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A Seminar Report on

NANOTECHNOLOGY

By

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CERTIFICATE

This is to certify that the Seminar entitled

NANOTECHNOLOGY

Submitted by

Himanshu Pravin Chavan

has successfully completed the Seminar Presentation under the supervision of Prof. S.V.Patil for the partial fulfillment of Bachelor of Engineering—Computer Engineering (specialization) of Savitribai Phule Pune University. This work has not been submitted elsewhere for the award of any other degree.

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Every work is source which requires support from many people and areas. It gives me immense pleasure to complete the seminar on **"NANOTECHNOLOGY"** under valuable guidance and encouragement of my guide **Prof. S.V.Patil**

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Abstract

Nanotechnology is one of the core basic technologies in the 21st century and the industrialization of nanotechnology promotes the transformation and upgrading of traditional industries. In view of the present situation and development trend of nanotechnology industrialization, the process and development elements of nanotechnology industrialization are analyzed. Nanotechnology industrialization is composed of technology development stage, industrial design and trial production stage, production capacity development stage, industrial realization stage. In the process of nanotechnology industrialization, innovative talents, technology, science and technology service support system, management element play a vital role. The purpose of this paper is to promote the industrialization of nanotechnology through the analysis of the process and development elements of nanotechnology industrialization.

Keywords: Nanotechnology, Environmental fields, Air pollution, Monitoring, Remediation

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Chapter-1

Introduction

1.1

Nanotechnology is recognized as one of the three core technologies supporting the development of science, technology and economy in the world. It is widely used in information, biology, medicine, chemical industry, environmental protection, aerospace, energy and national defense and other major technical fields. First of all, in the IT industry, nano-devices, which are used in the new generation of chips and memory and play a key role, will form the core competitiveness of the information industry in the future. Secondly, in the field of energy, nanotechnology can provide key technologies in new, efficient and alternative energy sources. Thirdly, in the field of environmental protection, nanotechnology can be used to control water, air and soil pollution. Finally, in the aspect of biomedicine, nanotechnology can be used to develop the early diagnosis of diseases, tissue and organ induced growth, cancer, cardiovascular and cerebrovascular diseases and other difficult targeted slow and controlled release drug therapy. Therefore, several countries in the world have made plans to continuously increase the investment in nanotechnology, seize the commanding heights of the future economy and science and technology, and lead the new industrial revolution [1, 2]. At present, nanotechnology is developing rapidly in the world, but there are still many problems to be solved in the industrialization of nanotechnology. For example, China is a major country in nanotechnology, but it is not yet a major country in the nanotechnology industrialization. The total number of published nanotechnology papers in China ranks first in the world, and the number of patented nanotechnology patents in China ranks second in the world (Figure 1). However, there are also many urgent problems to be solved.[6]

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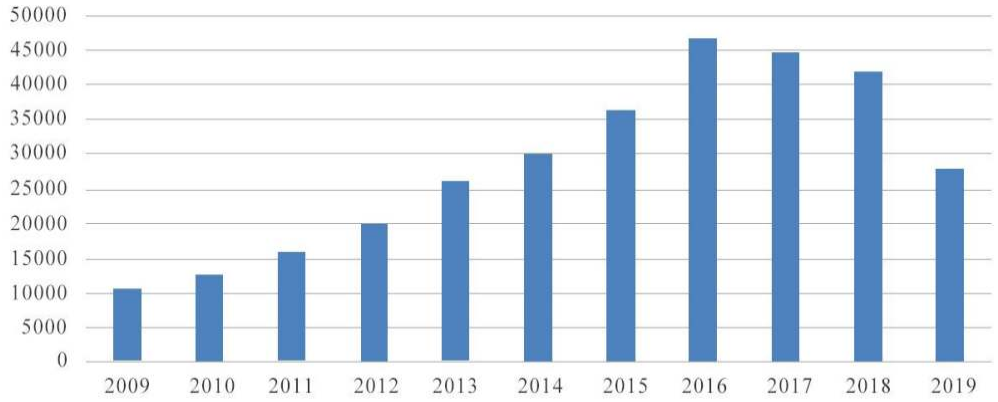


Figure 1. Annual change of the number of patents in China's nanotechnology field

The innovation and development of the industrialization of nanotechnology should not only consider the development of economy and science and technology, but also comprehensively analyze the process and development elements of the nanotechnology industrialization. This paper will analyze the industrialization process and development factors of nanotechnology, study the relationship between the elements, and promote the industrialization process of nanotechnology.

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Chapter-2

NANOTECHNOLOGY

Nanotechnologies are referred to the design, characterisation, production and application of structures, devices and systems by changing shape and size at the nanometre scale.

2.1 Definition of Nanoparticles

Nanoparticle possesses at least one dimension of 1 to 100 nm (ISO, 2010). Particles have diameter less than 100 nm exhibit new size-dependent properties compared with the bulk material. Nanomaterials with unique properties allow completely new applications to be found. There are several engineered nanomaterials such as carbon nanotubes, nanocomposites, 431 http://emsd.macrothink.org quantum dots, fullerenes, quantum wires, and nanofibers (Georgakilas et al., 2015). Today, a very broad range of commercial products exist already in the market, including metals, ceramics, polymers, smart textiles, cosmetics, sunscreens, electronics, paints and varnishes. Nanomaterials are therefore purposely manufactured by humans to achieve the specific characteristics of materials at the nanometric scale. On the other hand, there are also natural nanoparticles: for example, erosion dust or volcanic eruption dust or marine spray. Other nanoparticles are produced unintentionally during combustion phenomena: for example, when burning wood or burning diesel engines (Wagner et al., 2014).

2.2 Fundamental Properties

Nanomaterials have unique properties particularly because of the nanoscale features. Nanoparticles can exhibit totally novel characteristics due to their high surface/volume ratio which make them more reactive than bulk forms of the same materials (Mukherjee, 2016). A material (e.g. a metal) when in a nano-sized form can show properties which are totally different from those when the same material is in a non nano form. The nanomaterial will manifest different physicochemical properties when its size decreased (Mukherjee, 2016; Gillett, 2002). Elemental characteristics can change rather markedly at the nanoscale range: some change color, some get better at conducting heat or reflecting light, some become stronger, and some change or enhance

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magnetic properties (Hochella and Madden, 2005). Certain plastics at the nanometer range have the strength of steel. Tennis racquet manufactures already utilize nano-silicon dioxide crystals to improve equipment performance (Nanowerk , 2013; Heera and Shanmugam, 2015).The unique properties of these nanosized materials have advantages for several applications in various fields like biomedicine, pharmaceuticals, cosmetics, and environment (Loos , 2015).

2.3 Classification of Nanoparticles

Nanoparticles are mainly classified into four types (Fig.1) (Tiwari et al., 2013).

1. Zero- dimensional (0D) nanostructures: In this, all of the three dimensions are in the nano metric range. Ex. Nano particles or well separated nano powders.

2. One- dimensional (1D) nanostructure: In this, two dimensions are in the nano metric range and third dimension remains large. These structures have shape like rods. Ex. Nano tubes, Nano rods etc.

3. Two- dimensional (2D) nanostructure: In this, only one dimension is in the nano metric range while other two dimensions remain large. These display plane like structures. Ex. Nano thin films, Nano coating, Nano layers etc.

