



Environmental Remediation using Novel Sponges as an Effective Adsorbents

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Abstract

At present, the precious water resource is of concern due to its depletion by toxic elements and organic pollutants that result in environmental hazards. The present work comprises various sponge adsorbents with unique adsorption performance in environmental remediation. Researchers explored novel chitosan and cellulose-based sponge adsorbents as green materials in the adsorption of toxins. Chitosan sponge adsorbent (MIL-101(Fe)@CS Sponge) with adsorption capacity 4518 mg/g and polyurethane sponge-based adsorbent (RCS) with adsorption capacity 1263.5 mg/g were identified as superior sponge adsorbents in dye removal. The dye adsorption on sponge adsorbents occurred predominantly through the chemical adsorption mechanism with electrostatic interaction. The adsorption capacity of sponge adsorbents in environmental remediation is in the following order (Chitosan sponge>polyurethane sponge>Cellulose sponge> Graphene sponge>luffa sponge). The current interest among researchers in using bio-materials will provide a worthy challenge and the future possibility of designing novel sponge adsorbents with unique surface properties for various applications.

Keywords: Sponge Adsorbents; Adsorption Capacity; Environmental Remediation; Adsorption



Figure 1: Novel sponges as adsorbent.

Introduction

The present concern to preserve the quality of our precious water resources due to global climate change has generated more interest in water remediation. The toxic elements and organic pollutants in water even in low concentrations results in environmental hazards and is of major concern. The discharge of toxic effluents into the aquatic ecosystem causes irreversible health damage and death of people around the world [1-10]. The toxic dyes and heavy metal's presence in surface water impart

color and retard the percolation of sunlight with a negative impact on the photosynthetic activity of aquatic biota. To eliminate the toxic elements and organic pollutants present in the waste water, several treatment methods were used with varying success rates like the ion-exchange method, Photocatalysis, adsorption etc., In water remediation, some treatment methods were costly and not affordable, economically in less developed countries. The adsorption technique is a convenient and ideal method that is of significant interest to researchers, as some novel adsorbents used in water remediation was efficient with unique surface properties. Sponge adsorbents have a porous structure, high specific surface area, and easily recoverable nature from solution, by simple regeneration procedure [11-30]. The adsorption properties of hybridized sponges prepared by the introduction of nanomaterials were reported to increase the adsorption properties of the sponge. Sponge adsorbents proved efficient in the removal of toxic pollutants with good surface properties and high adsorption performance. The toxic contaminants present in surface water affect humans, plants, animals, and other living organisms and this necessitates the design of efficient sponge adsorbents with good adsorption capacity in environmental remediation. The graphene sponge, cellulose sponge, luffa sponge and chitosan sponge has attracted more researchers to develop novel sponge adsorbents in environmental remediation [31-40].

Graphene oxide sponge

Graphene oxide possesses more oxygen-containing functional groups including carboxylic groups, phenolic hydroxyl groups, and epoxide groups on its surface. 3D lightweight carbon-based sponge with high porosity exhibits poor mechanical properties, whereas lightweight GO-based porous 3D structure has outstanding compressibility and structural reliability. Hence, GO-based sponges were prepared and tested for their mechanical properties as a reusable pollutant adsorbent in environmental remediation.

Chitosan sponge

Chitosan could bind effectively to toxic pollutants as its coordination sites (amine and hydroxyl groups) can easily form charge neutralized complexes, also the biocompatible nature of chitosan, makes it to explore as a non-toxic adsorbent in adsorption of toxic pollutants. Chitosan sponges that possess suitable modifier/filler were ideal for practical use, due to highly accessible pore volume, durability at low density, and high reusability.

Cellulose sponge

Cellulose is an eco-friendly abundant biopolymer and the hydroxyl groups present in it possess superior mechanical strength. The nano-fibrillated cellulose surface possessing hydroxyl groups can be chemically modified with hydrophobic molecules. There are numerous research reports on cellulosic materials in different forms like fibers, nanocrystals, beads, etc., but cellulose adsorbents in sponge form was not fully explored. Recently, magnetic microparticles (Fe_3O_4) were coated on to cellulose sponge surface and this magnetite (Fe_3O_4) coated cellulose sponge being magnetic can be easily recovered from solution with the help of an external magnet. Modified cellulose and chitosan-based composites were found to possess high adsorption performance than the native cellulose/chitosan. Certain substitution techniques such as sulfation and amidation introduce new functional groups into the polysaccharide by replacing the proton from the hydroxyl group, giving rise to improved physicochemical properties of the adsorbent.

