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Overview on progress in waste water treatment and purification technology: A review

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Abstract:

Removal of various pollutants from waste water can be facilitiated by various methods. Conventional treatment methods include physical treatment followed by biological treatments, either attached growth or suspended growth. These methods have their own disadvantages like large land area requirements, disposal of the sludge produced in the treatments, operating problems under various conditions of temperature. Membrane technology is very promising and widely studied alternative. The current review aims at studying the research carried out for application of membrane technology for the wastewater treatment. During the review it was found that the membrane technologies such as electro dialysis, membrane bioreactors, anaerobic membrane bioreactors, reverse osmosis, ultrafiltration, microfiltration, nanofiltration etc. can be used effectively for wastewater treatment. High efficiency and low area requirement, compactness are key features of this technology. This technology can be combined with conventional aerobic and anaerobic treatment facilities to increase the effectiveness. Membrane technology is the most important method in achieving the objective of reuse of wastewater in an era of water scarcity in

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many parts of the world. The textile wastewater treatment is a big challenge to environmental chemist, engineers and the water authorities. Many dyestuffs used in textile dyeing and printing processes are non-biodegradable. Advanced treatment processes stand very high in providing true solution towards achieving destruction of such matter which cannot be destroyed by conventional treatment. We have made a sincere effort to take a review of the advanced treatment processes in this article.

Key words: waste water, anaerobic treatment, reverse osmosis, effluent, organic matter, Nano-technology.

1. INTRODUCTION

Effluent treatment involves science, engineering, business, and art. The treatment may include mechanical, physical, biological, and chemical methods. As with any technology, science is a foundation, and engineering makes sure that the technology works as designed. The appearance and application of water is an art(Adeleye, Conway et al. 2016).

Wastewater treatment in modern days has become very important because of the scarcity of water in many parts of the world and the health effect because of the polluted water. This calls for the effective, economical and feasible alternative for treatment. The new technology containing membranes is very attractive alternative. This paper aims at reviewing the research carried out in this area for removal of various pollutants in effluent with respect to the methods used, affecting parameters and the effectiveness. It was found during this review that the use of membrane technology is widely studied and explored. Many researchers have used the membrane bioreactors, electrodialysis, osmosis, anaerobic membrane treatment effectively for wastewater treatment. It was also observed that use of combined treatment with other methods like activated sludge process and other conventional purification system can be very effective(Adriaens 2003).

Water is one of the vital commodities that sustains and nurtures our life on earth and can be easily obtained from our surrounding. Fresh water is consumed daily for many purposes. The three largest consuming sectors worldwide are agriculture (70%), industry (19%) and domestic use (11%). Several factors such as overuse/misuse of water, pollution of water resources, improper management of water, climate change and population growth have led to a water scarcity crisis. According to the United Nations, around 1.2 billion people live in areas of physical scarcity, another 500 million people approach this situation and 1.6 billion people (one quarter of the world's population) are facing economic water shortage. The effects of water scarcity or water shortage are very severe and actions should be taken to defuse the resulting tensions and solve the problems. Some of the obvious negative effects of water scarcity can be seen from the figures provided by WHO, where more than 3.4 million people die each year from water-hygiene related causes(Ahamed, Yin et al. 2016, Tozlu, Özahi et al. 2016).

Besides that, water shortage also seriously threatens agriculture activities, which in turn reduce the food supply and cause starvation in some countries. The situation is worsened by the high population growth rate, by 80 million a year, which indicates that the demand for fresh water will only continue to increase in the near future(Ahamed, Yin et al. 2016).

In anticipation of the negative consequences that have arisen, solutions such as water recycling, water reuse, desalination and improvement of currently available water treatment plants have been suggested. Desalination and improvements in water treatment plants will be the focus of this paper. Desalination is a technology that utilizes brackish and seawater by rejecting the contaminants and minerals in the water to produce potable water (Risch, Loubet et al. 2014).

This technology has become more popular and applicable due to the inexhaustible source of seawater. For water treatment plants, stringent regulations on drinking water quality by governments and worsening qualities of feed water due to pollution are the two main contributing factors leading to the need for modifications and improvements to the plants to enhance their efficiency in treating groundwater and surface water (Akther, Sodiq et al. 2015).