4. Three- dimensional (3D) nanostructure: In this, all three dimensions are outside the nano metric size range. It may consist of group of nano wires, nano tubes, or different distribution of nano part

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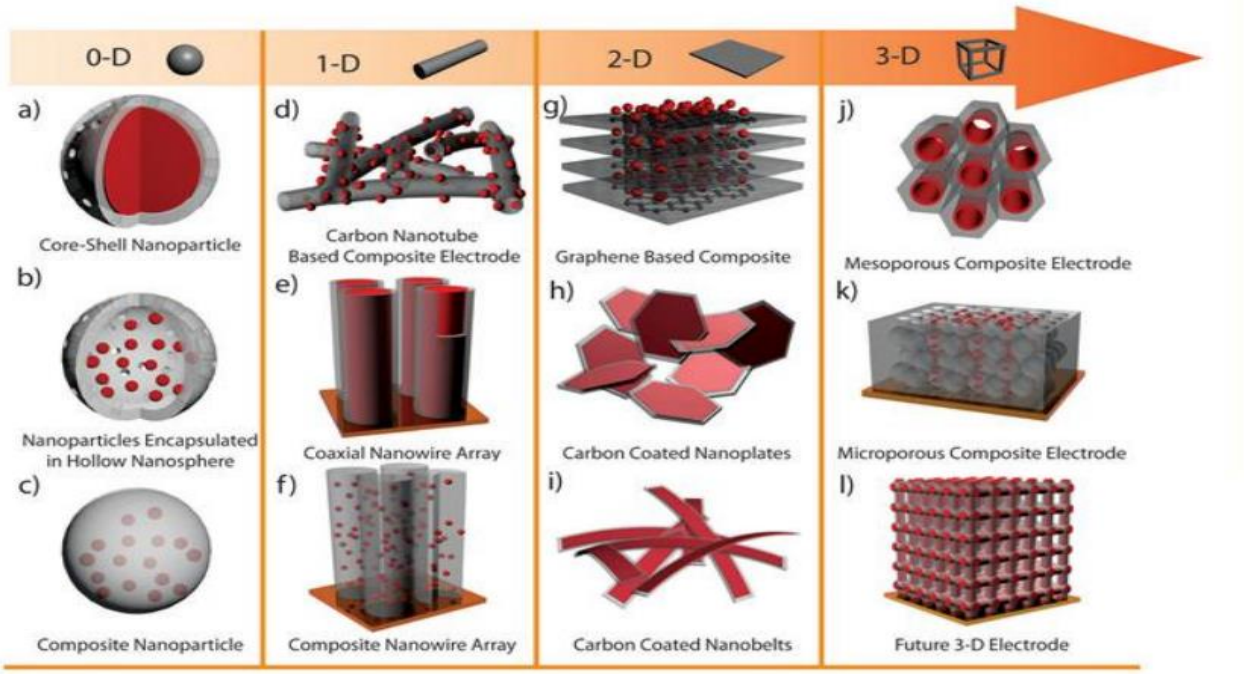


Figure 1. Nanomaterials are categorised according to their dimension

is the emergence of search engines as a fundamental element of the Internet. It is no surprise that Google is the most powerful Internet Company of our times. There is actually a much better way

3. Application Areas of Nanotechnology

Nanotechnology is fueling a revolution in manufacturing and production, creating new materials used in a variety of different fields, such as cosmetic, pharmaceutical, energy, catalytic materials, and environmental applications (Sattler, 2010; Logothetidis, 2012; INPI, 2009).Due to the great potential of this technology, there has been a worldwide increase in nanotechnology research investment. Some potential applications are mentionned in Table 1 (INCID, 2008).

Table 1. Nanotechnology areas of applications (Source: INCID, 2008)

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Areas	Applications
Automotive	Lightweight construction; Catalysts; Painting; Tires; Sensors; Windshield and body coatings
Construction	Materials; Insulation; Flame retardants; Surface coatings; Mortar
Electronics	Displays; Data memory; Laser diodes; Fiber optics; Optical switches; Filters; Conductive coatings; Antistatic coatings; Transistors
Engineering	Protective coatings for tools, machines; Lubricant-free bearings
Food and Drink	Packaging; Storage life sensors; Additives; Juice clarifiers
Medicine	Drug delivery systems; Contrast medium; Rapid testing systems; Prostheses and implants; Antimicrobial agents; In-body diagnostic systems
Textiles	Surface coatings; "Smart" clothes (anti-wrinkle, stain resistant, temperature controlled)
Chemical	Fillers for paints; Composite materials; Impregnation of papers; Adhesives; Magnetic fluids
Cosmetics	Sunscreen; Lipsticks; Skin creams; Toothpaste
Energy	Lighting; Fuel cells; Solar cells; Batteries; Capacitors
Environmental	Environmental monitoring; Soil and groundwater remediation; Toxic exposure sensors; Fuel changing catalysts; Green chemistry
Household	Ceramic coatings for irons; Odor removers; Cleaners for glass, ceramics, metals
Sports	Ski wax; Tennis rackets; Golf clubs; Tennis balls; Antifouling coatings for boats; Antifogging coatings for glasses, goggles
Military	Neutralization materials for chemical weapons, bullet-proof protection

4. Nanotechnology in Environmental Applications

Extensive industrial and agricultural activities are the main causes for the contamination of the soil, water and air at all levels (McMichael et al., 2003; Khan et al., 2014). Environmental contamination is one of the important issues that the world is confronting today, and it is expanding with each passing year and leading to grave and harmful effect to the earth. At present, the air contains various pollutants like CO, chlorofluorocarbons, volatile organic compounds, hydrocarbons, and nitrogen oxides. Water and soil are also contaminated with organic and inorganic compounds, the major sources for water and soil contamination are sewage water, industrial effluents, random use of pesticides, fertilizers, and oil spills (Khan et al., 2014; Das et al., 2015; Krug, 2009; Bhawana and Fulekar, 2012).Several traditional technologies have been already used to remediate all types of organic and toxic waste by adsorption, bio-oxidation, and chemical oxidation. In parallel, the rapid growth of nanotechnology has gained a great deal of interest in the applications of nanomaterials potential in improved systems for monitoring and cleanup including all the three phases of environment (Fig. 2) (Singh and Naveen, 2014). It can develop the pollutants sensing and detection and help in the improvement of novel remediation technologies. Nanomaterials are excellent adsorbents, catalysts and sensors due to their large specific surface areas and high reactivities. Some nanotechnology applications are nearly

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commercialized: nanosensors and nanoscale coatings to replace thicker, more wasteful polymer coating that prevent corrosion, nanosensors for dectection of aquatic toxins, nanoscale biopolymers for improved decontamination and recycling of heavy metals, nanostructured metals that break down hazardous organics at room temperature, smart particles for environmental monitoring and purification, and nanoparticles as novel photocatalyst for environmental cleanup (Khan et al., 2014; Das et al., 2015; Krug, 2009; Bhawana and Fulekar, 2012; Mehndiratta et al., 2013; Falahi and Abbasi, 2013; Chirag, 2015). It should be mentioned that due to the high variety of nanosystems techniques used for environmental treatment by several authors, so these are only summarized in the form of tables (Table 2) (Mansoori et al., 2008; Singh and Naveen, 2014) and we will focus in the next section on the nanotechnologies and applications in air pollution sector.

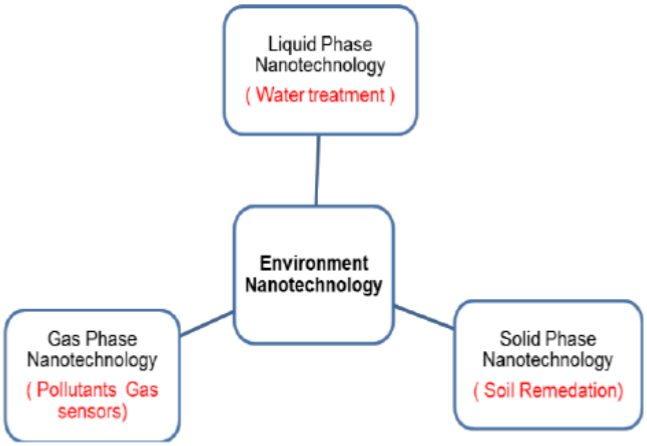


Figure 2. Nanotechnology application in the three phases of environment

(Source: Singh and Naveen, 2014)

Table 2. Nanotechnological applications in different environmental areas (Source: Mansoori et al., 2008)

