Wonders of Nanotechnology for Remediation of Polluted Aquatic Environs

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Abstract On earth, all forms of life wholly and solely depend upon the clean water sources for their survival. The freshwater ecosystems are home for large number of organisms from microscopic to macroscopic species. However, water pollution has changed the history of freshwater ecosystems due to addition of variety of pollutants. The problem of water pollution is getting worsened year after year which ultimately affects the limited freshwater resources. The anthropogenic activities have created a situation that may, in the coming years, cause permanent damage to the balanced structure of freshwater ecosystems. There are numerous techniques available for wastewater treatment prior to its discharge into recipient water bodies. But, due to one or other reasons, these conventional techniques fail to meet the demands of treating the wastewaters. Besides, efficiency of these available conventional techniques is also a matter of concern. The literature cited in this chapter suggests that nanotechnology could be a valuable, efficient and clean technology to treat the wastewaters. It is not selective to cleanup only organic based pollutants but efficient

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to remediate heavy metals (Cd^{2+}, Pb^{2+}, Zn^{2+}, Hg^{2+} and Cr^{3+}) and pesticides in wastewaters. Furthermore, due to an excellent adsorption and catalytic properties of nanomaterials, it has proven to have marvellous antimicrobial activity, pathogen detection and disinfectant quality for the treatment wastewaters.

Keywords Water pollution · Heavy metals · Nanotechnology · TiO_2 · Adsorption · Antimicrobial · Disinfectant

1 Introduction

Water one of the most precious liquid substance for all organisms living on the earth (Qu et al. 2013). Majority of the water (97%) on the surface of the ground is salt water while only 3% is available in the form of freshwater. Two-third of the 3% is in the frozen form and only 1% is in the assessable form (Radwan et al. 2011; Jose et al. 2018) and this dearth in reality a grim quandary for under developed cities (Smith 2009). The large share of world population (780 million) is still lacking the basic pure drinking water facility (WHO 2012; Vijayageetha et al. 2018). The uncontrolled rise in population is adding more problems on the water bodies as per one estimate the population of the world will reach upto 9 billion by 2050 and this rising population will increase water pollution by increasing amount of waste accumulation in water bodies (Sharma and Sharma 2012). The conventional methods like physico-chemical and microorganism based processes for removal of hazardous substances from wastewater (Bellona and Drewes 2007) are not economical and are also less efficient (Zekic et al. 2018). That is why new approaches like nanotechnology are continuously being examined to improve the available techniques for waste water treatment methods (Sharma and Sharma 2013). This technology relies on the relevance of materials on the nano level, so that new structures, components and materials can be built at this (atomic) level (Lens et al. 2013; Ayanda and Petrik 2014). The emergence of nanotechnology occurs billions of years ago in the nature when life began to start on the earth (El Saliby et al. 2009). Plants through the process of evolution, mutation and adaptation were capable of converting CO_2 into carbohydrate in the company solar energy (sunlight) (Roco 1999; El Saliby et al. 2009). Another example of a natural nanotechnology is “chemical catalysis” through “catalysts” or “enzymes” (Arora and Mathur 2017) as enzymes increase the rate of reaction (Smith 1997) and are also vital for the completion of the specific reactions. It is generally accepted that nanotechnology implies management of those materials and particles of at least one dimension ranging from 1–100 nm (Watlington 2005) and these particles and material are called nanomaterials or nanoparticles (El Saliby et al. 2009).