Luffa sponge

Studies conducted on luffa sponges in the recent past are primarily due to their low cost, lightweight, etc. Luffa consists of mainly xylan, cellulose, mannan, galactan, and lignin used in the removal of heavy metals as it has strong mechanical properties with plenty of hydroxyl groups. Among the immobilization methods, the polymer matrix was a common and widely used method, with certain disadvantages like high cost and limitation in diffusion. This problem is overcome by immobilizing fungal biomass on the luffa sponge. This research work may lead researchers and scientists to develop novel sponge adsorbents with unique properties for various applications.

Materials and Methods

The sponge adsorbents used in environmental remediation were prepared using various precursors like graphene oxide, chitosan, luffa, cellulose sponge etc. This systematic work was carried out through a systematic search in science direct from 2010 to present. The standard journals published on sponge adsorbents in environmental remediation in science direct were systematically analysed in this work, and the keywords used were adsorption, sponge adsorbents, adsorption capacity. The studies done on sponge adsorbents were divided into (i) graphene

sponge adsorbents, (ii) chitosan sponge adsorbents (iii) luffa sponge adsorbents (iv) cellulose sponge adsorbents (v) other sponge adsorbents, to identify the adsorption potential of sponge adsorbents in environmental remediation.

Results and Discussion

Sponge adsorbents in pollutant removal

In literature, different sponge adsorbents were synthesized and reported in pollutant removal. To synthesize efficient sponge adsorbents with promising adsorption performance precursors like chitosan, polyurethane, graphene, cellulose, etc. were suitably modified followed by freeze-drying to obtain efficient chitosan sponge adsorbents graphene sponge adsorbents cellulose sponge adsorbents and other sponge adsorbents employed in environmental remediation. The synthesis and adsorption mechanism of different sponge adsorbents were discussed under different headings.

Graphene sponge adsorbents in pollutant removal

Graphene sponge adsorbents were synthesized and employed in the adsorption of toxic pollutants proved to be efficient with high adsorption potential. The synthesis and adsorption mechanism of graphene sponge adsorbents with adsorption capacity >100 mg/g was analyzed and summarized below.

The graphene oxide (GO) prepared by adding Fe_3O_4 dispersion dropwise to GO with stirring, the resultant mixture was lyophilized to obtain Fe_3O_4 -GS. The adsorption of methylene blue (MB) onto the Fe_3O_4 -GS was studied. The adsorption capacity of the Fe_3O_4 -GS was much higher due to the porosity of the graphene sponge. The oxygen-containing groups on Fe_3O_4 -GS were reported to interact strongly with the positively charged MB dye. The adsorption capacity of Fe_3O_4 -GS for MB was 526 mg/g. The graphene sponge (GO), polyvinyl alcohol (PVA), and formaldehyde (FA) as the precursor to synthesize GPF sponge and tested the adsorption of methylene blue (MB) dye. The GO was added to PVA solution under stirring followed by the addition of FA solution to obtain GO-PVA-FA (GPF) solution. The GPF sponge was obtained by freeze-drying of GPF solution. The presence of abundant oxygen-containing functional groups on GO layers in the GPF sponge was attributed to the dramatic increase in adsorption capacity of the GPF sponge. The adsorption capacity of the GPF sponge increased as the pH level increased and reached 476 mg/g at pH 12. The adsorption

of MB onto the GPF sponge was due to the electrostatic attraction between the positively charged MB and negatively charged GO surface resulting in high adsorption capacity.

To a small amount of Fe_3O_4 with GO to prepare a magnetic graphene sponge (MGOS) in which GO was prepared by modified Hummers method and Fe_3O_4 was added to GO in the mass ratio of 1:40 and lyophilized. The MGOS obtained was tested for the adsorption of tetracycline. The high adsorption capacity of MGOS was due to the self-assembly of graphene oxide to form large sheets that impart large pores in MGOS. The Fe_3O_4 nanoparticles with negative surface charge were attached on GO to enable magnetic nature. The adsorption of tetracycline (TC) onto MGOS was moderately fast with the adsorption capacity reported as 473 mg/g. The synthesized graphene oxide wrapped melamine sponge (MS@GG) and tested its efficiency in lead removal. The adsorption of Pb(II) onto MS@GG was rapid and reached equilibrium in 30 minutes due to the surface active sites of GG along with the macroporous nature and hydrophilic structure of MS. Isotherm studies of Pb(II) adsorption onto MS@GG resulted in a high correlation coefficient (R^2) for the Langmuir model and it was speculated that MS@GG underwent monolayer chemisorptions with the adsorption capacity reported as 349.7 mg/g. The novel carboxymethyl cellulose and chitosan-based composite with sulfonated graphene oxide (CMC-SGO-GCC sponge) and tested the adsorption of sulfamethoxazole (SMX) and sulfapyridine (SPD) from wastewater. The XRD results of the CMC-SGO-GCC sponge confirm that chitosan and CMC were successfully grafted onto GO- SO_3H . The adsorption isotherm data of SMX adsorption onto CMC-SGO-GCC sponge indicated monolayer sorption and strong affinity for sulfamethoxazole (SMX) compared to sulfapyridine (SPD) with the adsorption capacity reported as 272.83-312.28 mg/g for SMX and 146.56-161.89 mg/g for SPD respectively.

