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Nanomaterials For Environmental Air Pollution Control: A Review

Harish Verma*[1], Shail Upadhyay[2], and Sanjeev Verma[3]

Department of physics, Indian Institute of Technology (BHU), Varanasi-221005, Uttar Pradesh, India

Department of Chemical Engineering & Technology, Indian Institute of Technology (BHU), Varanasi-221005, Uttar Pradesh, India

Chaudhary Charan Singh University Meerut-250001, Uttar Pradesh, India.

Abstract

Environmental pollution is a hot issue in today's world and it is the main cause of toxic chemicals including air pollution. At present, the contaminations such as CO, chlorofluorocarbons, unpredictable natural and inorganic mixes, hydrocarbons, and nitrogen oxides are containing in the air. This review is focused on the air pollutants, types, dominant sources, and consequently their possible impacts on human life. The status of air qualities shows in different cities of India during the Covid-19 lockdown and has been summaries introduction of nanotechnology, property of nanoparticles, and use of nanotechnology in environmental issues in this review. A comprehensive study on the development of the various nanomaterials and their applications for environmental remediation has been reviewed.

Key Word: Air pollution, Covid -19 lockdown, Nanomaterial, Control of air pollution.

1. Introduction

Environmental pollution is very important issues of the world in today. The numerous type of environmental pollutants categorized are air pollution, water pollution, land pollution, noise pollution, light pollution and plastic pollution. In this paper, I have discussed air pollution. Air pollution is a mixture of solid particles and toxic gas suspend in air. There are some main major source of air pollution as portable/Mobile source (released by motor vehicles, planes, trains, and various engines.), stationary source (fuel burning power source expending power plants, petroleum oil refineries, petrochemical plants, food processing plants), locale source (The commercial strategies through bulk substances handling,[7] combustion , minerals processing, brickworks, refineries, concrete cement works, iron and metallic making, quarrying, and fossil gasoline energy plants). In air pollution is present some contaminants as toxic gas (NO, NO_2, SO_2, CO_2, O_3, HCHO, and, TOLUENE), Hg, volatiles organic compounds (VOCs). These environmental air pollutants have the injurious impact of human health as human beings with heart or lung disease, poisonous impact through absorption into the blood (e.g. Pd, Cd, Zn), allergic or hypersensitivity effect (e.g. a few woods, flour grains, chemicals), bacterial and fungal infection (from live organism), fibrosis (e.g. Asbestos, quartz), cancer (e.g. Asbestos as naturally occurring silicate minerals, chromates salt $Cr2O^{2-}$), irritation of mucous membranes layers (e.g. Acid and alkalis), exacerbation of asthma and unexpected death. Due to pollution the temperature of the earth and seas change the climate cause as global warming and as a result of the excess over the atmosphere with greenhouse poisonous gases [1]. Fig 1.1 show the air pollutant emission sources examples power plants, dust, diffused sources, diesel generator sets, transport, industries, brick kilns etc.

