Application of Sustainable Nanocomposites for Water Purification Process

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1 Introduction

Water is one of the most vital bases for the living system and is used in daily life activities. Due to rapid industrial growth, natural water resources are affected by several water pollutants. The World Health Organization (WHO) 2014 report on water supply and sanitation estimated that 748 million people still lack safe drinking water, 2.5 billion peoples without access sanitation and 3900 children die every day due to poor quality water and communicable diseases [1]. These statistics indicated that water pollution by numerous pollutants becomes an alarming issue worldwide. Consequently, competent water treatment technologies have been established to raise the potential of water resources and to decline the challenges and concerns associated with water pollution. In this regard, nanocomposite has to play a significant role in the water purification technology including potable water treatment, wastewater desalination, and treatment in order to deliver the real technology to clean water at a lower price using less energy by decreasing further ecological impacts.

Nanomaterials are materials which have the structural components sized from 1 to 100 nm [2]. They have unique properties when compared with other conventional materials, such as mechanical, electrical, optical, and magnetic properties due to their the small size and higher specific surface area, nanomaterials [2]. In recent years, nanomaterials have been effectively applied to numerous perspectives as catalysis [3], medicine [3], sensing, and biology [4]. They have extensive applications to prevent several environmental problems like water and wastewater

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treatment. Because, nanomaterials have the potential to eliminate different toxins, for instance, heavy metals, organic pollutants, inorganic anions, and pathogens [5]. Zero-valent metal nanoparticles (nZVI), metal oxides nanoparticles, carbon nanotubes (CNTs) and nanocomposites are the most recent appropriate nanomaterials for water and wastewater treatment [6].

The nZVI is one of the most useful nanomaterials for water purification [7–9]. The nZVI has a role in water purification as an electron subscriber which encourages the conversion toxic metals to safe forms (the reduction of chromium from hexavalent into trivalent form), adsorption, co-precipitation processes and strong reducing ability [10]. The nZVI has discovered real application for eliminating various organic and inorganic pollutants such as polychlorinated compounds [11, 12], Nitrates, phosphates and perchlorates [13, 14], nitroaromatic compounds [15], organic dyes [16], phenols [17], heavy metals [18], metalloids [19], and radio elements [6, 20].

Other nanoparticles like silver (Ag), titanium oxide (TiO_2), zinc oxide (ZnO), iron oxides and CNT are applied in water treatment technology. Silver nanoparticles (AgNPs) are very noxious to microbes and hence have solid antibacterial effects for an extensive variety of microorganisms (viruses, bacteria, and fungi) [21]. AgNPs are the promising antimicrobial agents, which have been extensively used for water disinfection [21]. AgNPs have the removal potential for bacteria's like methicillin-resistant *Staphylococcus aureus*, ampicillin resistant *E. coli*, a common water contaminant, erythromycin resistant *Streptococcus pyogenes* and vancomycin-resistant *Staphylococcus aureus* [22], *Pseudomonas aeruginosa, Vibrio cholera* [23], *Bacillus subtilis* [24]. There are different ways of Nanosilver disinfection mechanisms such as the interaction of AgNPs with DNA, altering the membrane and altering the enzymatic activity and thus destroy it [25–28], the dissolution of AgNPs that able to react through the thiol sets of enzymes disable, and interrupt usual services the cell [29].

In nanocomposites (NCs), there is no a previous documented review of their application in water and wastewater treatment perspectives. NCs are formed through the combination of more than two materials having various physical and chemical properties and unique interface [28], [30]. Composites have many advantages than other compounds due to their unique characteristics such as high durability, high rigidity, high strength, gas-barrier features, corrosion resistance, low density, and heat resistance. The combination of the matrix (continuous phase) and the reinforced materials (dispersed) is knowns as composite materials. They are materials of the 21st century which are multiple phase materials a minimum one of the phase's displays sizes from the range 10–100 nm [31]. Todays, NC materials have developed as appropriate choices to overwhelmed restrictions of various manufacturing tools. NCs have wide practice in various fields such as life sciences, drug distribution schemes, and wastewater treatment. In NCs, the nanoparticles were merged within diverse functionalized materials like multiwall CNT, activated carbon, cheap graphene oxide, and polymeric media. NCs have a number of application in the area of food packaging [32–34], anti-corrosion barrier protection [31], biomedical [31, 35] and coating [36]. This chapter focuses on the exciting NC types and their current application in water purifications. Besides, the future perspective of nanocomposites in water treatment also addressed.

2 Conventional Water Purifications Technologies

Surface water (spring, rivers, and lakes) and unconventional water resources (which are not available for direct use. For example, wastewater, seawater and brackish water) are the major universal water resources potentials [37]. Globally, the upsurge in industrialization and urbanization with a quick population growth and weather change contributes to the pollution of freshwater resources [38–40]. Table 1 shows the available conventional water purification technologies such as coagulation and flocculation, air flotation and advanced oxidation processes. These methods are very quiet in removing the contaminants efficiently. However, these methods possess several challenges related to the formation of either secondary pollution or higher energy requirement. Therefore, a massive attention should be given to the improvement/innovation of technologies having ecologically friendly, low energy consumption and economical feasible treatments perspectives applicable to the feasible water sanitization systems. To meet the demand for clean water standards, many authors have been focused on the suitable and economically viable water purification approaches including water remediation, reclamation, and desalination [41].

Table 1 Water purification methods [24, 41]

Water purification technologies	Contaminate removed
Coagulation and flocculation	Turbidity, dissolved organic carbon, bacteria and chemical contaminants such as cyanide compounds, phosphorus, fluorides, arsenic etc
Boiling	Kill the bacterial cultures
Distillation	To destroy microbial cells and unwanted chemicals such as calcium, lead, magnesium
Ultraviolent treatment	Can achieve disinfection of about 99.99%
Ultrasound	Damage cellular structures of bacteria
Ozone	It is effective in eradicating tastes, odour, colour, iron, and manganese; and not affected by pH and temperature
Chlorine	Kills several waterborne pathogens
Catalytic process	Applied to breakdown down an extensive diversity of organic materials like organic acids, estrogens, pesticides, dyes, crude oil and microbes
Bioremediation	Eradicating heavy metals, organic toxins, pesticides and dyes by plant extracts and microbes.

3 Types of Nanocomposites and Its Application in Water Purification

The use of nanoparticles in water management has associated with some practical problems, such as accumulation, tough separation, drainage into the contact water, possess environmental and human health [30]. One capable approach to improve the application of nano-particulate materials is to develop NC materials that take advantages of both the hosts and impregnated nanoparticles (Fig. 1) [42]. NCs have the potential to mitigate the discharge of nanoparticles into the environment, and improves the suitability of nanotechnology with current infrastructures. The NCs are essentially multiphase solid material, including porous media, colloids, gels, and copolymers in a broad sense. The selection of hosts for nanocomposites is of great significance, and even dominates the performance of the resultant nanocomposites. Compared with free nanomaterials, the performance and usability of nanocomposites were significantly improved, in terms of nanoparticle dispersion, stability, and recyclability. Hence, nanocomposite materials could bond the gap between nanoscopic and mesoscopic scale. Till now, nanocomposites were believed to be the most likely way to forward water nanotechnology from laboratory up to the large-scale applications [41].

