the treatment of various aquatic pollutants due to 3D network structures, large surface area, hydrophobicity, and multiple functional groups [6-8]. Within this concern, the use of biopolymers as adsorbent materials in multidisciplinary fields has received great attention as environmentally-friendly sorbents for adsorptive water treatment [9]. Cellulose and its derivatives have received great attention owing to its distinctive structural feature, non-toxic, exciting physico-chemical properties, and good candidates for super adsorption capacity [10,11]. However, weak mechanical properties, low thermal stability, and intra and intermolecular hydrogen bond network in the cellulose polymer decrease its adsorption capacity [12]. To overcome limitations with cellulosic materials researchers have been reported different modification types like crosslinking, grafting, and adding filler into cellulose matrix to improve solubility and stability problems [13].

However, nano-adsorption technology offers advantages such as cost reduction, versatility, high removal efficiency, short cleanup time, and the possibility of regeneration/reuse of spent adsorbent [14,15]. The preparation of cellulose-based nano composites (CBNCs) has been found to be of growing interest due to its higher functional group and ease of surface modification, high strength, low cost, and renewability [16]. Different synthesis methods of CBNC have been widely reported by different researchers. The key drawback in cellulose-based nanocomposites synthesis using cross-linkers is the decrease in the number of sorption sites, with the rise in density of the cross-linker in crystalline domains, which then distorts the polymer matrix's original crystal structure [17,18]. Also, they are reported for the development of toxic and non-biodegradable nanocomposite hydrogel under alkaline conditions [19,20]. Homogeneous dispersion of filler into cellulose matrix improves the functionality, stability, solubility, and surface area and shows high uptake of target pollutants [21-26].

According to the Scopus database, the amount of publications on cellulose nanocomposite hydrogels has increased from one in 2010 to 50 in 2019, among which very few papers were devoted to physically cross-linked nanocomposite hydrogels (Figure 1) [27].

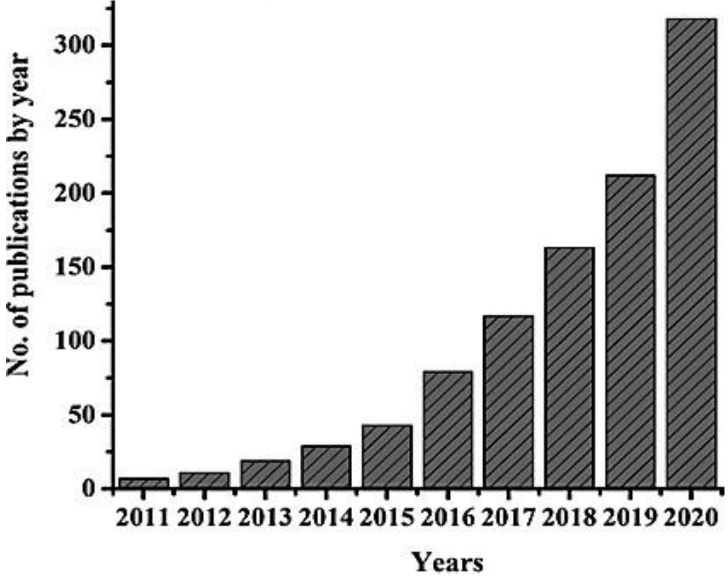


Figure 1. Hydrogel nanocomposites for removal of dyes during the period 2011–2020.

There are some recent reviews on CBNC for removing heavy metals and metal oxide-cellulose nano composite for removal of toxic heavy metals and dyes and hydrogel cellulose-based Nano composite for adsorption removal of methylene blue are among recently overviewed CBNCs. However, comprehensive overviews of the synthesis of porous CBNC hydrogel properties and its application are the current needs of the scientific community to grasp an overview of the current status [28-30]. The synthesis of a low-cost, reusable adsorbent with high removal efficiency for aquatic pollutants still needs further investigation [31]. The main objective of the review paper was to briefly highlight the most newly cellulose-based Nano composite synthesis methods and trials using cellulose as potential components to form hybrid/hydrogel with polymers, metals oxides, carbon- based and clay-based material for the development of new hybrid/ hydrogel nanocomposites component for various improved adsorption removals of heavy metals.

LITERATURE REVIEW

Preparation of cellulose based nanocomposite

The surface function of cellulose shows high surface energy and binding activity on the nano scale and can be modified by using various methods [31]. The development of CBNC materials using Nano Cellulose (NCs) has become a prominent research field due to excellent and tunable surface chemistry, high mechanical strength, low cost, biodegradability, biocompatibility, and renewability [32]. The main challenges of preparing CBNC include the generation of nanocellulose from natural resources, production on a larger scale, achieving uniform dispersion in polymer matrices, and control of hybrid composites at the nanoscale [33].

As recently reported cellulose-based nanocomposite production process is costly and needs a further reduction of production costs and improved production efficiency. The advantage and drawbacks of the

Most widely applied CBNC synthesis methods like solvent casting, electrospinning, precipitation, are critically assessed in this article.

Electrospinning nanocomposite synthesis methods

Electrospinning as a means to produce polymer fibers from solution was first introduced in the early 20th century and was patented by Form has in 1934 [34]. The synthesis method follows blending Nano Cellulose (NC) with suitable polymers. In electro spun synthesis methods, appropriate orientation of cellulose and polymer enhances tensile strength, young's modulus, and thermal stability and such types of nanocomposite synthesis methods mostly reported on cellulose- polymer-based hydrogel nanocomposites [35].

Electrospinning enables the production of nanocomposites fibers with different morphologies (fibers, hollow fibers, beaded fibers, etc.), porosity, and fiber diameters from a few nanometers to several micrometers. This fabrication technique typically produces multilayered composites with superior active surface areas, enhances tensile strength, and produces highly interconnected pores nano composites [36]. Such types of cellulose-based nanocomposite synthesis methods have the potential to improve the effective surface area as well as enhance the nanocomposite's surface chemistry for specific applications such as adsorptive filtration (Figure 2) [37].

