Chapter 2

Literature Review

2. Literature Review

The treatment of textile and pharmaceutical wastewater is a significant environmental concern because of the occurrence of various organic and inorganic pollutants, like dyes, heavy metals, and medications, Methneni et al. (2021). Traditional wastewater treatment methods, including membrane filtration, chemical coagulation, and biological processes, are often costly and may generate secondary pollutants. Adsorption, in contrast, has emerged as a more competent and cost-effective alternative for eliminating contaminants from wastewater, Satyam & Patra (2024). A growing interest has been directed towards low-cost adsorbents, like industrial wastes, natural materials, and agricultural byproducts, for treating single- and multi-component pollutant systems, Rial & Ferreira (2022). These materials are not only accessible but also provide a sustainable solution with minimal environmental impact, Lellis et al. (2019).

Our research focuses on developing a novel composite material based on Polyaniline (PANI), a conducting polymer with distinct physical and chemical properties like high surface area, chemical stability, and ease of production, which makes it an excellent material for wastewater treatment applications, Tohamy et al. (2022). The composite material is designed to enhance the adsorption capabilities of PANI by integrating it with other functional materials, further improving its efficiency in pollutant removal, Samadi et al. (2023).

In recent decades, the development of composite materials has gained attention, particularly in nanomaterial research, Sharma et al. (2024). It is acknowledged that no single material can fulfill all the desired properties for a specific application, thus the fabrication of composite systems offers a means to tailor and optimize material properties, Khan et al. (2019). PANI (PANI) stands out among conductive polymers because of its favorable features such as small synthesis cost, environmental sustanibility, redox behavior, and tunable conductivity, Sarojini et al., (2022), Rehman et al. (2024). However, challenges such as its insolubility and loss of conductivity at higher pH still exist, Qiu et al. (2023). To overcome these limitations, PANI is often applied as a coating on natural materials like agricultural waste to improve their adsorption properties, Imgharn et al. (2021). Its unique attributes, such as biodegradability and redox properties, make PANI an attractive candidate for dye and pollutant removal, Stejskal (2022).

Additionally, sand has emerged as a practical and economical adsorbent for dye elimination from industrial wastewater, Juzsakova et al. (2023). Its abundance in nature, low cost, and potential for modification make it a promising alternative to traditional adsorbents like activated carbon. Surface modification of sand can significantly improve its adsorption efficiency, offering a more affordable and sustainable solution for wastewater treatment, Ahmed et al. (2020). These developments highlight the potential of sand-based adsorbents to revolutionize industrial wastewater treatment by promoting environmental sustainability and reducing operational costs, Kumar et al. (2023).

2.1 PANI based composite used for dye removal

Table 2.1 PANI based composite used for dye removal

Adsorbents	Adsorbate	% Removal	Experimental conditions					Adsorption capacity (mg/g)	References
			Concentration (mg/L)	pH	Temperature ºC)	Contact time (min)	Adsorbent dosage (gm/L)		
PANI/Sodium alginate	(MB), Rhodamine B (RB), Orange-II (O-II), and Methyl orange (MO)	98	500	3, 9	35	4 h	0.1	555.5, 434.78, 476.19, 416.66	Majhi and Patra (2020)
Doped PANI/Zeolite	MB	99	10 ppm			210	0.5 mg/ml		Sodha et al. (2023)
PANI-nickel ferrite	MB	87	40	9			8	6.65	Patil and Shrivastava (2015)
PANI nano adsrbent	Amido Black 10B	95	30	6		30	0.1	142.85	Tanzifi et al. (2016)
PANI nano adsrbent	MO	98.84	30	10	65	60	0.15	75.9	Tanzifi et al. (2017)
Nanoporous hypercrosslinked PANI	Crystal violet (CV), MO	73.6 to 93.1 (CV), 65.8 to 90.5 (MO	100 ppm	7.3		60	5	245 and 220	V. Sharma et al. (2016)
Metalated highly self doped PANI	Safranin	82.5	40 ppm	9	25	75	2		Hassan and Fattah (2023)
PANI/zirconium oxide	MB		30		25	25	0.01	77.51	Agarwal et al. (2016)

Alginate–Montmorillonite–PANI	Reactive Orange 13		64.4	2.59	25	35		111.111	Ayazi et al. (2017)
Nano-Structured PANI	MB	91	6	7	35	60	2		Duhan and Kaur (2020)
PANI@WO3	Orange G	95	0.05	5	25	120	0.5	226.5	Hsini et al. (2021)
PANI/graphene, PANI/RGO	MB		1gm	7	50, 45	270	0.5	14.2, 19.2	El-Sharkaway et al. (2019)
PANI and PANI/Clinoptilolite	Acid Violet 90	90	100	2	30		0.5	153.85, 72.46	Akti and Okur (2018)
PANI-modified rice husk	Acid red 18		40 ppm	3	25		0.1	80.554	Shabandokht et al. (2016)
PANI and PANI-Alstonia scholaris leaves	Diamond green	92.1, 99.5	30-80 ppm	1	20	40, 90	1	0.911, 8.130	Kanwal et al. (2018)
PANI Functionalized Magnetic Mesoporous Silica	MO	96.96	20	4	50		0.003 g	65.13	Mahto et al. (2015)
Zinc ferrite—PANI	RB	99	2 ppm	2	25	40	0.5	229	Rachna et al. (2018)
Clay/PANI/Fe_3O_4	Brilliant green (BG), MB, Congo red (CR)	96.2, 99.6, 98.1	200	6.3		4 h		184.48	Mu et al. (2016)
PANI nanoparticles	CV	94.29	5		45		0.5	55.6	Saad et al. (2017)
PANI-polyvinylpyrrolidone, PANI-polyvinylpyrrolidoneneo	Acid red 52		80 ppm	2		90	0.05	159.36	Gouthaman et al. (2018)

dymium/ zinc oxide (PAPV-NZO)									
graphene/PANI/Fe_3O_4	BG, CR	92.4	100	6.3		2 h		248.76	Mu et al. (2017)
PANI-Doped Lignosulfonate	Malachite green, MB, CV	96.22	100, 250	8	85	300	20	250	Wu et al. (2023)
Mesoporous PANI-derived carbon	Acid red 1, Janus green B			7		6 h		736	An et al. (2020)
PANI@Fe-ZSM-5	Orange G							217	Imgharn et al. (2022)
Doped PANI@graphene oxide-multiwalled carbon nanotube composites	CR	96	200	5	30	640	0.02	60	Ansari et al. (2017)
PANI/sugarcane bagasse (Pan/SB), polypyrrole (PPy/SB), PANI/chitosan (PAn/Ch), PANI/starch, polypyrrole/starch	Acid Black-234		50 to 100	3	30-65	60	0.05	52.6, 100, 90.91, 90.0, 71.4, 66.6, 62.5v	Noreen et al. (2020)
PANI-coated kapok	MO		40 to 280 ppm	6.5		24 h	30	75.76	Herrera et al. (2018)
Nano PANI	Anionic sulphonated Acid Red 14	97	275	4		60	0.1	266	S. M. Ahmed et al. (2016)

Chitosan/PANI	Tartrazine	99.8	400	7.2		120	10	584	Sahnoun and Boutahala (2018)
PANI-tea Saponin	Acid blue 74, Congo red	-	-	6.2	30	24		4.985, 25.19	Zou et al. (2021)
Electrospun poly(methyl methacrylate)/PANI	Remazol Brilliant Blue R dye	87	1	5	25	60	-	110	Jankowska et al. (2020)
$CoFe_2O_4$/PANI	Acid Red 18	90	100	6		12	0.02	172.41	Mohammadi et al. (2021)
Graphene oxide/PANI	BG	95	200	7		30	0.05	142.8	M. A. Khan et al. (2021)
Grafted PANI	BG	97.7	70	7	25	0-180	0.025	94.46	A et al. (2019)
Prickly pear seeds/PANI	CR	91.14	20	6.6	25	60	1	17.14	Lahreche et al. (2022)
Hydroxyethyl cellulose/PANI/Polypropylene	RB, MO		300	8, 9	27	2 h	0.5	30.6, 29.3	Bajaber et al. (2022)
PANI@Hydroxyapatite	Orange G	98.04	50 ppm	6	25	120	0.5	332.246	Mchich et al. (2024)
PANI@ZnO	CR and MB	81, 76	150	5	25	60	10	69.82 , 59.23	Toumi et al. (2021)
PANI/Polystyrene	Direct blue dye 14	-	50	2	-	120	0.1	40	Eisazadeh et al. (2021)
PANI Nanocomposite	Eosin yellow	-	100	-	-	40	0.1	-	Danu et al. (2021)
PANI dispersed by Kevlar fiber	CR	-	25	-	25	100	25 mg	450	Liu et al. (2020)
Activated Carbon/PANI	MO	76.18	200	6	23	60	10 mg	192.52	Bekhoukh et al. (2021)
PANI coated bacterial cellulose	MO	99.52	1000 ppm	7	47	720	7.7 mg	300	Jahan et al. (2020)
PANI/MWCNTs	Sunset yellow, CR	93, 99	50 ppm	2	25	5	0.007	147	Aliabadi and Mahmoodi (2018)

PANI/Beidellite	Acid Yellow 194	99	-	3	25	24 h	0.15	123	Gengec et al. (2017)
PANI/Silver nanocomposite	BG	90	61.2	11	40	120	0.03	20.92	Salem et al. (2016)
PANI coated ligno-cellulose composite	Reactive Black 5	95	50	2	45	60	0.5	312.5	Ballav et al. (2015)
PANI-Encapsulated quartz sand	Orange G	82	100	6	45	105	1.5	130.94	Amjlef et al. (2023)
PANI/Biocomposite	Orange G		10	6	25	120	75, 225	3.8. 3.6	Imgharn et al. (2021)
Fe-Mn-Zr/PANI-NC	MO, Eosin yellow	96, 78	30	5	30	5	0.2	17.39, 117.65	Deb et al. (2021)
PANI/Fe3O4	Basic Blue			10	30	50	0.1	78.13	Muhammad et al. (2019)
PANI/Zinc titanate	CR	90	50-75			15		64.51	Singh et al. (2021)
Polyacid doped PANI	MB, Rose bengal	95	100	7	25	10	0.5	466.5, 440	Shen et al. (2018)
PANI@MoS2	CR		100	5	50	120	10 mg	70.921	Kumar et al. (2018)
chitosan/PANI	Acid Green 25, MB	97	52	4, 11	27	20	50 mg	240.4, 81.3	Minisy et al. (2018)
PANI nanoparticles	MB		10	3	25		0.01		Ayad et al. (2013)
PANI	MB		1.5 g/0.5 L	7		100		85.4	Mohamed et al. (2015)
PVC@graphene–PANI	CR		50	4.5	30				Kumar et al. (2015)
PANI)/polypyrrole	CR	100	0.4g/L	4	25	45	0.4	250.01, 66.66	Chafai et al. (2016)
PANI/TiO2	Acid red G	95	500 mg/L		35	5	2	454.55	Wang et al. (2015)
α- MoO3/PANI	Rhodamine B, CR	91	2.1×10-5mol/L	3	25	60		36.36, 76.22	Dhanavel et al. (2016)
PANI/ lignocellulose composite	CR	99.8	28.5	4.29	45	24 h	0.69	1672.5	Debnath et al. (2015)

Fe3O4@PAmABAmPD-TCAS	MB,MG	90, 92	20	8	30	3 h	1 mg	32, 29	Lakouraj et al. (2015)
PANI hydrogel	MB	96	50	4	45	12 h	20 mg	71.2	Yan et al. (2015)
PANI@Almond shell	Orange G	>93	50	2		120	0.5	190.98	Hsini et al. (2020)
PANI/SiO2	Amido Black 10B		90			90		99	Tanzifi et al. (2018)
PANI grafted biomass	MB, CV, Reactive Red 35, Fast Green,	44.44%, 645.83%, 67.88%, and 441.07%	0.0313 to 0.1563 mmol/L	11	30		0.01		Yadav et al. (2024)
PANI hollow nanotubes	MB, Acid green	90, 55		9, 3	25	50	10 mg	6.2, 6.1	Amer et al. (2018)
Cu(I)-PANI	Reactive Orange 16	94.77	100	4	45	90	0.06	392.156	Obulapuram et al. (2021)
PANI/Coal	RB		50	8	25	120	0.2	423.5	Sayed et al. (2023)
(PANI) grafted onto Posidonia (POS) fibers	Phenol Red						15		Ferchichi et al. (2024)
PANI/poly(vinyl alcohol)/montmorillonite hybrid aerogels	Reactive Black 5, MO, safranin		200, 200, 100	2, 7, 11	25	12 h	1.5, 1, 4	210, 190, 30	Lyu et al. (2022)

Majhi and Patra (2020) investigated the elimination of organic dyes from aqueous solutions by means of a novel pH-responsive nanocomposite made of sodium alginate (SA) and PANI. The composite combines PANI's high adsorption capacity with SA's biocompatibility to create a highly efficient and environmentally friendly adsorbent. Their findings showed that the PANI/SA nanocomposite demonstrated highest adsorption capability of 555.5 mg/g, 434.78 mg/g, and 416.66 mg/g, effectively removing both cationic dyes (MB and Rhodamine B) and anionic dyes (Orange-II and MO). The composite's efficiency across a range of pH levels, combined with its excellent reusability, makes it a sustainable alternative to conventional adsorbents, particularly for wastewater treatment in real-world applications.

