Chapter 13
Nanotechnology and Environment

13.1 Introduction

Whenever any new technology emerges there is rightfully a concern about its impact on social life, health and environment. This was seen when first trains were run. People were worried if there would be effect of travelling in a train. In the twentieth century many new technologies were developed and even a common man knows the benefits of new developments in science and technology. However, along with comforts achieved by adopting various technologies, mankind is now facing numerous problems. The problems are not limited to any small country or community, to rich or poor but by all. Major problems being faced are due to increased population in developing and underdeveloped countries, old and new diseases, depletion of natural resources like fossil fuel, oil and water, increased number of wars, terrorism and so on. Some of the problems are also related to global climatic changes, scarcity and quality of food and water as well as increased pollution in big cities. Therefore some often asked questions are: whether nanotechnology would help to solve or increase some of these problems? Do nanomaterials harm human bodies, animals or plants, may be by inhaling or by contact? Will nanomaterials pollute water, air and food?

We have seen from the earlier chapters that nanotechnology is capable of giving wonderful products at lower cost due to small amount of material requirement enabling their accessibility to large population. This is true for health care also. Therefore it is difficult to resist nanotechnology any more. Some scientists estimate that although there can be harmful effects of nanomaterials on environment and human bodies if proper care is not exercised, Nanotechnology can be so powerful that it would outweigh its own negative aspects. In this chapter we shall discuss (1) environmental pollution and role of nanotechnology and (2) effect of nanotechnology on human health.

S.K. Kulkarni, *Nanotechnology: Principles and Practices*,
DOI 10.1007/978-3-319-09171-6_13

13.2 Environmental Pollution and Role of Nanotechnology

Environmental pollution includes pollution or contamination of air, water and soil. When the level of chemicals, metal (ions), smoke, bacteria, viruses or pathogens increases beyond some tolerance limit for living animals it is pollution. The pollution of environment is an age-old problem and began when man learnt to make fire and started cutting wood for houses and other activities. When human settlements began and various civilisations flourished, the pollution problems, mainly water contamination, started. However until probably the nineteenth century the population on earth was not large and pollution problems were not severe. On one hand the advances in medical field accompanied by sophisticated electronic equipment, increased agriculture production, thanks to fertilizers, pesticides and improved technologies available for agriculture have resulted into human life span, it has also increased demands on houses, water, transport etc. to make life comfortable. There is a major threat of fossil fuel getting depleted to an alarming level on which we are dependent for our energy resources for all our activities. We continue with use of fossil fuel which contaminates air, as still it is cheaper than any other alternative energy. This in turn also gives rise to global warming i.e. possibility of increasing the overall temperature of the earth, resulting into melting of large icebergs on poles.

The industrial effluents, increased automobiles, trains and aircrafts add to water and air contamination. It is hoped (as well as believed) by the scientists that the nanotechnology will be able to reduce the stress on energy demands from fossil fuel by providing clean, alternate energy sources like photovoltaics and fuel cells at lower, affordable cost. As seen in the previous chapter, solar energy being abundant and almost inextinguishing source of light, if harnessed at low cost will solve our lighting problems. Nanotechnology-based solar cells may be dye-sensitized solar cells, quantum dots solar cells or organic solar cells and are possible to make in large quantities at lower price. Current obstacle is the high efficiency expected from these solar cells to become economically viable. However, future is bright and it is hoped that technological improvements will take place. Same is with fuel cells which is source of energy long awaited by the automobile industry for the onboard application. This is also a clean source of energy. When hydrogen gas is used as a fuel it only generates, along with the electricity, water and heat as the byproducts. The use of fuel cell powered vehicles will dramatically reduce the air pollution and demand for fossil fuel. Thus in both these energy sources the contamination will be eliminated unlike fossil fuel, at the source itself. We then need not worry as to how to reduce the pollution.

It has also been shown that nanocatalysts due to their increased surface activity are able to reduce the toxic products from exhausts of the vehicles running on petrol or diesel as the fuels. Therefore palladium, platinum and rhodium, in spite of their high cost are used for many decades. Some cheaper alternatives to these noble metal catalysts are nanoparticles of metal or oxy carbides in use. It should be remembered that these nanocatalysts were not purposely made ‘nano’ but many conventionally used catalysts happened to be nanoparticles.

Interestingly, gold, which is not a conventionally considered as a catalyst material (probably due to its non-reactive nature), in the nano size turns out to be a very good catalyst material. Gold nanoparticles impregnated in magnesium silicate hydrate clay, catalytically destroy odours in presence of ozone. Gold nanoparticles and even better gold-platinum alloy nanoparticles are able to dissociate unwanted trichloroethylene in ground water. Gold nanoparticles also interact with pesticides and are useful in removing them from water. It is also possible to use gold nanoparticles to remove one of the important toxic element mercury as a water effluent from coal mining industry. In view of the success of gold nanoparticles as a catalyst they were also used in the airconditioners to successfully remove CO from air in the rooms. It is also claimed by some scientists that the use of gold nanoparticles could reduce the hydrocarbon emission by 40 %.