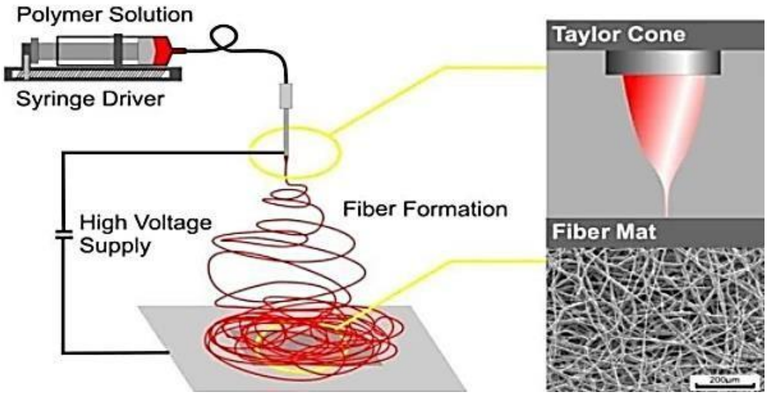


Figure 2. Electrospinning methods of nanocomposite synthesis.

Among the cellulose-based nanocomposite preparation techniques, the in situ formation shows several advantages due to the use of simple reaction procedures, light reaction conditions, and higher yield.

Solvent casting cellulose-based nanocomposite synthesis methods

The solvent cast synthesis methods start by dissolving cellulose materials in a volatile solvent, followed by incorporating other hybrid materials to form nanocomposites [38]. Then Stable colloidal suspension of nanocomposite film can be solidified into a favored shape and geometry *via* solvent removal [39]. The fabricated CBNC by solvent casting exhibit enhanced mechanical properties by acting as a nucleating agent [40-42]. However, these synthesis methods have a lot of limitations like a high volume of solvent with evaporating properties, need long solvent evaporating times, and some presence of residual solvent involved in reducing the quality of product cellulose-based nanocomposite and accounting for formed nanocomposite aggregations [43].

Different researchers have done a lot of trials to improve solvent casting nanocomposite synthesis methods. In general, nanocomposite preparation by the solution casting method should focus on two aspects; compatibility between cellulose-based materials and the matrix should be improved. Because both cellulose-based materials and the matrix are "forced" to disperse by the solvent; if the compatibility is too poor, it is likely that cellulose-based materials will self-assemble rather than connect with the matrix during solvent evaporation. Secondly, the proper solvent selection for suitable dispersion is crucial. Improper solvent selection may lead to high recovery costs and environmental pollution. In most cases in the solvent casting synthesis methods, water or N, N-Dimethylformamide (DMF) are used as dispersants for dispersion of hybrid components [44].

Choo, et al. reported excellent mechanical properties and strong binding affinity of nanocellulose-Polyvinyl Alcohol (PVA) hydrogel nanocomposites using water as a dispersant solvent. However, evaporation of the solvent during solution casting can easily lead to the agglomeration of nanocellulose, which seriously reduces the enhancement effect. More similarly, Miri, et al. synthesized cellulose nanocrystal graphene nano-sheet-based nanocomposite using water as a dispersant, the new functional hybrids of cellulose nanocrystal and Graphene Nanosheets (GNO) generated synergistic effects through interactions that effectively prevented the agglomeration of nanoparticles in the polymer matrix, improved the dispersion uniformity, and greatly improved the mechanical properties, thermal stability, and moisture absorption of the nanocomposite. In addition to the improvement in mechanical properties, the material also exhibited good water vapor barrier and thermal stability [45]. In addition to water, N, N-Dimethylformamide (DMF) is a widely used dispersant solvent for solvent casting nanocomposite synthesis and can be mixed with water and most organic solvents, except halogenated hydrocarbons. Compared with water, DMF is a better solvent and can dissolve both hydrophilic and hydrophobic components. However, when hydrophobic materials are used as the matrix, due to the poor compatibility between cellulose-based materials and hydrophobic materials, the research focus should be on improving the interface [46]. Cao, et al. prepared a series of novel Waterborne Polyurethane (WPU), Cellulose Nano Crystal (CNC), composites. By using Poly Capro Lactone (PCL) as the compatibilizer, the partially pre-synthesized WPU chain was grafted on the surface of CNCs, and the corresponding nanocomposite was obtained by casting and evaporation of DMF as the solvent. CNC surface grafting of the WPU chain and PCL soft segments jointly formed the crystalline domains; a eutectic was formed between the substrate and the packed continuous phase, which significantly enhanced the interface adhesion of CNC, thereby improving the thermal stability and mechanical strength of the nanocomposites. Although this synthesis method is time-consuming and uses harmful solvents and needs further enhancements in uniform dispersion of cellulosic materials and their hybrids without aggregation of nanocomposite forms.

Solvent casting nanocomposite synthesis methods

In solution coagulation synthesis of cellulose-based nanocomposite formation, silanes are efficient coupling agents to improve interfacial interaction by creating a chemical bridge between the material matrix and cellulose as filler to enhance the strength of composites. Solvent casting is not a suitable method for water-insoluble hybrid materials. The solution coagulation method involves the precipitation of solutes by adding coagulants (pure solvents) into well dispersion hybrid matric (solutions) and separating the solvents and obtaining the nanocomposite products. Unlike solution casting, solution coagulation can effectively prevent nanoparticles from accumulating because it avoids evaporation over a long period of time. Li, et al. prepared Poly Butyl Succinate (PBS)/Cellulose Nano Crystal (CNC) composites by solution coagulation with DMF as the matrix solvent, water as the strengthening solvent, and excess water as the coagulant. The overall crystallization rate of the nanocomposite increased significantly due to heterogeneous nucleation.