Nanotechnology got a major boost in 1980s by the coming of cluster science and scanning tunnelling microscope (STM). The current tools for the measurement of the nanotechnology include STM, scanning probe microscope, atomic force microscope and molecular beam epitaxy (Roco 1999; El Saliby et al. 2009). Nanotechnology is one of the broad research areas of today's era that involve the use of nano sized building blocks for the creation of new material and particle (Hu and Shaw 1998). Molecules which are made up of building blocks are arranged in nanostructures and nano materials with dimensions of 1–100 nm. The arranging and then assembling of building blocks in order to form large material is referred as "bottom up" approach (Wu et al. 1993). Materials at nano scale level are having different properties than normal size equivalents (Zekić et al. 2018). The main properties like stability, morphological characteristics, adsorption ability and degree of catalysis are maintained by the approaches utilised for the structuring of nanomaterials (Zekić et al. 2018). Nano-sized materials have unique properties completely different from the equivalent structures on the macro-level. The most important feature is the large surface to volume ratio, which is why they are suitable for different forms of water treatment *viz.,* adsorption, photocatalysis, membrane processes (Zekić et al. 2018). Thus nanostructures have completely different optical, electrical, magnetic properties, greater reactivity with neighbouring (polluting) atoms faster chemical processes (Hu and Shaw 1998; Lens et al. 2013; Chatuverdi et al. 2012; Zekić et al. 2018) and all these characteristics of nanomaterials make this technology attractive in terms of eliminating contaminants and making nanotechnology as a suitable technique for wastewater treatment (Kanchi 2014; Zekić et al. 2018). Nanotechnological wastewater treatment processes can be divided into three main groups including (a) treatment and remediation (b) sensing and detection (c) pollution prevention (Watlington 2005). Nanomaterials and nanoparticles are the recent and significant approaches for the remediation and treatment of wastewater (Hu et al. 2005; Mohan and Pittman 2007). The major environmental benefits of nanotechnology include stronger and lighter nonmaterial's, treatment and remediation of wastewater (Theron et al. 2008; Savage et al. 2008). The benefits of using nanotechnology in environment and industrial area has been observed but in future nanotechnology might be helpful in bringing innovations that can be helpful in solving the specific problems (Theron et al. 2008; Savage et al. 2008; El Saliby et al. 2009). Hence, nanotechnology is going to play an important role in addressing fundamental issues of health, energy and water (Binks 2007; El Saliby et al. 2009) but greatest emphasis has currently been placed on the treatment and remediation of wastewater (Zekić et al. 2018). Some nano particles destroy contaminants (oxidation in the presence of nanocatalysts), while other separate and isolate these contaminants (nano membrane filtration). Carbon nanotubes have been recognized for playing beneficial role in the adsorption of dioxins and are much more efficient than the conventional methods (Ren et al. 2011). The multiple benefits like high efficiency, economical waste water treatment and less utilization of large infrastructure of nanotechnology has made this technology more reliable for solving of the various emerging problems of the world (Qu et al. 2013; Vijayageetha et al. 2018).

2 Various Allied Techniques of Treating Contaminated Freshwater Based on Nanoproducts

2.1 Adsorption

Adsorption being economically viable (Onundi et al. 2010) is commonly employed for removal of organic and inorganic contaminants from wastewater (Qu et al. 2013). Adsorption involves the use of different materials like zeolites, alumina silicates, clay for removal of metals from solutions (Issabayeva et al. 2007; Nouri et al. 2009; Gupta et al. 2012). The high surface area and aspect ratio of the nanomaterial makes them one of the new adsorbent with superior performance (Yano et al. 2018). The use of multiwall carbon nanotubes is one of the best options as these have higher metal-ion sorption capacity (3–4 times) than the powder and granular activated carbon (Li et al. 2003; Yano et al. 2018). The available conventional adsorbent are less efficient as compared to nano-adsorbents as nano-adsorbent have high surface area, short intraparticle diffusion distance and tunable pore size which make them efficient for adsorption (Qu et al. 2013).