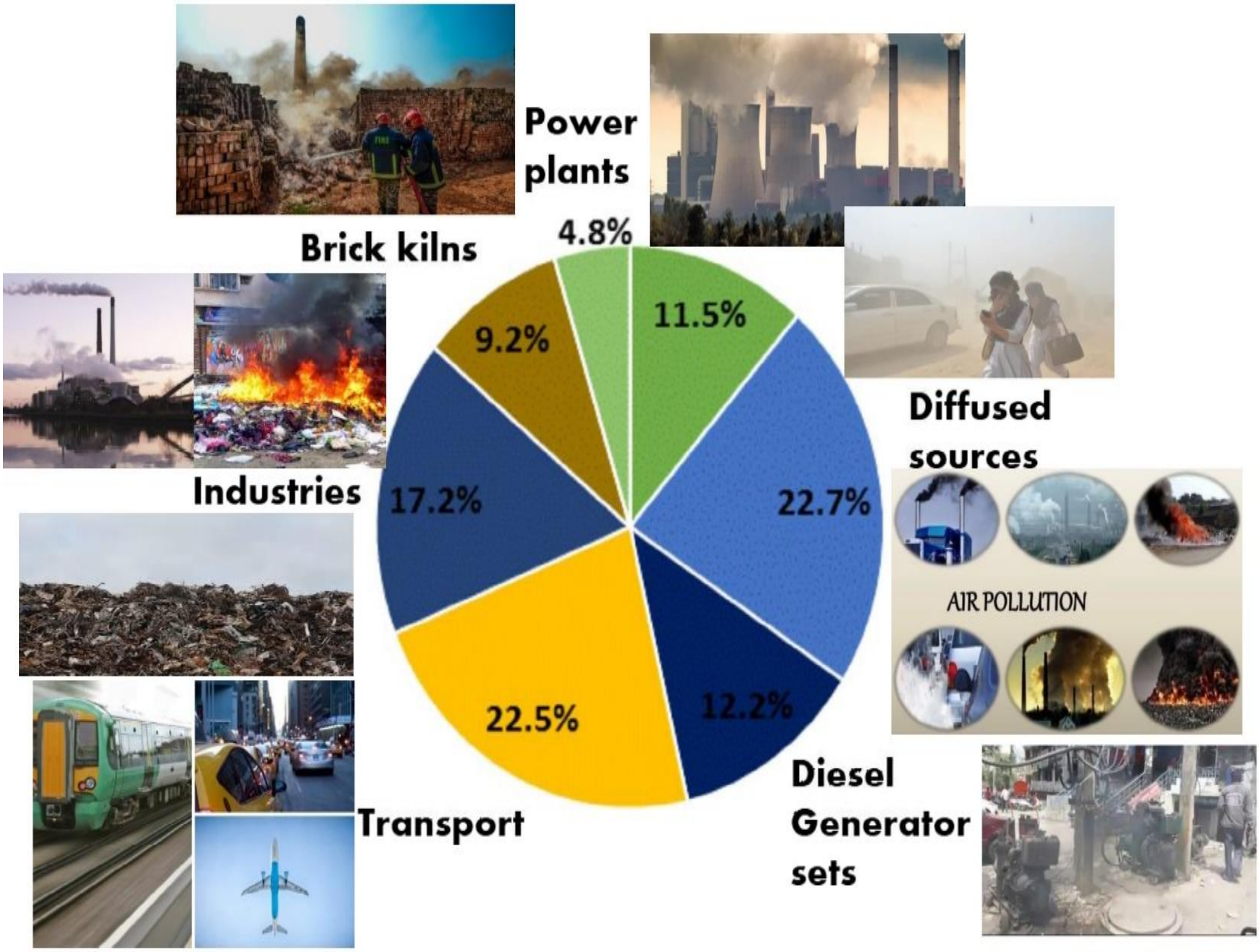


Figure 1.1 Percentage of all source of air pollution emission [82].

The observing data for the world driving megacities include, 100 nations distributed in April 2018 by WHO for the time of 2011 and 2016. In NCT Delhi (National Capital Territory of Delhi (**NCT**)), $PM_{2.5}$ is recorded exceptionally high and it is a long way past as possible according to National Ambient Air Quality System (NAAQS) and National Encompassing Air Quality Norms (NEAQN) [2]. COVID-19 is a profoundly infectious distinguished in Wuhan, China in December 2019. The infection of COVID-19, an across the nation lockdown is forced in India from spring 24th for three weeks up to 14th of April up to 3rd May, the 3rd period of lockdown be reached out till 17 May 2020 with the classification of environment into 3 zones for example Red, Orange, and Green. Simply following four days of starting lockdown instance as indicated by the official information from the Central Pollution Control Board (CPCB). Air quality decrease by the five significant contaminations (PM_{10}, O_3, SO_2, NO_2 and CO) air qualities in COVID–19 lockdowns. The survey of the effect of COVID-19 lockdown going on the air. For instance, considering the offers of family produced vehicle have extended by in any event 15%/year, the vehicle request is relished upon upward to rise as much as 200% somewhere in the range of 2015 and 2030, the automobile amounts are likely going to increment by 10.5%/year, even as power age be required to increment by 11.1% /year.

Table 1.1 Summary of modern study on COVID-19 and air quality impact of various cities of India[3].