1.1.Important term related to waste water treatment

BOD Biochemical Oxygen Demand Since oxygen is required in the breakdown or decomposition process of wastewater, its "demand" or BOD, is a measure of the concentration of organics in the wastewater.

COD Chemical Oxygen Demand The amount of chemical oxidant required to breakdown the wastes, also an indicator of the concentration of organics.

Dissolved Oxygen (DO) The amount of oxygen dissolved in the water. Measured in milligrams per liter.

Denitrification Biologically removing nitrate converting it to nitrogen gas.

Disinfection The use of chemicals to kill any disease causing organisms in the polished wastewater. UV light

Biosolids Rich organic material leftover from aerobic wastewater treatment, essentially dewatered sludge that can be re-used.

Activated Sludge Sludge that has undergone flocculation forming a bacterial culture typically carried out in tanks. Can be extended with aeration.

Advanced Primary Treatment The use of special additives to raw wastewater to cause flocculation or clumping to help settling before the primary treatment such as screening.

Advanced Wastewater Treatment Any advanced process used above and beyond the de facto typical minimum primary and secondary wastewater treatment.

Aerobic Wastewater Treatment Oxygen dependent wastewater treatment requiring the presence of oxygen for aerobic bacterial breakdown of waste.

Alkalinity A measure of a substances ability to neutralize acid. Water containing carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates can be alkaline. Alkaline substances have a pH value over 7

Anaerobic Wastewater Treatment Wastewater treatment in the absence of oxygen, anaerobic bacteria breakdown waste.

Wastewater Wastewater is "used" water, the water leftover after its use in numerous application such as industrial, agricultural, municipal, and domestic and on.

Turbidity A measure of how clear water is in Nephelometric Turbidity Unit (NTU), invisible to the average naked eye until readings in excess of 100 are reached, typically determined by shining light through a sample placed in a turbidimeter. (Metcalf,2003).

1.2. The problem related to waste water:

The principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without danger to human health or unacceptable damage to the natural environment. Irrigation with wastewater is both disposal and utilization and indeed is an effective form of wastewater disposal (as in slow-rate land treatment). However, some degree of treatment must normally be provided to raw municipal wastewater before it can be used for agricultural or landscape irrigation or for aquaculture. The quality of treated effluent used in agriculture has a great influence on the operation and performance of the wastewater-soil-plant or aquaculture system. In the case of irrigation, the required quality of effluent will depend on the crop or crops to be irrigated, the soil conditions and the system of effluent distribution adopted. Through crop restriction and selection of irrigation systems which minimize health risk, the degree of pre-application wastewater treatment can be reduced. A similar approach is not feasible in aquaculture systems and more reliance will have to be placed on control through wastewater treatment(Risch, Loubet et al. 2014, Yadav, Karmakar et al. 2016).

Table 1. Typical Characteristics and composition of Textile Wastewater

pH	6 – 10
Temperature	35 – 45 ^{0}C
BOD, (mg/L)	100 – 4000
COD, (mg/L)	150 – 10000
TSS, (mg/L)	100 – 5000
TDS, (mg/L)	1800 – 6000
Chlorides as Cl^-, (mg/L)	1000 – 6000
Total alkalinity, (mg/L)	500 – 800
Sodium as Na^+, (mg/L)	610 – 2175
Total Kje/dhl Nitrogen, (mg/L)	70 – 80
Colour (Pt – CO), Hazen units	50 – 2500

The most appropriate wastewater treatment to be applied before effluent use in agriculture is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements (Arar 1988). In many locations it will be better to design the reuse system to accept a low-grade of effluent rather than to rely on advanced treatment processes producing a reclaimed effluent which continuously meets a stringent quality standard (Alhaji, Sanaullah et al. 2016).