Sodha et al. (2023) developed a PANI composite doped with zeolite to degrade methylene blue in aqueous solutions. They found that the best conditions for maximum dye degradation were a catalyst dose of 0.5 mg/ml, dye concentration of 10 ppm, and a contact time of 210 minutes. Their results showed degradation efficiencies of 99.9%, 82%, and 71.38% for the PAZe-1, PAZe-5, and PAZe-10 composites, respectively, compared to 71.38% for pure PANI.

Similarly, **Patil and Shrivastava (2015)** utilized a PANI-nickel ferrite (PANI-$NiFe_2O_4$) nanocomposite for the remediation of methylene blue from an aqueous solution using a kinetic approach. The study determined that the best conditions for dye removal were a pH of 9, adsorbent dosage of 8 g/L, and primary dye concentration of 40 mg/L, yielding an adsorption ability of 6.65 mg/g. The experimental data was better suited to the Langmuir isotherm model, demonstrating monolayer adsorption and a primarily physical adsorption mechanism on the nanocomposite surface. This further highlights the potential of PANI-based composites for dye elimination applications.

The increasing prevalence of organic dyes in wastewater, particularly from textile industries, has led to a significant focus on developing efficient adsorbents for dye removal. Among these, PANI has garnered attention because of its exceptional characteristics like high surface area, chemical stability, and ease of modification. Several studies have explored the potential of PANI-based materials for dye adsorption, employing various approaches to improve their performance, including isotherm, kinetic, and thermodynamic analyses.

Adsorption of Amido Black 10B Dye Using PANI Nano-Adsorbents

Tanzifi et al. (2016) conducted a comprehensive study on the adsorption of Amido Black 10B dye from aqueous solutions using PANI nano-adsorbents. The study primarily focused on kinetic and isotherm studies to assess the efficiency of the PANI nano-adsorbent. The adsorption capacity, determined through a type 1 model, was found to be 14.32 mg/g, closely matching the experimental value of 14.29 mg/g. Isotherm analysis revealed the Freundlich model provided suitable for the experimental data, with a correlation coefficient of 0.9579, suggesting that adsorption happens on a heterogeneous surface with varying energy levels. Additionally, the Langmuir isotherm model indicated a extreme adsorption capacity of 142.85 mg/g, further highlighting the potential of PANI nano-adsorbents in dye removal. The separation factors, which fell within the range of 0 to 1, also supported the efficiency of the adsorbent for eradicating Amido Black 10B dye from water.

Adsorption of Methyl Orange Using PANI Nano-Adsorbents

In a follow-up study, Tanzifi et al. (2017) optimized the adsorption of methyl orange onto a PANI nano-adsorbent using an artificial neural network, which included kinetic, isotherm, and thermodynamic studies. The study demonstrated a significant increase in adsorption capacity with rising temperature and initial dye concentration. At 65°C, the adsorption capacity increased from 3.34 mg/g at a 10 mg/L dye concentration to 32.04 mg/g at a 100 mg/L concentration. A similar trend was observed at 25°C, with the adsorption capacity growing from 3.28 to 30.28 mg/g. Equilibrium was achieved within 60 minutes, which indicates the fast adsorption kinetics of the nano-adsorbent. Kinetic analysis show that the adsorption process followed pseudo-second-order kinetics, implying that chemisorption was the dominant mechanism. The maximum adsorption capacity stayed reported to be 75.9 mg/g. These results underscore the potential of PANI-based nano-adsorbents for the effective elimination of anionic dyes such as methyl orange under varying conditions.

Removal of Cationic and Anionic Dyes By Nanoporous Hypercrosslinked PANI

Sharma et al. (2016) developed nanoporous hyper cross linked PANI as adsorbent for together cationic (CV) and anionic (MO) dyes. The study demonstrated high adsorption capacities of 245 mg/g for CV and 220 mg/g for methyl orange, with complete dye removal occurring within 60 minutes. Additionally, surge the adsorbent dose from 3 mg to 5 mg resulted in a significant enhancement of adsorption capacities, reaching 65.8 mg/g for crystal violet and 90.5 mg/g for MO. The high adsorption efficiencies were attributed to multiple interactions between the adsorbent and the dye molecules, including π-π stacking, Lewis acid-base interactions, electrostatic attractions, and hydrogen bonding. This combination of mechanisms contributed to the ability of the PANI-based adsorbent to effectively eliminate twin cationic and anionic dyes, making it a versatile material for wastewater treatment.

Removal of Safranin Using a Metalated, Self-Doped PANI Nanocomposite

In a more recent study, Hassan and Fattah (2023) synthesized a novel metalated, highly self-doped PANI nanocomposite to enhance dye elimination efficiency. The nanocomposite was specifically tested intended for the adsorption of safranin from the aqueous solutions. The results indicated a maximum dye removal efficiency of 82.5% within 75 minutes, demonstrating faster uptake rates compared to organic copolymers. The adsorption efficiency was found to be highly dependent on pH, with the highest efficiency of 73.6% achieved at pH 9. This was consistent with the behavior of PANI in basic conditions, where deprotonation enhances its interaction with dye molecules. The study highlighted the promising potential of metalated, self-doped PANI nanocomposites as efficient adsorbents for organic dye elimination from wastewater.

The remediation of hazardous dyes from wastewater is critical for mitigating environmental pollution, particularly from industrial effluents. PANI based nanocomposites have appeared as capable adsorbents because of their high surface area, tunable properties, and ability to remove various dyes through adsorption. Several studies have investigated different forms of PANI composites and their efficacy in dye adsorption under varying conditions. This literature review explores recent advancements in the synthesis and usages of PANI nanocomposites for dye adsorption.

Adsorption of Dyes Using PANI/Zirconium Oxide Nanocomposites

Agarwal et al. (2016) synthesized and characterized a PANI/zirconium oxide (PANI/ZrO_2) nanocomposite, primarily aimed at dye adsorption applications. The study explored various parameters influencing adsorption, like contact time, temperature, and preliminary dye concentration. Longer contact times consistently led to enhanced dye elimination efficacy, representing that the adsorption rate improved with extended contact amid the dye and adsorbent. The experimental results demonstrated that PANI/ZrO_2 exhibited a monolayer adsorption capacity of 77.51 mg/g, conferring to the Langmuir isotherm model. This suggests that the PANI/ZrO_2 nanocomposite can be efficiently utilized for the elimination of dyes from wastewater, especially for dyes that exhibit monolayer adsorption characteristics on adsorbent surfaces.

Optimization of Reactive Orange 13 Adsorption Using Alginate-Montmorillonite-PANI Nanocomposite

Ayazi et al. (2017) examined the use of an alginate-montmorillonite-PANI (Alg–MMT–ANI) nanocomposite for the adsorption of the dye Reactive Orange 13 (RO13). RSM was used in the study to model and optimise the adsorption process. The maximal adsorption capacity (qm), as determined by the experiment, was 111.111 mg/g. 50 millilitres of RO13 solution were mixed with 72.39 milligrammes of the Alg–MMT–ANI nanocomposite to perform kinetic experiments. At room temperature, the initial dye concentration was 64.4 mg/L, and the pH of the solution was kept at 2.59. The quick and efficient nature of the adsorption process was demonstrated by the fact that it peaked in 35 minutes and subsequently stabilised during the next 100 minutes. These findings demonstrate the Alg–MMT–ANI nanocomposite's great potential for eliminating reactive dyes from wastewater, emphasising the need of optimising.

Removal of Methylene Blue Dye Using Nano-Structured PANI

Duhan and Kaur (2020) focusses on creating nano-structured PANI (PNB) to remove MB dye from wastewater. To investigate the effects of starting dye concentration, contact time, and adsorbent dose, batch adsorption experiments were conducted. A dye concentration of 6 mg/L, a contact period of 60 minutes, and a PNB dose of 2 g/L were determined to be the ideal parameters for dye removal. The adsorption system was found to be best described by the Freundlich isotherm model, which postulates that MB dye formed a monolayer on the PNB adsorbent's heterogeneous surface. The potential of PNB as an efficient adsorbent for eliminating colours from industrial effluents was demonstrated by the PANI nanofibers' 91% removal effectiveness for methylene blue.

Use of PANI-Coated Tungsten Trioxide for Orange G Dye Removal

Hsini et al. (2021) tungsten trioxide coated with synthetic PANI (PANI@WO_3) to extract orange G dye from watery solutions. The highest adsorption capacity of 226.50 mg/g was found in the Langmuir isotherm model, which was the best fit to the experimental data. The thermodynamic characteristics demonstrated that the adsorption process was endothermic and spontaneous. The promise of PANI@WO_3 as an efficient adsorbent for organic dyes is highlighted by its high adsorption capacity and spontaneous adsorption. PANI@WO_3 showed better performance than other dye removal adsorbents, which makes it a viable option for wastewater treatment applications.

Methylene Blue Removal Using PANI/Graphene Oxide and PANI/Reduced Graphene Oxide Composites

El-Sharkaway et al. (2019), PANI/GO and PANI/reduced graphene oxide (PANI/RGO) composites were used to investigate the adsorption of MB. According to their investigation, the best dye concentration for both composites was 50 mg/L, and the appropriate contact duration for maximal dye removal was 270 minutes. The maximal adsorption capacities for PANI/GO and PANI/RGO were 14.2 mg/g and 19.2 mg/g, respectively, with the optimal adsorbent dosages being 0.4 g and 0.3 g. These results highlight the efficiency of graphene oxide-based composites in raising PANI's dye removal adsorption capability. Both PANI/GO and PANI/RGO exhibited improved performance compared to pure PANI, indicating that graphene oxide significantly contributes to the overall efficiency of dye adsorption by providing additional active sites for interaction. PANI and its composites have garnered significant interest as adsorbents for dye elimination from aqueous solutions because of their tunable surface properties, environmental stability, and ease of synthesis. Current studies have explored the synthesis, characterization, and optimization of various PANI-based materials for the adsorption of different dyes. This literature review delves into the applications of these composites for dye removal, focusing on the impact of system variables, adsorption capacities, and the effectiveness of the materials across various studies.