The synthesized graphene oxide/chitosan sponge (GO/CS) and tested the performance of the sponge in the removal of methylene blue (MB) from water. The adsorption of MB onto GO/CS sponges was due to both electrostatic attraction and hydrophobic interaction. The CS concentration was varied in the GO/CS and the sponge formed upon freeze-drying, with a CS content of 9% was reported to have a high adsorption capacity of 275.5 mg/g for MB dye. The prepared S-doped graphene sponge by hydrothermal synthesis and used it as a recyclable adsorbent for Cu(II) ions. The

isotherm data of S-doped GO fitted well to the Langmuir model and the adsorption capacity was reported as 228mg Cu/g. Zhao [36] synthesized 1-aminopropyl-3-methyl imidazolium(mim) graphene oxide sponge (mim GO sponge) and tested it for the adsorption of Cr(VI) ions. The high adsorption capacity was reported to occur in mim GO sponge due to strong electrostatic interactions and reduction of HCrO_4^- to Cr(III) by π electrons on the mim GO sponge. The adsorption of Cr(VI) onto mim GO sponge was best described by the Langmuir model and the adsorption capacity was reported as 208.3 mg/g respectively.

The surfactant loaded graphene oxide sponge (GO/HDTMA sponge) synthesized and studied for the effect of adsorption time, pH, and ionic strength on the adsorption of Cu(II) and bisphenol A (BPA). The adsorption of Cu(II) onto the GO/HDTMA sponge was predominantly due to cation exchange between the negative charges on GO and the Cu(II) ions. In BPA adsorption onto GO/HDTMA sponge the elevated adsorption was attributed to the presence of HDTMA, where the positively charged head of HDTMA accepts electrons and the oxygen atom of a phenol group in BPA donates electrons. The GO/HDTMA sponge was unique as it can simultaneously uptake charged Cu(II) and uncharged BPA with the adsorption capacity reported as 59.7 and 141 mg/g for Cu(II) and BPA respectively.

The literature survey on various graphene sponge adsorbents (Table 1) reveal that Fe_3O_4 -GS is a promising adsorbent with good adsorption capacity in MB removal. If we examine the adsorption performance of the graphene oxide sponge adsorbents it is obvious that GO proved to be a promising precursor in preparing novel sponge adsorbents with good surface properties. The adsorption mechanism of the majority of the graphene sponge adsorbents proceeds via. electrostatic interactions between the adsorbate and graphene sponge adsorbents, and thus prove to be promising in environmental remediation.

S/N	Graphene oxide sponge adsorbents	Pollutant	Adsorption capacity
	Fe_3O_4 -GS	MB	526 mg/g
	GPF Sponge	MB	476 mg/g
	MGOS	TC	473 mg/g
	MS@GG sponge	Pb(II)	349.7 mg/g

CMC/SGO-GCC sponge	SMX	272.83-312.28 mg/g
	SPD	146.56-161.89 mg/g
GO/CS	MB	275.5 mg/g
S-doped graphene sponge	Cu(II)	228 mg/g
mim GO sponge	Cr(VI)	208.3 mg/g
KGM/GO sponge	MG	189.96 mg/g
GO/HDTMA sponge	BPA	141.0 mg/g
C_3N_4 /GO wrapped sponge	RhB	10.7 mg/g
	MB	69.7 mg/g
GO- OCH_2COOH sponge	Cu(II)	93.8 mg/g
GO Sponge	MB	19.6 mg/g
PLA@GO/CS	CV	-

Table 1: Graphene sponge adsorbents in environmental remediation.