3.1 Metal Nanocomposite

Polymer-supported nanosilver has recognized antibacterial properties of polyurethane and cellulose acetate impregnated nanosilver-fiber composites have good inhibition activity for Gram-positive and negative bacteria. The dispersion

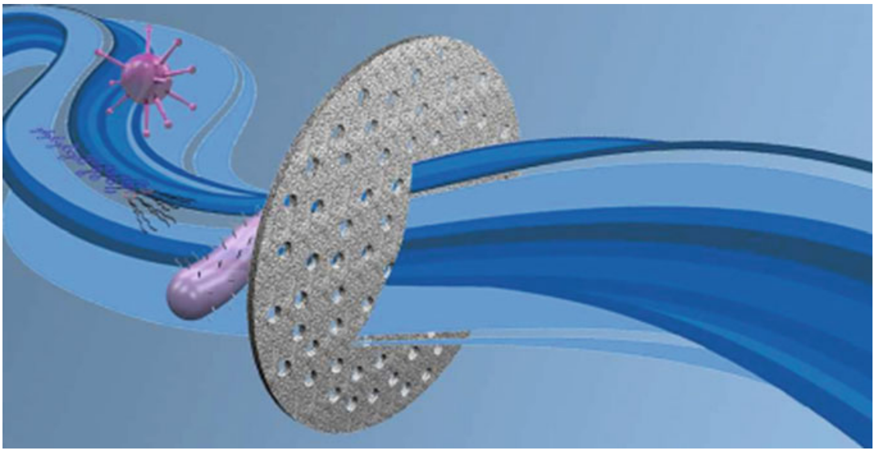

Fig. 1 Application of nanocomposite for water purification [42]

nanoparticle in polyurethane foam has gained effective antibacterial filters [43]. Once announced in polymeric membranes, a decrease of biofouling as well as good pathogen eradication efficiency was perceived. Nanosilver was also used in the making of economical1y feasible microfilters for handling drinking water which is mainly preferred in unreachable regions [44].

Silver-alginate composite beads were effectively prepared using three different methods. Specifically, the adsorption-reduction (AR), hydraulic retention time (HRT) and simultaneous gelation-reduction (SGR) composite beads were talented to succeed a disinfection effectiveness for portable water purifying. Those Composite beads equipped using diverse methods were established effective cleaning in the *E. coli* to various degrees. Both SGR and the AR beads confirmed equivalent disinfection efficiency but, the SGR beads released knowingly more Ag than the AR beads fix, indicating that the SGR beads may have a higher lifespan than the AR beads without losing sterilization success. These results weight the significance of improving the synthesis method in yielding material configurations that lead to the essential physical properties of numerous aspects [45].

The synthesized novel NC containing AgNPs and mesoporous alumina have been used for the elimination of dye compounds like methyl orange, bromothymol blue, and reactive yellow from synthetic waste. The results display that the silver/mesoporous alumina nanocomposite (Ag/OMA NC) was noble adsorbent for the elimination of anionic dyes from aqueous solution, and also this NCs had an antibacterial activity against both Gram-negative and Gram-positive bacteria [46].

The addition of AgNPs and *Moringa oleifera* seed powder were improved graphene structure which improves the removal efficiency of pollutants from liquid industrial waste like textile, tannery, and paper mill. The adsorption study of the adsorbents clearly revealed that the graphene loaded with AgNPs and seed powder of *Moringa. oleifera* composite (GAM) designated superior results compared to normal adsorbents due to the configuration of GAM sorbent which is recognized by the high surface area, biocidal action, adsorption activity AgNPs, and coagulation property of *Moringa oleifera*. Thus motivated the composite to be novel, economically feasible, and environmental suitable and promising adsorbent for water treatment [47].

Bimetallic nanocomposites supported on carbon are of great interest. Carbon supported bimetallic nanoparticles have reduced surface area which enhances their properties to a large extent. Nowadays, Water pollution is crucial problem happen due to existence contaminates like chemicals, microbes (fungi, bacteria, and virus) in water by human activities. Nanotechnology offers an alternative to the water purification. The bimetallic nanoparticles like ruthenium-palladium are used as reinforce to develop NC on the surface carbon matrix which had successfully helped in wastewater treatment having perchlorate as the main pollutant [31]. Others like, NCs of Au/Pd nanoparticles reinforced on TO_2 have been synthesis by microemulsion means and being used as an efficient photocatalyst due to their high light absorption ability. Bimetallic NCs of Fe/Ni-K have the capacity to remove DBG from the wastewater. The degree of eliminating DBG in the NC (Ni/Fe-K) is greater than that of separate kaolin and the bimetallic nanoparticles (Ni/Fe) [31, 48].

3.2 Metal Oxide Nanocomposite

The Metal oxide nanocomposite (MONC) are often used as adsorbents, photocatalyst, and devices to challenge environmental pollution problems. MONC are used merging with graphene, silica, other oxides, carbon nanotube (CNT), polymers for the removal of various organic and inorganic of pollutants [49]. Currently, removal of organic pollutants from wastewater is one of the most significant alarms in water pollution control. In last decade, the interest in solving global water pollution by means of photocatalysis is increased rapidly using metal oxide nanoparticles (TiO_2 and ZnO). However, the use of basic TiO_2 and ZnO nanoparticles are limited because of their extensive band gap and the high recombination rate of photo produced charges. Coupling is developing an approach to increase the destroying degree of organic contaminants under visible light conditions. MONC provide a current technique to modify the properties of semiconductor metal oxide photocatalyst through encouraging charge transfer processes and improving charge separation [50].

The alumina composite reinforced by CNTs was produced by rising CNT above Fe and Ni-doped energetic alumina. The composite was influenced by numerous factors able to initiated high capacity synthesis which is factors includes activated alumina, CNT, amorphous carbon and various surface functional groups such as carboxyl, carbonyl and hydroxyl present in the clusters [51]. Ihsanullah et al. [52] deliberated that the consequence CNT/Al_2O_3 for actual elimination of chlorophenol and phenol from aqueous solutions. Alumina ornamented onto the exterior of multi-well carbon nanotube (MWCNT) was an inspiring adsorbent for immediate removal of Cd^{+2} and trichloroethylene (TCE) from poisoned groundwater. Electrostatic interactions, the hydrogen bond interactions and the protonation or hydroxylation of Al_2O_3 are the adsorption mechanism of Al_2O_3/MWCNTs to remove Cd^{+2} and TCE from the polluted water Fig. 2 [53, 54].

