Chapter 14
Nanotechnology: A Modern Technique for Pollution Abatement

Bhat Mohd Skinder and Saima Hamid

14.1 Introduction

In 1974 “Professor Norio Taniguchi” coined the term “nanotechnology” at the University of Tokyo. Translated version of nanotechnology into English: “Nanotechnology is the production technology to get the extra high accuracy and ultra-fine dimensions, i.e., the preciseness and fineness on the order of 1 nm (10^{-9} meter in length).” Nanomaterials are defined as those materials which have structured components with at least one dimension less than 100 nm (Oberdorster et al. 2005). Nanoscience is the study of phenomena and material manipulation on atomic, molecular, and macromolecular scales in order to realize and exploit properties that vary considerably from those on a larger scale. Nanotechnology not only encompasses science, engineering, and technology on a nanoscale, but it includes imaging, measuring, modeling, and manipulating matter (Singh et al. 2020). Conventional techniques such as landfill disposal and isolation are somewhat efficient but costly and take enough time to reach targets, but nanotechnology could be a useful substitute for current site remediation practices (Salipira et al. 2007). Conventional techniques also produce undesirable byproducts like dichloroethylene, and vinyl chloride are byproducts during in situ remediation of trichloroethylene. It is extremely difficult to operate remediation of aquifers with existing standard procedures, because the “contaminants” such as “chlorinated hydrocarbons” rove to the water-table and core areas. Nanotechnology can effectively target all these limitations (Masciangioli and Zhang 2003). Nanoparticles offer numerous benefits and

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B. M. Skinder (✉) · S. Hamid
Department of Environmental Science, Centre of Research for Development, University of Kashmir, Srinagar, India

R. A. Bhat, K. R. Hakeem (eds.), *Bioremediation and Biotechnology, Vol 4*,
https://doi.org/10.1007/978-3-030-48690-7_14

can be transported easily due to their small size and large surface area (large surface results in high enzymatic activity) (Karn et al. 2009). Thus the particle size is extremely small in size and can be injected into the very small spaces of the underground contaminated sites without any excavation for the longer period of time as it remains active for a long time for the better treatment process (Zhang 2003). However, studies revealed that these NPs have limited movement from their injection point in remediation processes (Tratnyek and Johnson 2006). Nanoparticles can be attached to a concrete matrix to be used as free particles to treat "polluted water" or "gaseous stream," and movement of these NPs can be controlled by sedimentation process (Zhang 2003; Bora and Dutta 2014). Nanotechnology offers a wide variety of material types, including nanoscale zeolites, carbon-nanotubes, enzymes, dendrimers, metal-oxides, and bimetallic-particles, used for remediation purposes. Iron being a powerful reducing agent thus has an essential role in the remediation of pollutants like poly-halogenated organic compounds and heavy metals in the environment (Karn et al. 2009). Iron nanoparticles are most frequently used in remediation of surface pollutants such as petrochemicals and even subsurface pollutants like pesticides, chlorinated solvents such as tricholoroethylene (TCE), fertilizers, and heavy metals (Fig. 14.1) (Ponder et al. 2000; Shipley et al. 2010; Kanel et al. 2005; Watlington 2005; Rickerby and Morrison 2007). Pesticides such as 2,4-dichlorophenoxyacetic acid (2, 4-D) are also successfully degraded by magnetic NPs (Fang et al. 2011).

