOI

     Nama terakhir, inisial. (tahun). Judul artikel. *Judul Jurnal, Volume*(Issue), Halaman. https://doi.org/DOI

Saksono, N., Kartohardjono, S., & Yuniawati, T. (2016). High Performance Plasma Electrolysis Reactor for Hydrogen Generation using a NaOH-Methanol Solution. *International Journal Of Technology, 7*(8), 1422-1430. https://doi.org/10.14716/ijtech.v7i8.6901

- *Journal article*, URL

Andreff, W., Staudohar, P. D., & Streefkerk, R. (2000). The Evolving European Model of Professional Sports Finance. *Journal of Sports Economics, 1*(3), 257- 276. https://www.journal-of-sportseconomics.com/european-model-finance

- Bab dalam sebuah buku

Nama terakhir penulis bab, inisial. (tahun). *Judul*. Dalam Editor {inisial dan nama belakang} (Ed. Atau Eds.), *Judul buku* (Edisi., pp. Halaman). Penerbit.

John, B., & Benzema, K. (2014). *History of Alchemy*. Dalam A. B. Charice & K. L. Michael (Eds.), *Alchemy: An Introduction* (6th ed., pp. 50-60). Elsevier.

- Artikel jurnal, lebih dari 20 penulis

Setelah nama ke-19 beri titik tiga ". . . " lalu disambung dengan nama terakhir.

Andrew, A., Ben, B., Cynthia, C., Dan, D., Emily, E., Falcon, G. H., Genji, A., Jr., Hitamura, H., Isyana, S., Joe, J., Kamala, H., Litha, M. N., Methy, M., Nathania, N., Omagat, O., Pale, P., Queen, W., Raynald, R., Shane, S., . . . de la Zumba, A. B. C. (2020). Thermodynamics in Food Industry. *Journal of Thermodynamics, 2*(2), 222-244. https://doi.org/10.0000/334789537

LAPORAN SEMENTARA

1. Isi Laporan Sementara ditulis tangan, format mengikuti lembar yang disediakan, dengan isi mengikuti Proposal atau Laporan Praktikum.
2. Laporan Sementara memuat data hasil praktikum dengan format menyesuaikan materi masing-masing.
3. Tanggal Laporan Sementara diisi sesuai tanggal pelaksanaan praktikum.

LAMPIRAN

1. Seluruh referensi yang digunakan dalam Bab IV (selain referensi Proposal Praktikum) harus dilampirkan secara jelas dan di-*highlight*, terkhusus:
    - Nama jurnal dan judul artikel
    - Nama penulis
    - Pembahasan yang digunakan
2. Referensi yang dilampirkan harus berurutan sesuai dengan urutan pada Daftar Pustaka, dengan ketentuan 1 halaman menampung 1 lampiran halaman referensi.
3. Lampiran tidak menggunakan nomor halaman.

LEMBAR ASISTENSI

1. Lembar Asistensi diisi secara tulis tangan dan tidak perlu diganti setiap pengumpulan Laporan Praktikum.
2. Penulisan tanggal menggunakan format DD/MM/YYYY.
3. Lembar Asistensi diisi oleh Dosen Pengampu dan/atau praktikan mengikuti perbaikan yang diberikan.
4. Apabila tidak ada perbaikan dari Dosen Pengampu, maka Lembar Asistensi diisi dengan tanggal pengumpulan Laporan Praktikum pertama kali ke Dosen Pengampu dan tanggal ACC oleh Dosen Pengampu.

PROPOSAL PRAKTIKUM

UNIT OPERASI TEKNIK KIMIA

Materi:

Drying

Kelompok:

2-Selasa

Nama Anggota:
1. Christopher Nolan
2. Harry Potter
3. Lamine Yamal

LABORATORIUM UNIT OPERASI TEKNIK KIMIA

TEKNIK KIMIA FAKULTAS TEKNIK

UNIVERSITAS DIPONEGORO

SEMARANG

HALAMAN PENGESAHAN

PROPOSAL PRAKTIKUM

LABORATORIUM UNIT OPERASI TEKNIK KIMIA

UNIVERSITAS DIPONEGORO

Materi	: Kristalisasi	
Kelompok	: 4-Selasa	
Anggota	: 1. Steven Jacob	(NIM. 21030122120000)
	2. Paulo Coelho	(NIM. 21030122130000)
	3. Octave Levenspiel	(NIM. 21030122140000)
	4. Smith van Ness	(NIM. 21030122190000)