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Type of nanoparticle	Type of treatment	Removal target	advantage	Disadvantage
Nanoparticles based TiO_2	Photocatalyst oxidation	Organic pollutants	Non toxicity, Water insolubility under most conditions, photo-stability	High operation cost, Hard to recovery, sludge generation
Nanoparticles based iron	Reduction, adsorption	Heavy metals, anions, organic pollutants (dechlorination)	In situ remediation, soil & water treatment, Low cost, safe to handle	Hard to recovery, sludge generation, cost for sludge disposal, Health risk
Nanoparticles based Bimetallic	Reduction, adsorption	Dechlorination, denitrification	Higher reactivity than the iron nanoparticle	Hard to recovery, sludge generation,
Nanoclay	Adsorption	Heavy metals, organic pollutants	Low cost, Unique structures, Long-term stability, reuse, High sorption capacity, Easy recovery, large surface and pore volume	sludge generation
Nanotube & fullerene	Adsorption	Heavy metals, anions, organic pollutants	Treatment of pollution from air & water, exceptional mechanical properties, unique electrical properties, Highly chemical stability	High capital cost, low adsorption capacity, Hard to recovery, sludge generation, Health risk
Dendrimers	Encapsulation	Heavy metals, organic pollutants	Simple separation, renewable, large binding capacity, cost-effective, no sludge generation, reduce pollutant to the level of a few ppb, Treatment of pollution from soil & water	Costly
Micelles	Adsorption	Organic pollutants from soil	In situ treatment, high affinity for hydrophobic organic pollutant	Costly
Metal-sorbing vesicles	Adsorption	Heavy metals	Re-use, high selective uptake profile, high metal affinity	
Magnetite nanoparticles	Adsorption	Heavy metals, organic pollutants	Simple separation, no sludge generation	External magnetically field are required for separation, Costly
Nanofiltration & nanosieve membranes	Nanofiltration	Organic and inorganic compound	Low pressure than RO	Costly, prone to membrane fouling

5. Nanotechnology and Air Pollution Control

Air contamination is one of the world's most critical issues, and its definition is based on the changement in the natural atmospheric composition that is provoked by introducing different pollutants sources (chemical, biological or physical) resulting from human activity or industrial processes, such as carbon monoxide (CO), chlorofluorocarbons (CFC), heavy metals (As, Cr, Pb, Cd, Hg), hydrocarbons, nitrogen oxides, organic chemicals (VOCs, and dioxins), SO2, sand particles and biological substances (Fig.3) (Daly and Zannetti, 2007; Yu et al., 2009; Araújo et al., 2014; Ngo and Van de Voorde , 2014). Ecosystem (e.g., vegetation and living organisms) as well as the human health is affected by poor air quality causing different types of fatal diseases, for example, cancer, respiratory, and cardiovascular diseases. The World Health Organization (WHO) in 2014 declared that air contamination caused the death of approximately 7 million individuals

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exposed in one year (2012). The effect of pollutants on mortality is schematically given in Figure 4 (Ngo and Van de Voorde , 2014).

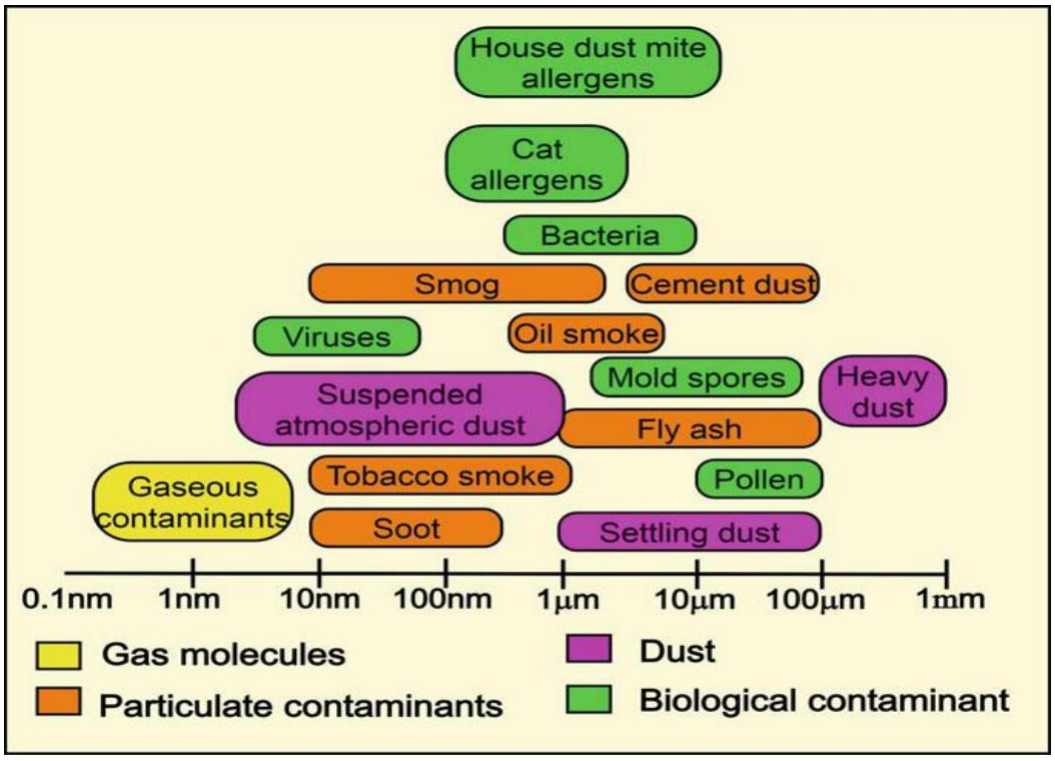


Figure 3. Different types of air contaminants

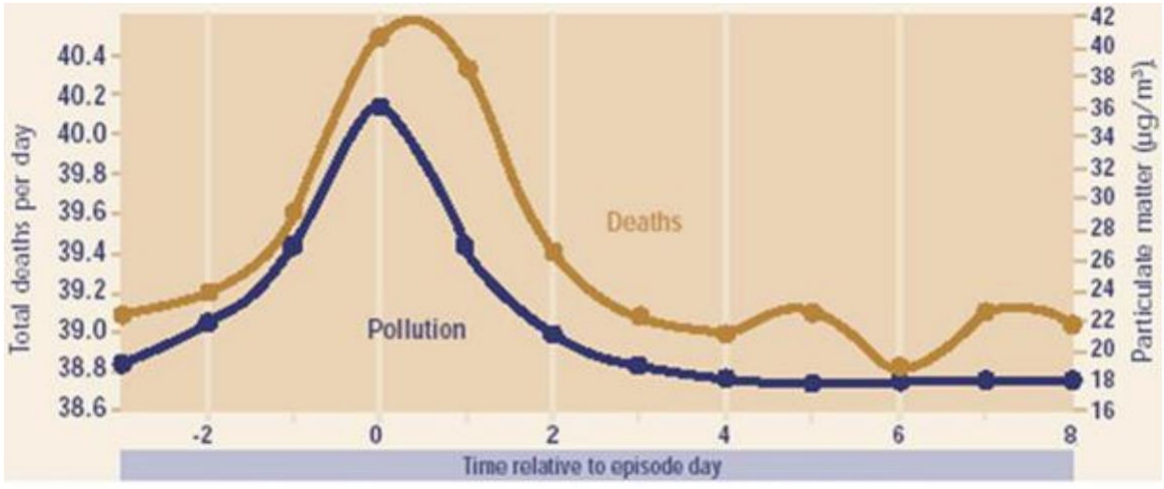


Figure 4. Effect of air pollution on mortality, 1986-94,Toronto, Canada

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There is a requirement for innovations that are able to detect, perceive and treat such little concentrations of contaminants in air. In this, nanotechnologies offer various possibilities to control air pollution.