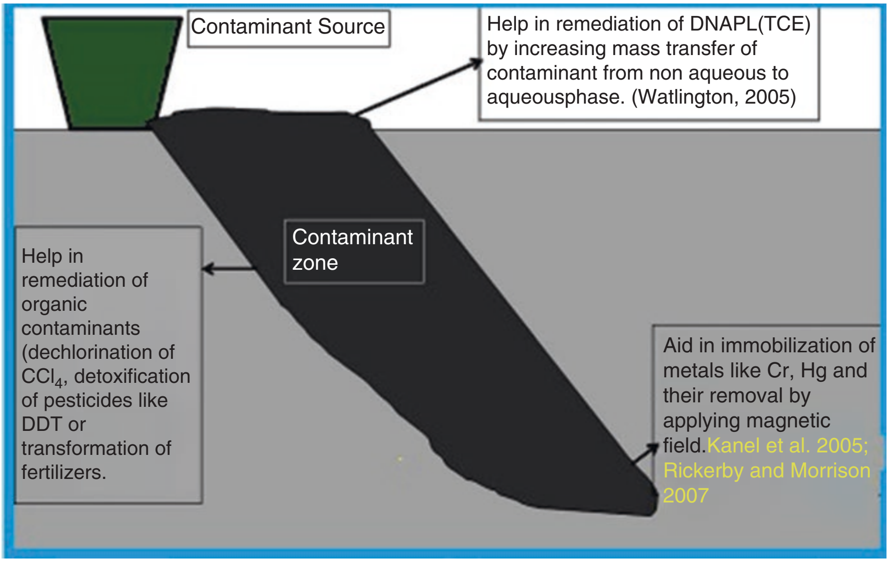

Fig. 14.1 Diagrammatic representation of the use of FeNPs for the degradation of various environmental pollutants (such as organic, inorganic, and petrochemical compounds)

14.2 Nanoremediation

Nanotechnology played a great role in microbial remediation as the greatest challenge in bioremediation has been to increase bioavailability/solubility and consequently the degradation rate. In the present situation, to increase the solubility of the "contaminant," surfactant micelles are used, but they tend to breakdown when contacted with the soil and interact with the liposome of microorganisms, thus regulating the competency of bioremediation. However, nanotechnologies have revealed an encouraging step in this direction. The solubilization rate of phenanthrene (PHEN) by using amphiphilic polyurethane (APU) NPs has increased significantly (Tungittiplakorn et al. 2005). These particles are made from antecedent chains of polyurethane acrylate anionmer (UAA) or poly(ethylene) glycol (PMUA), which have hydrophobic centers that show high PHEN attraction. By developing a nanoparticle-suspension competing with non-aqueous phase liquids (NAPLs), they improve polycyclic aromatic hydrocarbons (PAHs) desorption and movement. In contrast to surfactant, by altering the hydrophobic segment of the antecedent chain, the attraction of NPs to contaminant (hydrophobic) may be improved and mobility/movement may be better by regulating the load density of the altered NPs. Alternative benefit in bioremediation offered by NPs is in the form of NPs from magnetite. "Magnetite-NPs are formed under inert conditions by co-precipitation of ferrous and ferric salts." This technology instructs great industrial application in terms of cost-effectiveness, easier reusability, and separation. The magnetite NPs are used on *Rhodococcus erthyropolis* and *Pseudomonas delafieldii* as bacterial strains of biodesulfurization activity. The use of magnetite NPs demonstrated better activity of desulfurization. The cells covered with altered magnetite NPs from ammonium oleate showed repeated bio-desulfurization activity, and by using an external magnet, it can be collected on the surface of the flask (Li et al. 2009)

The methods involved in nanoremediation are use of reactive nanomaterials for the conversion and decontamination of pollutants. They (nanomaterials) are pollutant specific in both the "chemical reduction" and "catalysis" in the process of mitigation. For in situ remediation of groundwater or soil contamination, no water is pumped out or no soil is transported to other site/disposal sites for surface treatments (Otto et al. 2008). Different nanoscale materials such as: carbon nanotubes, metal oxides, fullerenes, zeolites, titanium dioxide (TiO_2), fibers, and various noble metals (bimetallic nanoparticles (BNPs), e.g., Ag-Au BNPs) are being used. Nanoscale zero-valent iron (NZVI) is currently most widely used in the nanotechnology.

14.3 NZVI

NZVI particle ranges from 10 to 100 nm in diameter. Typically, a noble metal can be added as a catalyst (e.g., palladium, silver, copper). There is a catalytic interaction between the "second metal" and iron (Fe) and also supports the dissemination and mobility of the NPs once inoculated into the ground (Tratnyek and Johnson 2006). There may be more than two metals in BNPs, the "second metal" is generally less reactive and promotes oxidation of Fe or transfer of electrons (EPA 2007). There are some noble metals, particularly palladium, catalyze de-chlorination, and hydrogenation, thus making remediation more efficient (Li et al. 2006). The fundamental chemistry of Fe′s reaction to pollutants in the environment (particularly chlorinated solvents) was broadly studied and applied in ZVI permeable reactive barriers (ZVI-PRBs) of micrometer scale. "Beta elimination" and "reduction chlorination" are the two main degradation pathways for chlorinated solvents. The most common occurrence of beta elimination is when there is direct contact between "contaminant" and "Fe particle."