Removal of Acid Violet 90 Using PANI and PANI/Clinoptilolite Composites Akti & Okur (2018) investigated the use of PANI and PANI/clinoptilolite composites to remove Acid Violet 90 from aqueous solutions. Their study examined the impacts of a number of characteristics in a batch adsorption setup, such as the starting pH (2 to 8), sorbent dose (0.5 to 4.0 g/L), and dye concentration (varying from 50 to 400 mg/L). With maximal dye adsorption capacities of 153.85 mg/g for PANI and 72.46 mg/g for the PANI/clinoptilolite composite, the results showed that adsorption followed the Langmuir isotherm model. The higher adsorption capacity of PANI highlights its efficacy in dye removal, whereas the reduced capacity of the PANI/clinoptilolite composite suggests a trade-off between the enhanced structural stability of clinoptilolite and the overall adsorption performance.

Adsorption of Acid Red 18 Using PANI-modified Rice Husk Composite

Shabandokht et al. (2016) explored the adsorption of Acid Red 18 dye with a PANI-modified rice husk (HCl-MRH) composite. The optimal dosage of PANI and HCl-MRH for maximum dye adsorption was ascertained 0.12 g and 0.16 g, respectively. A 40-ppm dye solution was treated for 180 minutes to attain equilibrium, with adsorption equilibrium achieved after 120 minutes. This indicates that the adsorption efficiency remained constant after this period, suggesting that both the PANI and rice husk composites were effective in achieving rapid dye removal. The usage of rice husk as economical adsorbent, in combination with PANI, underscores the potential of agricultural by-products in water treatment.

Eco-friendly Removal of Diamond Green Dye Using PANI/Alstonia Scholaris Composite

Kanwal et al. (2018) created an environmentally friendly PANI-Alstonia scholaris leaf (PANI/AL) composite to remove Diamond Green dye from aqueous solutions.The maximum monolayer homogenous adsorption capacities for PANI/AL and PANI were 8.130 mg/g and 0.911 mg/g, respectively, indicating that the PANI/AL composite had better adsorption capabilities than PANI alone. Furthermore, multilayer heterogeneous physiosorption capacities of 0.138 mg/g for PANI and 0.947 mg/g for PANI/AL were found. With adsorption values of 99.1% for PANI and 96.8% for PANI/AL, the maximum dye removal efficiency was attained at a pH of 1.0.The study demonstrates that the PANI/AL composite not only enhances adsorption performance but also provides an environmentally sustainable approach to dye removal.

Methyl Orange Adsorption Using PANI-functionalized Magnetic Mesoporous Silica

Mahto et al. (2015) A PANI-functionalized magnetic mesoporous silica (PANI-MS@FeO$_4$) composite was made for dye adsorption directed by magnetic fields. The study concentrated on how pH affected MO adsorption, and the maximum effectiveness of 96.96% was noted at a pH of 4. Electrostatic interactions between the positively charged PANI-MS@FeO$_4$ compound and the negatively charged MO dye were identified as the adsorption mechanism. This research demonstrates the potential for magnetic nanocomposites in dye adsorption, providing a reusable and efficient method for dye removal through magnetic separation.

Rhodamine B Dye Removal Using Zinc Ferrite–PANI Nanocomposite

Rachna et al. (2018) investigated the use of a zinc ferrite–PANI (ZF-PANI) nanocomposite for the adsorption of rhodamine B (RHB) dye. A ZF-PANI dosage of 0.5 g per 20 mL solution produced a maximum removal efficiency of 99% at a dye concentration of 2 ppm within 40 minutes, according to the study, which looked at the impact of dye concentration on adsorption efficiency.

These results demonstrate the strong adsorption capacity and quick removal rate of the ZF-PANI nanocomposite, which makes it a viable option for the effective treatment of wastewater that contains dyes.

Adsorption of Dyes Using Superparamagnetic Clay/PANI/Fe_3O_4 Nanocomposite

Mu et al. (2016) synthesized a two-dimensional superparamagnetic clay/PANI/Fe_3O_4 nanocomposite for dye adsorption and demonstrated its recyclability. Adsorption tests using 100 ppm concentrations of CR, MB, and BG dyes showed high adsorption efficiencies of 98.1%, 99.6%, and 96.2%, respectively. The nanocomposite's superparamagnetic characteristics made it simple to separate from the solution using an external magnetic field, which increased its effectiveness and allowed for repeated adsorption cycles.

Ultrasonicated Adsorption of Crystal Violet Dye Using PANI Nanoparticles

Saad et al. (2017) utilized PANI nanoparticles (PANP) for the elimination of Crystal Violet dye from water-based solutions using ultrasonication. The RSM was used to optimize adsorption conditions, with the study determining that 0.5 g of PANP in a 5 mg/L dye solution yielded a dye removal efficiency of 94.29%. Among the factors considered, the quantity of PANP was found to be the most significant in determining adsorption efficiency. The use of ultra-sonication accelerated the adsorption process, demonstrating that sonication-assisted adsorption is a feasible way for enhancing dye removal rates. The potential of PANI and its nanocomposites as adsorbents for the removal of dyes from aqueous solutions has been extensively studied. These materials can effectively adsorb dyes because of their distinct electrical, surface, and chemical characteristics; several research have concentrated on improving synthesis, characterisation, and adsorption performance.

Removal of Acid Red 52 Using Polymeric Nanocomposites

Gouthaman et al. (2018) synthesized polymeric nanocomposites and applied them to the elimination of Acid Red 52 dye from water solutions. They focused on the synthesis and characterization of a PANI-polyvinyl (PAPV-NZO) nanocomposite, performing kinetic and isotherm studies to optimize adsorption conditions. The study found that PAPV-NZO had a optimum dye adsorption capacity of 159.36 mg/g, with the optimal dosage of adsorbent being 50 mg and an ideal dye concentration of 80 ppm. The adsorption process achieved a removal efficiency of 99.6% at an acidic pH of 2, and kinetic and isotherm models confirmed the adsorption mechanisms, highlighting the composite's effectiveness for dye removal under optimal conditions.

Superparamagnetic Graphene/PANI/Fe_3O_4 Nanocomposites for Dye Adsorption

Mu et al. (2017) developed superparamagnetic graphene/PANI/Fe_3O_4 nanocomposites for the rapid separation and adsorption of CR dye. These nanocomposites achieved a high adsorption competence of 92.4% for a 100 mg/L CR solution within 2 hours. The adsorption kinetics followed a pseudo-second-order kinetic model, though the adsorption data fit well with the Langmuir isotherm model, indicating a maximum adsorption capacity of 248.76 mg/g. Furthermore, the composite exhibited high efficiency in removing mixed dyes, including both cationic BG and anionic CR, demonstrating its versatility as a dye adsorbent.

PANI-doped Lignosulfonate for Adsorbing Dyes and Heavy Metal Ions

Wu et al. (2023) conducted a comprehensive evaluation of PANI-doped lignosulfonate (LS/PANI) composites for the adsorption of heavy metals and dyes. The study optimized the adsorption conditions for malachite green dye, with the ideal parameters being 20 mg of adsorbent, 250 mg/L of dye concentration, 300 minutes of adsorption time, and a temperature of 358 K. The LS/PANI composite showed potential for removing both heavy metal and dyes ions from contaminated water, highlighting the versatility and high adsorption capacity of this material.

Mesoporous PANI-derived Carbon for Large Dye Molecules

An et al. (2020) examined employing mesoporous PANI-derived carbon (PDC) to remove big dye molecules. According to the study, the most effective PDC material outperformed commercial activated carbon by 8.1 times in terms of its adsorption capacity (Q_0) for Acid Red 1 (AR1). The higher adsorption capability of the PDC material for big dye molecules was demonstrated by the adsorption experiments, which were carried out in a model solution with a neutral pH of 7.0. This makes the PDC material a suitable choice for large-scale dye removal from water.

PANI@Fe-ZSM-5 Hybrid Composite for Orange G Dye Removal

Imgharn et al. (2022) created a hybrid composite of PANI@Fe-ZSM-5 to remove Orange G dye from aqueous solutions. The ion-exchange capabilities of Fe-ZSM-5, a zeolite material, were mixed with the adsorption qualities of PANI in this composite. The investigation demonstrated the strong affinity of the hybrid composite for dye molecules by reporting a maximum adsorption capacity of 217 mg/g for Orange G dye. A potential adsorbent for wastewater treatment applications, especially for the removal of synthetic dyes, the composite showed outstanding chemical stability and adsorption capability.

Adsorption of Cr(VI) and Congo Red Using PANI/Graphene Oxide/MWCNT Composites

Ansari et al. (2017) PANI doped with graphene oxide (GO), p-toluenesulfonic acid (pTSA), and multiwalled carbon nanotubes (MWCNTs) was investigated for their potential in adsorbing Cr(VI) and Congo Red from aqueous solutions. The structural stability of MWCNTs, the large surface area and functional groups of graphene oxide, and the conductivity of PANI were all used in this composite. The study found that maximum adsorption occurred in an acidic medium at 30 °C, indicating that the composite's surface was protonated in this pH range, enhancing its affinity for anionic contaminants like Cr(VI) and CR.

Biosorption of Acid Black Dye Using Biocomposites

Noreen et al. (2020) examined the removal of Acid Black dye using biocomposites made of sugarcane bagasse, chitosan, starch, PANI, and polypyrrole. The Langmuir isotherm model was used for the biosorption process, and the maximum adsorption capacities were found for PANI/sugarcane bagasse (PAn/SB) at 90.91 mg/g and polypyrrole/sugarcane bagasse (PPy/SB) at 100 mg/g. Polypyrrole/chitosan (PPy/Ch) and PANI/chitosan (PAn/Ch) shown good adsorption capabilities for the removal of Acid Black dye, according to the study. This suggests that these biocomposites might be used in sustainable, low-cost dye removal applications.

Removal of Methyl Orange and Copper (II) Ions Using PANI-Coated Kapok Fibers

Herrera et al. (2018) investigated the efficacy of PANI-coated kapok (Ceiba pentandra) fibers for removing methyl orange dye and copper (II) ions from aqueous solutions. The optimum sorption capacities were found that to be 81.04 mg/g for copper (II) ions and 75.76 mg/g for MO. In the experiments, a dosage of 30.0 mg of the composite was add to 20.0 mL of solution with varying primary concentrations (40–280 ppm). The initial pH values were set at 4.3 for copper ions and 6.5 for MO, and the solutions were agitated for 24 hours to achieve equilibrium. The study highlights the effectiveness of PANI-coated natural fibers as adsorbents for both metal ions and dyes.

Kinetic Study of Anionic Sulphonated Dye Removal Using Nano PANI

Ahmed et al. (2016) carried out a kinetic analysis with Baker's yeast and nano PANI to remove anionic sulphonated dye. They said that at an adsorbent concentration of 0.1% (w/v), the dye removal efficiency achieved 97%. At doses of 0.15% and 0.2% (w/v), respectively, removals were

94% and 93%, however efficiency decreased as dosage increased. With an initial dye concentration of 275 mg/L, a fixed adsorbent dose of 0.1 g, a pH of 4, and an agitation speed of 150 rpm, the tests were carried out in 250 mL Erlenmeyer flasks at room temperature for 120 minutes.

Tartrazine Removal Using Chitosan/PANI Composite

Sahnoun and Boutahala (2018) investigated the use of a chitosan/PANI composite for tartrazine adsorption. When evaluated with an initial tartrazine concentration of 400 mg/L and a composite dose of 10 mg at a pH of 7.2, the composite demonstrated an impressive maximum adsorption capacity of 584.0 mg/g. The potential of PANI composites to efficiently remove synthetic dyes from aqueous solutions is highlighted by this work.