What would nanotechnologies be able to do? Nanotechnologies have the ability to produce innovative materials with unique properties that can be used in different environmental fields. (Falahi and Abbasi, 2013; Chirag, 2015; Ngo and Van de Voorde , 2014). Nanomaterials with small size and high surface/volume ratio have extremely significant monitoring character. These properties permit the improvement of highly accurate and sensitive nano-sensors devices. Nanomaterials can be designed to effectively react with a contaminant and degrade it into non toxic products. In addition to the detection and treatment of the contaminated area by applying nanotechnological processes in air pollution control, they can also apply to reduce the pollution in the future by replacing the toxic materials used with other safety materials. Another important application is the coatings technology that are nanostructured such that they have resistance of pollutants and possess self-cleaning features. 5.1 Strategies of Nanotechnology to Control Air Pollution Problems Nanotechnology presents a number of potential environmental benefits in air pollution control. This could be mainly divided into three categories; remediation and treatment, detection and sensing, and pollution prevention (Sofian et al., 2012; Yadav et al., 2017). 5.1.1 Treatment and Remediation There are three major ways in which nanotechnology is being used to treat and reduce the different air pollutants; adsorption by nano-absorptive materials, degradation by nanocatalysis, and filteration/separation by nanofilters. Adsorption by nano-adsorptive materials Nanoscience and nanotechnology supposed that many of the present problems including air quality can be solved or greatly ameliorated using the nanoscale adsorbents, called nanoadsorbents. Carbon nanostructures have extremely physical properties like average pore diameter, pore volume, and surface area making them significant for industrial application as nanoadsorbents with high selectivity, affinity, and capacity. Further, the highly reactive surface sites or structures bonds can also play an important role in the adsorption (Gupta and Saleh , 2013; Wang et al., 2013). Moreover, the addition of other functional groups with oxygen can also provide new active sites for adsorption (Wang et al., 2013). In this context, Figure 5 provides examples of diferent carbon nanostructures: fullerene (0D), carbon nanotubes (1D), graphene (2D), graphite (3D) (Bergmann and Machado, 2015).

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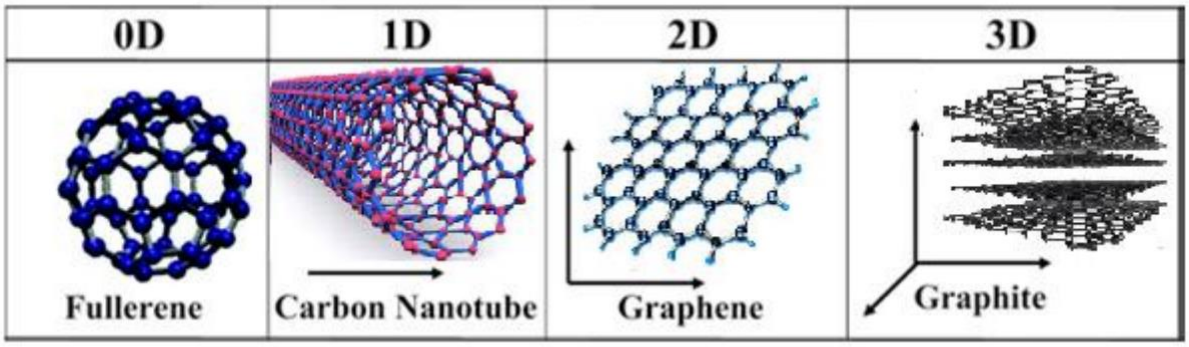


Figure 5. Examples for 0D, 1D, 2D, and 3D carbon nanostructures

The global warming is considered now the principal outdoor air problem that causes changing in land, water sources and climate everywhere throughout the world. This is mainly due to Greenhouse gases (GHGs) (IPCC, 2014). The later includes CO2, CH4, N2O, and fluorinated gases. Most of the greenhouse gasses have permenant negative effect on atmosphere because of their capability to remain in the climate for many years. Air contaminants can be remediated and treated by various methods using nanomaterials as adsorbents (Gupta and Saleh , 2013; Wang et al., 2013; Bergmann and Machado, 2015).The creation of the carbon nanomaterials as well as methods to remove high quantities of gas pollutants has greatly investigated in the research field (Terrones et al., 2010; Wang et al., 2013).The properties of nanoadsorbents structure permit a great interaction with organic compounds via noncovalent forces such as hydrogen bonding, electrostatic forces, π-π and hydrophobic interactions, and van der Waals forces (Ren et al., 2011). Furthermore, carbon nanotubes (CNTs) structure allows the combination of one or more surface functional groups (OH, COOH, C=O), which may increase the selectivity and the stability and influences the maximum adsorption capacity of the resulting system (Gupta and Saleh , 2013). CNTs, in particular, hold massive potential for applications because of their unique properties, such as high electrical and thermal conductivities, high strength, high hardness, and specific adsorption capacity (Wang et al., 2014).CNTs have cylindrical pores and adsorbent molecules interact with their carbon atoms on the surrounding walls. This interaction between molecules and solid surface depends on the pore size and geometry of pores. In addition, CNTs are more highly graphitic than the activated carbons. Thus, they have an adsorption capacity higher than activated carbons, which have slit or wedged pore shape (Ren et al., 2013). CNTs have 1D systems which result from graphene sheets (one or more) rolled up in a concentric form and exist in two forms as single walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) (Fig.

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6) (Zhao and Stoddart, 2009). Table 3 represents treatment techniques and conditions used by different researchers to eliminate and monitor the emission of the greenhouse gases and other air pollutants by differents nanoadsorptive materials.

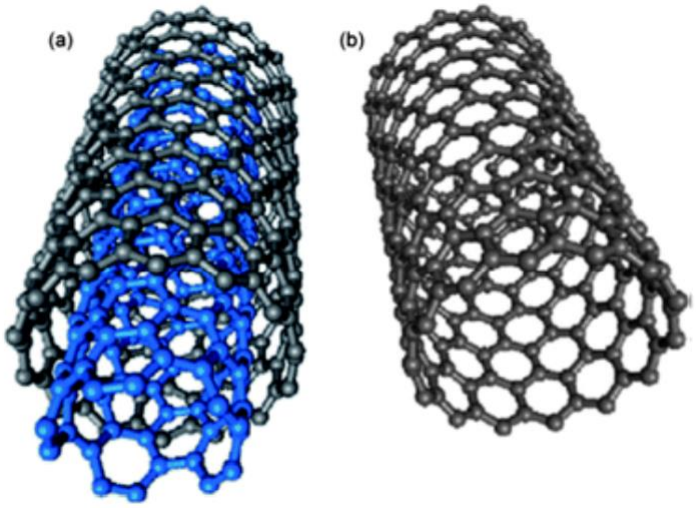


Figure 6. Structure representations of (a) MWCNT and (b) SWCNT

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Table 3. Treatment of greenhouse gases and other air pollutants by nanoadsorptive structures

Nanoadsorptive materials	Types of nanoparticles	Target pollutant gases	Removal mechanism	References
Carbon nanotubes (CNTs)	(SWNTs and MWNTs)	NO*x* (mixture of NO and NO_2)	NO and O_2 pass through CNTs and NO is oxidized to NO_2 and then adsorbed on the surface of nitrate species.	(Long and Yang , 2001; Zhang et al., 2012)
	(CNTs-APTS), Modified CNTs using 3aminopropyltrietho xysilane (APTS).	CO_2	Surface of CNTs with abundant amine groups that provide numerous chemical sites for CO_2 adsorption which makes CNTs adsorb more CO_2 gases at low temperature range (20-100 ℃).	(Su et al.,2009)
	SWNTs/NaClO	Isopropyl vapor	Physical adsorption by van derWaals forces and chemical adsorption onto adsorbent surface functional groups.	(Hsu and Lu, 2007)
	CNTs deposited on quartz filters	VOCs	It carried out by π- π interactions.	(Amade et al., 2014)
	Si-doped and Boron-doped SWCNTs	CO and CH_3OH gases	Physisorption or chemisorption, the electronic properties of SWCNT improves significantly the gas adsorption.	(Azama et al., 2017)
Fullerene	fullerene B_{40}	CO_2	high adsorption capacity for CO_2 by strong chemisorptions.	(Dong et al., 2015)
	fullerene-like boron nitride nanocage	N_2O	Adsorption and decomposition of N_2O.	(Esrafili , 2017)
Graphene	Graphene oxide (GO)/nanocomposits	CO_2, NH_3, SO_2, H_2S and N_2	Functional groups on GO are responsible for adsorption of gases, synergetic effect between the metal centers and GO surface promote the gases adsorption.	(Petit and Bandosz , 2009; Seredych and Bandosz , 2012; Wu et al., 2013)

a. Degradation by Nanocatalysis

Indoor air pollution has received significant attention since the early 1990s because people generally spend more than 80% of their time indoors and the indoor risk from inhalation of