TiO_2 is the new greater type of composites based Metal oxide. TiO_2 nanocomposite has received more attention in water purification due to its nontoxicity, and the ability for the photo-oxidative degradation contaminates such as MB [55], benzene derivatives [56], and carbamazepine [57] were powerfully photodegraded by CNT/TiO_2 composites. Researchers described that the bond of carbon-oxygen-titanium can enlarge the light absorption to longer wavelengths and hence potentially improvement of the photocatalytic action [53]. Senusi et al. [40] also indicated that synthesized TiO_2-zeolite NCs for the innovative water treatment of industrial dyes. The results indicated that the nanocomposite followed an adsorption concerned with photocatalytic degradation, which is mainly effective for eradicating trace dye compounds [40]. A novel Cu–TiO_2–SiO_2 NCs synthesized by a sol-gel method and used to degrade Rhodamine Blue in water modelling the dyes wastewater under both UV and visible light irradiation. Studies revealed that the Cu–TiO_2–SiO_2 nanocomposite has smaller crystalline size, higher surface area, and slight agglomeration by judging from the characteristic analysis. The Cu–TiO_2–SiO_2 nanocomposite exhibited higher photocatalytic activity than TiO_2 for the

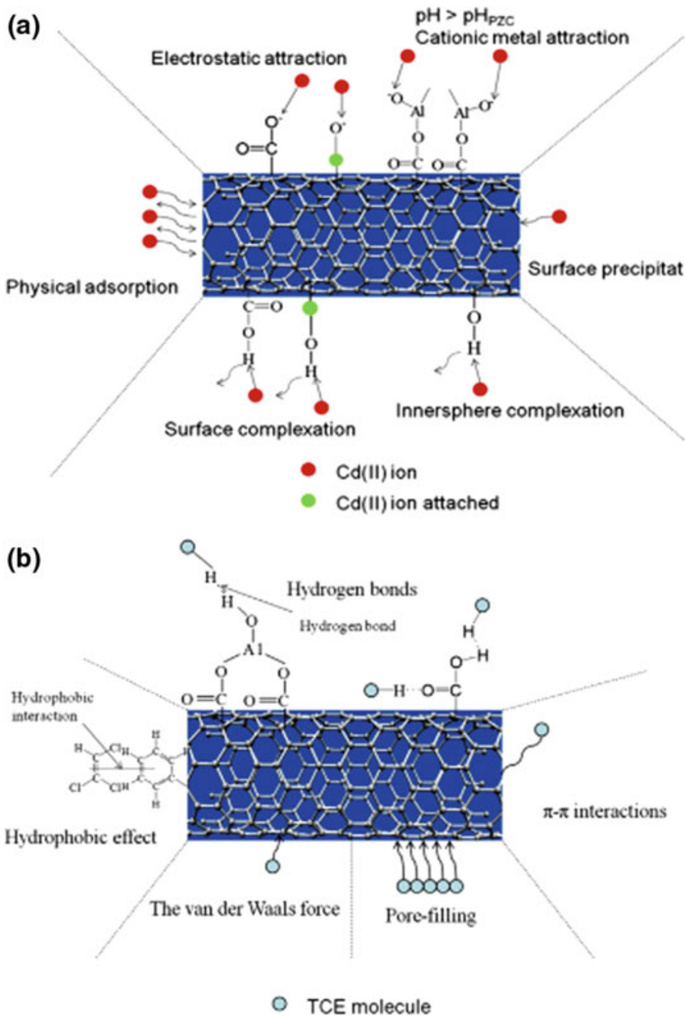

Fig. 2 The diagram representation of Cd(II) ion (**a**) and TCE (**b**) interface with Al2O3/MWCNTs [53]

degradation of Rhodamine Blue under both UV and visible light irradiation. The increase in the photocatalytic activity may be due to the lower recombination rate of electron-hole and the high dispersion of SiO_2 [58].

Iron oxides (i.e. Fe_2O_3 and Fe_3O_4) are unique and talented magnetic constituents which create a new composite with CNTs, and graphene. This is one of the greatest smart magnetic metallic oxides and has established extensive consideration due to its exceptional physical and chemical properties and several benefits such as high reversible capacity, rich abundance, cheap, and environmentally friend [54]. Magnetic nanoparticles are highly advantageous than nonmagnetic nanoparticles since they can simply isolate from water via a magnetic field. Magnetic field separation is a practice also allows simple isolation and recycled the adsorbents. Magnetic nanocomposites can be fabricated using magnetite (Fe_3O_4), maghemite (Fe_2O_3), and jacobsite ($MnFe_2O_4$) nanoparticles as reinforcer filling on a polymer matrix which permits easy separation of the composite from the aqueous solutions after the sorption process [29].

Researchers were investigated series of magnetic alginate polymers prepared and batch trials were shown to examine their capacity to eliminate heavy metal ions such as Co^{+2}, Cr^{+6}, Ni^{+4}, Pb^{+2}, Cu^{+2}, Mn^{+2}, La^{+3} and organic dyes (MB and MO) from aqueous solutions. Different types of iron oxide magnetic composites have been positively useful as an adsorbent for the elimination of various targets of impurities from water and wastewater such as naphthylamine [59], metals [59], phenol [59], and tetracycline [60], As^{+3}, As^{+5} [61], dyes [62]. Moreover, graphene-based iron oxide NCs have confirmed an exceptional adsorption capacity to fix extra heavy metals and organic dyes such as Cr^{+6}, Pb^{+2}, Co^{+2}, neutral red, MB etc. due to magnetic properties, high surface to volume ratio and rapid diffusion rate [59].

In addition to the above, Currently, many researchers have studied also on the practice of metal oxide NCs for water and wastewater purification. Currently, many scientists focus on the heavy metals removal due to their strong influence on health and environment. The Saad et al. [63] was to manufacture ZnO@Chitosan nanocomposite (ZONC) to eliminate Pb^{+2}, Cd^{+2} and Cu^{+2} ions from unclean water with optimal removal efficiency for Pb^{+2}, Cd^{+2} and Cu^{+2} ions at pH 4, 6 and 6.5 with adsorption capacity were 476.1, 135.1 and 117.6 mg/g, respectively. The researchers also studied nonstop adsorption-desorption cyclic outcomes established that ZONC can be reused after recovery of ions by EDTA solution, and the regenerate ZOCS used over without significant efficiency loss [63].

Singh et al. [64] investigated that BC_4/SnO_2 NCs was an effective catalyst for the degradation of industrial dyes such as Novacron red Huntsman (NRH) and MB. This composite is also discovered for catalysis destruction of industrial dyes. The Degradation study displays that 1 g/L catalyst concentration of BC_4/SnO_2 destroys NRH and MB dye up to nearly 97.38 and 79.41%, respectively, in 20 min using sun radiation. The catalyst can be recycled and recovered [64].

Zr-magnetic metal-organic frameworks composites (Zr-MFCs) are an amino-rich prepared by a facile and efficient strategy. The achieved Zr-MFCs were confirmed to be effective adsorbents with feasible adsorption ability and fast adsorption kinetics for metal ions and organic dyes removal from water. The amine-decorated MFCs were very efficient for metal ions and dyes elimination than row MFC-O. MFC-N confirmed the maximum ability for Pb^{2+} (102 mg g^{-1}) and MB (128 mg g^{-1}), while MFC-O revealed the maximum ability for MB (219 mg g^{-1}). Furthermore, Zr-MFCs have also good removal efficiency for anionic and cationic dyes from the miscellaneous solution by adjusting pH. Zr-MFC adsorbents can be simply improved by removing metal ions and/or organic dyes from the adsorbents with appropriate reagents without change adsorption capacity up to 6 generations. The attained results confirmed the prepared MFCs have the great application perspective as interesting adsorbents for water treatment [65].