City	Major Outcomes
India (New Delhi, Kolkata, Bangalore and, Mumbai)	Analysed the overall impact of social and travel restrictions in five major Indian cities, as well as the spatiotemporal variations in five measures across double-cross periods from March to April 2019 and March to April 2020 and 10-20 March 2020 (prior to lockdown) and 25th March to 6th April 2020. (during lockdown). With the exception of O_3, statistically significant decreases in all megacities were occurring for all toxins. In Delhi, concentrations of $PM_{2.5}$ (down by about 41 percent), PM_{10} (down by 52 percent), NO_2 (down by 51 percent), and CO (down by 28 percent) decreased during the lockdown stage compared to before lockdown. Other megacities have seen comparable declines.
India (22 urban communities in various regions)	examined data between March 16 and April 14, 2017 to 2020, examining the impact of lockdown methods on standards contamination (PM_{10}, $PM_{2.5}$, CO, NO_2, O_3, and SO_2) concentration declines. In lockdown times from earlier years (2017–2019), fixations decreased by up to 43 percent ($PM_{2.5}$), 31 percent (PM10), 52 percent (mean over the top PM risks), 10 percent (CO), and 18 percent (NO_2), while O_3 concentrations

	increased by 17 percent and SO_2 levels barely changed. Decreases in AQI of up to 44% in North India, 33% in South India, 29% in East India, 15% in Focus India, and 32% in overall India (West India).
Lucknow and New Delhi (India)	Analyzed essential air contamination information when lockdown (21-days). Considerable decrease in $PM_{2.5}$, NO_2 and CO was seen in both cities, with less noteworthy decrease in SO_2. Perceptible air contamination moderation was because of selection short and periodic lockdowns.

Figure 1.2c show the topographical map of India, showing the population of motor vehicle, population density, and locations, in Mumbai, Kolkata, Hyderabad, New Delhi, and Chennai. The effect of COVID-lockdown on air pollution over India is depicted in Figure 1.2a and b. An important instrument aboard the Terra and Aqua satellites, formerly known as EOS AM (Ante (before) Meridiem (midday)-1) and EOS PM (Post (after) Meridiem-1) satellites, is the MODIS-(Moderate Resolution Imaging Spectroradiometer) time series. 2020 (orange) and the following four years' AOD (Aerosol Optical Depth), [2016-19] mean (blue), and (b) percentage change in value of AOD (red) and OMI-Ozone Monitoring Instrument NO_2 (blue) with respect to four years [2016-19] mean during 1March – 6April over India. Respective broken lines show linear trends. It shows significant decrease in 2020 during lockdown period [83]. Figure 1.3 Shows change in concentration from 1st April, 2019 to 2020 of $PM_{2.5}$ (a) and PM_{10} (b).