2.2 Nano-adsorbents Based on Carbon Substances

2.2.1 Removal of Organic Susbstances

Carbon nanotubes (CNT) are an aromatic surface when the carbon atoms are in a sp^2-hybridization wrapped up in a tubular structure (Terronesa et al. 2010). The carbon nanotubes have unique electronic and mechanical properties which are dependent on chirality and diameter. The exceptional properties of carbon nanotubes make them one of the attractive option for various application like devices for energy storage, adsorption for many practical applications, such as, the development of devices for energy storage (Agnihotri et al. 2006) and adsorption with high sensitivity, selectivity and efficiency (Gupta and Saleh 2013; Ren et al. 2011). CNTs are efficient in the process of adsorption of various organic chemicals compared to activated carbon (Pan and Xing 2008) and high adsorption is because of large surface area and varied contaminant-CNT interactions. The available surface area for adsorption on individual CNTs is their external surfaces (Yang and Xing 2010). The adsorption capacity of the carbon nanostructure can be easily determined by its textural properties (Gupta and Saleh 2013). The surface of the carbonaceous nanomaterials surface can be photeric and other functional groups along with oxygen are added which provide new sites for chemical adsorption (Ren et al. 2011). CNTs forming loose bundles in the aqueous solution are due to the hydrophobicity of graphitic surface thereby reducing the efficiency of adsorption, while aggregates formation contain interstitial spaces which increases the adsorption sites thus increasing the efficiency of adsorption of various organic molecule (Pan et al. 2008). The activated carbon and CNT bundles have almost same specific surface area but activated carbon have micropores which are not assessable to bulky organic molecules (Ji et al. 2009). CNTs have large pores which increase the adsorption of bulky molecules thus have higher adsorption capacity because of more accessible sorption sites. CNTs strongly adsorb many of these polar organic compounds due to the diverse contaminant eCNT interactions including hydrophobic effect, pep interactions, hydrogen bonding, covalent bonding, and electrostatic interactions (Yang and Xing 2010). The p electron rich CNT surface allows pep interactions with organic molecules (Chen et al. 2007; Lin and Xing 2008). Organic compounds which have -COOH, -OH, -NH_2 functional groups could also form hydrogen bond with the graphitic CNT surface which donates electrons (Yang et al. 2008). The strong interactions between CNT and organic molecules occur through non-covalent forces such as hydrogen bonding, π–π stacking, electrostatic forces, van der Waals forces, and hydrophobic interactions (Rengaraj et al. 2007). Electrostatic attraction facilitates the adsorption of positively charged organic chemicals such as some antibiotics at suitable pH (Ji et al. 2009). Furthermore, the selectivity and stability of the system can also be increased as CNT allows the addition of one or more functional group that helps in increasing the efficiency of the system (Tarun et al. 2009; Sze et al. 2008). The chemical functional groups may be anchored to the CNT surface through functionalization or purification processes. The carbon nanotubes can be single-walled or multi-walled carbon nanotubes (MWCNT), depending on preparation condition (Li et al. 2003) and because of high stability and surface area, the CNT have attained great attention for the remediation of waste water. CRTs by the process of adsorption helps in the removal of heavy metals (Cd^{2+}, Pb^{2+}, Zn^{2+} and Cu^{2+}) from the waste water. CNT can be used not only as adsorbents but also as a support for adsorption materials (Wang et al. 2007).

2.2.2 Heavy Metal Removal

Oxidized CNTs contain various functional groups that increase the adsorption capacity for metal ions from the waste water (Rao et al. 2007). CNTs are better adsorbents than activated carbon for heavy metals (Li et al. 2003; Lu et al. 2006) as due to the unique properties; the adsorption is fast on CNTs. In order to fulfill these application, small quantity of materials is required and are independent of the material cost. The recent reports have shown that the removal of Hg and a bulky dye molecule was efficiently done by sand granules coated with graphite oxide (Rhodamine B) and was almost comparable to the efficiency of the activated carbon (Gao et al. 2011). The various metallic pollutants present in the waste water and industrial effluent can be easily removed by the nanoparticles of zero-valent form (Ponder and Darab 2000; Kanel et al. 2005; Ponder et al. 2001). Nanoparticles have also been used for the removal of many halogenated hydrocarbons, radionuclides and organic compounds. The removal rate of nanoscale zero-valent iron is 30 times higher for Cr(VI) and Pb(II) as compared to the iron powder. Iron oxide nanoadsorbent is helpful in removing of both the forms of arsenic (As (V) and As (III)) and removal rate is 5–10 times higher than the micron size counterpart. The major advantage is that by the application of magnetic field, iron oxide adsorbent can be easily separated. Nano alumina particles because of low cost and high stability is being used for the removal of metals like Pb, Cr, Cu, Cd and Hg (Pacheco and Rodriguez 2001) from the wastewater (Valente et al. 2004; Baumgarten and Dusing 1994). Nanoparticles known for its unique properties can effectively remove metals and other pollutants from the waste water (Sharma et al. 2009) Because of large number of active site in nano particles, the removal of the different chemical species from wastewater become easy (Hristovski et al. 2007). The difficulty in removing the heavy metals from waste water as no technology is available which can efficiently remove the metals from the wastewater but the use of nanotechnology is providing good alternative for the management of wastewater (Li et al. 2006a, b; Vaseashta et al. 2007).