PANI-Tea Saponin Nanocomposites for Dye Adsorption

Zou et al. (2021) PANI-tea saponin nanocomposites for dye adsorption were created at a minimal cost. They found that when pH levels rose, both the adsorption rate and capacity increased. The capacity peaked at about 6.2 pH, after which it started to decrease. This suggests that maximising dye adsorption requires pH adjustment.

Electrospun Poly(methyl methacrylate)/PANI Fibers for Laccase Immobilization

Jankowska et al. (2020) investigated the use of electrospun poly(methyl methacrylate)/PANI fibers for immobilizing laccase and facilitating dye decolorization. Using a laccase solution at 1 mg/mL, pH 5, and 25 ºC, they achieved maximum enzyme activity through both adsorption and covalent binding. The systems demonstrated removal efficiencies of 58% for covalently attached laccase and 87% for adsorbed laccase in decolorizing Remazol Brilliant Blue R dye.

Removal of Hexavalent Chromium and Acid Red 18 Using Superparamagnetic $CoFe_2O_4$/PANI Nanocomposites

Mohammadi et al. (2021) Superparamagnetic $CoFeO_4$/PANI nanocomposites were created to remove Acid Red 18 and hexavalent chromium ions in ultrasonic fields. It was discovered that the maximal monolayer adsorption capabilities for AR18 and Cr(VI) were 172.41 and 103.11 mg/g, respectively. The investigation showed that the composite efficiently adsorbs both pollutants by assessing the influence of contact duration on the removal efficiency.

Adsorption Characteristics of Carbon-Based Polymeric Nanocomposites

Khan et al. (2021) examined carbon-based polymeric nanocomposites for dye adsorption and found that BG's adsorption achieved equilibrium after 30 minutes, with a maximum capacity of 142.8 mg/g at pH 7. The pseudo-second-order kinetic model and the Langmuir isotherm provided a good description of the adsorption process, demonstrating the composite's great effectiveness in eliminating BG from aqueous solutions.

Silver-Doped Zinc Oxide-Enhanced Polymeric Nanocomposites

A et al. (2019) Silver-doped zinc oxide (Ag-doped ZnO) nanoparticles were synthesised and incorporated into a polymeric nanocomposite to increase the effectiveness of colour removal. When the adsorbent dose was 0.075 g, the dye concentration was 70 mg/L, and the pH was 2, they were able to obtain a maximum adsorption capacity of 94.46 mg/g. The use of metal oxide nanoparticles to increase adsorption capacity is highlighted in this work.

Activated Carbon from Prickly Pear Fruit Seeds for Congo Red Removal

Lahreche et al. (2022) investigated using a conductive polymer matrix and prickly pear fruit seeds to create activated carbon adsorbents for the elimination of CR. The study found that the Freundlich model best described the adsorption isotherm, with a maximum removal efficiency of

91.14% at ideal circumstances (pH 6.6, 1 g/L of adsorbent, and an initial dye concentration of 20 mg/L). The hybrid adsorbent demonstrated substantial stability, maintaining high efficiency over multiple adsorption-desorption cycles.

Hydroxyethyl Cellulose Grafted with PANI and Polypyrrole Biocomposite

Bajaber et al. (2022) synthesized and characterized a hydroxyethyl cellulose biocomposite grafted with PANI and polypyrrole for dye adsorption. The composite was effective in removing Rhodamine B and methyl orange dyes, with optimal pH values around 8–9 and starting concentrations of 300 mg/L. The ideal dosage of 0.5 g led to adsorption capacities of 30.6 mg/g for Rhodamine B and 29.3 mg/g for methyl orange.

Micro Composite-Based Hydroxyapatite Bio Crystal and PANI for Orange G Dye Removal

Mchich et al. (2024) created a hydroxyapatite bio crystal and PANI-based environmentally friendly micro composite for high Orange G dye removal from wastewater. The study demonstrated the efficacy of this composite for dye remediation by reporting a maximum percentage removal of 98.04% at 298 K, pH 6, adsorbent dose of 0.5 g/L, and an initial Orange G concentration of 50 ppm.

PANI@ZnO Hybrid Material for Congo Red and Methylene Blue Removal

Toumi et al. (2021) created a PANI@ZnO hybrid material to extract MB and CR from watery solutions. Maximum adsorption capacities of 69.82 mg/g for CR and 59.23 mg/g for MB were attained by the hybrid material during testing at 298 K and pH 5.0, demonstrating its promise as a flexible adsorbent.

Comparison of Various Adsorbents for Direct Blue Dye Removal

Eisazadeh et al. (2021) conducted a comparative study on numerous adsorbents for removing Direct Blue Dye 14 from aqueous solutions. Batch adsorption studies revealed that PANI-polystyrene (PANI-PS) exhibited significant potential, reaching adsorption equilibrium in 120 minutes. The study evaluated the effects of different adsorbent dosages, pH values, contact times, and primary dye concentrations on the overall adsorption process.

Iron Sulfide Functionalized PANI Nanocomposite for Eosin Y Removal

Danu et al. (2021) examined a PANI nanocomposite functionalised with iron sulphide for the removal of Eosin Y from water. The study investigated the impacts of various FeS/PANI doses (0.05 g to 0.35 g) and starting Eosin Y concentrations (10–60 mg/L) in 50 mL of 100 mg/L Eosin Y solution, offering insights into the effects of adsorbent dosage on the adsorption capacity.

Liu et al. (2020) examined the application of PANI distributed via Kevlar fibres for organic dye absorption, particularly Congo Red (CR). Because of the high starting dye concentrations and the abundance of adsorption sites, their data showed a quick adsorption rate during the first 50 minutes. In the tests, 25 mL of a CR solution and 25 mg of the generated adsorbent were combined in conical flasks on a thermostatic shaker that was set at 25°C and 120 rpm. The results showed that this composite material works well for quick dye adsorption, indicating that wastewater treatment applications may benefit from it.

Activated Carbon-PANI Composites

Bekhoukh et al. (2021) focused on the remediation of anionic MO from aqueous solutions applying activated carbon reinforced with conductive PANI. Their study highlighted the composite's superior adsorption capacity of 192.52 mg/g at 298 K and pH 6.0 compared to PANI alone, which achieved only 46.82 mg/g. The comprehensive investigation into the synthesis, characterization, and regeneration of this adsorbent emphasizes the advantages of combining activated carbon with PANI to enhance dye removal efficiency.

Bacterial Cellulose-PANI Porous Mats

Jahan et al. (2020) created permeable mats made of bacterial cellulose and PANI to remove bacterial pathogens and methyl orange from drinking water. A pseudo-second-order kinetic model (R2 = 0.999) was discovered to describe the adsorption process, and MO's maximal monolayer adsorption capacities were 222, 271, and 293 mg/g at 293, 310, and 320 K, respectively. This study illustrates the potential of utilizing biocompatible materials in conjunction with PANI to address both dye removal and pathogen elimination in water treatment.

Nanoparticle-Enhanced PANI Composites

Aliabadi and Mahmoodi (2018) PANI and polypyrrole nanoparticles, as well as their nanocomposite, were synthesised and characterised for the purpose of eliminating azo dyes like Congo red and sunset yellow. They used a polypyrrole/MWCNT composite to obtain an impressive 99% elimination efficiency for sunset yellow at a low pH of 2. This study emphasises how crucial pH and nanocomposites selection are to maximising dye removal.

Beidellite/PANI Composites

Gengec et al. (2017) optimized the production conditions for a beidellite/PANI composite aimed at removing Acid Yellow 194. Their findings showed that the maximum adsorption capacity remained 123 mg/g under specific conditions (T = 25°C, t = 24 h, pH 3, and 0.15 g adsorbent). As initial dye concentrations increased, the removal efficiency declined from 99% to 46%, demonstrating the necessity of optimizing operational parameters for effective adsorption.

PANI/Silver Nanocomposites

Salem et al. (2016) investigated the use of PANI/silver nanocomposite for vivid green dye adsorption. As the concentration of BG increased from 40 mg/L to 61.2 mg/L, their investigation showed that the adsorption capacity increased from 17.1 to 20.92 mg/g, but the removal efficiency reduced from 89.8% to 75%. The impact of dye concentration on the adsorption properties of PANI composites improved with silver is demonstrated in this study.

PANI Coated Ligno-Cellulose Composites

Ballav et al. (2015) investigated the effective elimination of Reactive Black dye from aqueous solutions by means of a PANI-coated ligno-cellulose composite. Their results indicated rapid sorption kinetics, with equilibrium established in 60 to 120 minutes, depending on the initial dye concentration. They also achieved significant desorption efficiency (up to 98%) using a 1:1 water-acetone mixture, emphasizing the recyclability of the adsorbent.

PANI-Encapsulated Quartz Sand

Amjlef et al. (2023) investigated using quartz sand encapsulated in PANI as an adsorbent to remove Orange G dye. An initial dye concentration of 100 mg/L, an adsorbent dosage of 1.5 g/L, and a contact period of 105 minutes were found to be the ideal adsorption conditions. The results show how effective the use of encapsulated composites in dye adsorption procedures is.

Biocomposites for Dynamic Regime Adsorption

Imgharn et al. (2021) biocomposites based on synthetic PANI that effectively remove Orange G dye. Their investigation assessed how adsorbent dose affected dye adsorption, proving the usefulness of these biocomposites in dynamic adsorption procedures.

Mixed-Phase Nanocomposites

Deb et al. (2021) investigated the use of a mixed-phase FeO_3, $MnFeO_4$, and ZrO_2 nanocomposite impregnated with PANI for the quick elimination of binary dyes. At pH 5.0, the highest adsorption capacities were found to be 217.39 mg/g for MO dye and 117.65 mg/g for EY dye, with removal efficiencies of almost 96% and 78%, respectively. The study emphasises how quickly the adsorption process occurs across a wide pH range.

Magnetite-PANI Composites

Muhammad et al. (2019) examined the use of PANI/magnetite (FeO_4) composites for the adsorption of Basic Blue dye. The highest dye adsorption capabilities were determined to be 78.13 mg/g for the PANI/FeO_4 composite, 47.977 mg/g for PANI, and 7.474 mg/g for FeO_4. The significance of hybrid materials in improving adsorption performance is shown by this study.

Polymer-Nanoparticle Composites

Singh et al. (2021) stated a dramatic enhancement in the adsorption of Congo Red dye using a PANI-zinc titanate polymer-nanoparticle composite. The study demonstrated approximately 90% adsorption of CR in just 15 minutes at initial concentrations of 50-75 ppm. The results indicate the effectiveness of combining polymers and nanoparticles for rapid dye removal.

Polyacid-Doped PANI

Shen et al. (2018) reported results on the use of polyacid-doped PANI for improved adsorption of cationic and anionic dyes. The potential of doped PANI for enhanced dye removal capabilities was demonstrated by the maximum reported adsorption capacities for MB and rhodamine B (RB) of 466.5 mg/g and 440.0 mg/g, respectively.

Kumar et al. (2018) proved the effectiveness of an organic–inorganic nanohybrid based on PANI@MoS2 for the removal of CR, exhibiting an adsorption capacity of 70.921 mg/g at ideal pH 5, 50 °C, and contact period of 120 minutes. Both p–p stacking and electrostatic interactions helped to enhance interactions between the CR molecules and the nitrogen-containing groups of the adsorbent, which defined the adsorption process.