Figure : 1. Image of waste water release from origin

Nevertheless, there are locations where a higher-grade effluent will be necessary and it is essential that information on the performance of a wide range of wastewater treatment technology should be available. The design of wastewater treatment plants is usually based on the need to reduce organic and suspended solids loads to limit pollution of the environment. Pathogen removal has very rarely been considered an objective but, for reuse of effluents in agriculture, this must now be of primary concern and processes should be selected and designed accordingly (Hillman 1988). Treatment to remove wastewater constituents that may be toxic or harmful to crops, aquatic plants (macrophytes) and fish is technically possible but is not normally economically feasible. Unfortunately, few performance data on wastewater treatment plants in developing countries are available and even then they do not normally include effluent quality parameters of importance in agricultural use(Al-Duri, Alsoqyiani et al. 2016). Adopting as low a level of treatment as possible is especially desirable in developing countries, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably.

2. DIFFERENT SOURCE OF WASTE WATER TREATMENT PLANTS:

Wastewater treatment plants may be distinguished by the type of wastewater to be treated, i.e. whether it is sewage, industrial wastewater, agricultural wastewater or leachate.

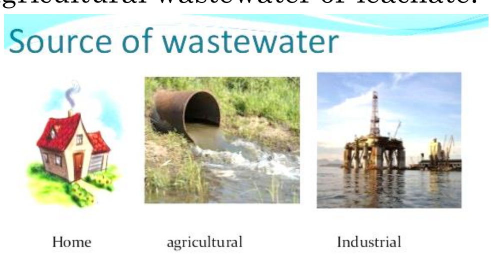

Figure: 2. Source of waste water treatment plant

2.1.Sewage treatment plants

A typical municipal sewage treatment plant in an industrialized country may include primary treatment to remove solid material, secondary treatment to digest dissolved and suspended organic material as well as the nutrients nitrogen and phosphorus, and - sometimes but not always - disinfection to kill pathogenic bacteria. The sewage sludge that is produced in sewage treatment plants undergoes sludge treatment. Larger municipalities often include factories discharging industrial wastewater into the municipal sewer system. The term "sewage treatment plant" is nowadays often replaced with the term "wastewater treatment plant"(Tozlu, Özahi et al. 2016, Al-Hamamre, Saidan et al. 2017).

2.2.Tertiary treatment

Tertiary treatment is a term applied to polishing methods used following a traditional sewage treatment sequence. Tertiary treatment is being increasingly applied in industrialized countries and most common technologies are micro filtration or synthetic membranes. After membrane filtration, the treated wastewater is nearly indistinguishable from waters of natural origin of drinking quality (without its minerals). Nitrates can be removed from wastewater by natural processes in wetlands but also via microbial denitrification. Ozone wastewater treatment is also growing in popularity, and requires the use of an ozone generator, which decontaminates the water as ozone bubbles percolate through the tank, but this treatment is energy intensive. Latest, and very promising treatment technology is the use aerobic granulation(Yuan and He 2015).

Figure 3. Real Waste waster treatment plant

2.3. Industrial wastewater treatment plants

Disposal of wastewaters from an industrial plant is a difficult and costly problem. Most petroleum refineries, chemical and petrochemical plants have onsite facilities to treat their wastewaters so that the pollutant concentrations in the treated wastewater comply with the local and/or national regulations regarding disposal of wastewaters into community treatment plants or into rivers, lakes or oceans. Constructed wetlands are being used in an increasing number of cases as they provided high quality and productive on-site treatment. Other industrial processes that produce a lot of waste-waters such as paper and pulp production has created environmental concern, leading to development of processes to recycle water use within plants before they have to be cleaned and disposed(Zhang, Wu et al. 2016).