Free-radical polymerization nanocomposite synthesis methods

Free-radical polymerization synthesis method involves a combination of grafting and crosslinking by generating free radicals to which chain growth occurs in succession [47]. The synthesis procedure follows the generation of free radicals (initiator, Free radicals react with the monomer to generate vacant active sites (propagation), and the formation of a polymer network through crosslinking (termination) [48]. This synthesis nanocomposite materials are widely used to adsorb a wide range of water contaminants due to their easy process ability and tailor-made properties (Figure 3) [51-53]. method several has several advantages; being easy to synthesize being, not easily affected by impurities, and is a convenient method to synthesize nanocomposite hydrogel for different applications [49]. In free radical polymerization, grafting is the modification of the cellulose polymer backbone using synthetic polymers such as acrylamide, acrylic acid, methacrylamide, and vinyl alcohol as support materials [50]. Grafting can occur *via* either a chemical or radiation. Chemical grafting involves using chemical reagents such as Ammonium Persulfate (KPS) or other chemical initiators. Radiation grafting involves initiating free radicals using UV visible or microwave radiation. These synthesis methods are also used to enhance the performance of hydrogels through the introduction of new functionalities from grafted monomers [54]. Furthermore, Al-Gorair, et al. synthesized pectin acrylic acid/ cellulose nanocrystal hybrid nanocomposite by γ irradiation and the results revealed that the presence of CNCs in the polymeric matrix enhances the swelling and adsorption properties of Pectin-PAAc/CNC. Polymer-based nanocomposite materials are widely used to adsorb a wide range of water contaminants due to their easy processability and tailor-made properties

Current status of cellulose based nano composites adsorbent

The hybrid hydrogel nanocomposite materials show fascinating physico-chemical characteristics and stable performance [55]. Today the most widely reported combination of polysaccharides polymers (eg. Cellulose/ derivatives) with materials such as; metal oxide, clay, polymer, and carbon materials.

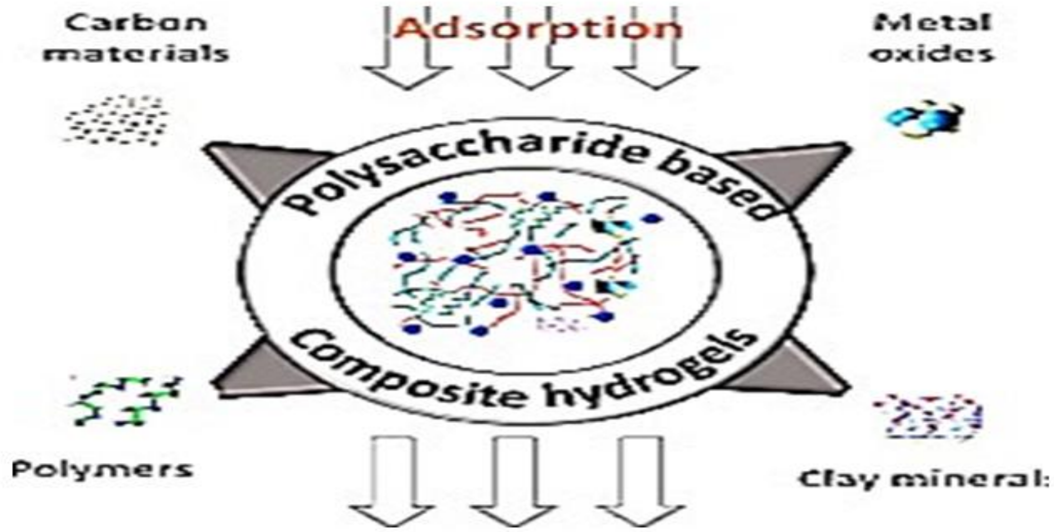


Figure 3. Nanocomposite filler with cellulose/nanocellulose.

Metal oxide- cellulose-based nano composites

Cellulose compounds appeared as aids in the assembly and stabilization of metal oxide nanoparticles to be more stable with good performance and, consequently, widen the application of metal oxides for different applications has been widely reported. Metal Oxide-Cellulose (MOC) Nano composites are an emerging area that offers the privilege of incorporating inorganic nanoparticles into natural-based materials for multifunctional applications. The synthesis of MOC nanocomposites should be carefully carried out so as to make sure that the metal oxide nanoparticles are well dispersed within the matrices of the cellulose so as to avoid the aggregation and extended OH groups of Cellulose could be modified functional groups of nanocomposites to improve their properties [56,57]. Metal oxide-modified CBNCs show improved chemical stabilities, optical, thermal, and mechanical strength, and also adsorption properties [58-61].

Among metal oxide-cellulosic material hybrid nanocomposites, magnetic CBNC has been attracted the intensive attention of many researchers due to its easy separation under the external magnetic field in adsorption technology [62,63]. Similarly, Li, et al. synthesized $MnFe_20_4$- Cellulose nanocomposite by in situ chemical precipitation methods followed by tert-butyl alcohol freeze-drying treatment at -35°C for 24 h. The as-prepared $MnFe_2O_4$ nanoparticles were well dispersed and immobilized in the micro/nanoscale pore structure of the cellulose aerogel, and exhibited superparamagnetic behaviour. The revealing strong magnetic responsiveness and unique structural features of that $MnFe_2O_4$/cellulose aerogel nanocomposite have possible uses for recyclable adsorbent for adsorption technologies applications (Table 1).

Table 1. Cellulosic material-metal oxide nanocomposite for adsorption removal of heavy metals.

Sample nanocomposite	**Synthesis methods**	**Pollutant**	**q (mg/g)**	**References**
CMC FeO	Impinging a stream rotating packed bed	Pb (II)	198.8	Fan, et al. 2019
Fe_3O_4-CMC	Ion imprinting technology	La (II)	61.5	Lin, et al. 2021
Fe_3O_4-CMC	Grafting polymerization	MB	34.3	Zhou, et al. 2021
CMC-cl-PAA/ Fe_3O_4-C_30B	Free radical polymerization	MB	1081.6	Malatji, et al. 2020
ZnO/Cellulose crystal	Polymerization	MB	64.49	Opeyemi, et al. 2020
Fe_3O_4/nanocellulose	Freeze dry method	Cr (VI)	2.2	Wei, et al. 2019
Fe_3O_4-CMC/GO	Co-precipitation methods	Cu (II)	198.98	Chen, et al. 2020
CMC coated FeO_4 SiO_2	Grafting polymerization	MB	22.7	Zirak, et al. 2018
CMC.cL-PAA/Fe_3O_4 C_3OB -Magnetic clay based CMC/poly acylic acid hydrogen hydrogel nanocomposites				

Clay modified cellulose-based nanocomposites

Modification of cellulose by introducing functionalized clay components improves both the physical and chemical properties of adsorbents [64]. The incorporation of clay into polymer matrix enhances chemical stability in strong acids and thermal stabilities by creating a protective barrier on the surface of nanocomposite (Table 2) [65-68].