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pollutants is higher than the outdoors one. Among the indoor air pollutants are VOCs which are considered as harmful gases to human health (Salthammer, 2016). Consequently, healthy indoor air quality in our environment requires special attention. Air pollution can be controlled using nanotechnology in several ways. One is through the use of semiconducting materials photocatalytic remediation, the exposure of these materials to a light with energy equal to that of its band gap led to the formation of electron-hole pair. The active surface is considered the most important catalyst properties where the reaction occurs. As the catalyst‟s size decreased, its active surface increased leading to the increase in the reaction efficiency (Özkar,2009). Nanotechnology can improve the nanoparticle size and molecular structure/distribution for the development of new nano-catalysts with increased surface area. Nanocatalysts are promising in ameliorating air quality and for reducing air pollutants to a lesser extent. Nanocatalytic system allows rapid and selective chemical transformations with excellent product yield coupled with the facility of catalyst recovery as compared with other conventional catalysts. Figure 7 represents scheme of comperative efficiency of homogeneous, heterogeneous and nanocatalysis (Singh and Tandon ,2014).

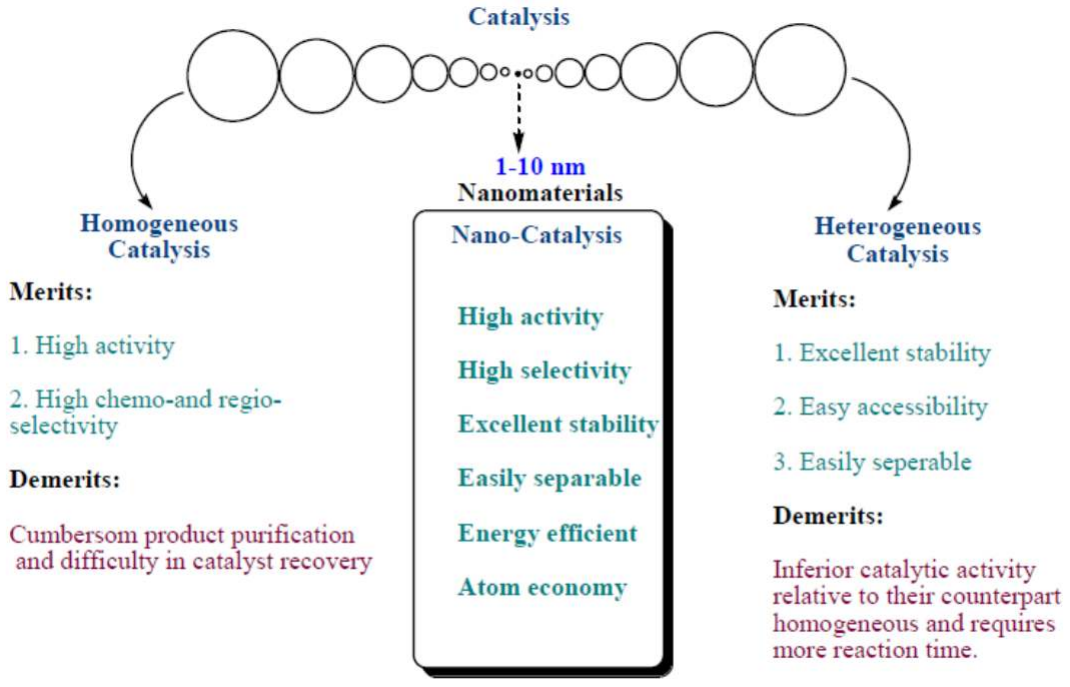


Figure 7. Comperative efficiency of homogeneous, heterogeneous and nanocatalysis

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The photocatalytic properties of titanium dioxide nanoparticles (TiO2) are being exploited to manufacture “self cleaning” coatings that are capable to depollution atmospheric contaminants such as nitrogen oxides, VOCs and other pollutants into less toxic species (Shen et al., 2015). In addition, TiO2 nanoparticles are used as antibacterial. The nanoparticles antibacterial activity was inversely proportional to particle size and relates to their capability to produce active carriers giving rise to active surface species. Generally, the photocatalytic reduction reaction can be divided into 4 main steps (Fig. 8): (1) pollutant adsorption, (2) electron-hole pair generation by absorbing sufficient incident photon energy, (3) electron-hole pair separation and their migration to the photocatalyst surface and (4) pollutant reduction (Low et al., 2017).

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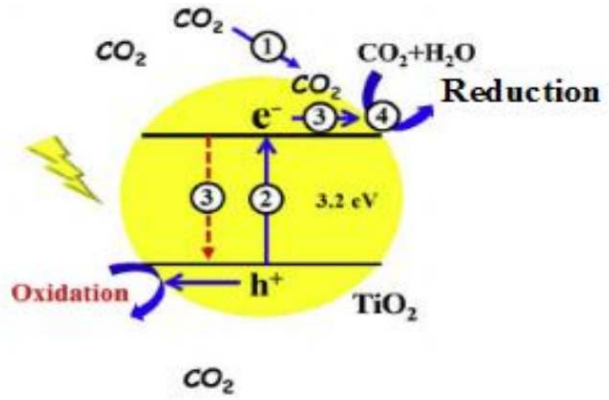


Figure 8. Schematic illustration of the adsorption and oxidation of CO on TiO_2

(Source: Low et al., 2017)

Currently, carbon nanostructures such as CNTs and graphene nanosheets have been widely used for increasing the photocatalytic efficiency of TiO_2 where, in composite of TiO_2-CNTs the electrons can be easily transfered through the CNTs and retard the electron-hole recombination (Low et al., 2017). The conduction band of CNTs lies at a more positive level compared to that of TiO_2, hence the electrons can be moved from TiO_2 to CNTs (Fig. 9).

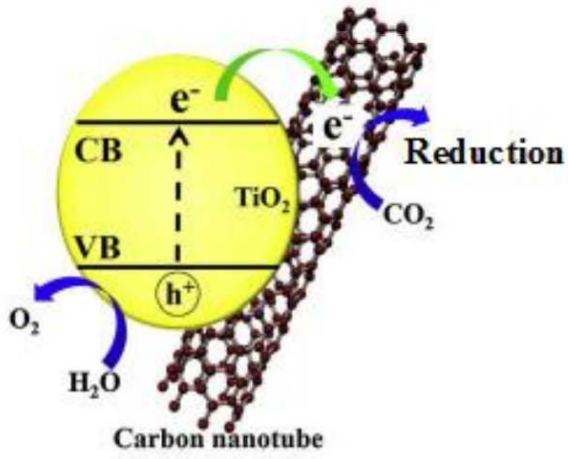


Figure 9. Schematic illustration shows the overall charge transfer mechanism in TiO_2/CNT nanocatalyst (Source: Low et al., 2017)

New synthesis methods for effective metal oxide nanocatalysts will help to reduce and may solve the air pollution problems. A nanofiber of silver, iron, gold and manganese oxide are some of the recently used nanoscale metals and metal oxides reported by the researchers that can be used in environmental control to remove several volatile organic compounds from industrial smokestacks.