2.2.3 Regeneration and Reuse

The adsorbent used is cost effective as it can be regenerated. The reduction of the pH is helpful in reversing the metal adsorption on CNTs and at pH less than 2, the recovery rate is almost about 100% (Li et al. 2006a, b; Lu et al. 2006). It has been observed that nano-adsorbent can he regenerated as well as reused for numerous times without effecting the adsorption capacity of the adsorbent (Lu et al. 2007).

2.3 Nano-adsorbents Based on Metals

Oxides of metals (Fe, Ti and alumina) are cheap and effective approach for the adsorption of toxic metals. The dissolved significantly adsorbs the concerned metal ions (Koeppenkastrop and Decarlo 1993; Trivedi and Axe 2000). Nanoparticles cleans the contaminates sites due to presence of large number of active sites show higher adsorption and with the decrease in the size the capacity of adsorption increases (Yean et al. 2005). Surface area of nanoadsorbents plays crucial role and enhances the capacity to remove the pollutants from wastewaters (Auffan et al. 2008, 2009). The “nanoscale effect” helps in the creation of the new adsorption site by changing the magnetite surface structure (Lucas et al. 2001; Auffan et al. 2009). The magnet based nanoparticles as the core material adsorbents provides the required role as presented in Fig. 1.

The volume and size of the pore can be controlled by adjusting the consolidation pressure (Sharma et al. 2009). Activated carbon acts as adsorbent for many contaminants but has limited capacity to absorb arsenic As (V) from the contaminated environment. The various metal oxide nanomaterials have good adsorption capacity as compared to the activated carbon (Deliyanni et al. 2003; Mayo et al. 2007). Metal oxide nanoparticles also can be impregnated onto the skeleton of acti-

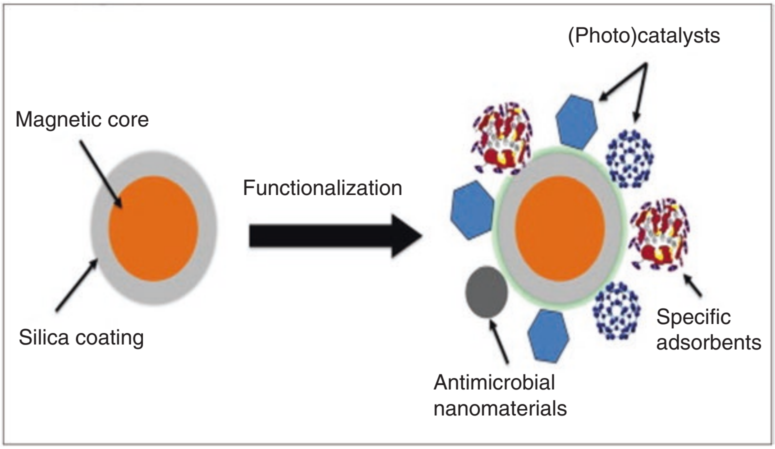

Fig. 1 Magnetic based nanoparticle coated with silica for wastewater treatment

vated carbon or other porous materials to achieve simultaneously removal of arsenic and organic co-contaminants, which favours point-of use (POU) applications (Hristovski et al. 2009a, b).

Photocatalytic degradation has attracted great attention since 1972 when Fujishima and Honda (Fujishima and Honda 1972) observed electrochemical photolysis of water on TiO_2 semiconductor electrode. This technique has been successfully applied in the degradation of contaminants from the wastewater. The contaminants can be easily degraded in the presence of light and catalyst into low molecular weight products which ultimately is converted into CO_2, H_2O, and anions (NO_3^-, PO_4^{3-} and Cl^-). The various kinds of photocatalysts are used but among them TiO_2 is most commonly studied because of its cheapness, photostability and biological stability (Guesh, et al. 2016; Rawal et al. 2013). Because of energy gap, ultraviolet radiation is required to separate charge and TiO_2 on irradiation with UV light generate reactive oxygen species (ROS) which can completely degrade contaminants in very short reaction time. Besides, TiO_2 NPs show little selectivity and thus are suitable for the degradation of all kinds of contaminants, such as chlorinated organic compounds (Ohsaka et al. 2008), polycyclic aromatic hydrocarbons (Guo et al. 2015), dyes (Lee et al. 2008), phenols (Nguyen et al. 2016), pesticides (Alalm et al. 2015), arsenic (Moon et al. 2014), cyanide (Kim et al. 2016), and heavy metals (Chen et al. 2016). The removal of heavy metals from the contaminated environment by using the nanoparticles (iron oxides nanoparticles and nonmagnetic hematite) has increased as these nanoparticles are simple and easily available. Thus these nanoparticles can be easily used for removal of heavy metals from the wastewater system (Lei et al. 2014; Ngomsik et al. 2012).