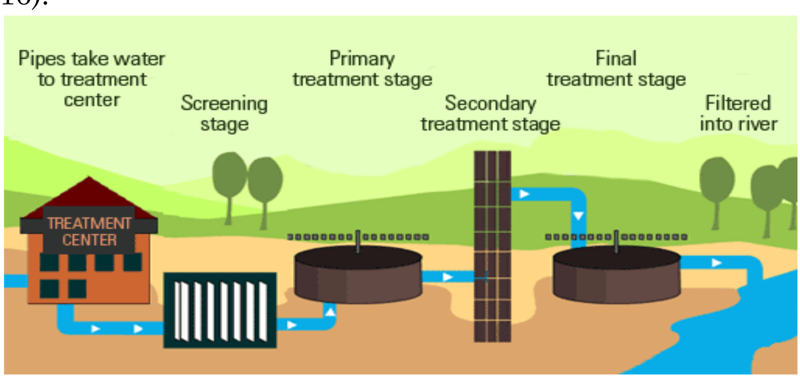

Figure :4. Schematic diagram of waste water treatment plant

Industrial wastewater treatment plants are required where municipal sewage treatment plants are unavailable or cannot adequately treat specific industrial wastewaters. Industrial wastewater plants may reduce raw water costs by converting selected wastewaters to reclaimed water used for different purposes. Industrial wastewater treatment plants may reduce wastewater treatment charges collected by municipal sewage treatment plants by pre-treating wastewaters to reduce concentrations of pollutants measured to determine user fees(Morone, Apte et al. 2015).

Although economies of scale may favor use of a large municipal sewage treatment plant for disposal of small volumes of industrial wastewater, industrial wastewater treatment and disposal may be less expensive than correctly apportioned costs for larger volumes of industrial wastewater not requiring the conventional sewage treatment sequence of a small municipal sewage treatment plant.(Rasool, Tavakoli et al. 2016)

2.4.Agricultural wastewater treatment plants

Agricultural wastewater treatment for continuous confined animal operations like milk and egg production may be performed in plants using mechanized treatment units similar to those described under industrial wastewater; but where land is available for ponds, settling basins and facultative lagoons may have lower operational costs for seasonal use conditions from breeding or harvest cycles(Yadav, Karmakar et al. 2016).

2.5.Leachate treatment plants

Leachate treatment plants are used to treat leachate from landfills. Treatment options include: biological treatment, mechanical treatment by ultrafiltration, treatment with active carbon filters and reverse osmosis using disc tube module technology(Ng, Head et al. 2016).

3.CONVENTIONAL DRINKING WATER TREATMENT PLANTS METHOD

Most current drinking water treatment plants use conventional treatment methods like coagulation–flocculation, sedimentation, sand filtration, disinfection and ozonation to produce fresh potable water. Raw water as feed to water treatment plants might come from groundwater, a well, or surface water such as rivers, lakes, ponds and reservoir systems. However, due to human activities such as disposing of industrial wastes and contamination of water resources, conventional treatment plants are having difficulty producing potable water effectively. This is mainly due to a significant drop in feed water quality.

This is happening especially in developing and underdeveloped countries as they do not have proper protection plans in place to preserve Modern technology and method for waste water treatment the quality of water resources and lawful regulations to prevent the dumping of industrial wastes into the waterway. Hence, conventional water treatment plants will only be able to remove either some or none of the emerging industrial pollutants in the water(Zaman and Swapan 2016).

3.1.Several shortcomings of traditional water treatment plants will be briefly discussed below:

3.1.1. Pollution of water resources

Water resources which have been seriously polluted require advanced treatment facilities in order for conventional water treatment plants to produce safe drinking water. Traditional treatment has been shown to be unable to remove toxins, pesticides, pharmaceutical residues, arsenic and herbicides from polluted water resources. More advanced treatment for pesticides such as oxidation with ozone and filtration by granular activated carbon (GAC) has been considered effective in pesticide removal but problems related to the process still arise. Some of these problems are due to the saturation of the activated carbon and the formation of toxic chemical by-products which may develop in the GAC filters. These weaknesses have driven the use of membrane technology, which can compete economically with those advanced treatment processes and also provide multifunctional capabilities(Lim, Lau et al. 2016, Passey, Hansen et al. 2016).

3.1.2. Vulnerability towards microorganism attack

It was reported that the biological treatment applied to the Mery-sur-Oise water treatment plant in France failed to prevent the growth of bacteria in the distribution system due to a high level of organic matter from the Oise River which prevented the treatment system from removing all the organic materials. This same phenomenon has been observed at the Cheng Ching Lake Water Works conventional water treatment plant, where algae and other microorganisms could not be completely removed by the system. Complaints were received from customers regarding the disagreeable taste and odor of the treated water. This is another weakness of conventional treatment methods(Lim, Lau et al. 2016).

3.1.3. Water hardness

In addition, water produced from traditional treatment plants may be too hard and need to be softened further. Traditional softening processes such as cold and hot lime softening and pellet softening require intensive consumption of lime and acids and will produce large quantities of sludge(Lovarelli, Bacenetti et al. 2016).