Chitosan adsorbents in environmental remediation

In the study done by researchers using chitosan sponge adsorbents in environmental remediation, the nano-MIL-101(Fe)@Chitosan hybrid sponge was unique with superior adsorption performance. To synthesize a high adsorption performance chitosan sponge adsorbent, Wang, *et al.* [7] mixed CS with acetic acid, followed by the addition of nano-MIL-101(Fe) under sonification. The product was freeze-dried and washed to obtain MIL-101(Fe)@CS sponge adsorbent. Characterization results of the hybrid sponge reveal that rhombic nano-MIL-101(Fe) particles were uniformly dispersed, and this provided more adsorption sites for Acid Red 94(AR 94). The rough surface, specific surface area, and the positive charge nature of nano-MIL-101(Fe) favor the adsorption of AR 94 onto MIL-101(Fe)@CS sponge. The adsorption mechanism of MIL-101(Fe)@CS sponge in dye removal is a chemical adsorption mechanism that proceeds via interactions such as electrostatic interaction, covalent bonds, and hydrogen bonding. Isotherm studies on AR 94 adsorption onto MIL-101(Fe)@CS sponge reveals monolayer adsorption with the adsorption capacity reaching 4518 mg/g. The CNT and glutaraldehyde were added and the resultant hydrogel obtained was freeze-dried to get carbon nanotubes stabilized in chitosan sponge (CNT-CS). The adsorption of fluoride from fertilizer

industry effluent onto CNT-CS was fast and reached equilibrium in 20min. The CNT in the adsorbent potentializes the adsorption. The high adsorption capacity (975.4 mg/g) was attributed to the high interaction areas of CNT and the chitosan functional groups (amino and hydroxyl) in sponge form. The chitosan solution was then freeze-dried to obtain the CS sponge adsorbent. The adsorption of Acid Blue 113(AB 113) onto the CS sponge adsorbent was due to chemical sorption with strong columbic attractions between the protonated amino group from chitosan and the sulfonic acid group from AB113. The adsorption isotherm study of chitosan sponge showed a high adsorption capacity of AB 113(687 mg/g). Zhang, *et al.* [11] mixed chitosan in acetic acid solution and the product obtained was homogenized with cellulose suspension. Glutaraldehyde was added to the creamy homogeneous suspension and the resultant yellow mixture was frozen and subsequently lyophilized to get chitosan/cellulose biocomposite sponge (CCS) sponge. The adsorption of Hg(II) onto CCS was tested and the surface groups responsible for Hg(II) chelation onto CCS sponge were identified from XPS studies. The results reveal that, C=N-C group on the CCS sponge primarily participated in the adsorption of Hg(II) ions. The adsorption was strong pH-dependent and the interaction between Hg(II) and CCS was attributed to electrostatic interaction and chemical chelation. The CCS sponge was cheap and ecofriendly, with superior adsorption capacity (495 mg/g) for Hg(II) ions.

Wang, *et al.* [7] synthesized a superior sponge composite, xanthate modified chitosan@titanate nanotubes (XCTS@TNTs sponge) and tested the adsorption of Pb(II) ions. Characterization results of XCTS@TNTs sponge before and after Pb(II) adsorption, reveal that the adsorption mechanism proceeds via. ion exchange interaction, surface complexation, and microprecipitation. The adsorption capacity of Pb(II) onto the sponge composite was as high as 342.47 mg/g. The Xanthate modified thiourea chitosan sponge (PXTCS and TXTCS) and tested the biosorption of Pb(II) ions. The isotherm data of PXTCS and TXTCS fitted well to the Langmuir model and the adsorption capacity was reported as 232.03 and 241.61mg Pb/g. The biosorption mechanism of Pb(II) adsorption onto PXTCS and TXTCS proceeds via electrostatic interaction, surface complexation, ion exchange, and microprecipitation. The hydrophobically modified chitosan sponge (HMCS sponge) and tested the adsorption of methyl orange (MO). The adsorption of MO

onto the HMCS sponge was due to both electrostatic interaction and hydrophobic interaction. The adsorption followed the Langmuir model and the adsorption capacity was reported as 168 mg/g.

The adsorption performance of chitosan sponge in removal of toxic pollutants (Table 2) was analyzed and it is evident that MIL-101(Fe)@CS Sponge proved efficient with superior adsorption capacity compared to all other adsorbents in environmental remediation. The high adsorption capacity of chitosan sponge adsorbents in dye removal was due to the chemical adsorption mechanism with electrostatic interactions being dominant in the dye adsorption process. In the removal of heavy metal ions by chitosan sponge adsorbents, electrostatic interactions, surface complexation, ion exchange interaction, and microprecipitation favors the adsorption process. A positive insight in designing novel chitosan sponge adsorbents may result in materials with unique surface properties for various applications.