2.4 Polymeric Nano-adsorbents

Dendrimers are the adsorbents that have the capacity of removing both organics as well as heavy metals from the water. Their interior shells can be hydrophobic for sorption of organic compounds while the exterior branches can be tailored (e.g., hydroxyl- or amine-terminated) for adsorption of heavy metals. The sorption of metals and organic pollutants on adsorbent is based on complexation, electrostatic interactions, hydrophobic effect and hydrogen bonding (Crooks et al. 2001). A dendrimer ultrafiltration system was designed to recover metal ions from aqueous solutions (Diallo et al. 2005). The dendrimers laden with metals is recovered by the process of ultrafiltration and by decreasing the pH to 4, the dendrimers can be regenerated.

2.5 Potential Application in Water Treatment

Nano-adsorbents because of numerous benefits can be easily integrated into existing treatment processes for the batter efficiency of the system (Vijayageetha et al. 2018). Nano-adsorbent applied in the powder form in slurry reactors can be highly efficient (Vijayageetha et al. 2018) but for the recovery of the nanoparticles, the additional system is required to be attached (Aragon et al. 2007; Sylvester et al. 2007; Vijayageetha et al. 2018; Li et al. 2018). Nano-adsorbents can also be utilised by loading beads or granules with the nano adsorbents in fixed or fluidized adsorbers (Qu et al. 2013). Fixed-bed reactors are usually associated with mass transfer limitations and head loss but it does not need future separation process (Qu et al. 2013; Miklos et al. 2018). Nano-adsorbents have been widely used for the removal of arsenic as nano-adsorbent show good performance and are also economical as compared to the other adsorbents (Aragon et al. 2007; Qu et al. 2013; Li et al. 2018; Vijayageetha et al. 2018). ArsenXnp an iron oxide nanoparticles and polymer (Vijayageetha et al. 2018) while ADSORBSIA is a nanocrystalline titanium dioxide medium as both are used for the removal of arsenic from the water (Aragon et al. 2007; Sylvester et al. 2007; Qu et al. 2013; Vijayageetha et al. 2018). ArsenXnp and ADSORBSIA have been employed in small to medium scale drinking water treatment systems and were proven to be cost-competitive (Qu et al. 2013; Miklos et al. 2018 Vijayageetha et al. 2018).

3 Nanofiltration

Nanofiltration (NF) is recent membrane filtration process for treatment of wastewater and is based on charge-based repulsion property and high rate of permeation (Kolpin et al. 2002; Sharma and Sharma 2012). Nano filtration is separation process whose cut off lies between that of reverse osmosis and ultrafiltration. Nanofilteration is also cost effective in comparison to reverse osmosis because of its lower operating pressure and high flow rate (Sharma and Sharma 2012). Nanofilteration membranes helps to remove hardness from the water to great extent as monovalent ions are partially permeable and shoe total impermeability towards bivalent salts (Sharma and Sharma 2012). NF can lower total dissolved solids (TDS) and hardness, reduce color and odor, and remove heavy metal ions from ground water (Kolpin et al. 2002; Koyuncu et al. 2001). The high efficiency of membrane filtration helps in removing of the different types of pollutants from the water and can also achieve desired water purification standards (Zekic et al. 2018). Nanofiltration is a high-pressure membrane treatment process but due to low drive pressure (Liu et al. 2008), less energy is consumed as compared to reverse osmosis (Zekic et al. 2018). Centrifugal pumps are most often used for the pressure and circulation of wastewater within the nanomembrane (Liu et al. 2008). The plant consists of a large number of modules, with different membrane configurations within each module (Kolpin et al. 2002; Sharma and Sharma 2012). In nanofiltration, the usual length of the module varies from 0.9 to 5.5 m, and the diameter ranges from 100 to 300 mm (Tchobanoglous et al. 2014). Nanofiltration produces water that meets highly stringent requirements in terms of water reuse (Zekic et al. 2018). Since this process remove all the types of pollutants present in the water and the further disinfection of water is less required (Liu et al. 2008; Sharma and Sharma 2012; Zekic et al. 2018).