Minisy et al. (2018) concentrated on a hybrid material of chitosan and PANI that demonstrated a maximum adsorption capacity of 81.3 mg/g for the cationic dye MB at pH 11 and 240.4 mg/g for the anionic dye Acid Green (AG) at pH 4. Their results showed a striking 97% dye removal efficiency at 27 °C, underscoring the hybrid material's potential for a variety of wastewater treatment uses. Ayad et al. (2013) introduced a simple synthesis approach for PANI nanoparticles (PANI NPs) and investigated their adsorption characteristics. They reported the use of an intra-particle diffusion kinetic model for the adsorption of MB, utilizing a dye concentration of 4.1 mg/L and an adsorbent dose of 0.01 g. Mohamed et al. (2015 used a 10 mM MB stock solution made by dissolving 1.5 g of MB in 0.5 L of Millipore water (0.3% w/w) and then diluting to get the required concentrations based on the Beer-Lambert law to investigate templated and supported PANI adsorbent materials. Kumar et al. (2015) investigated a unique method for creating functionalised PVC@graphene–PANI fibre bundles, highlighting the importance of pH in the dye adsorption process by observing that the maximum removal of CR happened at pH 4.5. Chafai et al. (2016) examined the adsorption of CR on PANI and polypyrrole, discovering that a full removal of the dye was achieved at adsorbent doses of 0.4 g/L for PANI and 1.73 g/L for PPY after 45 minutes of contact time. Wang et al. (2015) synthesized a PANI/TiO_2 composite by a notable adsorption capacity of 454.55 mg/g for Acid Red G, achieving adsorption equilibrium in approximately 5 minutes. They identified that increasing the dosage beyond 2.0 g/L did not enhance adsorption efficiency, leading to the selection of this dosage for subsequent experiments. Dhanavel et al. (2016) reported on an α-MoO_3/PANI composite for the effective elimination of RB and CR, achieving maximum adsorption capacities of 36.36 mg/g and 76.22 mg/g, respectively. The study emphasized that longer contact times increased dye adsorption, with equilibrium reached within 60 minutes and an adsorption efficiency of 91% at pH 3. Debnath et al. (2015) produced a PANI-lignocellulose composite with a remarkable CR adsorption capacity of 1672.5 mg/g, with almost total removal (99.85%) at ideal circumstances of 0.69 g/L of adsorbent, 28.5 mg/L of starting dye concentration, and pH 4.29. The study went into depth on how pH, dye concentration, and temperature all affect adsorption effectiveness.

Lakouraj et al. (2015) produced a new Fe3O4 supermagnetic/thiacalix[4]arene tetrasulfonate self-doped/PANI nanocomposite and examined the effects of temperature, kinetic time, pH, and dye concentration. A pseudo second-order kinetic model was found to match the adsorption data, and they reported maximal adsorption capacities of 32 mg/g for MB and 29 mg/g for MG.

Yan et al. (2015) synthesized a PANI hydrogel and assessed its adsorption properties for MB. The incorporation of phytic acid enhanced the adsorption capacity, achieving up to 71.2 mg/g. They investigated the cause of varying adsorbent mass on MB adsorption and analyzed the temperature effects by testing at different temperatures, maintaining a consistent reaction time of 12 hours.

The increasing pollution of water bodies due to industrial discharges necessitates the development of effective adsorbents for the elimination of hazardous dyes and heavy metals. PANI, a conductive polymer, has added consideration due to its excellent adsorption properties. This examination emphases on current studies that explore the synthesis, characterization, and application of PANI-based materials in removing contaminants from water.

Novel PANI Biocomposites

Hsini et al. (2020) examined the effectiveness of a new PANI@almond shell (PANI@AS) biocomposite for the extraction of Orange G dye (OG) and hexavalent chromium ions (Cr(VI)) from aqueous solutions. The investigation found that the maximal adsorption capacities for Cr(VI) and OG dye were 335.25 mg/g and 190.98 mg/g, respectively. The PANI@AS biocomposite showed promise for recurring wastewater treatment when it was regenerated using a NaOH solution. The biocomposite's PZC was determined to be 3.8, and ideal adsorption parameters were determined to be 50 mg/L at starting concentration, 120 minutes of contact time, 0.5 g/L of adsorbent dose, and 298 K of temperature.

PANI Nanocomposites for Dye Adsorption

Tanzifi et al. (2018) investigated the use of a PANI/SiO_2 nanocomposite for the adsorption of Amido Black 10B from aqueous solutions. According to their research, the adsorption effectiveness significantly dropped from 99.87% to 97.79% when the starting dye concentration rose from 30 mg/L to 90 mg/L. This result implies that although the PANI/SiO_2 nanocomposite has a large capacity for adsorption, efficiency starts to decrease at a certain concentration.

Yadav et al. (2024) investigated how the cationic dyes MB and CV and the anionic dyes Reactive Red 35 (RR) and Fast Green FCF (FG) could be adsorbed simultaneously on PANI-grafted biomass using its interface chemistry. They demonstrated a significant improvement in monolayer adsorption capacities: 44.44% for MB, 645.83% for RR, 67.88% for CV, and 441.07% for FG. They achieved this by optimising the circumstances impacting dye removal using a Box-Behnken design of RSM. According to the results, binary dye systems have synergistic effects.

Synthesis of PANI Nanotubes

Amer et al. (2018) highlighted the efficiency of PANI hollow nanotubes for the adsorption of both cationic and anionic dyes by reporting their in-situ production utilising Acid Green crystal. They discovered that MB and Acid Green had maximal monolayer capacities of 69.4 mg/g and 57.8 mg/g, respectively. It was shown that MB's adsorption capability decreased as the temperature rose, suggesting an endothermic adsorption mechanism.

Copper-PANI Composites

Obulapuram et al. (2021) examined a Cu(I)-PANI composite's adsorption capabilities for the elimination of Reactive Orange 16 dye. Using the Langmuir model, the study found a maximum adsorption capacity of 392.156 mg/g. Because there were more adsorption sites accessible on the composite, the dye removal % rose with increasing adsorbent dosages.

Coal-PANI Composites

Sayed et al. (2023) created a PANI/coal composite and assessed how well it removed RB dye. The adsorption duration was varied from 30 to 840 minutes under the experimental circumstances, which comprised a dye concentration of 50 mg/L, an adsorbent dose of 0.2 g/L, and a temperature of 25°C. The outcomes demonstrated the composite's potential for useful dye cleanup applications.

Anionic Dye Removal with Cellulosic Biomaterials

Ferchichi et al. (2024) aimed to eliminate the anionic dye phenol red (PSP) from aqueous solutions by creating a thin cationic PANI coating on Posidonia fibres. After 15 minutes of contact time, the investigation showed that PSP could be adsorbed with capacities of 37.8 and 71.5 µmol/g on POS@PANI-EB and POS@PANI-ES, respectively, reaching 97% and 50% adsorption.

Hybrid Aerogels for Dye Removal

Lyu et al. (2022) created hybrid aerogels of PANI, poly(vinyl alcohol), and montmorillonite for the effective adsorption of organic colouring contaminants. The study identified that the adsorption efficiency for various dyes approached equilibrium at specific dosages of the aerogels, with the best performance achieved at 1.0 g/L, indicating optimal conditions for effective dye removal.

2.2 PANI based composite used for antibiotic removal

Table 2.2 PANI based composite used for antibiotic removal

Adsorbents	**Adsorbate**	**(%) Removal**	**Experimental conditions**					**Adsorption capacity mg/g**	**References**
			Concentration (mg/L)	pH	Temperature (^{o}C)	Contact time (min)	Adsorbent dosage (gm/L)		
Reduced magnetic graphene oxide/PANI	Moxifloxacin, ofloxacin	99, 96	150 to 525 µgm/L, 15–40 µgm/L		70	55, 60	10	47.7, 27.33	Ullah et al. (2022)
PANI/Guar gum/acrylic acid hydrogel network	Gram-positive Staphylococcus aureus and gram-	-	-	7	80	150	60 mg	-	R. Sharma et al. (2015)

	negative Escherichia coli bacteria								
poly (vinyl alcohol-co-ethylene)/PANI metal	Tetracycline	86	250 ppm	6.7	25	60	2 mg/g	1555	Amaly et al. (2021)
PANI	Tetracycline	94	-	7	-	6 h	0.01	434.78	Liu et al. (2020)
PANIpolyethylene glycol/surfactant	Cefazolin	95	100	6	-	60	3	-	Arman et al. (2024)
PANI-ZrO2	Escherichia coli and Staphylococcus aureus				37	90	-	-	Masim et al. (2017)

The contamination of water sources by pharmaceutical residues poses significant environmental and health risks. PANI (PANI) and its composites have emerged as effective materials for the adsorption and remediation of several contaminants, together with antibiotics and dyes, from aqueous solutions. This review synthesizes recent findings on the efficacy of PANI-based constituents in the elimination of specific fluoroquinolones, dyes, and other pharmaceuticals.

Removal of Fluoroquinolones

Ullah et al. (2022) used a composite of reduced magnetic graphene oxide and PANI (RmGO/PANI) to study the elimination of certain fluoroquinolones, specifically ofloxacin (OFL) and moxifloxacin (MOX). An analysis of these fluoroquinolones' adsorption behaviour revealed that it followed the Langmuir isotherm model, suggesting a monolayer adsorption process on the RmGO/PANI material's surface. The composite's potential as an efficient adsorbent for eliminating these medicines from polluted water was highlighted by the discoveries that the maximal adsorption capacities for ofloxacin and moxifloxacin were 47.7 mg/g and 27.33 mg/g, respectively.

Biodegradable Hydrogels for Antibacterial and Dye Removal

R. Sharma et al. (2015) created conductive and biodegradable hydrogels based on guar gum polysaccharide for use in colour removal and antimicrobial applications. Following grafting and cross-linking, these hydrogels showed changed surface shape and a significant capacity for water absorption. Significant antibacterial capabilities were demonstrated, especially in semi-interpenetrating polymer networks (semi-IPNs) and interpenetrating polymer networks (IPNs), when the antibacterial activity was evaluated against strains of Staphylococcus aureus and Escherichia coli.

Nanofibrous Membranes for Tetracycline Removal

Amaly et al. (2021) discussed how hierarchical poly(vinyl alcohol-co-ethylene)/PANI metal complex nanofibrous membranes were used to successfully remove tetracycline from dairy manure. With tetracycline adsorption capabilities of 1100 mg/g and 600 mg/g, respectively, the EVOH/PAni-Cl-Cu^{2+} and EVOH/PAni-Cl nanofibrous membranes demonstrated remarkable performance. From dairy manure samples with an initial tetracycline content of 25 ppm, the EVOH/PAni-Cl-Cu^{2+} membrane maintained a dynamic binding efficiency of 450 mg/g while achieving an 86% removal efficiency throughout batch treatment.

Zeolite Imidazole Framework Composites

Liu et al. (2020) investigated the application of PANI as an interface layer for zeolite imidazole framework in-situ growth on regenerated cellulose aerogel. At an initial concentration of 250 mg/g, this composite, known as ZIF-67/PANI/RCA, had exceptional tetracycline adsorption capabilities, reaching a maximum capacity of 409.55 mg/g. The study confirmed the composite's potential for useful uses in wastewater treatment by demonstrating its exceptional recyclability.

PANI-Polyethylene Glycol Modified Adsorbents

Arman et al. (2024) investigated how well PANI-polyethylene glycol composites treated with surfactants removed cefazolin from aqueous solutions. The adsorbent demonstrated an adsorption capacity of 3 g/L by successfully removing a 100 mg/L concentration of cefazolin at a pH of 6 and a contact period of 60 minutes. These findings demonstrate how effectively surfactant changes may improve the adsorption capabilities of PANI-based materials.

PANI-ZrO_2 Composite for Multifunctional Applications

Masim et al. (2017) highlighted the antibacterial, anti-corrosion, and phosphate adsorption properties of a PANI-ZrO_2 composite, demonstrating its synergistic impact. In order to assess antibacterial effectiveness, the study used minimum bactericidal concentration (MBC) tests and agar diffusion experiments. The addition of ZrO_2 nanoparticles to the PANI matrix resulted in increased activity. There is a lot of promise for using this multipurpose composite in environmental cleanup.