Table 2. Current reports of clay modified cellulose-based nanocomposite adsorbent adsorption capacity.

Adsorbent	**Pollutants**	**qe (mg/g)**	**References**
Clay-cellulose nanocomposite	Cd (VI)	115.96	Abu-danso, et al. 2019
	Pb (II)	389.78	
Cellulose/diatomite	toluene	161.43	Nefzia, et al. 2019
CMC/modified magnetic bentonite	Cs (II)	80.5	Hu, et al. 2016
	Sr (II)	63	
	Co (II)	41.1	
Cellulose-bentonite zeolite	Brilliant	20. 71	Shamsudin, et al. 2019
	green		

The crystalline size of metal oxide and its dispersion on cellulosic Materials were found to be strongly governed by the pH conditions of the reaction solution.

Carbon-based material modified cellulose-based nano composites

Carbon-based hydrogel nanocomposites are hydrogels synthesized by incorporating materials such as Graphene Oxide (GO), biochar, AC, and carbon nanotubes. Highly emerging research interest of nanocellulose- nano-carbon based nanocomposite was due to synergetic effects, which are unachievable by taking cellulose nanocrystals and carbon nanomaterials separately. Synthesized cellulose-based nanocomposite from cationic nanocellulose and starch using different approaches, *i.e.,* acid hydrolysis, high-pressure homogenization, and high-intensity ultrasonication. It was also suggested that such cellulose-based nanocomposites have potential applications in adsorption technologies (Table 3).

Table 3. Cellulosic material-carbon based hybrid/hydrogel nanocomposite adsorption removal of heavy metals.

Sample nanocomposite	**Experimental setup**	**Pollutants**	**qe (mg/g)**	**References**
GO/CMC	Co=100 mg/L B=1.2 g/L	Atrazine	158	Khawaja, et al. 2021
MWCNT-COOH-Cellulose	T=25°C	MB	178.57	Kalili, et al. 2018
MWCNT-COOH-cellulose-MgO Np	t=55 min.		208.33	

Cellulose acetate-MOF derived porous carbon	pH=11 T=338 K Co=50 mg/L	Ni (II)	41.36	Tahazadeh, et al. 2021
Phosphorylated –CNC (water)/ MWCNT	pH=4.0	La (III)	21.23	
Phosphorylated –CNC(urea)/MWCNT	pH=4.0	La (II)	47.71	

In another study, Sharma, et al. developed reduced graphene oxide incorporated gun tragacanth-cl-N, N-dimethyl acrylamide hydrogel nanocomposite by microwave-assisted synthesis methods for adsorption removal of Hg^{2+} and Cr^{6+} ions. It is proved that the adsorption effectiveness of 99% and 82% were obtained for Hg^{2+} and Cr^{6+} ions, respectively, confirming that the developed adsorbents are highly efficient and can be employed for environmental remediation applications. The developed nanocomposites exhibited better thermal stability and interesting mechanical features.

The combination of cellulose-based material and nanocarbon has received tremendous interest due to the exceptional properties and outstanding synergetic effects that these powerful nanocomposite materials offer enhanced opportunities in water treatment, energy, environment, optics, and photonics, medical, biosensing, and optoelectronics. In general, the commercialization of cellulose–carbon hybrid nanocomposite materials need more effort and further improvements in functionality and performance, in addition, to the decrease in the production costs and environmental impacts another future issue is to be resolved.

Polymer modified cellulose-based nano composite

Cellulose-based -polymeric composites are widely used as primary supporting structures in different fields due to their combination of excellent mechanical properties with low density. It’s growing interest due to numerous surfaces -OH groups and ease of surface modification, high strength, low cost, and renewability. Polymer -cellulose-based Nano composites adsorbents are Super-absorbents are a loosely cross-linked network of hydrophilic polymers- cellulose that can absorb and retain a lot of aqueous fluids, and the absorbed water is hardly removable even under some pressure. They have high biocompatibility, biodegradability, and water uptake capacity, as well as low toxicity. The hydrophilic groups responsible for the high swelling of the polymeric chains are carboxyl, amino, amide, hydroxyl, and sulfonic. Butylina et al. were synthesized cellulose-based nanocomposite using different concentrations of polyvinyl alcohol (PVA; 5 and 10%) and nanocellulose. The effect of the CNC addition was both concentration-dependent and case-dependent. In general addition of CNC decreased the water content of the prepared hydrogels nanocomposites, decreased the crystallinity of the PVA, and increased the hydrogel’s compression modulus and strength to some extent. The performance of nanocomposite hydrogels in a cyclic compression test was studied; the hydrogel with low PVA (5%) and high CNC (10%) content showed totally reversible behavior after 10 cycles (Table 4).

Table 4. Adsorption removal capacity of polymer 002 Dcellulose-based Nano composites.

Sample Nano composite	**Experimental setup**	**Pollutants**	**Q max (mg/g)**	**Kinet ics**	**Isothe rm**	**References**
Polypyrrole/ CMC	pH=4-5 Time:1 hrs	Reactive red 56	104.9	PSO	Langm uir	Tanzif, et al. 2020
B:0.09 g/L Co:100 gm/L		Reactive blue 160	120.7	PSO	Langm uir	
Polypyrrole/n ano- cellulose	pH =2 B =75 mg	Cr(VI)	560	PSO	Langm uir	Alsaiari, et al. 2021
PSO-Pseudo-first-order, B-Represents the adsorbent dose						

DISCUSSION

Properties of cellulose-based nano composites adsorbent

As a lot of researchers are reported physical and chemical properties of cellulose are changed when combined in different forms with other materials to form a cellulose-based nanocomposite.