S/N	Chitosan sponge adsorbents	Pollutant	Adsorption capacity
	MIL-101(Fe)@CS Sponge	AR 94	4518 mg/g
	CNT-CS	F	975.4 mg/g
	CS	AB 113	687 mg/g
	CCS sponge	Hg(II)	495 mg/g
	XCTS@TNTs sponge	Pb(II)	342.47 mg/g
	PXTCS and TXTCS	Pb(II)	PXTCS - 232.03 mg/g
			TXTCS - 241.61 mg/g
	HMCS sponge	MO	168 mg/g

Table 2: Chitosan sponge adsorbents in environmental remediation.

Luffa sponge adsorbents in environmental remediation

In the search for novel adsorbents, the luffa sponge was explored as novel sponge adsorbents in the removal of toxic pollutants. The increased adsorption of TB dye molecule was due to the interaction of -NH, -OH, and -S of dye with the -OH groups on the surface of LS and LS-ZnNPs prepared penicillium simplicissimum immobilized with loofa sponge (PSILS) and explored the biosorption of Pb(II) and Cu(II) from aqueous media. The sorption isotherm of PSILS was well described by the Langmuir model and the adsorption capacity was reported as 152.6 and 112.3 mg/g for Pb(II) and Cu(II)

respectively. The sponge-immobilized fungal biomass (LSIFB) and tested the biosorption of Remazol Brilliant Blue R (RBBR). LS as an immobilization matrix in LSIFB significantly enhanced the biosorption capacity and the maximum RBBR biosorption capacity was reported as 101.06 ± 2.52 mg/g. Studies on luffa sponge adsorbents in adsorption of pollutants (Table 3) show that this sponge is not a superior sponge material in the removal of toxic pollutants.

S/N	Luffa sponge adsorbents	Pollutant	Adsorption capacity
	LS-ZnNPs	TB dye	129.87 mg/g
	PSILS	Pb(II)	152.6 mg/g
		Cu(II)	112.3 mg/g
	LSIFB	RBBR	101.06 ± 2.52 mg/g
	LCSA	Pb(II)	75.853 mg/g
	LSIBCS	Cr(III)	69.26 mg/g
	AN-g-loofah sponge	Cu(II)	51.40 mg/g
	Fungi isolate on luffa sponge	Pb(II)	-

Table 3: Luffa sponge adsorbents in environmental remediation.

Cellulose sponge adsorbents in environmental remediation

Studies done by researchers on cellulose sponge adsorbents in the removal of toxic pollutants reveal that cellulose sponge adsorbents were reported to be promising in the removal of toxic pollutants as discussed below: Amine functionalized cellulose sponge (AF-CS) was synthesized [25] by Nagarajan and Venkatanarasimhan and tested the adsorption of Cu(II) ions. The pre-treated cellulose sponge (CS) was added to epichlorohydrin dissolved in DMSO. The epichlorohydrin modified cellulose sponge was mixed with ethylenediamine and the product obtained was washed and dried to prepare an amine-modified cellulose sponge (AF-CS). Isotherm studies of AF-CS reveal the participation of both monolayer and multilayer adsorption. The mechanism for Cu(II) adsorption onto AFCS was analyzed using FTIR and FTIR-Raman analysis and the formation of Cu-N and Cu-O bonds was evident after Cu(II) adsorption. The maximum adsorption capacity of the AF-CS sponge was reported as 596.96 mg/g. Nagarajan and Venkatanarasimhan [14] synthesized magnetic microparticles decorated cellulose sponge (Fe_3O_4 -CS) and investigated its adsorption of As(V) ions. The adsorption of As(V) onto Fe_3O_4 -CS takes place due to strong chemical interactions and chemisorption

occurred via a bidentate binuclear complex formation. The adsorption of Fe_3O_4 -CS was clearly described by Langmuir model and the adsorption capacity was reported as 349.9 mg/g. Cellulose sponge (CA sponge) with high porosity and low density was synthesized and tested the adsorption of organic dyestuffs. The adsorption of methylene blue (MB) and crystal violet (CV) onto the CA sponge followed Langmuir isotherm. The high adsorption capacity of the CS sponge for MB and CV removal was ascribed to the porosity of the cellulose sponge and electrostatic interaction between the dye molecules and the CS sponge. The adsorption capacity was reported as 123.46 and 76.63 mg/g for MB and CV respectively. An eco-friendly cellulose-based nanostructure sponge (A-CNS and C-CNS) and tested the adsorption of Zn(II) and Cd(II) ions. The adsorption capacity for A-CNS calculated using the Langmuir model was reported as 139mg Zn/g and 100.2mg Cd/g. The adsorption capacity of B-CNS was reported as 108.6 mg Zn/g and 101 mg Cd/g.