Saad et al. [63] investigated a facile method for in situ fabrication of ZnO@Chitosan nanocomposite (ZONS), and the attained composite demonstrated noble ability and rapid kinetics for Pb^{+2}, Cd^{+2} and Cu^{+2} ions adsorption. The main advantage of this product is the recovery of metal ions and the significant ability for adsorption after many series of recycling. The ZONC demonstrations important feasibility in ecological remediation for wastewater treatment and can attain the increasing need for the purification of water resources [63].

3.3 Carbon Nanocomposite

A magnetic multi-wall carbon nanotube (MMWCNT) nanocomposite was used as an adsorbent for removal of cationic dyes from aqueous solutions. The MMWCNT nanocomposite was composed of viable multi-wall CNT and IONPs. The elimination of MB, neutral red and brilliant cresyl blue was deliberate using MMWCNT nanocomposite adsorbent. Investigations were carried out to study adsorption kinetics, the adsorption capacity of the sorbent and the effect of sorption dosage and pH values on the elimination of cationic dyes [66].

Mesoporous carbon with entrenched iron carbide nanoparticles (ICNPs) was effectively synthesized via a facile impregnation-carbonization method. Biomass was used as a carbon basis and an iron pioneer was rooted to create mesopores through a catalytic graphitization reaction. The pore conformation of the NCs structured by the iron pioneer loadings and the immovable ICNPs support as a dynamic component of magnetic isolation next sorption. The newly produced mesopores were established as a critical feature to increase the adsorption capacity of organic dyes while immovable ICNPs are responsible for the careful removal of heavy metal ions (Zn^{2+}, Cu^{2+}, Ni^{2+}, $Cr^{6+,}$ and Pb^{2+}). Composed with the desirable elimination of extra noxious heavy metal species (Cr^{6+} and Pb^{2+}), these mesoporous NCs show favourable applications in impurity removal from water. The facile material preparation permits appropriate scale-up production with economical feasible and lowest ecological impact [67].

Advanced technologies integrating with engineered nanoparticles into biochar fabrication schemes might increase the roles of biochar for numerous uses comprising soil fertility upgrading, carbon sequestration, and wastewater treatment. Inyang et al. [68], investigated that removal ability MB was evaluated in batch sorption using untreated hickory biochars (HC), bagasse biochars (BC) and CNT-biochar composites (HC-CNT and BC-CNT, respectively). The addition of CNTs considerably enriched the physiochemical properties of HC-CNT and BC-CNT such as extreme thermal stabilities, surface areas, and pore volumes. These results recommend that electrostatic magnetism was the principal devices for the removal of MB onto the biochar-nanocomposite. Hybridized CNT-biochar NC can be considered as capable, cheap adsorbent material for eliminating dyes and organic contaminants from water [68].

Carbon-nanocomposites (CNCs) are constituents that have two or more elements prepared to form a composite mixture with CNTs as the primary host synthesized the poly 1,8-diaminonaphthalene/MWCNTs COOH hybrid material which could be used as an active sorbent for the separation Cd^{+2} and Pb^{+2} at trace levels [40]. Muneeb et al. [69] was primed a new NCs from biomass used for the removal of selected heavy metals (As, Cr, Cu, Pd and Zn) from the wastewater. With the increase in pH, there was a decline in percentage adsorption of the metals [70].

Tian et al. [70] stated an eco-friendly, effective and synergistic nanocomposite development for new antibacterial agents using both iron oxide nanoparticles (IONPs) and AgNPs on the surface of graphene oxide (GO), resulted in novel GO-IONP-Ag nanocomposite. When associated with pure AgNPs, GO-IONP-Ag offers deliberately improved bacteriocidal action to both Gram-negative bacteria and Gram-positive bacteria. GO has the beautiful benefit through GO-IONP-Ag composite to kill Gram-positive bacteria at small agent concentration. Moreover, GO-IONP-Ag nanocomposite can simply reprocess by magnetic separation, low cost, and environmentally. In the account of those exceptional benefits, the developed GO-IONP-Ag nanocomposite can use for prospective requests as a multifunctional sterile agent in the diverse area [71].

3.4 Polymer Nanocomposite

Polymer nanocomposites (PNCs) are a superior type of tools which nanoparticles spread in a polymer matrix resulting in novel materials having unique physical and chemical properties [70]. Polymers are special supports for nanomaterials as they usually possess tunable porous structures, excellent mechanical properties, and chemically bounded functional groups. PNCs are prospecting materials for their sound performance in water and wastewater treatment. Adsorption of contaminant through PNC is among various treatment technologies, which is considered as an advanced tool in water treatment technology. PNCs often integrate the essential advantages of both the nanoparticles and the polymeric matrix [72]. PNCs could be synthesis by either joining nanoparticles into polymer structures or by fixing polymers to nanoparticles. Direct compounding and in situ synthesis are two leading approaches used in the manufacture of several PNCs as shown in Fig. 3 [41]. PNC has of great potential for pollutants removal including heavy metals (Cu, Pb, Cr (III), Ni), As, F, and P. The pollutants were often removed through multiple mechanisms including surface complexation, electrostatic attraction and co-precipitation [73].

These PNCs are avoided challenging issues such as nanoparticle dissolution, which is common when using free nanoparticles [72]. Some of the nanocomposites were also responsive to regeneration and recycle without significant capacity loss, which is critical from economic outlook. Since of the large size of the PNCs, they could be simply isolated from treated water.