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Nanogold based catalysts have extremely important treating effect on various contamination control studies to convert the toxic air pollutants (Singh and Tandon ,2014). For example, it can eliminate carbon monoxide from indoor air at room temperature. Another example, Au-Pt co-catalyst was found to be 100 times more active than that made of a conventional material for trichloroethylene (TCE) decomposition. As a concept, ZnO photocatalyst is currently being developed and is expected to have two functions to detect and reduce contaminants (Yadav et al., 2017). Table 4 presents an overview of the nano-technologies identified for reduction of air pollution and/or improvement of indoor or outdoor air quality including nanocatalysts involved, functionality, application areas and stage of development (Christensen et al., 2015).

Table 4. Nanocatalysts applications for air pollution reduction and air quality (Source: Christensen et al., 2015).

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Application/product	Involved "nano" (material, surface etc.)	Why is "nano" applied?	Development stage
Air pollution reduction by nano-treated surfaces (e.g. coated walls, roofs or pavement slabs, treated road surfaces, film materials with nano-TiO_2 embedded etc.)	TiO_2, at least commercially	Photocatalyst for NO_x and VOC removal	Commercially available, but not widespread
Catalytic industrial emission reduction (e.g. deNOx converter systems for power plants or incineration plants	Vanadium (V) (above all) Molybdenum	Catalyst for NO_x removal Removal of sulfur	Widely used for NO_x reduction, especially at coal-fired power plants. Used at e.g. refineries
Catalytic car exhaust emission reduction (catalysts for diesel cars)	Platinum (Pt), palladium (Pd), rhodium (Rh)	Catalyst primarily for NO_x removal	Widely used in diesel-fueled automobiles
Indoor air purification by nano-treated surfaces (treated/coated indoor walls, floors, desk tops)	TiO_2	Catalyst primarily for removal of VOCs and bacteria/viruses	Barely on the market as yet
Indoor air purification by photocatalytic reactors (domestic stand-alone electrical devices)	TiO_2	Catalyst primarily for VOC removal	A few commercial products exist
Indoor air purification by nano-treated filters (filters to be incorporated in centralised ventilation systems)	Silver (Ag)	Anti-bacterial biocide	A few commercial products exist

Today, the catalysts application under the solar radiation is considered as one of the most important targets in the photocatalytic field. Nanotechnology can lead to produce new nanocatalysts applied in visible light irradiation for air pollution control. For example, Bismuth oxybromide (BiOBr) nanoplate microspheres catalyst (Fig.10 a,b) was used to remove NO in indoor air under visible light ($\lambda > 420$ nm) at 400 ppb level, which is typical concentration for indoor air quality (Fig.10C) (Ai et al., 2015).

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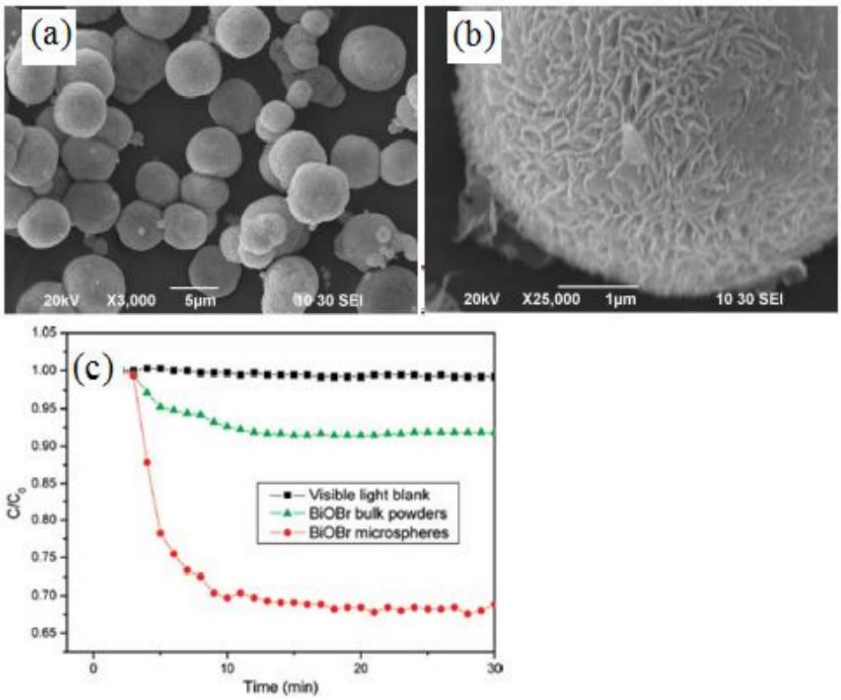


Figure 10. SEM images at low magnification (a), high magnification (b) of the BiOBr nanocatalyst and the decrease in NO concentration by BiOBr nanocatalyst under UV-visible light irradiation(c) (Source: Ai et al., 2015)

b. Filtration/separation by Nanofilters Another approach for air pollution control is nanostructured membranes that have pores small enough to separate different pollutants from exhaust. Research focuses on the improvement and optimization of nano-structured membranes to capture several gas polluants. Nanofibre-coated filter media are used for air filtration (e.g. dust removal) at industrial plants and for filtration of the inlet air for gas turbines) (Muralikrishnan et al., 2014). In particulate, filteration by nano-structured membranes is suitable for several VOCs vapors (Scholten et al., 2011).For example, formaldehyde (HCHO) imposes great challenges for its removal. Traditional photochemical techniques utilizing photocatalysts are not appropriate for the indoor HCHO removal due to the necessity of UV light illuminations and the danger of destructive ozone liberation (Miyawaki et al., 2012). Hence, the removal of formaldehyde has been improved through many techniques, for example, electrospun polyacrylonitrile (PAN)- based carbon nanofiber (CNF) membrane with high microporosity and abundant nitrogen-containing functional groups as effective adsorption sites was produced (Lee et al.,2010). A reasonable quantity of formaldehyde even at a low concentration was adsorbed onto the PAN-activated carbon nanofiber

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(ACNF). An additional example in indoor air pollutants is bioaerosols (aerosols of biological origin such as viruses, bacteria, and fungi), they can rapidly grow and provoke several diseases, such as allergies and infections. Silver nanoparticles and copper nanoparticles filters are widely used in the air filtration technology as antimicrobial materials to remove bioaerosols through air conditional processes. In this, many studies have cited that silver nanoparticles could successfully eliminate bacterial bioaerosols (Lee et al., 2010). One of the most environmental challenges is the removing of particulate matter (PM) which causes serious harm to public health. Metal−organic frameworks (MOFs) are crystalline materials with high porosity, tunable pore size, and rich functionalities, holding the promise for contaminant capture (Zhang et al., 2016). Here, nanocrystals of four unique MOF structures are processed into nanofibrous filters. The MOFilters show high removal efficiencies for PM2.5 and PM10 (Fig.11). These MOFilters can also be effective and selective to adsorb toxic gases such as SO2 when exposed in a stream of SO2/N2 mixture.

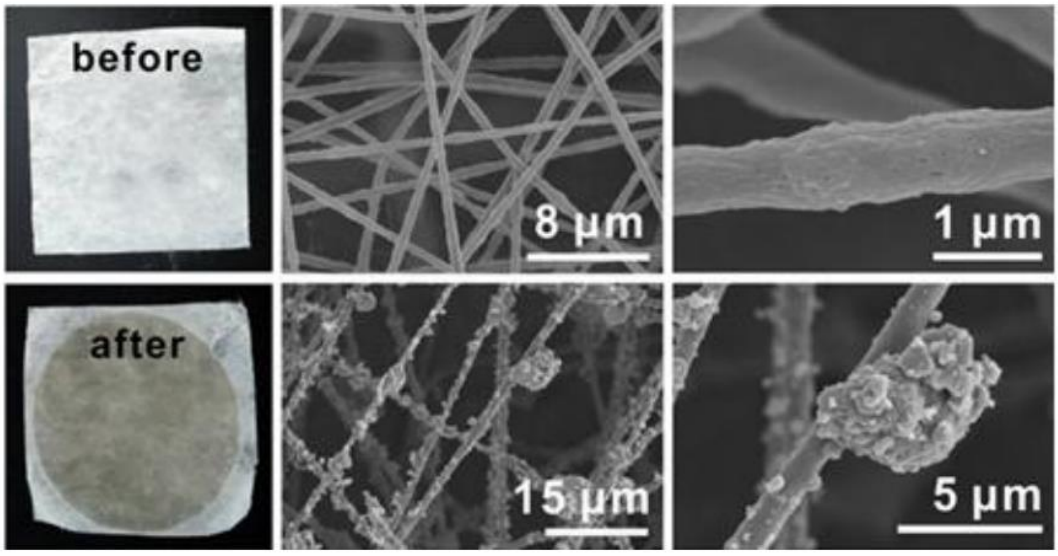


Figure 11. Photos and SEM images of the MOFilter before and after PM capture

5.1.2 Nanotechnology for Air Pollution Prevention Prevention of air pollution refers to a reduction in pollution sources and other practices that utilize raw materials, energy, utilities and other resources effectively in order to reduce or eliminate waste generation. Nanotechnology offers

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many innovative strategies to reduce waste production in various processes such as improving manufacturing processes, reducing hazardous chemicals, reducing greenhouse gas emissions and reducing the use of synthetic plastics.