Stability: Incorporation of inorganic fillers into the polymer matrix was found to enhance the thermal stability of Nano composite. Incorporation of nanofiller into cellulosic hydrogel matrix enhances thermal and mechanical properties, swelling, and adsorption capacity of the hydrogel nanocomposites (Figure 4).

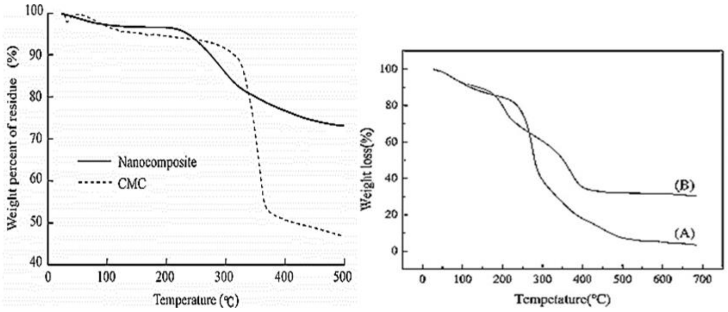


Figure 4. a) TGA curves of CMC and CMC/OMMT; b) TG for A. FeO/CMC and nanocomposite, FeO/CMC/GO Nanocomposites.

Compared with the cellulose of nanocellulose forms, cellulose-based nanocomposites have the advantage of high stability for excellent recycling utilization of adsorbents. Zhu, et al. reported the stability of CMC/GO nanocomposite for adsorption removal of MB dyes after nine consecutive cycles shows a slight decrease of adsorption capacity from 244.99 mg•g-^{1} to 227.02 mg.g^{-1} and the adsorption efficiency decreases from 97.99% to 90.81% (Figure 5).

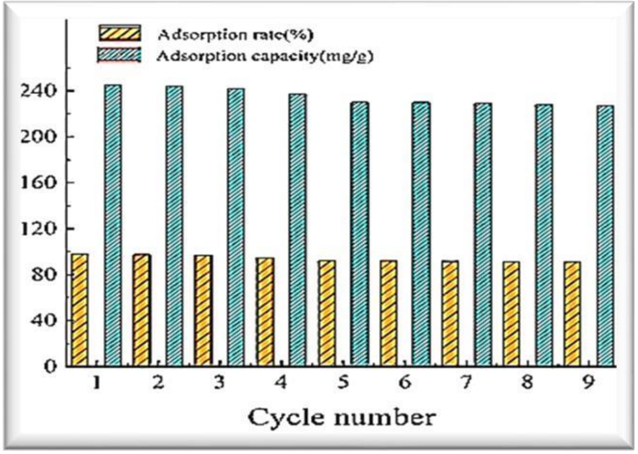


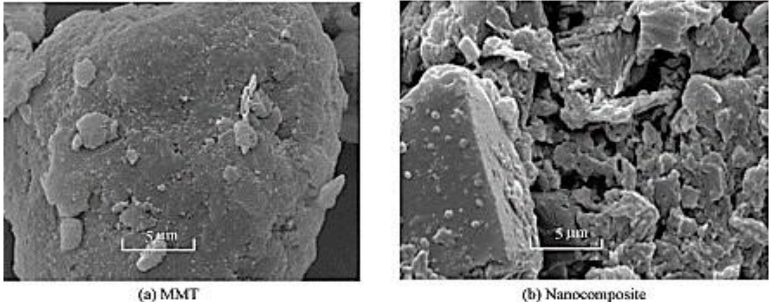
Figure 5. Adsorption capacity and stability of cellulose-based Nano composite adsorbent.

Porosity: Preparation of effective cellulose- inorganic nanofillers like metal oxide nanoparticles and clay into cellulose matric to form nanocomposites need an appropriate component ratio for further enhancement of surface porosity. Mukerabigwi, et al. synthesized hydroxyethyl cellulose/diatomite (HEC-g PAA/diatomite) nanocomposite increasing the appropriate amount of inorganic filler to the cellulose matrix enhances the pore volume of the nanocomposite (Table 5).

Table 5. Thermal stability and pore volumes of cellulose-based Nano composites.

Sample	**Thermal stability**	**Pore volume cm/g^3**
HEC-g-PAA/diatomite (6.wt %)	408 -597°C with 55.92% loss	0.00442
HEC-g-PAA/diatomite (12.wt. %)	412 -597°C with 52.05% weight loss	0.000759

Furthermore, Wei, et al. reported the incorporation of the proper amount of iron oxide nanoparticles into the cellulose matrix for nanocomposite preparation could be beneficial to its surface porosity improvement into cellulose-based nanocomposites and those nanocomposites with considerable numbers of pores and a large surface area show a good possibility of pollutants being absorbed into these pores (Figure 6).



(a) MMT (b) Nanocomposite

Figure 6. SEM image of Montmorillonite (MMT) and nanocomposites.

Selectivity: Most adsorbent are highly effective remediation of target pollutant at synthetic waste but due to effect of co-existing ions not fit for removal of pollutants form real wastewater containing different co-existing anions and cations. Thus, an efficient separation step is often required prior to recovery and removal of target pollutants effectively and interference-free of co- existing cations and anions (Table 6).

Table 6. Selective adsorption properties of cellulose based Nano composites.

Sample nanocomposite	**Pollutants**	**Qe (mg/g)**	**Kd (mL/g)**	**References**
Cellulose/ZrO_2	Ni (II)	4.95	91250.92	Khan, et al.
Nano composite	Fe (III)	0.89	216.55	
	Zr (IV)	0.7	162.79	
	Cu (II)	0.58	131.22	
	Cd (II)	0.57	128.67	
	Cr (III)	0.45	99.63	

	Zn (II)	0.41	89.32	
	Co (IV)	0.36	77.59	
Fe_3O_4/CMC	La (II)	22.5	0.124	Liu, et al.
	Ni (II)	5.8	0.0302	
	Cu (II)	5.9	0.0294	
	Cd (II)	0.8	0.00394	

Even though CBNCs adsorbent has a high capacity to be selectively adsorbed target pollutants from aqueous solutions, its adsorption removal was affected by co-existing cations and anions.