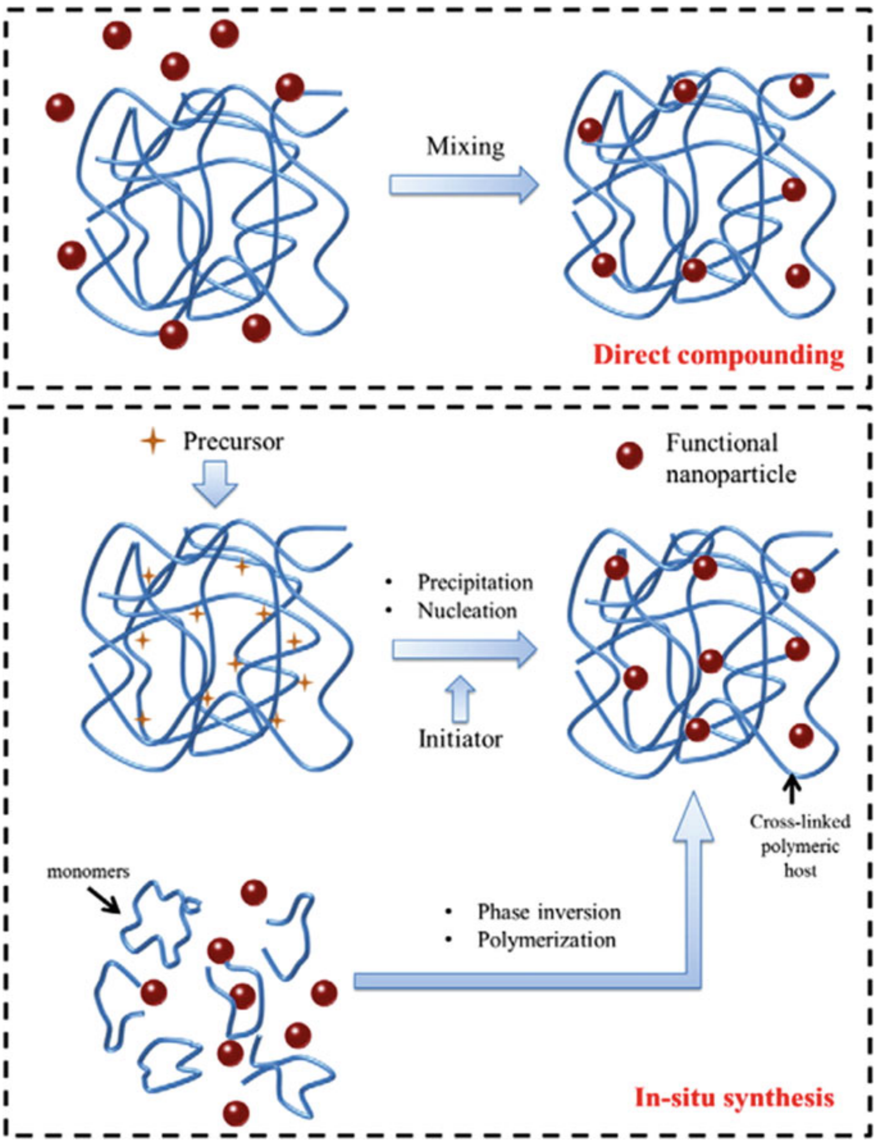

Fig. 3 Graphic of fusion methods for PNCs. Adapted with permission [41]

Alginate [74], macromolecule (polypyrrole) [75] polyaniline [76], porous resins [77] and ion-exchangers [41] are most extensively used polymeric hosts. New types of polymeric hosts are essentially bio-polymers such as chitosan and cellulose. They are plentiful in nature and eco-friendly. However, they could suffer a serious biodegradation problem in the long-term application. cellulose showed good chemical stability and mechanical strength, due to its densely and systematic aligned, hydrogen-bonded molecules, sound swelling resistance and its characteristics such as hydrophilicity and chirality. Chitosan is the another most naturally rich polysaccharide next to cellulose. Chitosan has exceptional features such as high reactivity, excellent complexation behaviour, and chemical stability. The amino and hydroxyl groups of chitosan aid as energetic sites for water pollutants [78]. Generally, cross-linked chitosan was insoluble even at low pHs, so that they might be applicable over a wide pH range. Djerahov et al. [78] prepared a steady CS-AgNPs colloid by diffusing the AgNPs sol in chitosan medium and additional recycled it to attain a cast film with high steadiness under packing and good mechanical strength. It showed efficient isolation and extraction of Al^{+3}, Cd^{+2}, Cu^{+2}, Co^{+2}, Fe^{+3}, Ni^{+2}, Pb + ^{2} and Zn^{+2} [40, 78].

Saxena and Saxena [79] developed Bimetal oxide fixed PNC by means of Alumina and IONPs with Nylon-6,6 and Poly (sodium-4-,styrenesulphonate) as polymer medium for pollutants elimination from the water. The prepared NCs have maximum pollutant removal capacities for all factors. The exclusion of total alkalinity, total hardness, calcium, magnesium, chloride, nitrate, fluoride, TDS and EC was 66.67, 42.85, 66.67, 25, 58.66, 34.78, 63.85, 41.27 and 41.37% respectively by this composite. This is an indication period towards emerging multifunctional and profitable PNCs for water remediation requests [79].

CNTs powerfully sorb varied polar organic compounds attributable to the stuff miscellaneous interfaces together with hydrophobic impact, peppiness interactions, covalent bonding, valence bonding, and electrical connections. The π-electron wealthy CNT apparent allows energy exchanges with carbon-based molecules with C=C bonds. Organic compounds that have used functional groups like –COOH, –OH, $–NH_2$ might additionally kind a bond with the graphitic CNT exterior that pays electrons. Electricity magnetism enables the surface assimilation of exciting carbon-based chemicals like some antibiotics at appropriate pH range. PNCs are sorbents tailored adsorbents which are talented for eliminating different types of pollutants. Their internal shells can be hydrophobic for sorption of organic compounds while the exterior channels can be tailored (e.g., –OH or $–NH_2$) for sorption of inorganic pollutants like heavy metals. complexation, electrostatic interactions, hydrophobic effect, and hydrogen bonding are the mechanism established during sorption process [80].

Carboxymethyl-cyclodextrin polymer adapted Fe_3O_4 nanoparticles (Copolymers) was manufactured for selective elimination of Pb^{2+}, Cd^{2+}, Ni^{2+} ions from wastewater. The adsorption efficiency of metallic ions was influenced by the factors like contact time, a dose of copolymers pH, ionic strength, and temperature. At equilibrium condition in single sorption way, the optimum uptakes of the adsorbent for Pb^{2+}, Cd^{2+}, and Ni^{2+} were 64.5, 27.7 and 13.2 mg g^{-1} respectively at 45 min and 25 °C. The PNC improved the sorption capacity since of the chelating abilities of the several hydroxyl and carboxyl sets in polymer support with metal ions. In mixed adsorption experiments, CDpoly-MNPs might favorably high sorption of Pb^{2+} ions with an attraction order of $Pb^{2+} \gg Cd^{2+} > Ni^{2+}$ [81].

Khaydarov. et al. [82] studies a new technique for emerging nanocarbon-conjugated polymer nanocomposites (NCPC) by means of carbon colloids as nanoparticle and polyethyleneimine as a matrix for metal ions removal from water. The researchers have been examined the efficiency of NCPC depends on size carbon colloids, synthesis NCPC and its chemical features, the ratio of carbon colloids and polyethyleneimine, the speed of coagulation NCPC, interaction mechanism, removal potential NCPC against pH. The bonding capacity adsorbent was 4.0–5.7 mmol/g with divalent metal ions at pH 6 which sorption has above 99% removal efficiency for Zn^{2+}, Cd^{2+}, Cu^{2+}, Hg^{2+}, Ni^{2+}, Cr^{6+} [82].

Clay can found the suitable matrix for varnish of polyaniline. The characterization outcomes of NC established that the clay sheet was develop layered in the synthesis NC. Parameters like contact time, pH, and concentration were determined the adsorption capacity of modified adsorbent. The researchers were announced new clay NC which use of polyaniline improved clay nanocomposite as an adsorbent for water purification of lead ions. It can be used as talented sorption scheme incoming water and wastewater treatment in order to eliminate lead ion [83].

Nithya and Sudha [84] studied using chitosan-g-poly(butyl acrylate)/bentonite NC as an adsorbent for chromium, lead and other significant physicochemical water quality parameters such as total solids (TS), biological oxygen demand (BOD), chemical oxygen demand (COD), total hardness, salinity, turbidity and conductivity from the tannery wastewater. The effect of some parameters, such as contact time, pH and dose adsorbent was assessed. The outcomes showed that NC can be used tannery wastewater treatment containing heavy metals powerfully [84].