The application of nanotechnology is able to create an environmentally friendly substance or material, replacing widely used toxic materials. The advantage of this technology is the increased efficiency, reduced system costs and whole replacement, as well as reduced environmental impact. Examples of environmentally friendly materials that can be produced using nanotechnology are (Yadav et al., 2017): **biodegradable plastics** have specific structure for degradation, **non-toxic-nanocrystalline composite materials** to substitute the electrodes of lithium-graphite in rechargeable batteries, and **new types of nanomaterials** having better performance and less toxicity instead of traditional materials. As an example, carbon nanotubes can provide better functionality than the conventional cathode tubes that contain many toxic metals. Other example of environmentally friendly substance is self-cleaning glasses, for example, Activ™ Glass, market product from Pilkington (Yadav et al., 2017). The glass has an extraordinary covering made of TiO2 nanocrystals which, when exposed to sunlight, interacts in two pathways: the first one is the degradation of any organic pollutants deposited on the glass, The second way, under rain, water droplets form a sheet, then the pollutants on the surface are picked up by water and wash off the glass (Fig.12) (Yadav et al., 2017).

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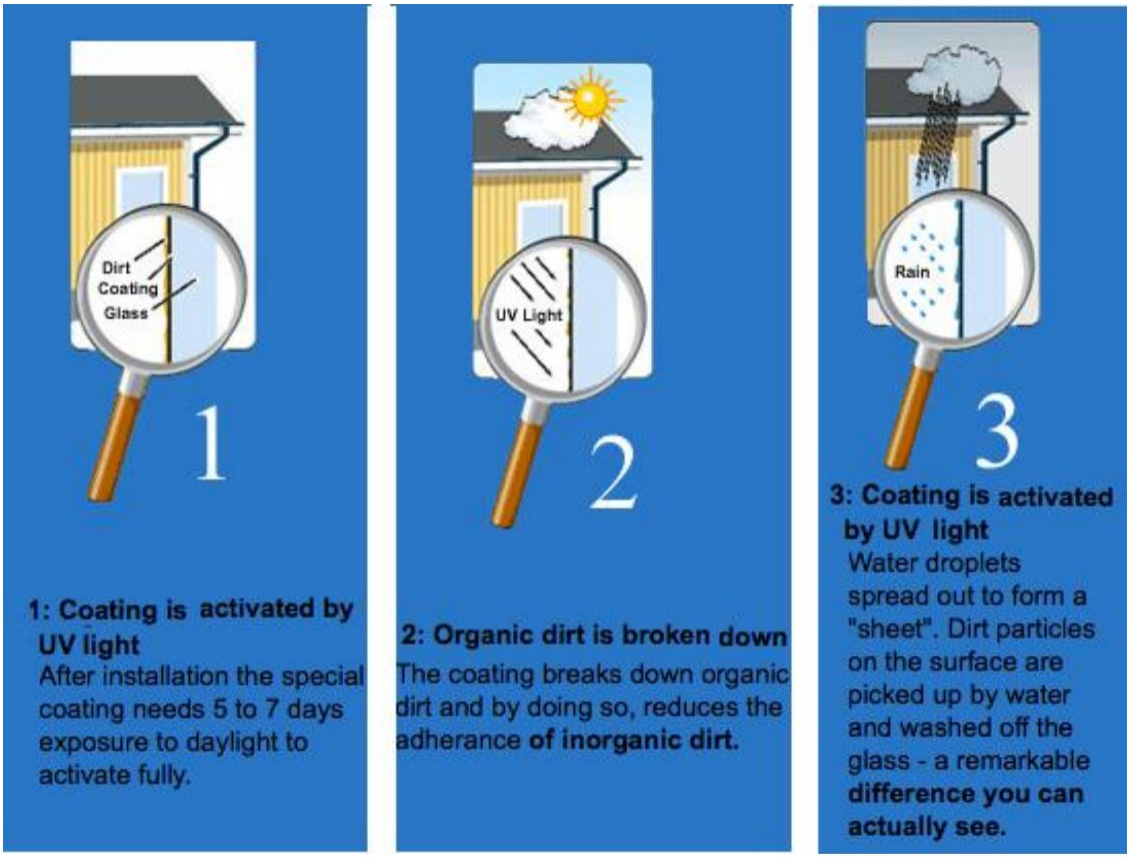


Figure 12. Explanation on how Pilkington Activ™ Self-cleaning Glass works as described by the manufacturer (http://www.pilkington.com) (Source: Yadav et al., 2017)

5.1.3 Sensing and Detection

Large increases in process control, ecosystem monitoring and environmental based decision can occur if the available contaminant detection technology is more sensitive and less expensive. Sensing and detecting the pollutants in air is an essential step in the control process. Conventional methods (Physical, chemical and biological) are used to detect the nature and the concentration of the pollutant present. Even though these attempts are highly accurate and specific, they need sampling and consecutive analysis in the laboratory. These methods require more time, a lot of expertise and furthermore are costly. As a result, these techniques are incapable of determining the exact composition and type of the pollutant under field conditions. At present, nanotechnology plays a significant role in sensing the pollutants by improving sensors more specific and sensible

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for air monitoring. Nanoensors are presently being utilized for the detection of several toxic compounds at ppm and ppb levels in different environmental systems (Zhou et al., 2015).Nanotechnology plays an important role in sensing via many ways (Zaporotskova et al., 2016) : at first, the nanoparticles are able to be coated with several chemical and biological ligands helping to improve the sensor specificity. Secondly, the surface/volume ratio of the nanoparticles allowed to vary the size and shape of the nanoparticles thus controlling the interaction with the pollutant molecule. Finally, the conductivity and sensitivity are improved via construction nanoparticles of different metals.New innovations have developed in the utilization of nanotechnology in environmental sensors, the main advantages of these sensors are; faster, high specifity, can detect the microorganisms (e.g. bacteria) at a lower concentration, rapid response and detection of numerous analytes in the same device (Bhawana and Fulekar, 2012; Kim et al., 2016). Nanotechnology will permit the production of very-small „multiplex" sensors, thus leading to the decrease in the analysis cost and the number of devices used for the analysis.

Development in nanoelectronics will permit the creation of nanosensors fit for continuous detection. Carbon nanotube based sensor is one example of nanosensor used for sensing various gases like NH3, NO2 or O3 (Ye et al., 2015; Azama et al., 2017). During contacting with these gases, the nanotubes electrical resistance is markedly changed, then measured. Several examples of nanostructural materials and/or devices developed for detection a variety of pollution control is highlighted in Table 5.

Consequently, nanoparticles-based sensors can be a reasonable apparatus for quick recognition of air contaminants. Much advance in such manner has been made with the innovation of intelligent dust, made of an arrangement of light computerized nanosensors, which can stay in the environment for a considerable period of time. In addition to be smaller and accurate than others, these nanosensors are cost effective due to very limited power usage and effective performance.