Water and soil pollution is mainly due to various human activities, industrial effluents in which organic molecules (like dyes), inorganic ions of metals like Cu, Hg, Cd etc., pesticides, fertilizers, septic tank seepage are mixed. Although ground water (from larger depths from the earth surface) should be free from most contaminants due to industrial, agriculture and other human activities, it often contaminates due to seepages, mines, agricultural activities as well as natural minerals contamination. It can also have pathogens like bacteria and viruses and different salts. Therefore to provide fresh drinking water to humans and animals is quite challenging. This is mostly done by municipal organisations at some central water distribution system. The dirty water is usually treated with alum to remove large dirt particles by sedimentation and then filtered using sand and charcoal. This is followed by ozone, chlorine or UV radiation treatment to remove the bacterial contaminants before it is circulated to the village, town or city population. It is found that these treatments do not remove most of the nanoparticles like carbon nanotubes.

The problem with nanoparticles in this regard is that they often have organic ligands attached to their surfaces and some of them like carbon nanotubes (CNT) are hydrophobic in nature. They do not get removed by conventional treatments and are a potential health threat if they enter human (animal) body. It has been reported that CNTs and other fibre-like nanoparticles can lead to a lung disease known as fibrosis which was reported few decades back caused by asbestos fibres. As we shall see below some of the nanoparticles either due to their small size (small $<$10–20 nm size particles can easily penetrate the cells) or their large surface activity can be harmful. Thus it is necessary that nanoparticles should not mix with water. On the other hand some research shows that carbon nanotubes and even graphene are best water filters. Silver nanoparticles are being used in water filters, airconditioners, bandages and washing machines. It is known that silver is traditionally proven antibacterial material. Although use of silver nanoparticles in the above applications is justified, there is a concern that when it goes into water treatment tanks it also kills some useful bacteria/ingredients in water. Therefore there is a concern about the use of silver nanoparticles in these applications. Similarly CNTs used in inverse osmosis cartridges used to remove cations in water need to be studied carefully.

Interestingly, nanomaterials-based photocatalysts are developed which can dissociate organic pollutants and remove them. Some such catalysts are nano ZnO, TiO_2, SnO_2, Fe_2O_3, CdS, MoS_2, ZnS, CdS and PbS. Thus, some estimates claim that nanotechnology will in fact reduce the air and water pollution that we have today.

It may be added here that along with the synthetic nanomaterials like metal nanoparticles of gold, silver, copper, platinum, transition metal nanoparticles, quantum dots of CdS, ZnS, CdSe, ZnSe, PbS, SnO_2 etc., magnetic nanoparticles, fullerenes, carbon nanotubes, graphene etc. we also have a huge variety of naturally occurring nanoparticles like silica nanoparticles, zeolites, iron oxides and various organic particles. Such particles are produced mostly in volcanoes, fires, erosion or by marine waves.

Important question to be discussed here is which are the techniques available to us to detect the pollutants in air, water or soil. In fact there is a huge list of methods or sensors available today. Some of them are gas chromatography, high performance liquid chromatography, ion and ion exclusion chromatography, atomic absorption or emission spectroscopy, electrode methods, fluorescence and biosensors. Depending upon the analyte, the sensitivity may vary from ppm to even ppb level. However, gold and silver nanoparticles (in different morphologies) based Surface Enhanced Raman Spectroscopy (SERS) are considered to be best amongst all for their extremely high sensitivity (single molecule sensitivity). The requirements of any good detector/sensor are its high sensitivity, selectivity, and real time measurement. Simple design and portability are additional advantages. SERS sensors are proving themselves not only for heavy metal ion, CNT, graphene and organic molecule detection but explosives like TNT (2,4,6-trinitrotoulene), and DNT (2,4, dinitrotoulene) in water and soil. SERS sensors have additional advantage that they do not require complicated sample preparation for testing.

Nanotechnology is still in its early stages. It has demonstrated its ability to sensitively detect the pollutants as well as remove them if they occur. The future efforts would be to avoid or reduce the pollution as much as possible with the use of clean energy resources like solar cells and fuel cells for the global energy needs. Some of the experiments show that unintentionally the nanoparticles can mix into our environment and their removal would be challenging.

13.3 Effect of Nanotechnology on Human Health

We saw in the previous section that nanotechnology may help reduce the air, water and soil pollution through its nanocatalysts like silver, gold and some other particles as well as produce electricity/energy using nanotechnology like in solar and fuel cells which promise to provide clean energy at low cost. As fossil fuels are depleting as well as polluting our planet to a great extent, we do not have any other option but to embrace a technology which promises us the products we need to cater the needs

of very huge population i.e. newly emerged nanotechnology. No other option is available. Yet, we also have to be aware of pros and cons of using this technology so that we can extract benefits from it and avoid its disadvantages.