3.5 Membranes Nanocomposite

In membrane technology, porous materials are plays capturing role to trap pollutants. Inclusive, numerous forms of membranes with diverse pore sizes engaged in water treatment process including microfiltration, ultrafiltration, reverse osmosis and nanofiltration membranes which depend on their shared materials that would be clean out through each process as shown Fig. 4 [42]. The existing membranes have numerous challenges for water purification, such as the exchange link between permeability, selectivity and low resistance to fouling. Recent progress in nanotechnology have offered the growth of the new generation membrane for water purification [40]. Nanocomposite membrane (NCM) has a great role in water purification and reuses for several bases of water such as drinking water, brackish, seawater, and wastewater treatment. NCM is an innovative type of membranes prepared by merging complex constituents with nanomaterials that are developing as a promising tool to answer membrane separation problems. The innovative NCM can be deliberate to fulfil exact water purification uses by calibration their assembly and chemical characters (e.g., water-heating, porousness, charge density, and thermal and mechanical stability) and announcing distinctive functionalities (e.g., medicinal drug, photocatalytic or adsorbent capabilities). The advance of membranes with high permeability, rejection and smart protective property is way

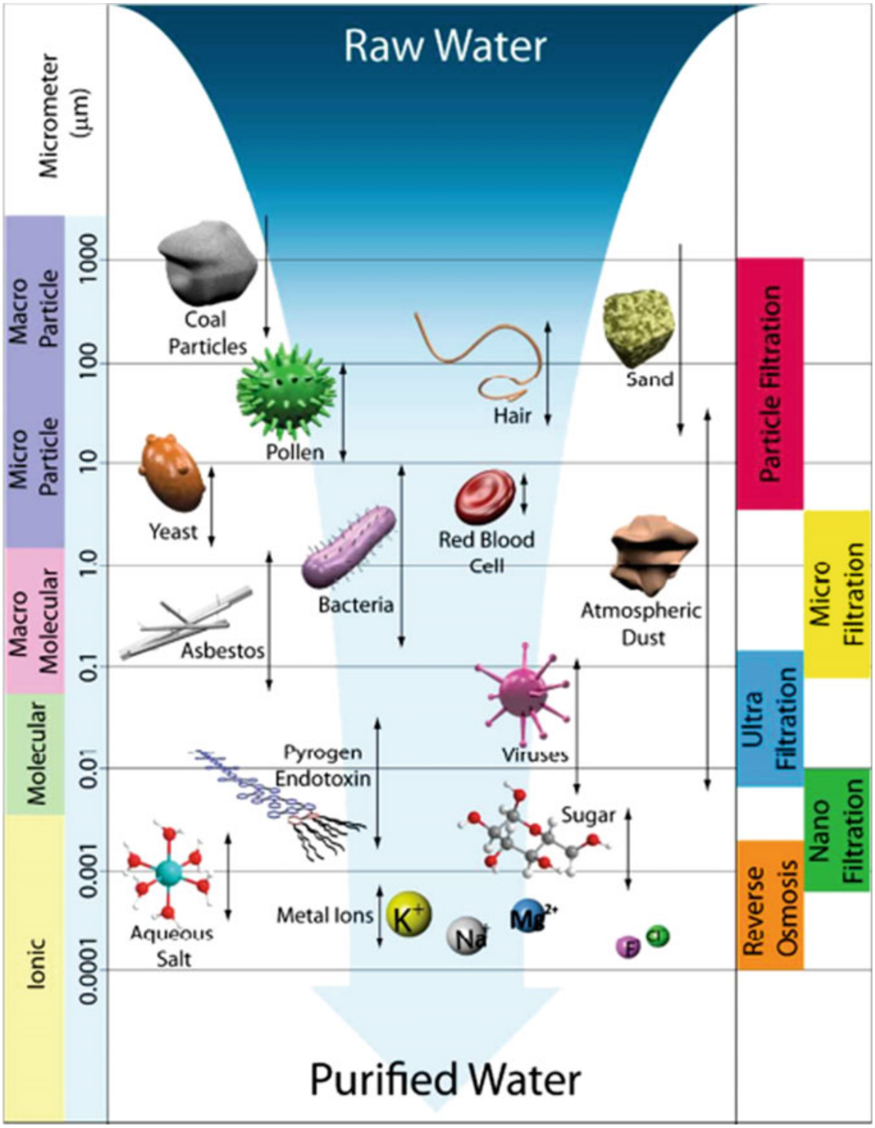

Fig. 4 Schematic illustration of membrane filtration [42]

required for water purification beneath the context of energy potency and cost-effectiveness. According to membrane assembly and position of nanomaterials, they can be classified into four groups: (1) conventional nanocomposite, (2) thin-film nanocomposite (TFN), (3) thin-film composite (TFC) with nanocomposite substrate, and (4) surface-located nanocomposite [85].

In water treatment applications, membranes have to significantly determine hydrophilicity, surface structure, and high toughness with respect to physico-chemical and mechanical stability. Pore size and porosity have also strong significant in membrane separation practices. NCM is a mixture of material that can have nanoscale inorganic and/or organic solid phases in a porous structure. These nanoscale constituents enrich membrane assets that would other not be fulfilled by the polymer only [85]. Nanomaterials can improve numerous characteristics of mechanical strength, thermal stability, antifouling properties, permeability, and selectivity which have enhanced membrane separations process. Various constituents such as CNTs, graphene and GO, silica and zeolites, metal and metal oxides, polymers, dendrimers and biological nanomaterials are used in NCM to improve water purification performance [86, 87].

NCM able to reflect as a novel class of filtration tools containing hybrid medium membranes and surface active membranes. Hybrid medium membranes use nanofillers, which are auxiliary to a medium material. In most cases, the nanofillers are inanimate and fixed in a polymeric or inorganic oxide medium. These nanofibers article has larger specific surface area leading to a higher surface-to-mass ratio [88]. NCMs are materials which have no single application of separating pollutants from water. They are also introducing new functionalities such as adsorption [89], photocatalysis [90], antimicrobial activity [91] and surface modification [91] which promoted adsorbing, degrading, and/or deactivating contaminates.

Most of the researchers have confirmed that the integration of nanomaterials into polymers besides to adjust assembly and physicochemical assets like hydrophilicity, porosity, and charge density, chemical, the thermal and mechanical stability of membranes, they are also announced exceptional characteristics such as bactericidal and photocatalytic features into the membranes. The effects of nanofiller on the performance of on the 3 type's NCMs are explained as follows.

3.5.1 Conventional Nanocomposite Membranes

Synthesis of CNM is commonly built on phase inversion (PI) technique in which nanofibers are discrete in polymer solution previous to the PI method as shown Fig. 5 [85]. It can be synthesised in either flat area or deep fiber arrangements. CNM is mostly applied in microfiltration or Ultrafiltration methods because it's typical porous arrangement.

It is known to join nanoparticles inside the polymer medium to create efficient membranes with an exact ability to adsorb heavy metals from water. For instance, incorporated PANI/Fe_3O_4 NPs inside polyethersulfone (PES) [92] and chitosan drops inside ethylene vinyl alcohol (EVAL) medium [93] had to remove Cu (II) water. Both outlooks have confirmed the opportunity of making CNM for the adsorptive elimination of impurities from water.