Semarang, 10 Agustus 2025

Mengesahkan,

Dosen Pengampu

Carl Branan

NIP. 196000000000000000

HALAMAN PENGESAHAN

PROPOSAL PRAKTIKUM

LABORATORIUM UNIT OPERASI TEKNIK KIMIA

UNIVERSITAS DIPONEGORO

Materi	: Kristalisasi	
Kelompok	: 4-Selasa	
Anggota	: 1. Steven Jacob	(NIM. 21030122120000)
	2. Paulo Coelho	(NIM. 21030122130000)
	3. Octave Levenspiel	(NIM. 21030122140000)
	4. Smith van Ness	(NIM. 21030122190000)

Semarang, 10 Agustus 2025

Mengesahkan,

a.n. Dosen Pengampu,

Asisten Pengampu

Alan Foust

NIM. 21030122130000

DAFTAR ISI

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

DAFTAR LAMPIRAN

LAPORAN SEMENTARA

LEMBAR PERHITUNGAN

DATA PENDUKUNG (opsional)

REFERENSI

LEMBAR ASISTENSI

LAPORAN SEMENTARA

PRAKTIKUM OPERASI TEKNIK KIMIA

Materi :

(MATERI)

NAMA : (NAMA LENGKAP) NIM : (NIM)

GROUP : (NOMOR) - (HARI PRAKTIKUM)

REKAN KERJA : (NAMA LENGKAP)
(NAMA LENGKAP)
(NAMA LENGKAP)

LABORATORIUM OPERASI TEKNIK KIMIA
TEKNIK KIMIA FAKULTAS TEKNIK
UNIVERSITAS DIPONEGORO
SEMARANG

I. TUJUAN PERCOBAAN

II. PERCOBAAN

2.1 Bahan Yang Digunakan

2.2 Alat Yang Dipakai

2.3 Cara Kerja

2.4 Hasil Percobaan

Semarang, ...

PRAKTIKAN

MENGETAHUI
ASISTEN

TTD.

(NAMA LENGKAP)	(NAMA LENGKAP)	(NAMA LENGKAP)	(NAMA LENGKAP)
NIM. (NIM)	NIM. (NIM)	NIM. (NIM)	NIM. (NIM)

REFERENSI

International Journal of Biological Macromolecules 279 (2024) 134996

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

journal homepage: www.elsevier.com/locate/ijbiomac

Review

Chitosan-blended membranes for heavy metal removal from aqueous systems: A review of synthesis, separation mechanism, and performance

Kavitha Edward [a,*], K.M. Yuvaraj [a], Ashish Kapoor [b]

[a] Department of Chemical Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, Potheri, Kattankulathur 603203, Chengalpattu District, Tamil Nadu, India.

[b] Department of Chemical Engineering, Harcourt Butler Technical University, Kanpur, Uttar Pradesh 208002, India

A R T I C L E I N F O

Keywords:
Chitosan
Membrane filtration
Hybrid membrane
Membrane synthesis
Heavy metal removal
Environmental remediation

A B S T R A C T

The environmental pollution caused by heavy metal ions has become a serious global environmental issue. Heavy metal contaminants released from industrial effluents, agricultural runoff, and human activities, can enter into water resources. The toxicity of these heavy metal ions even at trace concentrations presents a substantial hazard to both aquatic systems and human well-being. The membrane separation processes have become more promising sustainable techniques for the separation of metal ions from the effluent. The research efforts have been concentrated on improving the synthesis of membranes and membrane materials to facilitate the sustainable separation of heavy metals. The application of chitosan in the fabrication of membranes is getting more attention. Chitosan, a natural polysaccharide derived from chitin, is abundant in nature and has active hydroxyl and amino groups suitable for the separation of heavy metal ions. It exhibits excellent chelating tendency, biocompatibility, and biodegradability. The functionalization of chitosan to improve its mechanical strength, chemical stability, and antifouling properties has become an ongoing area of research. This review examines the synthesis and efficient applications of chitosan blended membranes. The review concludes by outlining the current challenges and proposing future research prospects to enhance the applicability of chitosan-blended membranes in environmental remediation.