For example: the pathway of tricholoroethylene (TCE) (EPA 2007).

$$\mathrm{TCE} + \mathrm{Fe}^{0} \rightarrow \mathrm{Hydrocarbon\quad products} + \mathrm{Cl}^{-} + \mathrm{Fe}^{2+} / \mathrm{Fe}^{3+}$$

Under reducing circumstances endorsed by nZVI in ground water, the following reaction takes place:

$$\mathrm{PCE} \rightarrow \mathrm{TCE} \rightarrow \mathrm{DCE} \rightarrow \mathrm{VC} \rightarrow \mathrm{Ethene}$$

where PCE: perchloroethylene
DCE: dichloroethylene
VC: vinyl chloride

Nanoscale Fe particles are very active in transforming and detoxifying different environmental pollutants, including organic chlorinated solvents, polychlorinated biphenyls (PCBs), and organo-chlorine pesticides. Amending FeNPs can improve the speed and efficiency of remediation processes.

14.4 Nanotechnology and Wastewater Treatment

Nanotechnology is very efficient and flexible, and multifunctional processes are designed to deliver inexpensive water, quality wastewater treatment, and high-performance resolutions that rely less on large infrastructures (Qu et al. 2013a, b). Nanotechnology promises not only to overwhelm main tests faced by current treatment technologies, but also to provide novel treatment abilities that might permit the fiscal use of unconventional water sources to multiply the water supply.

14.4.1 Bioactive NPs for Water Disinfection

As a result of population "explosion," water contamination due to germs and additional pollutants get worsened, but nanotechnology provides alternatives for cleaning the water bodies and fulfilled the need of clean water. The alternative provided by nanotechnology is antimicrobial nanotechnology (Li et al. 2008; Mamadou et al. 2009). Several experiments have been made by using different nanomaterials for antimicrobial activities and have revealed significant results (Li et al. 2008). Some antimicrobial experiments are briefly highlighted below:

- Bacterial cell components and viruses are damaged by ROS (reactive oxygen species) formed by photocatalytic process (e.g., ZnO, TiO_2, and fullerol).
- The bacterial cell wall gets dwindling (e.g., AgNPs, ZnO, chitosan, peptides, carboxyfullerene, and CNTs).
- Disruption of mitochondrial energy transduction (e.g., Ag and aqueous fullerene NPs).
- Synthesis of DNA and activities of enzymes gets inhibited (TiO_2).
- The combination of magnesium oxide (MgO), AgNPs, and cellulose acetate (CA) fibers acts as potential biocide against bacterial spores, Gram +ve and Gram –ve bacteria (Savage and Diallo 2005).

14.4.2 Nano-adsorbents Based on Metal

Metal oxides like iron oxide, titanium dioxide, and alumina are low cost and effective adsorbents for heavy metals. The absorption and adsorption are regulated by complexation between dissolved metals and oxygen in metal oxides (Koeppenkastrop and Decarlo 1993). It is a two-step process: In the first step, metal ions get rapidly adsorbed on the outside surface, and in the second step, there is a speed limiting intra-particle diffusion along microporous walls (Trivedi and axe 2000). Due to high specific surface area, the shorter intra-particle diffusion space and the larger number of sites for surface reactions (i.e., corners, edges, vacancies). Their nanoscale counterparts have faster kinetics and greater adsorption capacity. For example, adsorption of arsenic (As) increased more than 100 times as nano-magnetite particle size fell from 300 to 11 nm (Yean et al. 2005). This increase in adsorption was attributed to the increase in specific surface area as magnetite particles of 300 and 20 nm have alike surface area and stabilized As adsorption capacity (Auffan et al. 2008, 2009). However, when particle size was reduced to <20 nm, the standardized adsorption capacity of the specific surface area increased, with 11 nm magnetite NPs absorbing three times more As, proposing a “nanoscale effect.” This “nanoscale effect” has been accredited to the change in the structure of the “magnetite surface” creating new adsorption sites (vacancies) (Auffan et al. 2009). Some Fe oxide NPs, e.g., nano-maghemite and nano-magnetite, may be super-paramagnetic besides high adsorption capacity. Magnetism is extremely volume-dependent as it stems from the atomic magnetic dipole’s collective interaction. When size of a ferro or ferrimagnetic substances decrease to the critical value (40 nm), the magnet changes from multiple domains to a single domain with greater magnetic sensitivity (Yavuz et al. 2006). If the size decreases further, magnetic particles are converted into superparamagnetic, losing permanent magnetic moments when reacting to an external magnetic flux that permits easy magnetic field separation and recovery. In a core