2.3 PANI/Sand used for dye removal

Table 2.3 PANI/Sand used for dye removal

Adsorbents	**Adsorbate**	**% Removal**	**Experimental conditions**					**Adsorption capacity (mg/g)**	**References**
			Concentration (mg/L)	pH	Temperature (ºC)	Contact time (min)	Adsorbent dosage (gm/L)		
PANI-encapsulated quartz sand	Orange G	94.14	100	6	25	180	1.2	85.49	Amjlef et al. (2023)
PANI/Glauconite	CR	77	5	7	25	420	0.02	14.1	Salah et al. (2022)

The increasing pollution of water bodies by dyes, particularly from industrial and textile sources, poses significant environmental challenges. Effective and sustainable methods for the removal of these dyes from wastewater are critical. PANI (PANI) and its composites have shown promise as effective adsorbents for various dyes due to their tunable properties and high surface area. This review focuses on recent advancements in the application of PANI-based composites for the removal of dyes, particularly Orange G and CR.

PANI-Encapsulated Quartz Sand for Orange G Removal

Amjlef et al. (2023) improved the adsorption of Orange G dye from aqueous solutions by creating a composite material of PANI-encapsulated quartz sand (QS@PANI). The study included both computational and experimental assessments to assess the composite's performance. According to the findings, the increased number of active sites accessible for adsorption may be the cause of the improved dye removal effectiveness.

An optimal dosage of 1.2 g/L of QS@PANI produced a phenomenal removal rate of 94.14%, achieving the maximum removal efficiency of Orange G. It was determined that the maximal adsorption capacity at this dose was 78.45 mg/g. According to the study, there are saturation points in the adsorption process since increasing the adsorbent dosage over 1.2 g/L did not result in appreciable increases in dye removal efficiency. These results highlight the potential of materials encapsulated in PANI for use in wastewater treatment.

PANI/Glauconite Nanocomposite for Congo Red Removal

Salah et al. (2022) explored the use of a PANI/glauconite nanocomposite for the elimination of CR dye from textile wastewater. The study investigated the adsorption performance of both raw and modified glauconite at 25 °C and pH 7, revealing clearance efficiencies of 77% and 91%, respectively. The enhancement in performance was attributed to the modification of glauconite, which increased its adsorption capabilities.

The impact of different experimental conditions on the kinetics and isotherms of CR adsorption were examined by batch experiments. The glauconite/PANI (Gl/PAN) nanocomposite's maximum adsorption capacity increased from 11.9 mg/g for raw glauconite to 14.1 mg/g for the modified composite, according to the isotherm study. The findings suggested a monolayer adsorption on a surface with a limited number of identical sites, demonstrating that the Langmuir isotherm model correctly reflected the experimental data.

2.4 Sugarcane bagasse used for dye removal

Table 2.4 Sugarcane bagasse used for dye removal

Adsorbents	**Adsorbate**	**(%) Removal**	**Experimental conditions**					**Adsorption capacity (mg/g)**	**References**
			Concentration (mg/L)	**pH**	**Temperature (ºC)**	**Contact time (min)**	**Adsorbent dosage (gm/L)**		
Sugarcane bagasse (SB) and modified SB	Direct red (DR)80		215.8-1028.9	4.9, 2	25	48 h	1	4.2, 28.9	En-Oon et al. (2016)
Sugarcane biomass	Red 4B	92.99	50	2	25	260		37.13	Crespao et al. (2020)
SB	MB	97.6	5		45	24 h	4.38	9.41	Siqueira et al. (2020)
SB/Iron salts	MB		6			60		5.39	Da Silva et al. (2019)
Chemically Modified SB	MB		0.833	5		30		84.7458	Utomo et al. (2015)

Trimellitated SB	safranin-T (ST) and auramine-O	54.12	1.005, 0.374 mmol/L	4.5	25	24 h	0.2	0.94, 0.43	Fideles et al. (2019)
Ionic Liquid Pretreated and Fermented SB	Azo, CR		300	4.5	30		0.10%	543.589	Ejaz et al. (2021)
Magnetic SB activated carbon	MB		87.94	8	30	120	5	36.14	Jiang et al. (2019)
SB	MB	99.3	25	6	25	20	0.2	49.261	Kerrou et al. (2021)
SB beads, SB modifed with TiO_2 beads, SB modifed with MgO beads, SB modifed with Al_2O_3 beads, SB modifed with ZnO beads	DR 28	81.90, 85.23, 92.67, 87.30, 83.73	15, 20, 15, 25	3	35	24 h	20	94.27	Praipipat et al. (2024)
Treated SB	MB, drimaren red	>90, 60			65			228	Mondal et al. (2022)

SB impregnated with Fe_2O_3	MB, MG, Reactive Red 535, Remazol Brilliant Blue R	93.7, 88.8	10	9, 8.4	25	6 h	0.1	7.7	Buthiyappan et al. (2019)
Carboxylate-functionalized SB	MB	95	100	7	30	180	1	296.74	Wang et al. (2018)
Cellulose/SB	CR and auramine-O		200	8	25	12, 9 h		1117.8, 1223.3	Martins et al. (2017)
SB/CH_2OSB/carbonaceous SB	MG	90, 70, 89	29.1		30, 40, 45	25, 25, 20	0.3, 0.4, 0.1		Tahir et al. (2016)
Activated carbon from SB/natural zeolite	MB	88.6	30 ppm	10	25	45	50	51	Mohamed et al. (2022)
SB powder	Reactive red 120	94.62	15	3		60	0.2		Ahmad et al. (2018)
Chitosan/SB	Remazol red	99.8		6	25	60	150		Hamzah et al. (2022)
SB Pulp	MB	95	100	7	25	15	20		Elshabrawy et al. (2023)

SB/KOH	MB	97	100 ppm	12	55	90	0.1	195.44	Al-Mokhalelati et al. (2021)
SB	MB	73.29	36.7	5.77	15-35	120	1.21		Aghilesh et al. (2021)
Biochar SB	CV, MB	90, 95	30	7	25	15, 45	20	73.55, 68.80	Moharm et al. (2022)
SB	MB, CV	98.3, 98.2	50	8	35	60	2.5, 0.5		Kumari et al. (2023)
Sodium alginate/NaOH treated activated SB	MG	97.99	25	8		115.43	0.3	12.42	Das et al. (2020)
Cellulose nanocrystals SB/polyacrylic acid/active carbon	MB	86.3	50 ppm	7	25	120	50	43.15	Almuslem et al. (2023)
SB nanocellulose	RB	95	10 ppm	12	50	45	0.06		Vijayan et al. (2023)
SB	MG	99.3	114.5	5.85	30	96 h	0.11	20.6	Li et al. (2018)
SB	Reactive Red 24	85	250	3	27	60	1	77.41	Van et al. (2021)

Cellulose nanofiber SB	MB, CR	99, 71.5	100, 300	7, 5	25	3	0.5	200, 111.1	Sankararamakrishnan et al. (2020)
Chemically modified SB	Optilan yellow and Lanasyn brown	98.23, 98.76	33, 24		30	50, 60		0.187, 0.137	Samchetshabam et al. (2018)
SB	MB	91.6	100	5.5	25	200	0.5	17.4345	Meili et al. (2019)
SB	Optilan Red	93.5	30 ppm	6.04	30	60	10	0.7434	Gita et al. (2017)
SB biochar	CV		20	5	20		0.2	97.46	Kumari et al. (2024)
SB	Reactive Black-5, Acid orange 10		25	3		60	0.6		Abdelghaffar et al. (2019)
Pozzolan and SB	MB	99	50	5	10	30	0.1	455.46	Dzoujo et al. (2022)
Chemically modified SB	Acid red 1	82	400	2	30	60	0.05	205.1	Kamran et al. (2022)

SB ash	Acid red 27	75	30	2	30	240	4	15	De Santana et al. (2024)
Chemically Modified SB	Direct Fast Turquoise Blue	99.3	20	9	30	240	0.4	8.4	Ly et al. (2020)
Cationic dialdehyde cellulose SB	Eriochrome Black T	92.6	100	2	25	30		563.3	Gomes et al. (2023)
SB	MB	98	50	4.8	50	60	0.1	85.8	D. Wang et al. (2022)
SB waste	MB	83.2	250	8	30	600	0.08	136.5	Jawad et al. (2021)
SB Biochar	MG	99.99	3000	7.5	60	51.89			Vyavahare et al. (2018)
Polyethylenimine Modified SB	MO	82	0.1	7	30	240	0.15	30	N. B. Mohamed et al. (2017)
Modified SB	CR	95	0.7	6.7	25	364	0.08	790.7	Yu et al. (2016)

Modified SB	Acid orange 7		200	7	25	120		144.93	Malek et al. (2016)
Carboxylate-functionalized SB	CV	100	125	7	45	720	0.2	692.1	Ferreira et al. (2015)
SB	Turquoise Blue PG		150	5	30	120	0.05g/50 ml	69.73	Bhatti and Nausheen (2014)

Water pollution due to the discharge of synthetic dyes from industrial processes is a growing environmental issue. Efficient removal of these dyes from wastewater is essential to safeguard aquatic ecosystems and human health. Sugarcane bagasse, an agricultural byproduct, has emerged as a promising biosorbent due to its abundance, low cost, and biodegradability. This review examines current observations that explore the usage of sugarcane bagasse and its modified forms for the adsorption of various dyes from aqueous solutions.

Adsorption of Direct Red 80 Dye

En-Oon et al. (2016) used sugarcane bagasse and modified sugarcane bagasse to study the adsorption of Direct Red 80 dye. The adsorption capabilities of 1.0 g of raw sugarcane bagasse and modified sugarcane bagasse were found to be 4.2 mg/g and 28.9 mg/g, respectively, at an initial dye concentration of 1,028.9 mg/L during their experiments. The modification's notable increase in adsorption capacity emphasises how crucial surface area and active sites are to improving dye removal efficiency.

Biosorption of Red 4B Dye

Crespao et al. (2020) investigated the use of Pleurotus ostreatus-colonized sugarcane biomass to remove Red 4B dye, offering a sustainable dye treatment option. The impact of temperature, pH, contact duration, and concentration on the biosorption process was investigated. It appears that acidic circumstances facilitate the adsorption process since the maximum biosorption capacity was attained at pH 2.0. The authors emphasized that the interactions involved might extend beyond electrostatic attractions, pointing to the complexity of biosorption mechanisms.

Methylene Blue Adsorption

Siqueira et al. (2020) assessed sugarcane bagasse as a successful biosorbent for the removal of Methylene Blue by examining the process's kinetics, isotherms, and thermodynamics. The maximum adsorption capacity was found to be 9.41 mg/g at 45 °C following a 24-hour contact period. According to the study, sugarcane bagasse is effective at treating low-concentration dye solutions because it was able to remove 97.60% of the MB at an initial concentration of 2 mg/L.

Optimizing Sugarcane Bagasse Composites

In a study by Da Silva et al. (2019), The production parameters of sugarcane bagasse and iron salt composites were optimised for dye adsorption, and the results showed that the ideal surface area for MB adsorption was found at an initial concentration of 6.0 mg/L. The specific area was relatively low (53 m²/g), but the composite showed a maximum capacity of 5.39 mg/g, demonstrating its potential despite certain limitations.

Chemically Modified Sugarcane Bagasse

Utomo et al. (2015) focused on using chemically modified sugarcane bagasse (NSGB) to remove Methylene Blue; their research showed that adsorption efficiency varied with NSGB dosage and contact time, especially at an initial MB concentration of 3.739 mg/L and pH 5. The results showed that modified sugarcane bagasse could improve dye removal under certain conditions, which further supports the versatility of sugarcane bagasse as an adsorbent.