Alsaiari, et al. synthesized polypyrrole/Nanocellulose Cellulose (ppy/NC) based nanocomposite for adsorption removal of Cr (VI) in the presence of 0.1 m interfering ion (Figure 7).

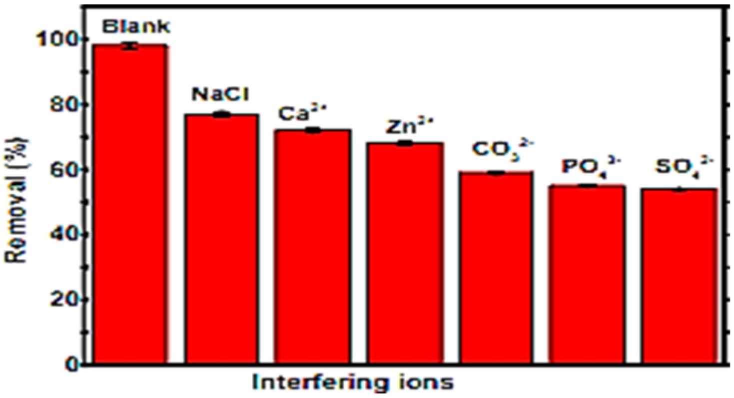


Figure 7. Effect of co-existing ion in adsorption removal of Cr (VI) on CBNC adsorbent.

CONCLUSION

This seminar reviews the fast-growing research area and intended to highlight the up-to-date synthesis methods and utilization of Cellulose-Based Nano Composites (CBNCs) hybrids are not only expanded the number of applications but also has enhanced their physical and chemical properties like thermal and mechanical stability, selectivity, and porosity. The development of CBNC materials is relatively a new concept, which is mostly limited to academic discipline but is expected that nanocomposite hybrids will certainly be commercially available in the future. Cellulose-based nanocomposites as next-generation materials require further improvements in functionality and performance in addition to the reduction of production costs and environmental impact. Organic solvents and toxic chemicals should be replaced with greener synthesis methods during the preparation of the cellulose-based nanocomposites because they are harmful to the environment and limits their actual applications to use as commercial products.

REFERENCES

1. Abouzeid RE, Khiari R, El-Wakil N, Dufresne A (2019). Current state and new trends in the use of cellulose nanomaterials for wastewater treatment. Biomacromolecules. 20:573–597.

2. Akter M, Maitry Bhattacharjee, Avik Kumar Dhar, Fahim Bin Abdur Rahman, Siddika Haque, Taslim Ur Rashid and S M Fijul Kabir (2021). Cellulose-based hydrogels for wastewater treatment: a concise review. Gels. 7:30.

3. Aktes B, Koytepe S, Ulu A, Gurses C, Thakur VK (2020). Chemistry, structures, and advanced applications of nanocomposites from biorenewable resources. Chem Rev. 120:9304-9362.

4. Al-Gorair AS, Sayed A, Mahmoud GA (2022). Engineered superabsorbent nanocomposite reinforced with cellulose nanocrystals for remediation of basic dyes: isotherm, kinetic, and thermodynamic studies. Polymers. 14:567.

5. Aloui H, Khwaldia K, Hamdi M, Fortunati E, Kenny JM, Buonocore GG, Lavorgna M (2016). Synergistic effect of halloysite and cellulose nanocrystals on the functional properties of pva based nanocomposites. ACS Sustain Chem Eng. 4:794–800.

6. Bayramoglu G, Arica MY (2018). Adsorption of Congo red dye by native amine and carboxyl modified biomass of Funalia trogii: Isotherms, kinetics and thermodynamics mechanisms. Korean J Chem Eng.

35:1303–1311.

7. Bayramoglu G, Kunduzcu G, Arica MY (2020). Preparation and characterization of strong cation exchange terpolymer resin as an effective adsorbent for removal of dispersed dyes. Polym Eng Sci. 60:192–201.
8. Biliuta G, Coseri S (2019). Cellulose: a ubiquitous platform for eco-friendly metal nanoparticles preparation. Coord Chem Rev. 383:155–173.
9. Butylina S, Geng S, Laatikainen K and Oksman K (2020) Cellulose nanocomposite hydrogels: from formulation to material properties. Front Chem. 8:655.
10. Cao X, Habibi Y, Lucia A (2009). One-pot polymerization, surface grafting, and processing of waterborne polyurethane-cellulose nanocrystal nanocomposites. J Mater Chem. 19:7137-7145.
11. Capron I, Rojas OJ, Bordes R (2017). The behavior of nano cellulose at interfaces. Curr OpinColloid Interface Sci. 29: 83–95.
12. Chai HB, Chang Y, Zhang YC, Chen ZZ, Zhong Y, Zhang LP, Sui XF, Xu H, Mao ZP (2020). The fabrication of polylactide/cellulose nanocomposites with enhanced crystallization and mechanical properties. Int J Biol Macromol. 155:1578–1588.
13. Chaichi M, Hashemi M, Badii F, Mohammadi A (2017). Preparation and characterization of a novel bionanocomposite edible film based on pectin and crystalline nanocellulose. Carbohydr. Polym. 157:167–175.
14. Chen Y, Cui J, Liang Y, Chen X, Li Y (2020). Synthesis of magnetic carboxymethyl cellulose/graphene oxide nanocomposites for adsorption of copper from aqueous solution. Int J Energy Res. 1–11.
15. Chen X, Huang Z, Luo SY, Zong MH, Lou WY (2021). Multi-functional magnetic hydrogels based on millettia speciosa champresidue cellulose and chitosan: Highly efficient and reusable adsorbent for congo red and Cu^{2+} removal. Chem Eng J. 423:130198.
16. Choo K, Ching YC, Chuah CH, Julai S, Liou NS (2016). Preparation and Characterization of Polyvinyl Alcohol-Chitosan Composite Films Reinforced with Cellulose Nanofiber. Materials. 9:644.
17. Da Costa JS, Bertizzolo EG, Bianchini D, Fajardo AR (2021). Adsorption of benzene and toluene from aqueous solution using acomposite hydrogel of alginate-grafted with mesoporous silica. J Hazard Mater. 418:126405.
18. Duranoglua D, Ismet˙ Gül Buyruklardan Kayaa, Ulker Bekera, Bahire Filiz Senkal, (2012). Synthesis and adsorption properties of polymeric and polymer-based hybrid adsorbent for hexavalent chromium removal. Chem Eng J. 181–182:103–112.
19. El-saied, El-Fawal EM (2021) Green superabsorbent nanocomposite hydrogels for high-efficiency adsorption and photo-degradation/reduction of toxic pollutants from wastewater. Polym Test. 97: 107134.
20. El-Sherif H, El-Masry M (2010). Superabsorbent nanocomposite hydrogels based on intercalation of chitosan into activated bentonite. Polym Bull. 66: 721–734.
21. Fan H, Ma X, Zhou S, Huang J, Liu Y, Liu Y, (2019). Highly efficient removal of heavy metal ions by carboxymethyl cellulose immobilized Fe_3O_4 nanoparticles prepared *via* high-gravity technology. Carbohydr Polym. 213:39–49.
22. Fathi B, Foruzanmehr M, Elkoun S, Robert M (2019). A novel approach for silanetreatment of flax fiber to improve the interfacial adhesion in flax/bio epoxy composites. J Compos Mater. 53(16):2229–2238.
23. Ghorai S, Sinhamahpatra A (2012). Novel biodegradable nanocomposite based on XG-g-PAM/SiO_2: Application of an efficient adsorbent for Pb^{2+} ions from aqueous solution. Bioresour. Technol. 119:181–190.
24. Gouda M, Wedad Al-Bokheet and Mohamed Al-Omair (2020). In-Situ deposition of metal oxides nanoparticles in cellulose derivative and its utilization for wastewater disinfection. Polymers. 12:1834.