3.1.4. Disinfection by-products

In order to remove viruses and bacteria, chlorination has been applied as a disinfection method. However, this will create another adverse problem, which is the formation of disinfection by products that are carcinogenic and difficult to remove(Wen, Wang et al. 2016).

4. TYPES OF METHOD FOR PROCESSING OF WASTE WATER

4.1. Reverse osmosis

Reverse osmosis is a well developed technology which has already been applied in many branches of industry, as well as in various nuclear centres in the world. There was long-time experience with a reverse osmosis plant in Chalk River Laboratories in Canada, where tubular and spiral wound RO modules were used for mixed aqueous waste processing. Australian Nuclear Science and Technology Organisation (ANSTO) considered membrane technology as feasible for upgrading its existing effluent treatment plant. The pilot plant constructed by ANSTO consisted a pre-treating stage made of tubular ultrafiltration modules, two passes for permeate purification and two stages of concentration by RO spiral wound modules. At Nine Mile Point Nuclear Power Plant (United States) two units: unit 1 (610 MWe) and unit 2 (1225 MWe) operated with "zero-liquid"discharge were equipped with a full-scale reverse osmosis systems based on Thermex to treat floor drains and other low level wastes in the nuclear plant. In Wolf Creek Nuclear Power Plant reverse osmosis with ultrafiltration pre-treatment for floor drains and other wastes was used. Bruce Nuclear Power Plant (Canada) developed ultrafiltration and reverse osmosis for processing the wastes from chemical cleaning of steam generator. The combination of ultrafiltration with reverse osmosis was also applied at Comanche Peak Nuclear Power Plant (United States) for floor drains, resin sluice water and boron recycling water processing. Ultrafiltration coupled with reverse osmosis was installed at unit 1 of Dresden Nuclear Power Plant (United States) to process a batch of low level radioactive wastes contaminated by transuranic (TRU) elements. Microfiltration and reverseosmosis were employed for the treatment of reprocessing wastes at the Savannah River site(Shenvi, Isloor et al. 2015, Lee, Jin et al. 2016).

Table:2. Filtration Scope of different Membranes

Process	Pore size (Micro)	Mol. wt.	Examples / Ose
Min	0.001 – 2.0	7,10,00,000	Bacteria,
Ultra	0.002 – 0.1	1000–2000000	Colloids, Virus, Protein etc
Nano	0.001 – 0.07	180 – 15000	Dyes, Pesticides, divalent ions, etc
R.O.	<0.001	<200	Salts & ions

4.2. Nanofiltration

Nanofiltration (NF) process allows separating monovalent from multivalent ions, which are retained by the membrane with pores in 0.001–0.01 µm size range. The process can be used for separation of organic compounds of moderate molecular weight from monovalent ions present in the solution. The well-known application of NF in the nuclear industry is boric acid recovery from contaminated cooling water in nuclear reactor. There are some examples of applications and studies described in literature(Lee, Jin et al. 2016).

4.3. Ultrafiltration

Ultrafiltration (UF) uses membranes of pore sizes between 0.001 and 0.1 µm. In such a case dissolved compounds pass through the membrane, while colloid and suspended matters are rejected by UF membrane. In nuclear industry UF can be used for removal of all substances, which are present in radioactive waste in colloidal or suspended form. Ultrafiltration can be also applied as a pretreatment stage before reverse osmosis. Very often ultrafiltration is combined with sorption, precipitation or complexation in one hybrid process of enhanced ultrafiltration. Small ions bound by macromolecular agents form complexes, which can be retained by UF membrane.

Radioactive cations can be also separated in precipitation process forming less soluble particles (carbonates, phosphates, and oxalates or hydroxides) which can be later retained by UF membrane. The hybrid complexation-UF or precipitation-UF methods are effectively applied in several plants processing α-bearing radioactive waste streams(Yin, Qian et al. 2014).

4.4. Microfiltration

Microfiltration (MF) membranes reject bigger particles and macromolecules with size of 0.1–1 μm. In nuclear technology the process is used either for pre-treatment purposes or for concentration of coarse particles after precipitation process. For high level radioactive wastes the ceramic filters are applied giving for some types of effluents high decontamination and concentration factors(Rana, Kalla et al. 2016).