3.1 Nanomaterials for Water Disinfection

Some nanomaterial like chitosan, silver nanoparticles, titanium dioxide, fullerene nanoparticles, carbon nanotubes (Duhan et al. 2017; Zekic et al. 2018) have great adsorption capacity but are also known for their antimicrobial activity (Feng et al. 2000; Inoue et al. 2002; Kumar et al. 2004; Yamanaka et al. 2005; Amin et al. 2014). Being mild oxidant and inert, these nanoparticles does not create any harmful by-product in the water (Buzea et al. 2007; Zekic et al. 2018). Nanomaterials can be applied in various manners like by direct action on bacterial cell, oxidation of cellular component for the treatment of the water (Li et al. 2008, 2011; Zekic et al. 2018). The use of nanotechnology for the disinfection of wastewater has certain drawbacks (Chorawala and Mehta 2015; Zekic et al. 2018) as for the removal of micro-organism from the wastewater, the nanoparticle must come in direct contact with their cell membrane (Feng et al. 2000; Inoue et al. 2002; Kumar et al. 2004; Yamanaka et al. 2005; Chorawala and Mehta 2015; Zekic et al. 2018). Therefore, some nanomaterials (carbon nanotubes) need to be strongly connected to the reactive surface (Khan et al. 2017; Zekic et al. 2018). Also, the deficiency of nanotechnology in disinfection processes is that there is no residual, i.e., subsequent antimicrobial activity in wastewater (Lens et al. 2013).

3.2 Membranes Processes

The basic goal of water treatment is to remove undesired constituents from water (Qu et al. 2013). The use of membrane for wastewater treatment helps to remove the pollutants thus allowing the use of water from the unconventional source (Qu et al. 2013). A major challenge of the membrane technology is the inherent trade off between membrane selectivity and permeability (Khan et al. 2017; Zekic et al. 2018). The major drawback in the utilization of the pressure driven membrane processes is the higher energy consumption which ultimately affects the life of the membrane (Qu et al. 2013). The performance of membrane systems is largely decided by the membrane material (Gehrke et al. 2012; Feng et al. 2013; Qu et al. 2013). Various function (permeability, fouling resistance) can be improved by the inclusion of functional nanomaterials into membranes and this also help in degradation of the different pollutants (Fathizadeh et al. 2011; Kim and Deng 2011; Gehrke et al. 2012; Feng et al. 2013).

3.3 Nanofiber Membranes

The use of polymers, ceramics or metals in order to produce ultra fine fibre is known as electrospinning. The process is very simple and economical to make fibre and the produced fibre have high porosity as well as surface area (Cloete et al. 2010; Jayavarthanan et al. 2017). The diameter, morphology, composition, secondary structure, and spatial alignment of electrospun nanofibers can be easily manipulated for specific applications (Jayavarthanan et al. 2017). Although nanofiber membranes have not been largely used for treatment of water but have been widely exploited for air filtration application (Nowack et al. 2011; Kim et al. 2012). Nanofibre membrane with high rejection rate can easily remove small size particles without affecting the life of the membrane (Ramakrishna et al. 2006). Thus they have been proposed to be used as pre-treatment prior to ultrafiltration or reverse osmosis (Nora and Mamadou 2005; Quang et al. 2013). For example, by incorporating ceramic nanomaterials or specific capture agents on the nanofiber scaffold, affinity nanofiber membranes can be designed to remove heavy metals and organic pollutants during filtration (Ursino et al. 2018).