In the CNM research area, TiO_2 has also merged into numerous membrane mediums to deliver membrane with photocatalytic actions. TiO_2 has been extensively used for water treatment since its exceptional photocatalytic action, solidity,

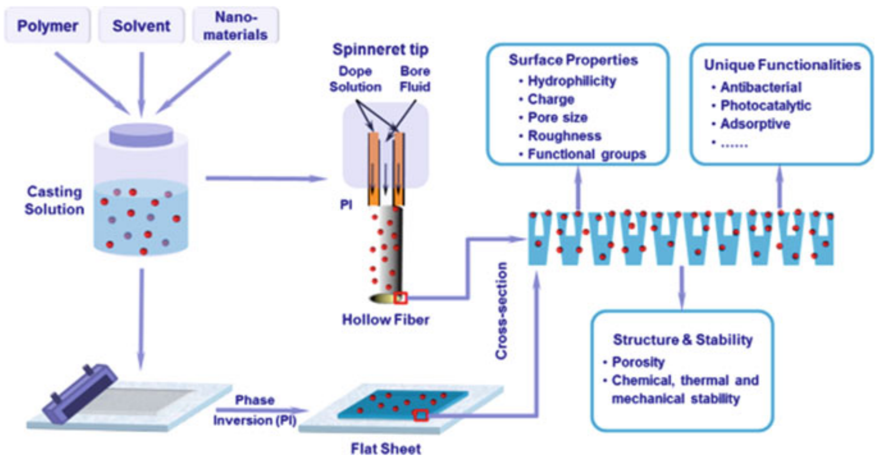

Fig. 5 Production of conventional CNM through the PI process [85]

and simplicity for its fabrication [84]. Evolving antimicrobial membranes will be expected to increase membrane efficiency and lifespan meaningfully which benefits to deliver microbes free clean water. For example, Ag is an excellent biocidal that usually used as an antimicrobial agent in CNM [85, 94]. AgNPs introduced into various metrics such as cellulose acetate [84], PSU [84], and PES [95] enhanced the membrane anti-bacterial activity, virus removal, and biofouling resistance respectively. The efficiency of CNM can be improved by the role reinforcement as indicated in Table 2.

Table 2 Type and role of reinforcement for conventional nanocomposite membrane [84, 91, 96–101]

Type of Reinforcement	Role of Reinforcement
Carbon Nanotube	Incorporation for improved properties such as anti-biofouling and good strength
metal oxide (TiO_2, ZnO, SiO_2, Al_2O_3, Fe_3O_4)	Adjusts the assembly and physicochemical assets, such as hydrophilicity, Porosity, charge density, and chemical, thermal, and mechanical stability of membranes. Introduces the unique characteristics such as antifouling, and photocatalytic action into the membranes.
Metals (Ag, Cu, Se)	Antimicrobial functionality
Nano clay	Improvement in abrasion resistance
Organic Material	Enhance in hydrophilicity, upgrading sorption capacity, and anti-compaction, the antifouling performance of resultant membranes.
AgNPs	Reduce biofouling
Zeolite	Improvement hydrophilicity, advance cross-linking property and increase membrane inflexibility
Biomaterial	Water-channel membrane proteins
Hybrid material	Synergistic effect

3.5.2 Thin-Film Nanocomposites

Thin film nanocomposites (TFNs) membrane contains an extreme tinny wall sheet above a more permeable assistant material. TFN is interfacially synthesized by reverse osmosis or nanofiltration membrane which is extensively applied to remove heavy metals, desalinate seawater/brackish water, hardness causing salts, organic contaminants like pesticides, insecticides and disinfection intermediates. Researchers have been focused to advance water flux, toxin elimination, and antifouling characteristics of TFC l (1) to adapt the auxiliary film thus the linkage among the wall layer and the second layer might be improved, and (2) to enhance the wall layer by changing the IP settings, i.e. exchanging monomers, applying physical layering [102]. Materials like zeolites, CNTs, silica, Ag, and TiO_2 used for CNM synthesis have also been discovered to make TFN membranes [85, 101].

In general technologies yield NCs, a novel theory has been projected centred on diffusing nanomaterials into the extremely tinny wall to increase membrane efficiency for water purification [84]. The known production method is done the in situ IP course among aqueous phenylenediamine (MPD) and trimesoylchloride (TMC) organic solution as shown in Fig. 6. The nanofiller able to spread either in aqueous or an organic phase.

The additions nanoparticle make ready the thin films membranes to yield benefit of the properties of the nanomaterials. Adding of nanoparticles to in between polymerization routes or exterior accessory by self-assembly has announced the concept of TFN, which offer possible profits of improved separation efficiency, reduction fouling, antimicrobial action, and other novel properties. Like TFC membranes, TFN membrane performance can be achieved with nanoparticle

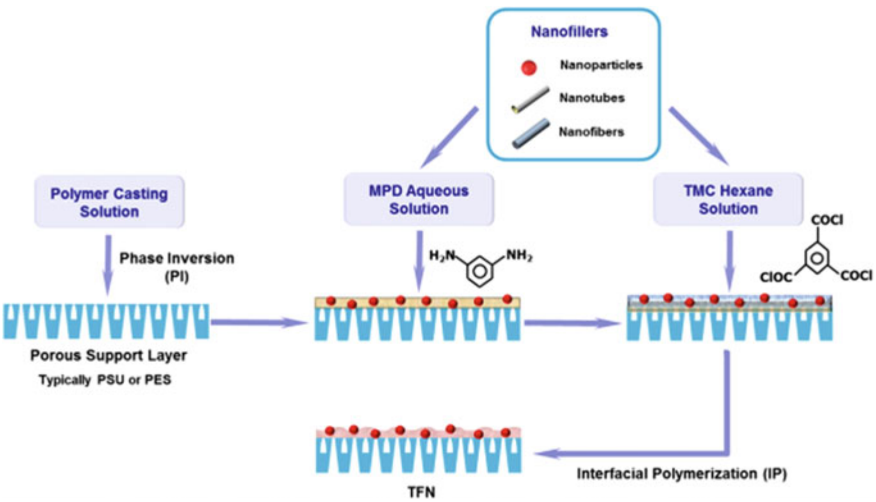

Fig. 6 Production of TFN membranes through the IP method [85]

Table 3 Summary of TFN membranes with nanocomposite substrate [85, 103]

Type of reinforcement	Role of reinforcement
Carboxylic MWNTs	Better antifouling and anti-oxidative properties
Zeolite	Salt elimination; Fighting to physical compaction
MWNTs	Increase the flexible strength of substrate and salt elimination
Ag-zeolite/ PA-PSf	Improved water penetrability, Reduced tendency for biofouling
Titania/PA-PES	Reduced porousness and improved elimination at small unit additions, Improved permeability and reduced salt refusal beyond 5 wt%
Zeolite/PA-PSf	Improved interaction with water and superficial charge, Reduced superficial irregularity, Improved water penetrability by 80%
Zeolite/PA-PSf	Improved interaction with water, Increased water penetrability, Improved salt removal in RO testing

Note PA Polyamide, *PSf* Polysulfone, *PES* polyethersulfone

additions to the preserve membrane the coating film, or both. Like CNM, The efficiency of TFN can be improved by the role reinforcement as indicated in Table 3.