Microfiltration was tested as a pre-treatment step in RO installation constructed at AECL Chalk River Laboratory (Canada) for mixed low-level radioactive wastes processing. The MF hollow fibre membranes removed the suspended solids larger than 0.2 μm. The filtrate from MF formed the feed for the spiral wound reverse osmosis system; the backwash solution underwent further volume reduction in thin-film evaporator(Shenvi, Isloor et al. 2015).

4.5. Electric membrane processes

The main processes, in which the electric potential is the driving force and that are carried on with the use of ion-exchange membranes, tested in the context of application in nuclear technologies, are electroosmosis, electrodialysis, and membrane electrolysis. Electroosmosis was used for dewatering sludge after filtration or gravitational sedimentation. With this method high retention factors with minimal membrane fouling were achieved. Electroosmosiswas accompanied by electrophoretic transport that reduced fouling and prevented small charged particles passing through the membrane. The result was a 99.99%-retention factor, while the volume reductionfactors were lower due to the reduction in transport velocity with increasing conductivity of the liquid (Ghaffour, Bundschuh et al. 2015).

5. NANOTECHNOLOGY IN WASTE WATER TREATMENT AND NANOMATERIALS USED IN WATER TREATMENT

With the development of nanotechnology, its application in water and wastewater treatment is becoming imminent. Over the past decades, there are numerous studies available on such topic. In this section, we provided a brief review of some typical application of nanotechnology in water and wastewater treatment, i.e., adsorption and separation, catalytic oxidation, disinfection and sensing (Marcet, Alvarez et al. 2016, Zhang, Wu et al. 2016).

The advancement of nanotechnology is highly dependent on the innovation of various nanomaterials. In this chapter, a number of nanomaterials that could be used in water and wastewater remediation were introduced. Their synthesis, removal of contaminants and the underlying mechanism were discussed(Islam, Pandey et al. 2016).

5.1. Carbon based nanomaterials

5.1.1. Graphene based nanomaterials

Graphene is a single carbon layer of the graphite structure (IUPAC), presenting an ordered honeycomb network structure. It often exhibits excellent thermal and electrical conductivity. Graphene oxide (GO) is a monolayer graphene with a highly oxidative form, which consists of a variety of oxygen-containing functional groups, such as hydroxyl, carboxyl, carbonyl and epoxy groups. Reduced graphene oxide (RGO) is more defective and less conductive than graphene but is relatively easy to be modified by other functional groups (Avouris and Dimitrakopoulos, 2012(Zhang, Wu et al. 2016)).

5.2. Metal & metal oxides nanoparticles

Nanosized metals and metal oxides have received ever-increasing attentions because of their high performance and low cost for contaminants removal. Nanosized metals and metal oxides mainly include nanosized zero-valent iron, ferric oxides, aluminum oxides, manganese oxides, titanium oxides, magnesium oxides and cerium oxides. Nanosized magnetic adsorbents have also turned up in recent years. A number of studies suggested that nanosized metals and metal oxides exhibit favorable sorption towards metallic contaminants such as arsenic cadmium, chromium uranium , and other common pollutants such as phosphate and in terms of high capacity and selectivity(Lee, Jin et al. 2016, Zhang, Wu et al. 2016).

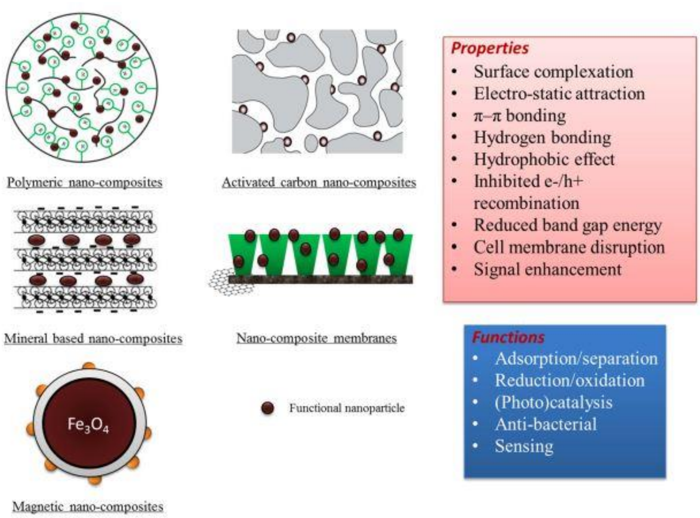

Figure 5. Illustration of typical environmental nanocomposites and nano-enabled properties.