1. Introduction

Water pollution is a crucial environmental issue that has evolved significantly over time due to a complex interplay of factors, including human activities, industrialization, and urbanization. This evolution has transformed water pollution from a localized concern to a global crisis, with profound implications for ecosystems and human well-being [1]. In the early stages of human civilization, water pollution was relatively limited in scope and impact. Most human settlements were small and dispersed, and their wastewater primarily consisted of organic materials that could be naturally degraded by aquatic ecosystems. Pollution was largely localized and had minimal effects on larger water bodies. However, as human populations grew and settled into larger communities, the nature of pollution began to change. The concentration of people in urban areas led to increased generation of sewage and waste, which often found its way into nearby rivers and streams. The discharge of industrial waste and raw sewage into the water resources created an environmental and public health crisis, the development and use of synthetic chemicals, including pesticides, fertilizers, and industrial compounds, introduced a new class of pollutants into water bodies. These chemicals posed unique challenges due to their persistence and ability to disrupt ecosystems. Efforts to combat water pollution have included the development of environmental regulations, the improvement of wastewater treatment technologies, and increased awareness of the importance of preserving clean water sources. However, the challenges remain significant. Balancing the needs of a growing global population with the preservation of clean and accessible water is an ongoing struggle.

Among the various water pollutants, heavy metals stand out as particularly pernicious. These elements do not biodegrade, which means that once released into the environment, they persist for long periods, accumulating in soils, sediments, and water bodies. Lead, mercury, cadmium, chromium, etc., are known for their toxic nature and ability to persist in the environment. They can enter water bodies through multiple routes, including industrial effluents, agricultural discharge, and atmospheric deposition. The various sources of heavy metal

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https://doi.org/10.1016/j.ijbiomac.2024.134996
Received 10 April 2024; Received in revised form 10 July 2024; Accepted 21 August 2024
Available online 23 August 2024

contaminants are metal processing units, electroplating, textile and leather outlets, nuclear power plants [2]. Heavy metals are categorized by their high density and harmful effects to eco systems. Heavy metals such as lead, mercury, chromium, arsenic, cadmium etc., even with low-level exposure can lead to developmental delays in children, cognitive impairments, and a range of health issues in adults. The neurotoxic effects of lead are particularly concerning, as they can result in irreversible damage to the nervous system [3]. Mercury, especially in its organic form as methylmercury, poses a significant threat to human health [4]. Cadmium exposure is associated with kidney damage, respiratory problems, and an increased risk of cancer [5]. Hexavalent chromium, a highly toxic form of chromium, is a known carcinogen. Prolonged exposure to this heavy metal through industrial processes or contaminated water sources can increase the risk of lung cancer and other health issues [6]. The environmental impact of heavy metals is equally concerning. Some heavy metals can volatilize into the air, contributing to atmospheric pollution. Efforts to mitigate the menace of heavy metals, governments and international organizations have established regulations to limit the release of heavy metals into the environment.

To address this challenge, various technological solutions have been established for the sustainable separation of heavy metal ions and purification of the effluent. The solutions range from conventional methods to innovative, advanced technologies, each with its own set of advantages and limitations. Conventional techniques like, coagulation involves the addition of chemicals known as coagulants (e.g., aluminum sulphate or ferric chloride) to water [7]. These coagulants counteract the electrical charges present on suspended particles, leading to their aggregation (flocculation) and subsequent settling. This process can effectively remove heavy metal ions along with other impurities. Chemical precipitation relies on the addition of precipitating agents, such as lime or sodium hydroxide, to water containing heavy metal ions [8]. This causes the heavy metals to form insoluble precipitates, which can then be separated by sedimentation or filtration. Adsorption involves the use of adsorbent materials like activated carbon, zeolites, or specific ion-exchange resins to attract and capture metal ions present in the effluent [9]. The affinity of adsorbents towards heavy metal ions makes this technology more promising for their separation. Processes like electrocoagulation and electrooxidation utilize electrodes to trigger chemical reactions, aiding in the separation of metal ions from effluent [10].