25. Han L, Wang W, Zhang R, Dong H, Liu J, Kong L, Hou H (2019). Effects of preparation method on the physicochemical properties of cationic nanocellulose and starch nanocomposites. Nanomaterials. 9:1702.

26. Hokkanen S, Bhatnagar A, Sillanpaa M (2016). A review on modification methods to cellulose- based adsorbents to improve adsorption capacity. Water Res. 91:156–73.

27. Jamshaid A, Hamid A, Muhammad N, Naseer A, Ghauri M, Iqbal J, Rafiq S, Shah N.S, (2017). Cellulose-based materials for the removal of heavy metals from wastewater – an overview. Chem BioEng Rev. 4:1–18.

28. Jung W, Riahinezhad M, Duever TA, et al. (2015). Case studies with mathematical modeling of free-radical multi-component bulk/solution polymerizations: part 1. J Macromol Sci Part A. 52:659–698.

29. Karnib M, Kabbani A, Holail H, Olama Z (2014). Heavy metals removal using activated carbon, silica and silica activated carbon composite. Energy Procedia. 50:113–120.

30. Kian LK, Jawaid M, Ariffin H, Karim Z (2019). Isolation and characterization of nanocrystalline cellulose from roselle-derived microcrystalline cellulose. Int J Biol Macromol. 114:54–63.

31. Lee K, Kim K (2005). Stress-strain behavior of the electrospun thermoplastic polyurethane elastomer fiber mats. Macromol Res. 13: 441–445.

32. Li YD, Fu QQ, Wang M, Zeng JB (2017). Morphology, crystallization, and rheological behavior in poly (butylene succinate)/cellulose nanocrystal nanocomposites fabricated by solution coagulation. Carbohydr Polym. 164:75–82.

33. Liu L, Chang S, Wang Y, Zhao H, Wang S, Zheng C, Ding Y, Ren S, Zhang J and Guo Y.R, (2021). Facile fabrication of ion-imprinted Fe_3O_4/carboxymethyl cellulose magnetic biosorbent: removal and recovery properties for trivalent La ions. RSC Adv. 11:25258–25265.

34. Ma J, Sun Z, Wang Z, Zhou X, (2016). Preparation of ZnO–cellulose nanocomposites by different cellulose solution systems with a colloid mill. Cellulose. 23:3703–3715.

35. Makhado E, Pandey S, Kang K, Fosso-Kanke E (2019a). Microwave-assisted synthesis of xanthangum-cl-dimethyl acrylamide hydrogel-based silica hydrogel as adsorbent for cadmium (II) removal. In Int'l Conference on Science, Engineering, Technology and Waste Management. 1: 1–6.

36. Makhado E, Pandey S, Modibane KD, Kang M, Hato MJ (2020). Sequestration of methylene blue dye using sodium alginate poly (acrylic acid) ZnO hydrogel nanocomposite: kinetic, isotherm, and thermodynamic investigations. Int J Biol Macromol. 162:60–73

37. Makhado E, Pandey S, Ramontja J (2019c). Microwave-assisted green synthesis of xanthan gum grafted diethylamino ethyl methacrylate: efficient adsorption of hexavalent chromium. Carbohydr Polym. 222:114989.

38. Malatji N, Makhado E, Modibane KR, Ramohlola KE, Maponya TC, Monama G.R and Mpitloane J Hato MJ (2021). Removal of methylene blue from wastewater using hydrogel nanocomposites: A review. Nanomat Nanotech. 11:1–27.

39. Malatji N, Makhado E, Ramohlola K. E, Modibane K. D, Maponya T.C, MonamaG.R, MpitloaneJoseph Hato MJ (2020). Synthesis and characterization of magnetic clay-based carboxymethyl cellulose-acrylic acid hydrogel nanocomposite for methylene blue dye removal from aqueous solution. Environ Sci Pollut Res Int. 27:44089-44105.

40. Miljkovic MV, Momcilovic M. Stankovic M. Cirkovic B, Laketic D Nikolic G, Vujovic M (2018). Remediation of arsenic contaminated water by a novel carboxymethyl cellulose bentonite adsorbent. Appl Ecol Environ Res. 17:733-744.

41. Mashile PP, Nomngongo PN (2021). Magnetic cellulose-chitosan nanocomposite for simultaneous removal of emerging contaminants: adsorption kinetics and equilibrium studies.Gels. 7:190.