3.5.3 TFC with Nanocomposite Substrate

This membrane has been established to look at the consequences of nanofiller on membrane compassion manners. During this category, oxide nanoparticles were entrenched into the postscript substrate [104] that utilized at IP process to arrange TFC film. The ready membrane displays a better primary porousness and minor flux failure throughout the compassion related with the first TFC one. The nanoparticles deliver necessary automated care to moderate the failure of permeable arrangement and resist thickness decline. Membranes with NC substrate tolerate so much less physical compassion and show a vital role in sustaining high water porousness [96].

Nanocomposite membrane coated with nano-TiO_2 shown higher catalytic and/or photo activity properties. For instance, TiO_2 imbedded PES membrane showed enhanced antifouling capability while a novel anatase/titanate nanocomposite membrane simultaneously remove Cr (VI) and 4-chlorophenol through adsorption and photocatalytic oxidation. Impregnation of AgNPs into the membrane would allow fabricating thin-film nanocomposite with an excellent antibacterial performance for water treatment [41].

An important number of articles on membrane nanoscience has motivated on production of multipurpose membranes by addition of nanoparticles into polymeric or inorganic membranes. Hydrophilic metal oxides (e.g., Al_2O_3, TiO_2, and zeolite), antimicrobials (e.g., AgNPs and CNTs), and photocatalytic nanomaterials (e.g., bi-metallic nanomaterials, TiO_2) are the nanomaterials used this application.

The additional water loving metal oxide nanoparticles played a great role to decline fouling by improving the membrane hydrophilicity while the adding of metal oxide nanoparticles such as alumina [105], silica, zeolite [79] and TiO_2 has contributed to increasing membrane surface hydrophilicity, water permeability, or fouling resistance to polymeric ultrafiltration membranes. Besides to this, this metal and/or metal oxide nanoparticles also aid to improve the mechanical and thermal solidity of polymeric membranes, decreasing the destructive influence of compassion and heat on membrane porousness [79, 106].

Qin et al. [107] investigated that handling the wastewater effluent generated from oil refinery and shell gas was difficult since this type of waste effluent was contaminated by contents of oils and salts. This type of wastewater was difficult to treat using conventional membranes because the membrane was severe fouling or failure by salts. The researchers developed another NCFO membrane for succeeding direct oil/water isolation and desalination. This NCFO membrane was accumulated an oil preventing and salt eliminating hydrogel separating layer on surface GO nanosheets imparted polymeric sustenance layer. The hydrogel separating layer governs strong water heating that leads to superior antifouling competency under several oil/, water emulsions, and the imparted GO in support layer can considerably moderate interior concentration polarization by decreasing FO membrane. Compared with viable FO membrane, the new membrane establishes triple water flux, higher eliminations for oil (>99.9%) and salts (>99.7%) and pointedly worse fouling attraction when examined with replicated shale gas wastewater as shown the Fig. 7. These combined benefits will validate this new NCFO membrane with wide requests in handling highly salty and oily effluents [107].

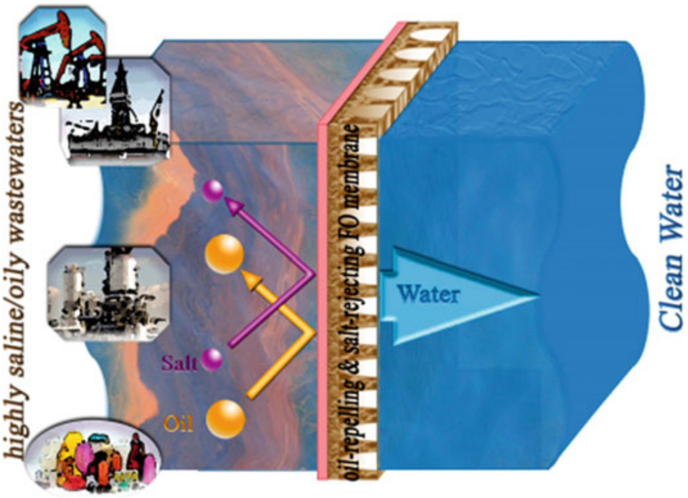

Fig. 7 Illustration of immediate oil/water separation and desalination by Hydrogel/GOFO membrane [107]

4 Future Outlooks

In this chapter, the most extensively studied nanocomposite, Metal nanocomposite, nanocomposite zero-valent metals (Ag, Pb, and Zn), MONCs (TiO_2, ZnO, and iron oxides), PNCs and MNCs were highlighted. Moreover, their applications in water purification were discussed in detail. Since the current rapid water demand development and sustainable application, NC look exceptionally favourable materials for water purification.

However, more studies are quiet required to solve the NC encounters. Still, now, insufficient types of nanocomposite are available commercially. Meanwhile, less production price is critical to confirm their extensive requests for water purification, future research has to devote to developing the commercial competence of NCs. Moreover, with progressively widespread applications of the NCs in water treatment, there are increasing alarms about their potential noxiousness to the environment and human health. Existing evidence in the literature has discovered that numerous NCs. However, principles for evaluating the noxiousness of NCs are somewhat inadequate at present-day. Hence, widespread assessment of the toxicity of NC is the crucial necessity to confirm their real applications. What is more, the assessment and contrast of the performance of numerous NC in water purification are recognized standards. It is hard to relate the performances of diverse nanoparticles and figure out talented NC that merits extra application. Consequently, the performance assessment tool of the NC in water purification ought to be perfected in the future.

5 Conclusion

Growing demand and deficiency of clean water as a result of rapid urbanization, population growth, and climate disruption have become unparalleled urgent global issues. Globally, Water purification is a priority issue for human use, ecosystem management, agriculture, and industry. The water sanitization process using nanoparticles are quite efficient. However, these are linked with some weakness such as aggregation, tough separation, and leakage into the contact water, environmental impact and human health. Therefore, to improve water treatment process system, researchers have been paid to develop eco-friendly, energy efficient and low price for sustainable water purification. The nanocomposites are basically multiphase solid materials, including porous media, colloids, gels, and copolymers in a broad sense. The selection of hosts for nanocomposites have a great consequence, and even controls the performance of nanocomposites in water purification. Compared with free nanomaterials, the efficiency and usability of nanocomposites were significantly improved, in terms of nanoparticle dispersion, stability, and recyclability. Nowadays, nanocomposites were supposed to be the supreme likely way of advancing water nanotechnology from lab study to large-scale application.

A number of the researcher was investigated nanocomposites synthesis from metal, metal oxide, carbon, polymer and membrane are the common materials used for water purification. Polymer nanocomposites (PNCs) are a superior class of materials which nanoparticles (NPs) dispersed in a polymer matrix resulting in novel materials having unique physical and chemical properties [74]. Polymers are special supports for nanomaterials as they usually possess tunable porous structures, excellent mechanical properties, and chemically bounded functional groups. Polymer-based nanocomposites (PNCs) are prospecting materials for their sound performance in water and wastewater treatment. Nanocomposite membrane has a great role in water purification and reuses for various sources of water such as drinking water, brackish, seawater, and wastewater treatment. Nanocomposite membranes is an innovative type of membranes prepared by merging polymeric materials with nanoparticles are developing as an encouraging solution to above challenges.

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