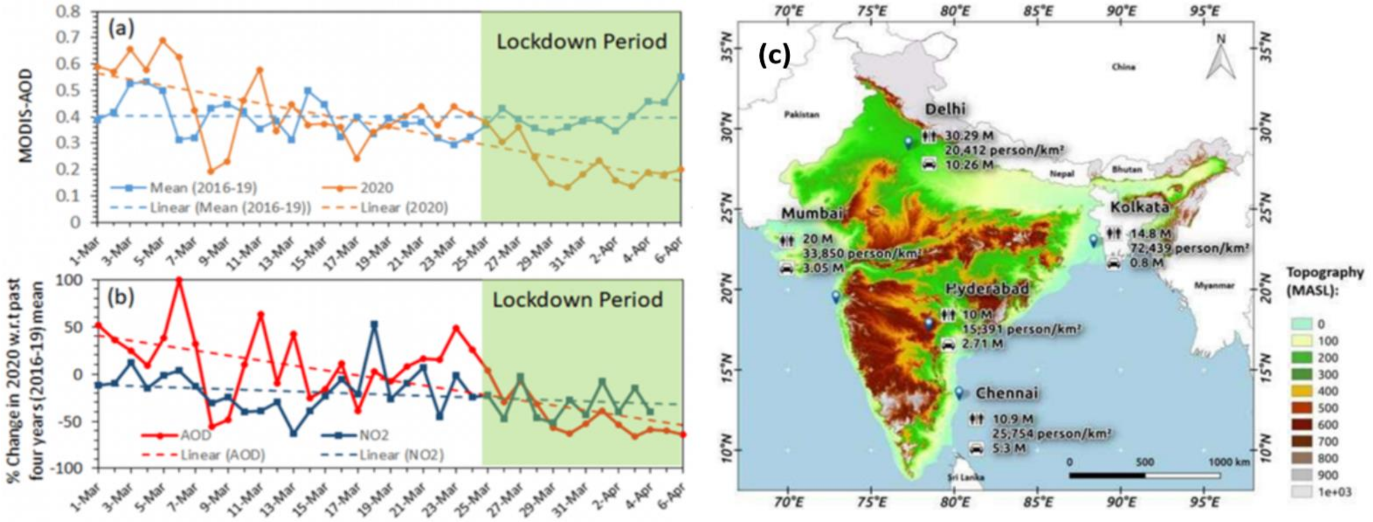


Figure 1.2 (a) shows the impact of COVID-lockdown on air pollution over India [83], (b) The Topographic map of India, showing the locations, population density and vehicle population in Chennai, Delhi, Hyderabad, Kolkata and Mumbai. The references to the human and motor vehicle population and data used in the figure [3], (c) topographic map of India, show the locations, population density and motor vehicle

population in Chennai, Delhi, Hyderabad, Kolkata and Mumbai at references to the human and motor vehicle population.

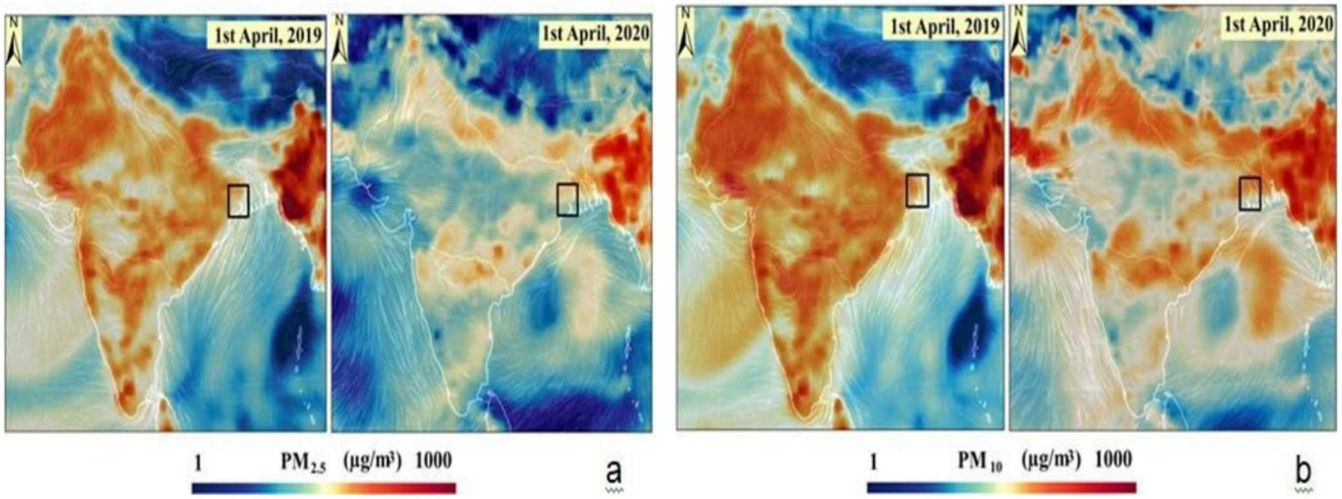


Figure 1.3 Variation in concentration of PM (1^{st} April, 2019 to 2020 of $PM_{2.5}$ (a) and PM_{10} (b)) [4].