42. Mbakop S, Nthunya LN, Onyango MS (2021). Recent advances in the synthesis of nanocellulose functionalized–hybrid membranes and application in water quality improvement. Processes. 9:611.

43. Mohammed M Adnan, Antoine RM Dalod, Mustafa H Balci, Julia Glaum and Mari-Ann Einarsrud, (2018). Review on in situ synthesis of hybrid inorganic–polymer nanocomposites. Polymers. 10:1129.

44. Nthunya LN, Masheane ML, Malinga SP, Nxumalo EN, Barnard TG, Kao M, Tetana ZN, Mhlanga SD (2016). greener approach to prepare electrospun antibacterial β- cyclodextrin/cellulose acetate nanofibers for removal of bacteria from water, acs sustain. Chem Eng. 5:153–160

45. Opeyemi A, Oyewo, Adeniyi A, Bruce Sithole B, and Maurice S, Onyango (2020). Sawdust based cellulose nanocrystals incorporated with zno nanoparticles as efficient adsorption media in the removal of methylene blue dye. ACS omega 5:18798-18807.

46. Qian SP, Zhang HH, Yao WC, Sheng KC (2018). Effects of bamboo cellulose nanowhisker content on the morphology, crystallization, mechanical, and thermal properties of PLA matrix biocomposites. Compos Part B: Eng. 133:203–209.

47. Qiu KY, Netravali AN (2014). A review of fabrication and applications of bacterial cellulose- based nanocomposites. Polym Rev. 54:598–626.

48. Ranganathan N, Joseph Bensingh R, Abdul Kader M (2018). Synthesis and properties of hydrogels prepared by various polymerization reaction systems. In: Mondal M (ed) Cellulose- based superabsorbent hydrogels. Polymers and polymeric composites: a reference series. Cham: Springer, Springer Nature Switzerland AG. 1–25.

49. Ray D, Sain S (2015). Review: in situ processing of cellulose nanocomposites. Compos-A: Appl Sci Manuf. 83:19-37.

50. Riva L, Fiorati A, Punta C (2021). Synthesis and application of cellulose-polyethyleneimine composites and nanocomposites: a concise review. Materials. 14:473.

51. Salama A, Abouzeid RE, Owda ME, Cruz-Maya I, Guarino V (2021) Cellulose–silver composites materials: preparation and applications. Biomolecules. 11:1684.

52. Samiey B, Cheng CH, Wu J (2014). Organic-inorganic hybrid polymers as adsorbents for removal of heavy metal ions from solutions: A review. Materials. 7:673–726.

53. Samir MASA, Alloin F, Sanchez JY, El Kissi N, Dufresne A (2004). Preparation of cellulose whiskers reinforced nanocomposites from an organic medium suspension.Macromology. 37:1386–1393.

54. Sharma B, Thakur S, Trache D, Yazdani Nezhad H, Thakur VK (2020). Microwave-assisted rapid synthesis of reduced graphene oxide-based gum tragacanth hydrogel nanocomposite for heavy metal ions adsorption. Nanomaterials. 10:1616.

55. Shi X, Zhang X, Ma L, Xiang C, Li L (2019). TiO_2-doped chitosan microspheres supported cellulose acetate fibers for adsorption and photocatalytic degradation of methyl orange. Polymers. 11:1293.

56. Shojaeiarani J, Bajwa DS, Chanda S, (2021). Cellulose nanocrystal based composites: a review. composites part c: open access

57. Sinha V, Chakma S (2019). Advances in the preparation of hydrogel for wastewater treatment: A concise review. Elsevier Publisher, UK.

58. Sivakumar R, Lee NY (2022). Adsorptive removal of organic pollutant methylene blue using polysaccharide based composite hydrogels. Chemosphere. 286:131890.

59. Sruthi R, Shabari M, (2018). Removal of lead from textile effluent using citrus aurantium peel adsorbent and aloe barbadensis gel adsorbent, Int J Eng Res Technol. 5:3881.

60. Supramaniam J, Low DYS, Wong SK, Tan LTH, Leo BF, Goh BH, Darji D, Mohd Rasdi FR, Chan KG, Lee LH (2021). Facile synthesis and characterization of palm cnf-zno nanocomposites with antibacterial and

reinforcing properties. Int J Mol Sci. 22:5781.

61. Trache, Thakur VK (2020). Nanocellulose and nanocarbons based hybrid materials: synthesis, characterization and applications. Nanomaterials.10:1800.
62. Trache D, Thakur VK, Boukherroub R (2020). Cellulose nanocrystals/graphene hybrids—a promising new class of materials for advanced applications. Nanomaterials. 10:1523.

63. Valencia L, Kumar S, Emma M Nomena, Salazar-Alvarez G, and Aji P Mathew (2020). In-Situ growth of Metal oxide nanoparticles on cellulose nanofibrils for dye removal and antimicrobial applications. ACS Appl Nano Mater. 3:7172−7181.
64. Voisin H, Bergström L, Liu P, Mathew AP (2017). Nanocellulose-based materials for water purification. Nanomaterials. 7:57.

65. Wang M, and Wang L, (2013). Synthesis and characterization of carboxymethyl cellulose/organic montmorillonite nanocomposites and its adsorption behavior for Congo red dye. Water Sci Eng. 6:272-282.
66. Wang H, Luo P, (2020). Preparation, kinetics, and adsorption mechanism study of microcrystalline cellulose-modified bone char as an efficient Pb (II) adsorbent. Water Air Soil Pollut. 231:328. [Crossref][Googlescholar][Indexed]
67. Zhang L, Zeng Y, Cheng Z. (2016). Removal of heavy metal ions using chitosan and modified chitosan: A review. J Mol Liq. 214:175–191.
68. Zirak M, Abdollahiyan A, Eftekhari-Sis B (2018). Carboxymethyl cellulose coated Fe_3O_4 SiO_2 core-shell magnetic nanoparticles for methylene blue removal: equilibrium, kinetic, and thermodynamic studies. Springer Publisher, Netherlands.