Trimellitated Sugarcane Bagasse

Fideles et al. (2019) reported on trimellitated sugarcane bagasse as a flexible adsorbent for the removal of cationic dyes from aqueous solutions. Their research discovered that the maximum adsorption capacity values were lower than unity in both mono- and bicomponent systems due to antagonistic interactions between dyes. This study highlights the potential challenges in the simultaneous adsorption of multiple dye types.

Ionic Liquid-Pretreated Sugarcane Bagasse

Ejaz et al. (2021) investigated the usage of ionic liquid-pretreated and fermented SCB for CR elimination. The results showed that untreated sugarcane bagasse had a removal efficiency of 90.36%, while the pretreated and fermented forms achieved efficiencies of approximately

98.35% and 97.70%, respectively. The thermodynamic, isotherm, and kinetic studies revealed distinct adsorption properties, indicating enhanced performance due to the treatment processes.

Iron Oxide/Activated Carbon Magnetic Composites

Jiang et al. (2019) shown the use of iron oxide/activated carbon magnetic composites generated from sugarcane bagasse for the adsorption of cationic dyes. The study indicated that the pH range of 2–10 did not significantly impact MB adsorption, which reached a maximum capacity of 36.14 mg/g. This study demonstrated the effectiveness of magnetic composites in dye removal applications by investigating the effects of temperature and contact time on dye adsorption.

Sugarcane Bagasse for Methylene Blue Removal

Kerrou et al. (2021) investigated the use of sugarcane bagasse to remove MB dye from wastewater, and the findings demonstrated that the percentage of MB elimination increased significantly at a low concentration of 25 mg/L, reaching a maximum removal efficiency of 97% with an adsorbent mass of 0.2 g. The study also reported a maximum adsorption capacity of 49.261 mg/g, suggesting that sugarcane bagasse has the potential to be an effective adsorbent for dye removal.

Cationic Oxides and Dioxides from Modified Sugarcane Bagasse

Praipipat et al. (202 examined how well modified sugarcane bagasse beads produced cationic oxides and dioxides removed the dye Direct Red 28 (DR28). The modified sugarcane bagasse beads showed the maximum removal effectiveness of 94.27%, whereas all investigated materials were able to adsorb more than 81% of DR28 at a concentration of 50 mg/L. This study underscores the importance of modifying sugarcane bagasse to enhance its adsorptive properties.

Biodegradable Hydrogel from Sugarcane Bagasse

In another study, Mondal et al. (2022) developed a biodegradable hydrogel from treated sugarcane bagasse, achieving over 90% removal of Methylene Blue and 62% removal of Drimaren Red dye. The reaction conditions were optimized to maximize yield, and the resulting hydrogel exhibited a remarkable water absorption capacity of 228.0 g/g. This innovative approach demonstrates the versatility of sugarcane bagasse in developing sustainable materials for wastewater treatment.

Iron Oxide-Impregnated Sugarcane Bagasse

Buthiyappan et al. (2019) SCB was treated with synthetic iron oxides to assess its adsorption effectiveness. The study used 0.7 g/L of the iron-impregnated sugarcane bagasse at pH 8.4 and discovered that the adsorbent had a dye adsorption capacity of 7.2 mg/g within 6 hours of contact, removing 93.7% of the dye and 88.8% of the colour. The study examined a range of dye types, such as anionic Remazol Brilliant Blue R and cationic MB, demonstrating the wide range of applications for this environmentally friendly adsorbent.

Carboxylate-Functionalized Sugarcane Bagasse

Wang et al. (2018) centred on using sugarcane bagasse with carboxylate functionalisation as a sustainable adsorbent to remove Methylene Blue. The maximal monolayer adsorption capacity of carboxylate-functionalized SCB was 296.74 mg/g at 30 °C, which was much more than that of untreated sugarcane bagasse (77.16 mg/g), according to the research. The adsorption process was rapid, with nearly 95% MB removal achieved within 3 hours, demonstrating the potential of functionalized bagasse for effective dye removal.

Optimization of Sugarcane Bagasse for Dye Removal

Martins et al. (2017) optimised sugarcane bagasse and cellulose oxidation for the adsorptive extraction of Auramine-O and CV from aqueous solutions. Crystal Violet and Auramine-O were shown to have maximal adsorption capabilities of 1117.8 mg/g and 1223.3 mg/g, respectively. Strong interactions between the dyes and the oxidised bagasse were shown by the adsorption isotherms, which suited the Langmuir and Konda models well.

Natural and Modified Sugarcane Bagasse for Dye Removal

Tahir et al. (2016) investigated the use of both natural and modified SCB for dye removal, finding that the development of novel surface functional groups and an increase in surface area in the modified bagasse resulted in an estimated removal effectiveness of 89%. Various temperatures between 303 K and 318 K were tested to identify optimal adsorption conditions.

Activated Carbon from Sugarcane for Methylene Blue Adsorption

Mohamed et al. (2022) investigated the effective adsorption of MB dye using sugarcane-derived activated carbon that has been treated with natural zeolite. A maximum adsorption capacity of around 51 mg/g was found under ideal circumstances (25 °C, pH 7) at a starting concentration of 30 ppm. The study examined the effects of pH, initial dye concentration, and contact duration.

Biosorption of Reactive Red 120

Ahmad et al. (2018) shown how well sugarcane bagasse powder works as a biosorbent to remove the colour Reactive Red 120. At a dye concentration of 15 mg/L and a pH of 3, the batch tests showed a maximum adsorption percentage of 94.62%. According to the results, sugarcane bagasse is a good choice for treating wastewater that contains dyes.

Integration of Chitosan and Sugarcane Bagasse

Hamzah et al. (2022) investigated using sugarcane bagasse and chitosan together as an adsorbent to remove Remazol Red colour. According to the study, treated sugarcane bagasse performed better than untreated bagasse at an equilibrium time of 60 minutes and an optimal adsorbent dose of 150 mg. In acidic circumstances (pH 4), the removal efficiency was favoured, suggesting that pH should be taken into account in order to maximise adsorption efficacy.

Sugarcane Bagasse Pulp for Dye Removal

Elshabrawy et al. (2023) examined how well sugarcane bagasse pulp treated dye-containing effluent. With an initial dye concentration of 100 mg/L, a temperature of 25 °C, a pH of 7, and an adsorbent dosage of 20 g/L at a shaking speed of 130 rpm, the study determined the ideal conditions for dye removal. With a removal effectiveness of 95.135%, it was shown that 15 minutes was the ideal contact time for maximal colour removal. Interestingly, it was discovered that a greater adsorbent dosage of 40 g/L was not required because the 20 g/L dose worked well and cut the amount of adsorbent material used in half.

Adsorption of Methylene Blue onto Sugarcane Bagasse-Based Adsorbents

Al-Mokhalelati et al. (2021) investigated MB's adsorption onto adsorbent materials based on SCB. The ideal MB solution concentration for both treated and untreated sugarcane bagasse was found to be 0.1 g/50 mL by their batch adsorption investigations. The optimal parameters for adsorption were determined to be 90 minutes of contact time, pH values between 5 and 9, 0.1 g of dose, and an initial MB concentration of 100 ppm. This work demonstrates how SCB may be used effectively in regulated dye adsorption.

Artificial Intelligence in Biosorption Optimization

Aghilesh et al. (2021) used artificial intelligence to maximise textile wastewater biosorption utilising SCB and other agricultural waste. Several factors influencing dye removal were investigated in the study, including temperature (15°C to 35°C), pH (4–8), starting MB concentration (10–50 mg/L), and biosorbent dose (0.5 g to 2.5 g). The potential of AI in optimising biosorption processes was demonstrated by the notable increases in dye removal efficiency at an ideal biosorbent dose of 1.21 g, pH 5.24, and MB concentration of 31.24 mg/L.

Biochar from Sugarcane Bagasse for Dye Removal

Moharm et al. (2022) The adsorption process was well-described by the Langmuir isotherm model, with maximum adsorption capacities of 114.42 mg/g for MB and 99.50 mg/g for CV. This study highlights the potential of biochar made from sugarcane bagasse in treating wastewater that is dye-laden. A biochar biosorbent was created from agricultural waste to efficiently remove cationic dyes.

Integrated AI Models for Dye Detoxification

In a subsequent study, Kumari et al. (2023) combined response surface methodology and artificial neural networks to forecast the detoxification of hazardous dyes, specifically MB and CV, using Saccharum officinarum L. biomass. The results showed that, under ideal conditions, a constant agitation speed of 120 rpm for one hour could achieve maximum dye removal efficiencies of 98.3% and 98.2%, respectively. This study highlights the effectiveness of combining computational models with experimental data for optimizing dye removal processes.

Biodegradable Activated Sugarcane Bagasse Charcoal Beads

Das et al. (2020) studied the use of biodegradable sodium alginate/NaOH-treated activated sugarcane bagasse charcoal beads to treat MG dye. The study found that the optimal conditions for malachite green adsorption were 0.2 g/L of adsorbent mass, 115.43 minutes of contact time, and a pH of 8. The adsorption efficiency reached 97.88% at an initial concentration of 25 mg/L, indicating the efficacy of modified SCB in dye removal.

Nanocomposite Films for Organic Dye Adsorption

Almuslem et al. (2023) described the creation and properties of thin films of cellulose nanocrystal/polyacrylic acid nanocomposite for the adsorption of organic dyes. At an adsorbent mass of 50 mg, a dye concentration of 50 ppm, and a contact time of 120 minutes at 25 °C, the film—which was made up of 64 weight percent cellulose nanocrystals, 16 weight percent polyacrylic acid, and 20 weight percent activated carbon—showed a high dye removal efficiency of 86.3% and an adsorption capacity of 43.15 mg/g. The potential of novel materials made from sugarcane bagasse for dye adsorption is demonstrated in this work.

Bagasse Nanocellulose-Filled Composite for Dye Removal

Vijayan et al. (2023) created a composite polyurethane xerogel packed with bagasse nanocellulose to effectively adsorb RB colour. Numerous factors that impact adsorption were examined, including the amount of adsorbent (0.02-0.06 g), pH (6-12), temperature (30-50 °C), and contact duration (30-90 minutes). After 45 minutes of contact time, the ideal circumstances of pH 12, 50 °C, and an adsorbent dosage of 0.06 g produced a clearance rate of almost 95% at an initial dye concentration of 10 ppm.

Nano-Biomaterials for Malachite Green Removal

Li et al. (2018) investigated the removal of malachite green from aqueous solutions using novel nano-biomaterials. A temperature of 31.5 °C, an initial concentration of 114.5 mg/L, a pH of 5.85, and an adsorbent dose of 0.11 g/L were found to be the ideal parameters for MG removal. Under these conditions, a remarkable removal efficiency of 99.3% was achieved, emphasizing the effectiveness of nanomaterials in wastewater treatment.

Enhancement of Dye Adsorption with Biochar

Van et al. (2021) focused on enhancing the adsorption of Reactive Red 24 using biochar derived from agricultural waste, modified with ZnO nanoparticles. The study demonstrated the efficacy of modified biochar in dye removal by reporting RR24 adsorption capacities of 81.04 mg/g for CRHB-ZnO_3 and 105.24 mg/g for SBB-ZnO_3 at an initial dye concentration of 250 mg/L, pH 3, and a contact duration of 60 minutes.

Hierarchical Nano Fe(0)@FeS Composite for Dye Treatment

Sankararamakrishnan et al. (2020) created a hierarchical nano Fe(0)@FeS composite for organic dye treatment using agricultural waste. The composite showed maximal adsorption capabilities of 111.1 mg/g for CR and 200.0 mg/g for Methylene Blue. The rapid degradation kinetics observed for MB, with a 70% intensity decrease within three minutes at pH 7, highlights the potential of this bionanocomposite in dye removal applications.