In preparing novel sponge adsorbents in the adsorption of toxic pollutants researchers used cellulose sponge adsorbents and reported superior performance in the removal of toxic pollutants (Table 4). AF-CS adsorbent was reported to be efficient in the adsorption of Cu(II) ions. The high adsorption capacity of cellulose sponge adsorbents in dye removal was attributed to electrostatic interactions and in heavy metal adsorption, strong chemical interactions and chemisorptions dominate the adsorption process. A positive insight to prepare novel cellulose sponge adsorbents with a highly porous nature may yield novel sponge materials with unique surface properties in water remediation.

S/N	Cellulose sponge adsorbents	Pollutant	Adsorption capacity
	AF-CS	Cu(II)	596.96 mg/g
	Fe_3O_4 -CS	As(V)	349.9 mg/g
	CA sponge	MB	123.46 mg/g
		CV	76.63 mg/g
	A-CNS and C-CNS	Zn(II)	A-CNS (138.9 mg/g) C-CNS(108.6 mg/g)
		Cd(II)	A-CNS (100.2 mg/g) C-CNS(101.0 mg/g)
	CA/Z composite sponge	Cu(II)	28.57 mg/g
		Ni(II)	16.95 mg/g

Table 4: Cellulose sponge adsorbents in environmental remediation.

Other sponge adsorbents in environmental remediation

Several studies in synthesizing novel sponge adsorbents were carried out by researchers and tested its adsorption in the removal of toxic pollutants. The adsorption studies of some novel sponge adsorbents were discussed below.

Jin., *et al.* Prepared [1] a regenerative carboxylated sponge (RCS) by modifying polyurethane (PU) sponge and tested the adsorption of methylene blue. The PU sponge was ultrasonically cleaned and immersed in a methanol solution containing N-(3, 4-Dihydroxyphenethyl) acrylamide (DOPAm) and Dopamine hydrochloride (DOPA) to prepare a vinylated sponge (VS). The VS was immersed in a water reaction solution containing AA, APS, and DI water to get the carboxylated sponge (CS). The CS was then immersed in a water solution of triethylamine to synthesize regenerative carboxylated sponge (RCS). The high adsorption of MB onto the RCS sponge was attributed to intermolecular interactions between MB and the RCS sponge surface that includes π - π interaction, hydrogen bonding, strong charge attraction, and weak charge attraction. The adsorption of MB onto the RCS sponge was due to chemisorption as inferred from the high correlation coefficient (R^2) of the pseudo second-order kinetic model. The static adsorption rate of the RCS sponge was very fast with the adsorption capacity reported as 1263.5 mg/g. Novel biomass derived carbonaceous sponge (CS) with a hierarchically porous structure with rich functional groups for the removal of crystal violet (CV), methyl orange (MO), and methylene blue (MB) from water. The synthesis of the hierarchically porous biomass-derived carbonaceous sponges (CS) was a two-step process via a facile combined approach of Hydrothermal carbonization (HTC) followed by the freeze-drying process to obtain magnetic carbonaceous sponge (MCS). The adsorption of dyes onto the CS sponge was due to physical confinement and electrostatic attraction. The molecular size of CV may be more suitable with the pore size of the CS sponge and hence, this is the key factor for the adsorption of dyes by physical confinement. The molecular size of CV may be more suitable with the pore size of the CS sponge and the measured adsorption capacity was $CV > MO \approx MB$. The rich oxygen-containing functional group on the surface of the CS sponge also enhances the adsorption of CV, MO, and MB by electrostatic interaction. The adsorption capacity of CS towards MB, MO, and CV were reported as 0.0769 g/g, 0.2218 g/g, and 1.0384 g/g respectively. MCS has high adsorption capacity of 0.0635 g/g, 0.0977 g/g and 0.8634 g/g for MO, MB and CV respectively.