The fundamental causes for the contamination of the air is the main causes produce in Modern and agricultural activities in the world [1]. The exclusive pollutants just like chlorofluorocarbons, polythene, volatile organic compounds, CO, nitrogen oxide, and hydrocarbons are found in air. Some numerous improvements used to remediate an extensive variety of toxic and organic waste through chemical oxidation, bio-oxidation, and adsorption. As shown by pollutants sensing, detection, and aid in the creation of new cleanup technologies. Nanosensors and nanoscale coating are some promising applications of nanotechnology, as are nanosensors for the detection of aquatic poisons, nanoscale biopolymers for improved decontamination, and nanoscale coating to replace thicker, incrementally inefficient polymer covering that prevent corrosion. In addition to nanoparticles acting as photocatalysts for environmental monitoring and purification, nanostructured metals that break down hazardous organics at ambient temperature [5].

Table 1.2 Distinctive regular regions of nanotechnological applications[6]

Sort of nanoparticles	**Type of treatments**	**Removal targets**	**Advantages**	**Disadvantages**
Nanoparticles based TiO_2	Photo catalyst oxidation	Organic pollutants	Non-poisonousness, insoluble in water in most situations, and photo stability	High operating costs, difficult recovery, and production of sludge
Nanoparticles based iron	Reduction, adsorption	Heavy metals, anions, natural contaminations (dechlorination)	Treatment of soil and water, in situ remediation, low cost, and safety	recovery challenges, sludge production costs, and health risks
Nanoparticles based Bimetallic	Reduction adsorption	Dechlorination, denitrification	Higher reactivity Tha the iron n nanoparticles	Hard to recovery, sludge generation,
Nano clay	Adsorption	Heavy metals, natural pollutants	Exceptional structure, low cost durability, reusability, high limit of sorption, Large surface and pore volumes, easy recovery	Sludge-generation
Nanotube and fullerene	Adsorption	Heavy metals, anions, natural pollutants	Treatment of contamination from air and water, outstanding mechanical properties, remarkable electrical properties, Highly chemical stability	High capital cost, low adsorption limit, Hard to recovery sludge generation, Health risk
Dendrimers	Encapsulation	Heavy metals, natural pollutants	Simple separation, sustainable, large binding limit, financially savvy, no muck age, diminish poison to the degree of a couple of ppb, Treatment of contamination as of soil and water	Costly

Micelles	Adsorption	Organic poisons from soil	High affinity for hydrophobic natural pollutant in situ treatment	Costly
Metal-sorbing Vesicles	Adsorption	Heavy metals	Re-use, high specific take-up profile, high metal affinity	
Magnitite nanoparticles	Adsorption	Heavy metals, natural pollutants	Simple division, no sludge generation	External magnetic field are required for separation, costly
Nanofiltration & Nano sieve membranes	Nanofiltration	Organic and inorganic compound	Low pressure than RO	costly, prone to membrane fouling

In this review article targets of the current investigation is (i) Define the air contaminations and identification the air contamination in different nanomaterials are produce as indicated by various methods, (ii) Nanotechnology utilized all around contaminations (iii) The air poison fixations in Delhi and different nations(cities) of the pre and during lockdown periods, (iv) to measure the air quality because of the lockdown guideline during Lockdown period and Source of air pollution.

2. Air pollution control with the help of nanotechnology

Nanotechnology presents environmental advantages in air pollution control. They can be mostly divided into four classes [7];

2.1 Remediation and treatment,
2.2 Air Pollution prevention with the help of nanotechnology
2.3 Environmentally friendly materials (environmentally materials)
2.4 Detection and sensing.

2.1 Remediation and treatment

There are three type of nanotechnology is individual utilized to treat as well as reduce the diverse air pollutants.

2.1.1 Adsorption by nano-adsorptive materials

Nanoscience and nanotechnology hypothesized that the current issues with climate quality utilize the nanoscale adsorbents, known as nano adsorbents. Materials focused to the nanoscale can all at once show a mixture of properties, occurring a micro scale, attributable to two affects [8]: (A) The first involve the surface impact, which can exist clarify via (i) have regularly surface particles evalute inner atoms, (ii) have considerably an increasingly free energy surface presented (this increased surface area and surface particles result increase of surface energy related with the particles), and (iii) the fact that rate of chemical reaction increase with developing increase the surface area of a material. (B) the volume impacts, which may be a direct (i) a lower wavelength (higher frequency and higher energy),(ii) a blue shift of particles for optical absorption spectra, (iii) super paramagnetic to occur while the molecule be smaller than the magnetic field in a material, and (iv) the course to, in a free electron model, average energy spacing increases expansions same as the measure of particles is decreased and this improves the catalytic material properties of nanoparticles [9] .