6. Future Promising of Nanotechnology for Turning Air Pollutants into Fuel

For increasing the energy needs and limiting greenhouse gas emissions in the future, the power capacity requierements on a large scale will need to be provided from renewable sources. The conversion of carbon dioxide and water into fuels in a solar refinery represents a potential solution

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for decreasing greenhouse gas emissions. The two principal possibilities for CO2 conversion include (1) catalytic conversion using solar-derived hydrogen and (2) direct reduction of CO2 using H2O and solar energy (Fig. 13) (Herron et al., 2015). The advanced nanotechnologies are greatly related to solar-to-fuel conversion, that needs for an intensive research and development effort to bring such processes to be commercialized. The nanostructured materials can play a significant role in improving the reaction efficiency and the rate of CO2 reduction into fuel chemicals. Nanotechnology incorporated in this item by developing several novel carbon nanomaterials used for CO2 capturing and also nano-catalysts that are responsible for the catalytically conversion of CO2 and H2O to fuels (Raj et al., 2017). Hence, it reduces the carbon dioxide emissions from many industries, gives a significant solution for the Earth warming problems, and produces additional source of energy.

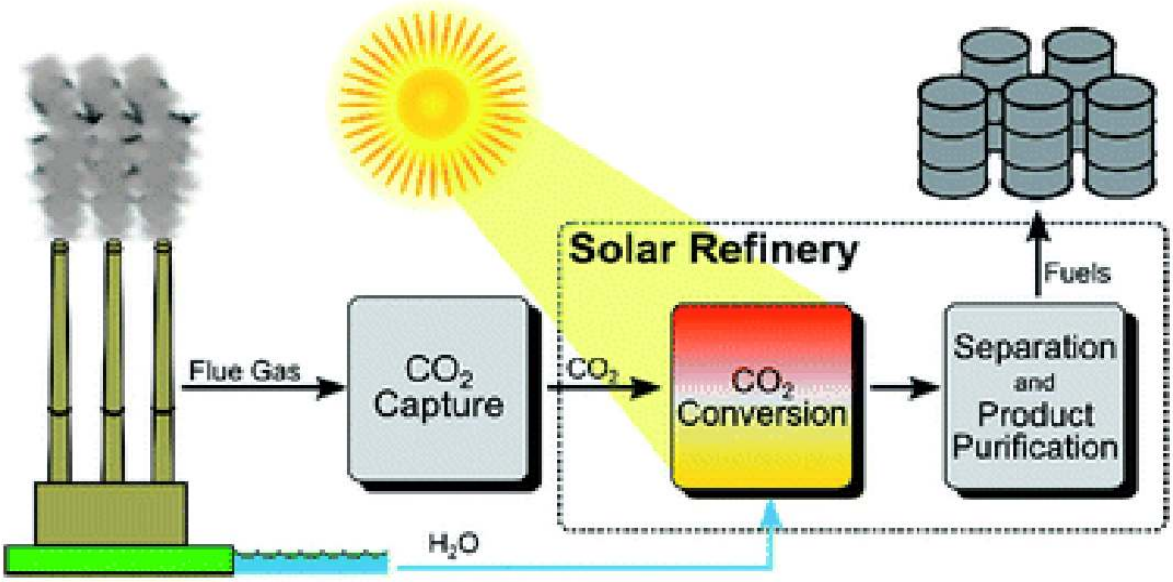


Figure 13. Conversion of carbon dioxide and water into fuels in a solar refinery

7. Regulation of Nanotechnology

Keeping in mind the broad range of application of nanotechnologies summarized previously, there is no dought that the nanotechnologies will also form a set of risk. The use of nanoparticles in environmental remediation applications will lead to the release of air-borne particles into the environment. Estimating their risks in the environment requires an understanding of their mobility in the environment, bioavailability and distribution in food chain, may negatively affect ecosystem and health impacts. To ensure that nanoscale materials are manufactured and used in a manner that

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protects against human health and environmental risks, in 2009, EPA (Environmental Protection Agency) began work on a TSCA regulation (Toxic Substances Control Act) (EPA, 2017), that would be applicable to all nanoscale materials. It would have two components: a) Significant New Use Rule (SNUR) EPA has permitted limited manufacture of novel nanoscale materials through the use of approval orders or Significant New Use Rules (SNUR) under TSCA. Prior to manufacturing chemicals or introducing them into commerce, manufacturers of new chemical substances must provide more information to the Agency for review. EPA can take action to ensure that chemicals that may or will pose an unreasonable risk to human health or the environment are effectively controlled. b) Information reporting rule This rule requires companies that manufacture (including import) or process certain chemical substances already in commerce as nanoscale materials notify EPA of certain information including: specific chemical identity, production volume, methods of manufacture, processing, use, exposure and release information, available health and safety data. By collecting such data, EPA will finally be able to draw a clearer picture of the nanomaterials for commercial and scientific use.

8. Conclusions

The applications of nanomaterials in environmental fields are referred to as "environmental nanotechnology." Because nanoparticles have unique properties such as magnetic, optical, electrical and high structural properties, they have a considerable potential to substitute existing materials. Nanotechnology is widly applied in monitoring and remediating existing different air and environmental pollutants and also preventing new pollution. Nanoparticles are used in applications in novel sensing technologies for pollutants detection at lower concentrations. The capability of nanoparticles to be coated with several ligands and control surface area/volume ratio by means of changing its shape permits to make a design of high selective, sensitive, and specific sensors. Nanoparticles can also incorporate in clean up air contaminants via adsorption, oxidation and filteration techniques. In adsorption removal technique, nanoparticles have the ability to adsorb maximum amount of air contaminants owing to its large surface area. In the oxidation treatment process, nanocatalysts catalyze the reactions in faster rate in comparison to bulk material, therefore, the consumed energy is reduced during degradation or the contaminants are prevented to release. Another approach is using nanostructured membranes for air pollution control and capture of several pollutants like VOCs. Air filtration technology using antimicrobial nanoparticles is broadly applied to remove bioaerosols. Nanotechnology is also used to prevent the formation of

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pollutants or contaminants by creating an environmentally friendly substance or material, replacing widely used toxic materials, as well as reduced environmental impact. The nanotechnology also plays a promising and vital role in the improvement of rapid and accurate environmental process to decrease or prevent emissions or to convert contaminants to useful byproducts.

9. Future Perspectives

Throughout the world, there are numerous nanotechnology facilities and research team works. It is probably there is extensive duplication of research, and lack of communication. It is vital to orient research in relation to environmental pollution control issues by nanotechnology, and actively finding international partnerships, to realize the expected goals. In order turn this research into applications, there has to be an opportunity for developers to profit. This will depend on legislation/ fiscal laws, new, enviromental-friendly developments, thus providing the power for industry to rapidely bring urgently new products and processes to the market place. Nanotechnologies are important solution vectors in our economic environment. It is necessary to develop new methods to assess development for a better understanding of nanotechnology- based innovation. Nanocatalysts for sustainable air purification are mostly still under development or just at the start of being ready for practical use. For catalysis research, the implications of further progress in nanocatalysis and the broad applications to the environment underscore the importance of this area for future investment. Science-based protocols to build and control composite particle structures should stimulate the development of improved methods for catalyst scale-up and large scale manufacturing that will be needed to broadly allow penetration of nano-engineered materials into new commercial catalyst applications. As a result, nano-materials and applications are already in the market and a large volume of new applications is expected over the next several years. The implementation of green chemistry principles for the production of nanoparticles must be grown markedly to create novel materials that are eco-friendly, cost effective and stable with great importance in wider application in the areas of environmental pollution remediation. Encouragement of optimal future use of nanotechnology in recycling approach of different wastes, this essentially means the use of wastes (whether gases, substances or whole products) to produce new materials or compounds that lead to an "industrial ecosystem" around the world. The final goal of future-nanotechnology ensuring sustainable optimal use of gases waste is to see the outputs of one production process become the inputs for another one in the industrial process chain.

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