The synthesized functionalized polyurethane sponge (PUSDS-20) and tested the adsorption of MB from aqueous solution. The polyurethane (PU) sponge was modified by immersing it in a methanol solution containing N-(3, 4-dihydroxyphenethyl) acrylamide (DOPAm) and DOPA. The product PUSD was modified via polymerization by immersing PUSD in an aqueous solution of Sodium p-styrenesulfonate (SPS) and ammonium persulfate (APS) to synthesize PUSDS-10 and PUSDS-20 respectively. The high adsorption of MB onto PUSDS-20 was due to the strong intermolecular forces of electrostatic attraction followed by π - π interaction and hydrogen bonding. The adsorption of MB dye onto PUSDS was rapid and the adsorption capacity was found to be 857.6 mg/g. Liu., *et al.* [18] synthesized cross-linked polyethyleneimine (PEI) on a monolithic melamine sponge premodified with polydopamine (PDA) (PEI@PDA/MS) and tested the adsorption of Acid Red 18 (AR 18) and Pb(II) ions. The PDA was modified using pristine MS as the monolithic matrix. The PDA/MS was mixed with ethanol, glutaraldehyde, and polyethyleneimine (PEI) and sonicated to obtain PEI@PDA/MS. The adsorption of Pb(II) and AR 18 onto PEI@PDA/MS was mainly driven by chelating and electrostatic interactions. The amine groups-rich surface and highly open porous structure of PEI@PDA/MS is evident from the high adsorption capacity of AR 18 and Pb(II), reported as 464.53 and 231.81 mg/g respectively. Novel Forager sponge-loaded superparamagnetic iron oxide nanoparticle (SPION) and studied the adsorption of As(III) and As(V). The SPION was synthesized and Forager Sponge was loaded with SPION to develop the new adsorbent material synthesized polymer-brush grafted MF sponges and studied the adsorption of Cu(II) ions/The PEI grafted sponge (MF sponge/Pdop/PEI) was reported with adsorption capacity of 3.74mmol/g for Cu(II) and 0.67 mmol/g for Pb(II).

Nanofiber aerogel sponge (NFAs) was synthesized from short pullan/polyvinyl alcohol/polyacrylic acid nanofibers and tested the adsorption of Methylene blue (MB). The open porous structure of NFAs is favorable for the mass transport of MB. The NFAs proved to be a promising adsorbent for cationic dye (MB) with a high adsorption capacity (383 mg/g).

Liu., *et al.* [19] synthesized a novel MgO hybrid sponge-like carbonaceous composite (HSC) and employed it as an adsorbent for the removal of As(V), Pb(II), and Methylene blue (MB). The adsorption of As(V) onto HSC was dominated by surface

deposition, while carbon π - π^* transition and carbon π -electron both played a major role in Pb(II) and MB adsorption. MgO hybridization approach resulted in an economical and promising carbon sponge composite to capture As(V), Pb(II), and MB from aqueous solution. The adsorption capacity was reported as 157, 103, and 297 mg/g for As(V), Pb(II), and MB respectively. Keratin sponge was synthesized and tested the adsorption of Cr(III) ions. The functional groups like carboxyl, amino group, and hydroxyls present on the keratin sponge have a greater affinity for Cr(III) ions. The adsorption of Cr(III) onto the Keratin sponge was due to vanderwall forces, electrostatic attraction, and hydrogen bonding. The adsorption capacity of keratin sponge under optimized conditions was reported as 270 mg Cr(III)/g.

Liu, *et al.* [18] prepared PU@PDA@MSN sponge by immobilizing mesoporous silica nanoparticles (MSNs) onto the polydopamine (PDA) coated polyurethane (PU) sponge (PU@PDA). The adsorption capacity of the PU@PDA@MSN sponge was due to the plenty of amino group and carboxyl groups to bind the pollutants. The adsorption of Pb(II) and 2,4,6-Trichlorophenol(TCP) onto PU@PDA@MSN sponge was studied via batch mode experiments and the adsorption capacity was reported as 104.2 mg/g and 184.2 mg/g for Pb(II) and TCP respectively. The synthesized 4-(vinyl benzyl) - N-Methyl-D-glucamine (VbNMG-100 cryo sponge) and tested the adsorption of As(V) and Cr(VI) ions. The adsorption of As(V) and Cr(VI) onto the VbNMG-100 cryo sponge is controlled by electrostatic and hydrogen-bonding interactions. The adsorption kinetics of the VbNMG-100 cryo sponge reveals that pseudo second-order model provided the best fit and the adsorption of As(V) and Cr(VI) involves chemisorptions. The VbNMG-100 cryo sponge sorption was well described by Langmuir isotherm and the adsorption capacity was reported as 76.3 mg/g and 130.9 mg/g for As(V) and Cr(VI) respectively. Wang, *et al.* [7] synthesized MoS₂-glue sponge and tested the adsorption of Rhodamine B(RhB). The adsorption of RhB onto the MoS₂-glue sponge was due to electrostatic attraction. The MoS₂-glue sponge shows a high correlation coefficient for SIPS isotherm (0.9829) and Freundlich isotherm (0.9099) suggesting multilayer adsorption towards RhB dye. The adsorption capacity of the MoS₂-glue sponge was reported as 127.39 mg RhB/g. A novel chelating sponge (PVA-M-H-sponge) was prepared and tested the adsorption of Ni(II) and Cd(II) ions. The adsorption capacity of Ni(II) and Cd(II) onto the PVA-M-H sponge is higher due to the chelating interaction and porous