Bioremediation relies on the use of microorganisms, such as bacteria and algae, for the separation of heavy metals from aqueous stream. These organisms can either adsorb heavy metals onto their cell surfaces or transform them into less toxic forms through metabolic processes [11]. Bioremediation is considered an environmentally friendly approach. In some cases, complexation using chelating agents such as ethylenediamine tetraacetic acid or diethylenetriamine pentaacetic acid can also be employed to form complexes with heavy metal ions. These complexes are then easily removed from the water. Ion exchange resins containing functional groups can be used for the selective removal of heavy metal ions from wastewater. It is also possible to regenerate the resins for reuse [12]. Amidst all these conventional processes, membrane separation processes are emerging as a sustainable solution to separate the heavy metal ions and for the purification of the industrial effluent. Optimal material selection and improved membrane synthesis techniques have the potential to render membrane separation processes compatible with sustainable practices. There are only limited works in the development of chitosan blended membranes for the application of heavy metal removal. There are quite a few literature reviews representing the methodology of chitosan blended membranes. This review focuses on the incorporation of functionalized chitosan to enhance selective capability, strength, and stability. This review also explores the heavy metal separation mechanism, the currently followed strategy, and necessary developments required in the future.

2. Membrane separation processes

Membrane technology, especially pressure driven processes such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, has gained prominence for its precision in removing heavy metals. Membranes act as discriminating barriers, enabling the passage of water molecules while retaining heavy metal ions based on their size and charge. This technology offers exceptional removal efficiency and can handle complex water matrices. Amid these advanced methodologies, membrane separation processes have been emerging as a promising one, offering the twin virtues of selective separation and effectiveness.

Membrane technology offers a promising solution to the challenges posed by heavy metal pollution. At its core, membrane processes rely on selectively permeable barriers, called membranes, to separate different components of a mixture based on size, charge, and other characteristics. Membrane processes excel in achieving high removal efficiencies for heavy metals. Their ability to isolate heavy metal ions from complex matrices of pollutants ensures effective treatment even in challenging conditions. Membranes can be tailored to target specific heavy metals of concern. By modifying membrane materials or incorporating functional groups, it is possible to enhance the selectivity of the membranes for particular metal ions. Unlike some conventional methods that rely heavily on chemicals, membrane processes often require fewer chemicals for effective treatment. This reduces the generation of chemical waste and associated costs. Membrane technology is scalable and can be adapted to accommodate treatment at various scales, from small-scale water purification systems to large industrial applications. Membrane processes generate minimal waste compared to some conventional methods, which can produce significant volumes of sludge or chemical byproducts.

2.1. Complexation ultrafiltration

In recent years, the ultrafiltration process has been getting the attention of researchers for wastewater treatment. This process relies on the size exclusion principle to separate contaminants from water. Since ultrafiltration depends on the separation of pollutants based on their size and pore size distribution of the membrane, the separation of heavy metal ions which are smaller compared to the pores of the membrane is not effective. The quest for an appropriate technology utilizing UF for removing metal ions from the effluent resulted in the emergence of complexation ultrafiltration. Complexation ultrafiltration (CUF) is a process wherein complexing agents, typically water-soluble polymers, are introduced into wastewater containing heavy metals. Due to the affinity of polymer ligands towards the metal ions, they form complexes with metal ions that can be readily captured by UF membranes. The separation of metal ions by CUF has been attempted by many researchers using several synthetic polymers such as polyethylenimine, carboxymethyl cellulose, polyacrylic acid, etc. The promising outcomes on the removal of metal ions through CUF have been reported in the literature. Since, most of the polymers used as the complexing species are expensive, complex and nonbiodegradable, the attention has been focused on biopolymers which are cheap, readily available, and biodegradable.

An important aspect of membrane-based water treatment is the customization of membrane chemistry and structure to enhance the highly selective removal of toxic heavy metal ions from aqueous stream. There has been a substantial development of technology for the fabrication of novel membranes for the separation of toxic heavy metals from wastewater.

Variety of polymers such as polyether sulfone (PES) [13–15], polyvinylidene fluoride (PVDF) [16–19], cellulose acetate (CA) [20,21], polyacrylonitrile [22–24], polytetrafluoroethylene [25,26], etc., have been employed for the fabrication of membranes. To improve the mechanical strength, water permeability, porosity, film-forming tendency of membranes various composite based membranes such as graphene-