3.4 Nanocomposite Membranes

The large number of studies on nanotechnology has aimed to create synergism by adding hydrophilic metal oxide nanoparticle (Al_2O_3, TiO_2, and zeolite) into inorganic membrane. The main goal of adding hydrophilic metal oxide nanoparticles is to reduce fouling by increasing the hydrophilicity of the membrane. The addition of alumina (Maximous et al. 2010), zeolite (Pendergast et al. 2010) and TiO_2 increase hydrophilicity as well as permeability of the membrane. The addition of metal oxide nanoparticles including alumina, silica (Bottino et al. 2001), and zeolite to polymeric ultrafiltration membranes has been shown to increase membrane surface hydrophilicity, water permeability, or fouling resistance. By addition of inorganic nanoparticle, the stability of the membrane increases thereby reducing the impact of heat on the membrane (Ebert et al. 2004; Pendergast et al. 2010). Antimicrobial nanomaterials (nano-Ag and CNTs) doped on the membrane surface can be helpful in reducing the biofilm formation and inhibit the attachment of bacteria on the membrane thus prevent the biofoiling of the membrane (Mauter et al. 2011; Zodrow et al. 2009) on the membrane surface as well as inactivate viruses (De Gusseme et al. 2011). The membrane doped with photocatalytic nanoparticle results in combining of the unique properties for the degradation of the contaminants and efforts are also running for the development of photocatalytic inorganic membranes consisting of nanophotocatalysts (Choi et al. 2006).

4 Thin Film Nanocomposite (TFN) Membranes

The main focus in the development of thin film nanocomposite is the doping of nanomaterial (zeolites, nano-Ag, nano-TiO_2 and CNTs) on the thin film nanocomposite. The properties of the membrane is totally dependent on the nanoparticle which is added to the membrane. The most widely used dopant which help to increase the permeability and create negative charge (Lind et al. 2009a) of the membrane is nano-zeolites (Fathizadeh et al. 2011; Kim and Deng 2011; Gehrke et al. 2012; Feng et al. 2013). One study reported water permeability increased up to 80% over the TFC membrane, with the salt rejection largely maintained (Jeong et al. 2007). TFN membranes doped with 250 nm nano-zeolites at 0.2 wt% achieved moderately higher permeability and better salt rejection (>99.4%) than commercial RO membranes (Lind et al. 2010). It was hypothesized that the small, hydrophilic pores of nano-zeolites create preferential paths for water. The permeability of water increased with pores filled with zeolite can be due to the problem at zeolite polymer interface. Nano-zeolites were also used as carriers for antimicrobial agents such as Agþ, which imparts anti-fouling property to the membrane (Lind et al. 2009b). Incorporation of nano-TiO_2 (up to 5 wt%) into the TFC active layer slightly increased the membrane rejection while maintaining the permeability (Lee et al. 2008). TiO_2 under UV irradiation can degrade contaminants and also inhibit the activity of microorganisms (Qu et al. 2013) and also reduces the biological fouling (Fathizadeh et al. 2011; Kim and Deng 2011; Gehrke et al. 2012; Feng et al. 2013; Qu et al. 2013). However, the close adjacency between the photocatalyst and the membrane may also lead to detrimental effects on polymeric membrane materials, which needs to be addressed for long-term efficacy (Chin et al. 2006). CNTs (unaligned) also found their application in TFN membranes due to their antimicrobial activities (Fathizadeh et al. 2011; Kim and Deng 2011; Gehrke et al. 2012; Feng et al. 2013;

Qu et al. 2013). Covalently bonded SWNTs to a TFC membrane surface (Tiraferri et al. 2011). This approach is advantageous as it uses relatively small amount of the nanomaterial and minimizes perturbation of the active layer.

5 Photocatalysis

Nanocatalysts can effectively be used for chemical oxidation of organic and inorganic pollutants in water in advanced oxidation processes (Lens et al. 2013). These processes are based on formation of highly reactive radicals that react easily with pollutant molecules. The application of this process is often limited because of the extremely high costs of providing required energy (UV lamps, ozonators, ultrasonicators, etc.) (Lens et al. 2013). Photocatalysis is the most significant oxidation process. This is a chemical reaction change that is induced by adsorption of a photon whose energy is greater than the energy needed to overcome the interstitial of two electron shells (valentine and conductive) of a semiconductor. When the photon illuminates the catalytic surface, the electron (negatively charged particle) is transferred from the valentine shell to the empty conduction shell and leaves a "hole" behind it with a positive charge. This "e-h" pair ("electron-hole") creates highly reactive radicals that bind the molecules of pollution and thus break them down (Bora and Dutta 2014). However, there are several technical challenges that have to be met to enable broader practical application of this process, including – optimization of catalysts in the exploitation of available light energy – more efficient separation of nanocatalysts after treatment and re-application improvement of selective properties during chemical reactions.