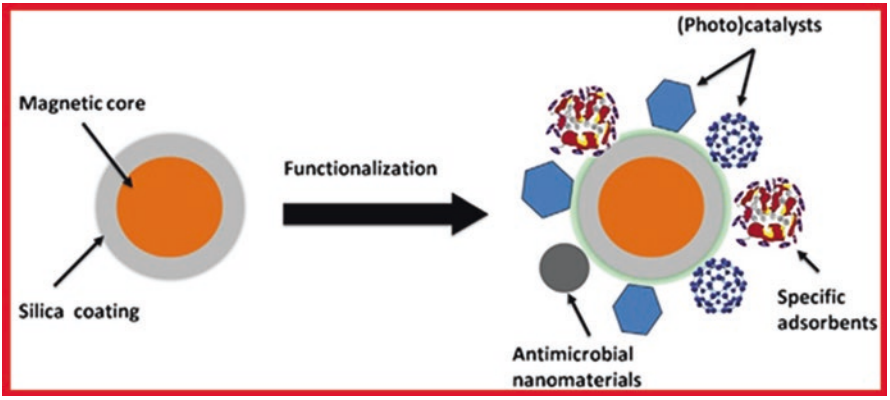

Fig. 14.2 Nanoparticles with multifunctional magnetic parts

shell nanoparticle structure, magnetic NPs are used as the core material, shell delivers the desired function, and the magnetic core performs magnetic separation. Silica is used as silica coating and helps in functionalization (Fig. 14.2).

By applying moderate pressure, nanocrystals of metal oxide are compacted into porous pellets without significantly affecting their surface area (Lucas et al. 2001). Nanomaterials based on metals were experimented to eliminate a range of heavy metals such as Hg, Cr, As, Pb, Cd, Cu, and Ni. They also demonstrated great potential for activated carbon outcomes (Sharma et al. 2009). The As removal application has attracted a great deal of attention among them. Despite being a good adsorbent for various organic and inorganic pollutants, activated carbon has restricted As capacity, especially As(V) (Daus et al. 2004). Several nanomaterials of “metal oxide” with nano-sized magnetite and TiO_2 have revealed superior performance of “As adsorption” to “activated carbon” (Deliyanni et al. 2003; Mayo et al. 2007). Metal(hydr)oxide NPs can also be infused on the activated carbon skeleton or other materials (porous) to immediately remove As and organic co-contaminants that favor point-of-use (POU) applications (Hristovski et al. 2009a, b)

14.5 Regeneration and Reuse

Metal oxide nano-adsorbents can be easily regenerated by altering the pH value of a solution, and its adsorption capacity is well maintained even after several reuse cycles and renewal (Sharma et al. 2009; Hu et al. 2006). However, there are reports of reduced adsorption capacity after regeneration (Deliyanni et al. 2003). Nano-adsorbents based on metals can be formed at comparatively low cost. The great capacities of adsorption, easy to separate, low cost, and easy renewal make it technologically and economically advantageous.

14.6 Carbon-Based Nano-adsorbents

14.6.1 Removal of Organic Contaminants

Nano-adsorbents based on carbon, for instance, “carbon nanotubes (CNTs),” are cylindrical and are discovered as replacements for activated carbon. CNTs are categorized as single-walled carbon-nanotubes(SWCNTs) and multi-walled carbon-nanotubes (MWCNTs). CNTs have great specific surface area with adsorption sites that can be highly evaluated. They can also modify their surface chemistry accordingly (Yang and Xing 2010). CNTs’ hydrophobic surface in aqueous medium forms loose bundles/aggregates that reduce the “active surface area” but are great-energy sites for organic contaminant adsorption in water (Pan and Xing 2008). The availability of bigger pores and extra-reachable sorption sites in bundles are reasons for CNT’s adsorption of huge organic contaminants (Ji et al. 2009). CNTs may also adsorb polar organic molecules due to various CNT-pollutant interactions like hydrophobic effects, covalent bonding, H-bonding with acids, connections with polycyclic aromatic hydrocarbons, OH-groups, amines, and electrostatic interactions with +vly charged organic pollutant molecules such as antibiotics (Ji et al. 2009; Lin and Xing 2008; Yang and Xing 2010).