Performance Evaluation of Agro-Waste Adsorbents

Samchetshabam et al. (2018) carried out a thorough investigation into the performance assessment and chemical modification of agricultural waste for the column-mode removal of textile dyes. Metrics including breakthrough ratio (Ce/C0), adsorption capacity (q), and removal efficiency (R%) were used to gauge the adsorbent's efficacy. The study reported that over 90% of various dyes and more than 80% of effluent from textile industries were removed. Notably, a maximum removal of 98.76% was achieved for Lanasyn brown dye at a concentration of 20 ppm within 60 minutes, highlighting the potential of modified agro-waste in industrial applications.

Adsorption Characteristics of Agro-Industrial Wastes

Meili et al. (2019) examined how MB adsorbs different agro-industrial wastes, such as SCB. Different MB concentrations (100, 150, 200, and 250 mg/L) were used in their studies, and 0.5 g of sorbent was allowed to encountered it for 200 minutes at 110 rpm. This study elucidated the adsorption behavior of agro-waste materials, indicating their capacity for dye removal under varying concentration conditions.

Prototype Column Bed Device for Dye Removal

Gita et al. (2017) developed a prototype column bed device utilizing SCB for the elimination of Optilan Red dye. Their findings indicated that more than 93% dye removal could be achieved within a concentration range of 10–50 ppm. The column-based system effectively treated dye effluents from the textile sector, demonstrating a high removal efficiency of over 90%. The maximum elimination observed was 93.5% at a concentration of 30 ppm within just 10 minutes, showcasing the rapid adsorption capability of the system.

Machine Learning Approaches in Dye Treatment

In a recent study, Kumari et al. (2024) investigated machine learning techniques for SCB biochar-based textile wastewater treatment. Their statistical calculations showed that, under the following circumstances, an adsorbent dosage of 0.4 g, pH of 5, CV concentration of 40.1 mg/L, and temperature of 20 °C produced an ideal removal efficiency of 97.46%. The effectiveness of machine learning in enhancing the dye removal procedure is illustrated by this study.

Modified Sugarcane Bagasse for Anionic Dye Removal

Abdelghaffar et al. (2019) intensive on the effectiveness of modified SCB for the removal of anionic dyes such as Acid Orange 10 (AO10) and Reactive Blue 5 (RB5). Their experiments examined the impact of varying dye concentrations (25 to 300 mg/L) on color removal percentages, revealing that the modified SCB's removal efficiency decreased with increasing dye concentration. The study established optimal conditions for dye removal, which varied based on the specific dye being tested.

Geopolymer-Biochar Composites for Methylene Blue Adsorption

Dzoujo et al. (2022) produced geopolymer-biochar composites from pozzolan and SCB for the adsorption of MB. Their results indicated a substantial increase in adsorption capacity with higher biochar content, ranging from 24.44 mg/g in GP0 to 455.46 mg/g in GP10—an 18-fold increase. The study also predicted the required amount of adsorbent to achieve 99% removal of MB in various volumes of effluent, illustrating the enhanced capabilities of composite materials.

Kinetics and Thermodynamics of Acid Red 1 Removal

Kamran et al. (2022) discussed the use of chemically modified sugarcane bagasse-based biocomposites to remove Acid Red 1 dye, as well as the kinetics, isotherms, and thermodynamics of this process. pH = 2, dose = 0.05 g, contact duration = 60-75 min, and an initial dye concentration of 400 mg/L were found to be the ideal batch adsorption parameters. The efficiency of the modified biosorbents was demonstrated by the maximal adsorption capacities, which varied between 143.4 and 205.1 mg/g under these circumstances.

Adsorption Characteristics of Sugarcane Bagasse Ash

De Santana et al. (2024) used SCB ash (SCBA) to study the adsorption properties of the commercial colour Acid Red 27. They found that an adsorption equilibrium was attained in around 4 hours, that the appropriate SCBA dose was 4 g/L, and that the perfect pH for dye removal was 2.0. The equilibrium data was best fitted by the Freundlich isotherm, and the maximum adsorption capacity was determined to be 15 mg/g. This work demonstrates SCBA's potential as a practical dye removal adsorbent.

Modified Sugarcane Bagasse for Direct Fast Turquoise Blue Removal

Ly et al. (2020) investigated the removal of Direct Fast Turquoise Blue dye using chemically modified sugarcane bagasse. At pH 9, the modified SCB's highest adsorption capacity was 8.40 mg/g. By adding 0.4 g of adsorbent to 50 mL of dye solution at a concentration of 20 mg/L, they investigated the impact of contact duration while highlighting the significance of pH in maximising adsorption effectiveness.

Cationic Dialdehyde Cellulose Microfibers for Dye Removal

Gomes et al. (2023) Detailed studies on the effective removal of Eriochrome Black T (EBT) from aqueous solutions using cationic dialdehyde cellulose microfibers. According to their results, the highest adsorption capacity was 563.30 mg/g when EBT was present at a concentration of 5.0 mg/L, a cDAC suspension was present at 7.5 mg, and the final volume was 15 mL. The study further demonstrated creative dye removal techniques by examining the impact of pH on dye adsorption capacity and removal efficiency.

Valorisation of Sugarcane Bagasse for Pollutant Removal

Wang et al. (2022) investigated the use of sugarcane bagasse as a residue adsorbent for the elimination of pollutants and for the extraction of sugar. With 98% of MB eliminated by both SCB and SCB extract (SCBE), as well as noteworthy removal rates for Cu2+ ions, the study demonstrated strong pollutant removal capabilities. The potential of sugarcane bagasse as an efficient adsorbent was demonstrated by the greatest adsorption amounts, which were 85.8 mg/g (MB by SCB) and 77.5 mg/g (MB by SCBE).

Microporous Activated Carbon from Biomass Waste

Jawad et al. (2021) created microporous activated carbon from waste biomass activated with KOH and examined how well it adsorbs MB dye. 136.5 mg/g was the highest adsorption capacity measured. The study looked at how adsorbent dose affected the removal of MB and showed that, while keeping other parameters constant, raising the dosage from 0.02 g to 0.08 g greatly increased removal efficiency from 10.5% to 83.2%. These findings emphasize the importance of optimizing adsorbent dosage to achieve efficient dye removal.

Response Surface Methodology for Malachite Green Dye Removal

Vyavahare et al. (2018) optimised the MG dye adsorption onto sugarcane bagasse biochar using response surface methodology (RSM). Even at a concentration of 3000 mg/L, the biochar, which was prepared at 800 °C, demonstrated good adsorption effectiveness. With a remarkable removal effectiveness of 99.99%, the ideal circumstances determined by the Box–Behnken RSM model were a pH of 7.5, a temperature of 60 °C, and a contact duration of 51.89 minutes. This study demonstrates how well RSM works to optimise dye adsorption procedures.

Polyethylenimine Modified Sugarcane Bagasse for Methyl Orange Removal

N. B. Mohamed et al. (2017) examined the application of SCB modified with polyethylenimine as an adsorbent for the removal of MO dye. Their findings showed that a maximum removal effectiveness of 82.78% was achieved under ideal circumstances, which included a contact period of 240 minutes, an initial dye concentration of 0.01 g/L, an adsorbent dose of 0.15 g/50 mL, a temperature of 30 °C, and a pH of 7. This study emphasises how chemical changes might improve the ability of agro-waste materials to adsorb dyes.

Congo Red Removal Using Modified Sugarcane Bagasse

In a study by Yu et al. (2016), to remove Congo red dye from aqueous solutions, several amine compounds modified sugarcane bagasse were used. A dye solution with starting concentrations ranging from 0.05 to 0.9 g/L was used in the adsorption isotherm tests, and a solution concentration of 0.7 g/L combined with 0.08 g of modified SCB was used in the kinetic investigations. The adsorption kinetics of modified agro-waste adsorbents are better understood thanks to this work.

Cetylpyridinium Bromide Modified Sugarcane Bagasse for Acid Orange 7

Malek et al. (2016) discussed the use of cetylpyridinium bromide modified SCB for the adsorption of Acid Orange 7 (AO7). The trials, which were carried out in batch mode, showed an amazing adsorption capacity of 144.928 mg/g. The study assessed the effects of beginning pH levels (2–9), initial CPBr concentrations, and initial AO7 concentrations (5–1000 mg/L) on the adsorption efficiency, showing that these factors had a major impact on dye removal.

Kinetic Studies of Crystal Violet Adsorption

Ferreira et al. (2015) examined the CV dye's adsorption kinetics and found that equilibrium was achieved after 12 hours. With a maximum capacity of 692.1 mg/g recorded at 45 °C, the results showed that the quantity of CV adsorbed rose with temperature. According to these results, temperature is a critical factor in increasing the adsorption capacity of biosorbents.

Equilibrium and Kinetic Modeling for Turquoise Blue PG Dye Removal

Bhatti and Nausheen (2014) investigated in detail the kinetic and equilibrium modelling for the removal of Turquoise Blue PG dye using inexpensive biosorbents made from agricultural waste. Numerous factors were assessed, such as pH levels (5–9), temperature (30–60 °C), biosorbent dose (0.05–0.30 g), contact duration (0–180 minutes), starting dye concentration (10–200 mg/L), and many more. With the best results found at a pH of 5 and smaller biosorbent doses, the modified biosorbent demonstrated a maximum biosorption capacity of 69.73 mg/g for the dye, demonstrating the potential for efficient dye removal in real-world applications.

2.5 Research Gap

Limited Understanding of Interaction Mechanisms

- Polyaniline and sand composite material as adsorbent for the removal of dye MB and antibiotic (Doxycycline) not reported yet.
- Sugarcane bagasse (SCB) adsorbent for the removal of dyes (MB, MO, NR) simultaneously not reported yet.
- There is a lack of comprehensive studies investigating the underlying mechanisms of dyes adsorption and antibiotic degradation on PANI/sand and SCB adsorbents, necessitating a detailed mechanistic understanding.

Optimization of Synthesis Conditions

- Current research often overlooks the optimization of synthesis parameters for PANI/sand and SCB adsorbents, which can significantly affect their structural properties and adsorption efficiency.

Diversity of Dyes and Antibiotics Tested

- Most studies focus on a narrow range of dyes and antibiotics; broader investigations are needed to evaluate the effectiveness of PANI/sand and SCB adsorbents composites against various contaminants with differing physicochemical properties.

Long-term Stability and Reusability

- Research is limited on the long-term stability and reusability of PANI/sand and SCB adsorbents, which are critical for practical applications in wastewater treatment.

Environmental Impact Assessments

- There is a need for more studies assessing the environmental impacts of using PANI/sand and SCB adsorbents, particularly concerning the degradation products of antibiotics and dyes.

Batch vs. Continuous Flow Systems

- Current research primarily focuses on batch adsorption studies; further investigation into the performance of PANI/sand and SCB adsorbents in continuous flow systems is essential for practical wastewater treatment applications.

Comprehensive Kinetic and Isotherm Studies

- Existing studies often provide limited kinetic and isotherm analyses; thorough characterization of these dynamics is necessary to enhance predictive models for real-world applications.

Cost-Effectiveness and Scalability

- There is insufficient exploration of the cost-effectiveness and scalability of producing PANI/sand and SCB adsorbents, which is crucial for their commercial viability.

Synergistic Effects with Other Materials

- Limited research has explored the potential synergistic effects of combining PANI/sand and SCB adsorbents with other materials (e.g., nanoparticles or additional biosorbents) to enhance adsorption and degradation performance.

Field-Scale Applications

- Most research is conducted in laboratory settings; there is a significant gap in studies evaluating the performance of PANI/sand and SCB adsorbents in real-world field applications and their effectiveness in treating industrial effluents.

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