6 Trace Contaminant Detection

In trace organic or inorganic contaminant detection, nanomaterials can be used in both concentration and detection. CNTs have great potential for environmental analysis of trace metal or organic pollutants as they offer high adsorption capacity and recovery rate as well as fast kinetics. The pre-concentration factors for metal ions were found to be between 20 and 300 with fast adsorption kinetics (Duran et al. 2009). CNTs have also been extensively studied for pre-concentrating a variety of organic compounds, many of which were done in real water samples (Cai et al. 2003; Chin et al. 2006). Adsorption of charged species to CNTs results in changes of conductance, providing the basis for the correlation between analyte concentration and current fluctuation (Mauter and Elimelech 2008). Other nanomaterials such as nano-Au and QDs have alsobeen used. Nano-Au was used to detect pesticides at ppb levels in a colorimetric assay (Lisha and Anshup Pradeep 2009), modified nano-Au was shown to detect Hg^{2+} and CH3Hgþ rapidly with high sensitivity and selectivity (Lin and Tseng, 2010). QD modified TiO_2 nanotubes lowered the detection limits of PAHs to the level of pica-mole per liter based on fluorescence resonance energy transfer (Yang et al. 2010a; da Silva et al. 2011). A nanosensor based on CoTe QDs immobilized on a glassy carbon electrode surface was reported to detect Bisphenol A in water at concentrations as low as 10nM within 5 s.

7 Nanomaterials for Adsorption of Pollutants

Nanoparticles possess two important characteristics that make them very good adsorbents. These are the large specific surface of nanomaterials and surface multifunctionality or the ability to easily chemically react and bind to different adjacent atoms and molecules (Fig. 1). These characteristics make nanoparticles not only effective adsorbents for various contaminants in wastewater but also allow for long-term stability, as this also results in adsorbent degradation (with the addition of catalytic properties of nanoparticles) and improves the adsorption efficiency. With the discovery of carbon nanotubes (Iijima 1991), a new carbon-based adsorption material was introduced to the world. Compared to the best known such material - activated carbon - carbon nanotubes possess approximately the same large specific surface, but their great advantage lies in the structure of nanomaterials and a much better arrangement of carbon atoms. In addition, nanomaterials possess unique mechanical, electrical, chemical, optical and many other characteristics that allow them to have much better adsorption properties for some contaminants (heavy metals and organic pollutants). This is why they are called the “material of the 21st century” (Ren et al. 2011). Besides carbon nanotubes, metal based nanoparticles also have adsorption characteristics. The most common metal oxides used as adsorbents are iron oxides (Fe_xO_y), silicon (Si), titanium (Ti) and tungsten (W). They are mainly used for adsorption of heavy metals and radionuclides (unstable nuclides). The adsorption process is based on the electrostatic interaction of dissolved metals in wastewater and the nanoadsorbent surface. Changing the pH of the solution can significantly affect the strength of this interaction. Thus, the surface of the nano adsorbent may be: acidic, with positive charge attracting anions basic, with a negative charge attracting cations from waste water (Crane and Scott 2012; Qu et al. 2013)

8 Conclusion

Water pollution has created widespread problems and becomes a concern to all. There are limited resources of freshwater available for consumption and sustaining the life. But, these sources nowadays has badly damaged due to growing anthropogenic activities. Convention treatment technology has plenty to offer in the form of remediating the pollutants from wastewaters, but fail to deal with treating huge quantity of polluted waters ecofriendly. Nano technology has proven to be a valuable technology, which has least negative impacts on environment. It is not selective to cleanup only organic based pollutants but efficient to remediate heavy metals and pesticides in wastewaters. Furthermore, due to an excellent adsorption and catalytic properties of nanomaterials, it has proven to have marvellous antimicrobial activity, pathogen detection and disinfectant quality for the treatment wastewaters.

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