14.6.2 Removal of Heavy Metal Ions

Heavy metal pollution is very dangerous to an aquatic system. To remove cadmium (Cd^{2+}) from aqueous solutions, surface-oxidized CNTs with H_2O_2, $KMnO_4$, and HNO_3 are used (Li et al. 2003). CNT oxidation may have higher adsorption capacity with faster kinetics for metal ions. The oxidized CNT surface includes functional groups which have good heavy metal ion adsorption capacity such as carboxylic acid (COOH), hydroxyl (OH), and carbonyl (Fig. 14.3). The initial metal ion concentration, temperature, contact time, and solution pH play important roles in sorption of cadmium (Cd^{2+}) ions onto raw-MWCNTs, o-MWCNTs(oxidized-MWCNTs), and e-MWCNTs (ethylenediamine-functionalized MWCNTs). The experiments have shown that adsorption of Cd^{2+} ions by o-MWCNTs and

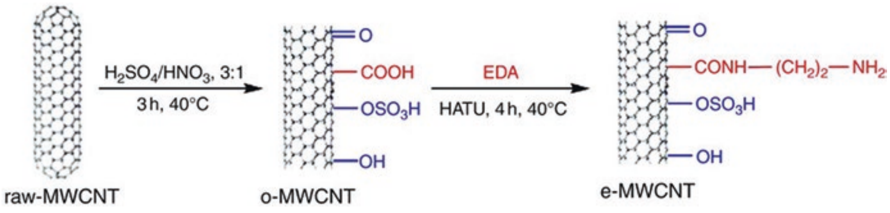

Fig. 14.3 Oxidation of functional groups on CNT surfaces

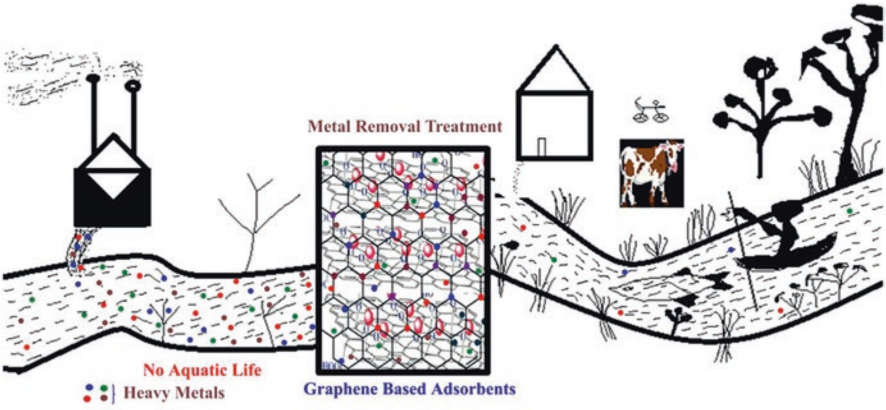

Fig. 14.4 Role of nano-adsorbents based on graphene in abatement of heavy metal pollution (Kumar et al. 2019)

e-MWCNTs was strongly pH dependent (Vukovic et al. 2010). Similarly nano-adsorbents based on "graphene" and its derivatives play an important and key role in the effective abatement of heavy metal pollution (e.g., lead (Pb-II)) (Fig. 14.4) (Kumar et al. 2019)

14.7 Nanotechnologies in Air Pollution Abatement

14.7.1 *Nanotechnology for the Adsorption of Toxic Gases*

Nanotechnology not only cleans the "waste water" but also plays an important role in the cleanup of toxic gasses in an ambient air. There is a hexagonal arrangement in the graphene sheet of carbon atoms of CNTs along the axis of the tube. The strong interaction occurs between two dioxin rings and CNT surfaces. In addition, dioxin molecules interact through a porous wall, i.e., 2.9 nm, on the entire surface of nanotubes, and may raise the potential for adsorption within pores if there is a possibility of overlapping events. Strong oxidation resistance of CNTs also benefited from high temperature regeneration of the adsorbent. As SWCNTs as well as MWCNTs, CNTs are unique macromolecules with a single-dimensional structure, thermal stability, and extraordinary chemical properties. As superior adsorbents, these nanomaterials have revealed good potential to remove different types of organic and inorganic contaminants, together in an aqueous environment and air streams. The pore structure and functional group plays an important role in CNTs adsorption capacity of pollutants. SWCNT and MWCNT's have potential applications because of their unique electronic properties and structures. SWCNTs, for instance, have been conveyed to be a chemical sensor of NO_2 and NH_3. The electrical resistance of SWCNTs changed significantly, either up or down, on exposure to NH_3or NO_2 gas. You can also use SWCNTs and MWCNTs as hydrogen storage. CNTs were also used as quantum nanowires, emitters of electron fields, supports for catalysts, etc.