5.3. Noble metal nanoparticles

Noble metals were commonly referred to certain transition metals like Gold (Au), Silver (Ag), Platinum (Pt) and Palladium (Pd). They usually have high ionization energy owing to their small atom size, hence low oxidation potential. However, at nanoscale, their ionization energy and oxidation potential changed substantially, allowing many novel reactions with noble metal feasible. The synthesis method of noble metal nanoparticles was commonly through reduction of the corresponding metal salts and controlled nanocrystal nucleation and growth with a stabilizing agent. In many cases, polymers and surfactants were employed to enhance the stability of noble metal nanoparticles(Li, Liu et al. 2016, Zhang, Wu et al. 2016).

6. CONCLUSION

The review summarizes the research and studies carried out for the application of membrane technology for wastewater treatment. The membrane technology is promising method for removal of various pollutants such as organic matter, solids, turbidity and various heavy metals. The membrane technologies used for the wastewater treatment includes electrolysis, reverse osmosis, anaerobic membrane bioreactors. Membrane technology has many advantages such as less area requirement and high removal efficiency. Membrane technology can be combined with conventional treatments as per requirement for more effective treatment of waste water.Ozonisationetc are used to maintain quality of effluent. Membranes methods are widely being used. Multiple effect evaporation with crystallizers is also being used Reverse Osmosis method is very good. The reuse is a need of the how in textile industry. The reuse or recycle in textile industry is a must and the technologies are available for this. This ultimately reduces effluent treatment cost by the way of water, chemical recovery, reduction in problems like scale formation, corrosion inhibition, etc.Nanomaterials are widely explored as highly efficient adsorbents, (photo)catalyst and disinfectant for water treatment. Generally, they exhibited various merits, such as high capacity, fast kinetics, specific affinity towards targeted contaminants, enhanced photocatalytic response for a broad light spectrum, and strong anti-bacterial activity. Rapid depletion of primary resources, increasing emission and waste releases into the environment and recent advocate in circular economy formed strong driving forces for evaluation of sustainability of recovery of metals from secondary resources such as wastes. They are arguably the most promising candidate for the development of next generation water treatment technology. Of particular note is that, there are still many obstacles to overcome for engineering application of nanomaterials. Nanomaterials are usually unstable, tend to agglomerate due to the presence of van der Waals forces and other interactions. It is still challenging to recycle nanomaterials from treated water except for magnetic nanoparticles, render the use of nanomaterial uneconomic or sometimes unfeasible. Last but not the least, the long-term fate, transformation and toxicity of nanoparticles are not clearly understood.

7. RECOMMENDATIONS

Despite the encouraging outcomes from the use of hybrid/integrated membrane systems in water treatment plants and RO desalination plants, integrated/hybrid membrane systems still have some shortcomings/unknown areas that require further detailed study. Coagulation has been shown to be one of the best candidates for fouling reduction. However, coagulant residuals from pretreatment processes using either aluminum sulfate (alum) or ferric chloride may also have negative effects on membrane performance. Furthermore, excessive use of PACl coagulant and PAC adsorbent dose showed the possibility of adverse effects on membrane performance as well as membrane permeability. The effects of excessive use of additives have not been well studied. Recently, carbon nanotube adsorption technology has drawn special attention from researcher due to its capability to remove bacterial pathogens, natural organic matter (NOM) and cyanobacterial toxins from polluted water. However, the production costs of carbon nanotubes are quite high, and it has potentially significant safety and environmental impacts on the ecosystem if the adsorbent media are inadvertently released from the filter. Thus, further work should include investigating the effects of type and dose of additive on membrane fouling, performance, economic and environmental aspects so that the applicability of integrated membrane systems can be thoroughly accessed.

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