structure of the spongy adsorbent. The adsorption capacity of the PVA-M-H-sponge for Ni(II) and Cd(II) was reported as 65.39 and 125.11 mg/g respectively.

Several researchers prepared sponge adsorbents to study the adsorption of toxic pollutants. The literature reveals the reported adsorption performance (Table 5) of other sponge adsorbents in the adsorption of toxic pollutants. It is evident that Polyurethane sponge as a precursor to prepare sponge adsorbents. Regenerative carboxylated sponge (RCS) and functionalized polyurethane sponge (PUSDS-20) were reported as efficient adsorbents in adsorption of organic dyes. Biomass-derived carbonaceous sponges (CS) also proved efficient in the adsorption of toxic dyes.

S/N	Other sponge adsorbents	Pollutant	Adsorption capacity
	RCS Sponge	MB	1263.5 mg/g
	CS	CV	1.0384 g/g
		MO	0.2218 g/g
		MB	0.0769 g/g
	MCS	CV	0.8634 g/g
		MB	0.0977 g/g
		MO	0.0635 g/g
	PUSDS-20	MB	857.6 mg/g
	PEI @PDA/MS	AR 18	464.58 mg/g
		Pb(II)	231.81 mg/g
	Forager sponge loaded SPION	As(V)	12.09 mmol/g
		As(III)	2.11 mmol/g
	MF sponge/pdop/PEI	Cu(II)	3.74 mmol/g

Table 5: Cellulose sponge adsorbents in environmental remediation.

On analyzing the adsorption capacity of all the sponge adsorbents in the removal of toxic pollutants, the adsorption performance of the chitosan sponge adsorbent (MIL-101(Fe)@CS Sponge) with adsorption capacity 4518 mg/g and PU sponge adsorbent (RCS) with adsorption capacity 1263.5 mg/g were reported as high adsorption capacity sponge adsorbents in dye removal. The adsorption capacity of different sponge adsorbents in environmental remediation is in the following order (Chitosan sponge> PU sponge>Cellulose sponge> Graphene sponge> luffa

sponge. The adsorption mechanism in the majority of sponge adsorbents in dye removal proceeds via electrostatic interactions. The heavy metal adsorption by other sponge adsorbents occurs by chelating interaction, electrostatic interaction, and hydrogen bonding interactions. In order to synthesize new, eco-friendly cellulose/chitosan sponge adsorbents more research is essential. A positive lead to develop novel sponge adsorbents may result in efficient sponge adsorbents with unique surface properties for various applications.

Conclusion

The literature work on various sponge adsorbents proves that there is significant interest for researchers to prepare novel sponge adsorbents in the removal of toxic pollutants. The adsorption capacity of different sponge adsorbents in environmental remediation is in the following order (Chitosan sponge> polyurethane sponge>Cellulose sponge> Graphene sponge> luffa sponge. Chitosan sponge adsorbent proved to be efficient in the removal of AR 94 with the highest adsorption capacity (4518 mg/g). The adsorption mechanism of sponge adsorbent in dye adsorption is by chemical adsorption mechanism with electrostatic interaction being dominant in dye adsorption process. If the analyze the adsorption capacity of all the sponge adsorbents from literature, CS sponge adsorbent, and PU sponge adsorbents were superior with high adsorption capacity (>1100 mg/g). A positive effort in synthesizing novel sponge adsorbents may prove effective and give fruitful results in the future. Also, novel sponge adsorbents that are already reported may suitably be modified/developed to get unique materials for various applications.



Figure 2: Environmental remediation.

Declaration

We declare that this work submitted for publication in the given journal has not been published already or under consideration for publication in any Journals/Conferences/Symposia/Seminars.

Conflict of Interest

The authors of the article are hereby declaring that they have no interest of conflict.

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