Dioxin adsorption and associated compounds (e.g., polychlorinated dibenzofuran and polychlorinated biphenyls) are stable and extremely toxic contaminants. Dibenzo-p-dioxins belong to a family of compounds containing two rings of benzene, linked by two atoms of O_2. It contains in-between 0 and 8 atoms of chlorine attached to the ring. Dibenzofuran is a similar yet distinct compound in which oxygen bridges only one of the connections among two benzene rings. Dioxin toxicity varies as per the number of chloro-atoms. Dioxins that have only one or no chloro-atom are non-toxic, whereas dioxins that have more than one chloro-atom are toxic. Tetraklorodibenzo-p-dioxin (TCDD) is a compound known to be carcinogenic and affects the immune and endocrine systems to humans. These compounds are mainly generated from the incineration processes of wastes of organic compounds (10–500 ng/m^3). Dioxin emission regulations are complex and vary from country to country. Nevertheless, dioxin concentrations should generally be reduced to <1 ng/m^3. Since 1991, in Europe and Japan adsorption using activated carbon has been widely used to eliminate dioxins from incinerators. There is higher efficiency of dioxin removal by activated carbon adsorbent as compared to normal adsorbents, since the bonding energy between activated carbon and dioxin is much higher than the other adsorbent such as clay, α-Al_2O_3, and zeolites (Cudahy and Helsel 2000). However, keeping in view the toxicity of dioxin, it needs a more proficient adsorbent than activated carbon to lessen the emissions of dioxin to a minor level. CNTs have been revealed efficient in dioxin removal as dioxins have strong interaction with CNTs almost three times stronger than interaction with activated carbon (Long and Yang 2001a, b). This could be due to the curved surface of the nanotube compared to the flat sheet surface which provides stronger interaction forces among CNTs and dioxin (Bhushan 2010). Developing technologies to eradicate emissions of NO_x from the fossil fuel combustion have made significant efforts. Common adsorbent for removing NO_x at low temperatures includes activated carbon, zeolite, an ion exchange, and FeOOH distributed on active carbon fiber. Due to the reactivity of "surface functional groups," NO can be adsorbed effectively to activated carbon, but not significant. Long and Yang (2001a, b) found that CNTs can be used to remove NO as an adsorbent. NO_x adsorption may be associated with unique CNT structures, electronic properties, and functional surface groups. When NO and O_2 pass through CNTs, NO is oxidized to NO_2 and then gets adsorbed on the surface of nitrate(NO_3) species. The absorption of NO_x amounted to about 78 mg/g CNTs. Mochida et al. (1997) supported this idea by reporting NO to NO_2 oxidation at room temperature on activated carbon fiber. Similarly, oxides of sulfur (SO_x) also get adsorbed on CNTs compared to NO_x, although the adsorption rate is not promising when CO_2 is present.