When nanomaterials will be produced in large quantities and used by mankind, it is expected that some part of it could unintentionally return to environment. Some nanomaterials would sweep in water or air while they are synthesized or when the used products get thrown after their use, as garbage. They are then bound to partially return to humans and animals through water they drink or food they eat. Hence some of the nanomaterials in water are found to be difficult to remove. What happens to the nanoparticles we may eat, drink or inhale? Do they harm our body? What kind of health problems would they create? Some nanoparticles intentionally will be injected or transmitted in bodies to cure some diseases like cancer, Alzheimer or carrying out surgeries. What would happen to them? Is it safe to have treatments based on nanotechnology? As many of the animal trials are successfully carried out, there is possibility that we may see many medicines, medical imaging and surgeries based on nanotechnology taking place. Therefore the scientists are now quite concerned about toxic effects of nanotechnology. Although much more needs to be done about the toxicity problem, few experimental results (on rabbits, fish or mice) are available now and are briefly discussed below without getting into the actual details.

Small size of nanoparticles increases their uptake as well as their interaction with the body tissues or cell. This can release free radicals which in turn can give rise to oxidative stress, damage of protein, DNA or cell membrane. It is quite easy for nanoparticles to get mixed in the blood stream due to their small size and reach various body parts. They can then damage the organs in short time inhibiting the new cell growth or causing cell death. Kidneys are found to be affected by the carbon nanotubes. CNTs are also known to cause fibrosis—a lung cancer.

Titania (TiO_2) nanoparticles are known to be very efficient photocatalyst material. TiO_2 nanoparticles also interact with bacteria. It is found that TiO_2 nanoparticles in the water treatment plants destroy even the useful bacteria in water. Same is true about fullerenes in water. This is not desired. The most popular application of TiO_2 nanoparticles is in the dye-sensitized solar cells. They are also used in cosmetics. It has been reported that TiO_2 nanoparticles have size selective effects on DNA. While particles of TiO_2 larger than 500 nm did not affect DNA but $\sim$20 nm size particles interacted with DNA and broke it completely. The TiO_2 particles of even much smaller size i.e. $\sim$2–5 nm showed inflammation in the body.

There is a strong drive in using formulations with ZnO, TiO_2, gold, silver, iron oxide, silica etc. in some cosmetic formulations, sunscreens, moisturizers, sprays etc. Cosmetics usually have liposomes, nanoemulsions, solid lipid particles, nanocapsules, nanoparticles or metal oxide nanoparticles in their formulations. Nanoparticle-based sunscreens are popular because the face looks more natural than with white sunscreen lotions (older sunscreens). Some of the nanoparticles penetrate the skin quite fast. This is sometimes desired in some treatments like in anti aging treatments. The particles are expected to repair some cells at depth. However it

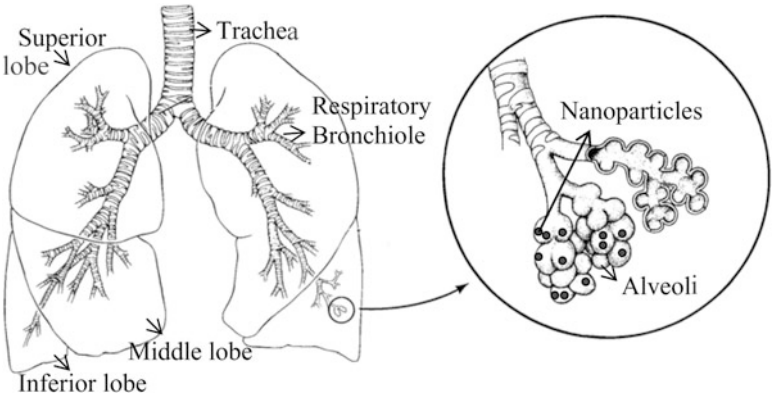

Fig. 13.1 Human respiratory system

was found that some nanoparticles could cross the blood-brain barrier (in mice) and penetrate the cells in brain and damage them. Inhaling of nanoparticles or spray also can let the particles reach the brain.

Liposomes (bilayered vesicles) also have fast skin penetration. They can also be potentially harmful. Fullerenes also are used in some cosmetics and one needs to know its effect.

Particles of size around 50 nm can affect cells and ∼30 nm can affect central nervous system. Endings of our respiratory tree consist of small packets known as *Alveoli*, which are 0.3 μm in size. They get affected by particles of size around 70 nm. In general small particles with size <0.1 μm affect our respiratory system (see Fig. 13.1) and other organs.

Details about nanomaterials and size dependent effects are not fully known yet. More work is necessary to understand the effects of nanomaterials on environment and human/animal bodies. On one hand nanotechnology may solve many of our energy, health diagnosis, medical treatment, pollution detection and removal problems and yet on the other hand it may threaten our health due to our ignorance. Perhaps the extensive research in future will teach us how to profitably use the nanotechnology in controlled way, which particles (material compositions and sizes) should be used for the benefit and which should be avoided to protect our environment and ourselves.

Further Reading

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