Global warming is one of the main apprehensions at present times across the globe. Lots of efforts were made to control greenhouse gases like CO_2, methane, nitrous oxide, etc. One of such efforts was the introduction of Kyoto Protocol which came into the power from February 16, 2005, for the capture like carbon sequestration and storage of CO_2 released from different fossil-fueled factories/power plants. Different CO_2 capture technologies have been investigated, including adsorption, absorption, cryogenic, membrane, and others (White et al. 2003; Aaron and Tsouris 2005). The most advanced process recognized between these technologies was adsorption–regeneration technology. However, there is still too high energy needed for the absorption process. The Intergovernmental Panel on Climate Change (IPCC) decided that designing a large-scale adsorption process could be practicable and developing a new generation of material capable of efficiently adsorbing CO_2 would undoubtedly increase the effectiveness of adsorptive separation in a flue gas application (Metz et al. 2005). These adsorbents include molecular baskets based on activated carbon, SWNTs, silica adsorbents, zeolite, and nano-porous silica. The chemical modification of CNTs will be able to capture CO_2. In general, CO_2 adsorption performance on modified CNTs increases as relative humidity increases, but it decreases as temperature increases. In addition to NO_x and SO_x, atmospheric reactions such as soot, nitrous acid, poly-aromatic compounds form many chemical substances and volatile organic compounds (VOCs) are also removed from the air (Santiago and Indarto 2008; Natalia and Indarto 2008; Indarto et al. 2009; Indarto 2012). There has been advancement in novel materials that removes VOCs, NO_x and SO_x from air at room temperature. This novel material is highly porous manganese oxide produced by AuNPs (Sinha and Suzuki 2007). Tests were conducted using three main components of organic indoor air pollutants to demonstrate the effectiveness of this catalyst: acetaldehyde, toluene, and hexane. It has been revealed that such catalysts removed and degraded all the three pollutants effectively as compared to the conventional catalyst systems. One of the reasons for successful removal of pollutants is porous manganese oxide having much greater surface area than all the previously compounds known. This greater surface area makes volatile molecules more adsorbent, and adsorbed pollutants are effectively decomposed. Due to the presence of free radicals, surface degradation is very effective. The presence of Au NPs helps to reduce the typically very high barrier of radical formation. This process has opened up the possibility of applying additional nano-metal components (Sinha and Suzuki 2007).

14.7.2 Nanotechnology for Pollution Sensors and Detectors

Long-term introduction to particulate matter and heavy metal pollution has long been agreed to be an important factor in initiating health problems. Particulate sizes in urban areas typically range from 100 to 300 nm in diameter, whereas heavy metals can be found in different concentration ranges (Johnston 2002). Furthermore, microorganisms cannot break down heavy metals. There is a high degree of difficulty in recovering contaminated soil with heavy metal that increases pressure in the development of sensors on-site that can be detected (Choi 2003). Rapid and accurate sensors capable of sensing contaminants at the molecular level can increase human capacity to protect human health and environmental sustainability, where the available contaminant sensing technology is extra-sensitive and less expensive. One of the desired technologies is a continuous monitoring tool capable of providing information, particularly in very short analytical time about pollutants (Masciangioli and Zhang 2011). A “nanocontact sensor” has been developed, and “this sensor” can detect certain metal ions without the need for preconcentration. This sensor is particularly suitable for detecting heavy metal ions on-site, including radioactive elements. Nanocontact sensors can be made in miniature size and automatic mode so they can be easily used on site or brought to the ground. The uses of these sensors are also cheap (cost-effective) because they ate using simple electrochemical techniques made from conventional microelectronics manufacturing equipment (Tao 2002). Biosensors based on nanotechnology were developed using biomaterials (Staiano et al. 2010). Liu et al. (2007) have found a way to increase the test strips nanoprobe sensitivity to enable a portable biosensor to be created. Portable biosensors are capable of detecting people exposed to chemicals quickly. Wang et al. (2007) produced a label nanoparticle in the Pacific Northwest National Laboratory (PNNL), which enables sensors to sense and infer biomarker signals. The approach is based on the immunoassay method of electrochemistry. This method involves using specific antibodies to attract disease biomarkers. The supply of ‘label’ on the second nanoparticle antibody amplifies the signals of the biomarker. This increases the sensitivity level that will improve the detector’s accuracy in identifying biomarker concentrations in biological samples (Lin and Gavaskar 2004; Smart et al. 2006). Nanowires and nanotube-based sensors offer remarkable capacity as chemical and biological sensor materials (Smart et al. 2006). SWCNTs exhibited a quicker response and advanced sensitivity than conventional samples currently used to detect gas molecules like NO_2 and NH_3. In this case, gas particles are bonded directly to the SWCNT surface and affect the sensor’s electrical resistance. The ability to attain greater sensitivity at room temperature is additional benefit of SWCNTs as sensors. Conventional solid sensors are usually operated at 200–600 °C temperatures.

14.7.3 Cantilever Sensors

A cantilever sensor is a device made from a nano-coated silicon and is sensitive to specific pollutants (Filipponi and Sutherland 2010). Typically, a cantilever is 10–500 μm in length, but it is less than several micrometers thick. Nano-coated cantilever array interactions between pollutants because the array to bend as a result of surface pressure changes. A laser beam can detect pollutant mass quantitatively and will measure the small bending. To sense VOCs, pesticides, heavy metals, and harmful bacteria such as salmonella, cantilever sensors were developed. Figure 14.5 illustrates a schematic diagram of biosensors based on cantilever. The molecular probe (sample) is only suitable for the target molecule. The cantilever arm will bend and react when the target molecule is attached. The reaction will thus detect and signal the presence of target molecules.

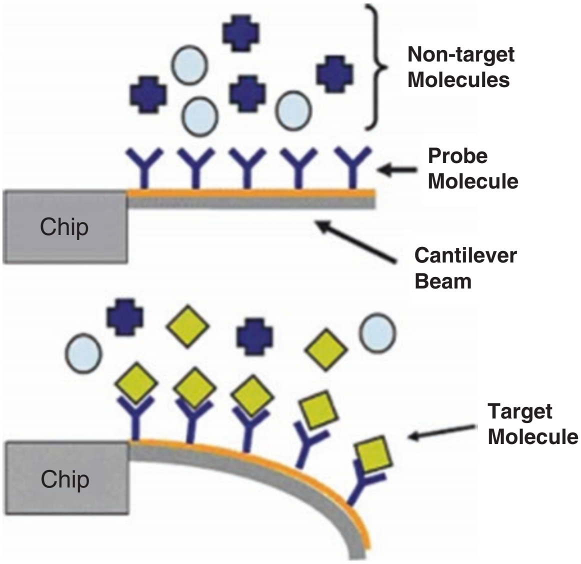

Fig. 14.5 Principle of working of cantilever-based biosensors: (**a**) before and (**b**) after interaction between the "target molecule" and the "probe"

14.7.4 *Other Advances in Nanotechnology Sensors*

Some of the sensor based technologies are listed below (Berger 2008)

1. Functionalized-tetraphenylsilole NPs are used to detect cancer substances in minute concentrations. Examples are Cr(VI) and Ar(V) for detectable substances.
2. The use of peptide nanoelectrodes was based on the thermocouple concept. A peptide molecule is placed in a separation gap of "nano-distance" to form a molecular junction. Once a specific metal ion is connected to the gap, a unique value will result in the electrical current being conducted. The metal ion is easily identified.
3. Composite electrodes (nanotubes and copper) to detect organo-phosphorus pesticides, carbohydrates, etc.
4. Nanospheres of polymers were made to measure organic pollutants at very small concentrations in ppb.

14.8 Green Manufacturing

Green manufacturing involves developing industrial processes, e.g., water-based processes, take preference over organic solvent-based processes, reducing or minimizing the use of harmful substances and using energy-efficient processes. The development of aqueous micro emulsions as a substitute to VOCs in the cleaning industry is an example of green nanotechnology. Though nanotechnology risk offers a wide variety of potential uses and speedy advances, this technology may have unintentional effects on the environment and human health as well. Materials that are offensive in majority form, but can be converted highly toxic on the nanoscale if they arrive and build up in the supply of "drinking water" and the "food chain" and are not biodegradable. A specific concern is the intake of airborne NPs and their impact on lungs, with recent studies showing a similar response by the human body to certain forms of CNT as asbestos particles when inhaled in adequate quantities cause lung diseases (Buzea et al. 2007). There is a lack of understanding about fate and behavior of NPs in the environment and humans, thus exacerbating these concerns in current situation. The development of this technology, however, is very early and the amount of testing for toxicity and potential health risks is extremely limited (Wickson et al. 2011). Research on nanotechnology risk assessment to determine the potential impacts of NPs on the environment and human health is crucial in helping to balance the benefits of the technology and the potential unintentional consequences (Hyder 2003; Metz et al. 2005). Scientific authorities recognize this as a major challenge as they monitor the enormous volume of various NPs produced.

14.9 Conclusion

Nanotechnology has been proved among one of the best emerging environmental nanotechnology that revolutionized the pollution abatement processes through sophisticated techniques producing the less toxic toxicants as byproducts and also used to prevent pollution from occurring. It has replaced conventional technologies which are high cost, low efficiency, and not environmental friendly. Nanotechnology has been proved best in the cleanup process of every type of pollution like waste water (including heavy metal pollution), air, and soil pollution. It is also possible to use NPs and nanotubes as sensors for toxic substances, especially substances that are hard to sense with conventional technology because of very small in size and concentrations. Although nanotechnology has many applications, it needs to be further studied to evaluate its risk.

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