2.1.1.1 Classification of nanomaterials as nanoadsorbents

Nanomaterials are commonly separated into group dependent lying on their movement in adsorption application which is dependent upon their normal surface properties and advance external fictionalizations. Nanoparticles contain metallic nanoparticles (Au NPs), metallic oxide NPs (Al_2O_3 or TiO_2), nanostructure variegated oxides (nanostructure two-fold Fe− Ti mixed oxide molecule), and magnetic NPs (Fe_2O_3).

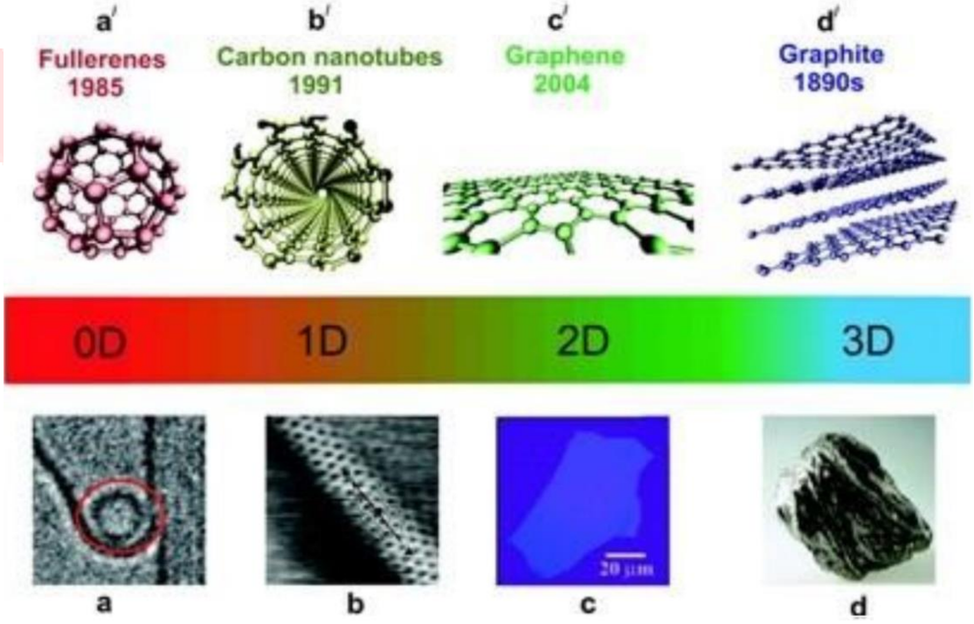


Figure 2.1The examples of special carbon nanostructures (CNs): fullerene (0D), nanotubes (1D), grap hene (2D) and graphite (3D) carbon models for 0D, 1D, 2D, and 3D carbon nanostructures (CNs)[10]

Based on their sorbent qualities, carbon nanomaterial (CNMs), which also includes carbon nanosheets, carbon nanoparticles, and carbon nanotubes, are a significant group (CNSs). Additionally, silicon nanomaterials (SiNMs) include silicon nanoparticles (SiNPs), silicon nanosheets (SiNSs), and silicon nanotubes (SiNTs). Nanofibers (NFs), nanoclays, polymer-based nanomaterials (PNMs), xerogels, and aerogels are specific nanomaterials that have been developed for adsorption procedures. 1-100 nm sized structures have a significant impact on a number of scientific disciplines, including chemistry, electronics, medicine, biology, and material sciences. The intrinsic composition, evident size, and unintentional surface structure of NPs all have a direct bearing on their physical, material, and chemical properties. [11].

The CO_2 emission is a part in the global warming and environmental climate change; in this manner, broad research have attempted worldwide to create practical materials for CO_2 capture. It has been accounted for that worldwide environmental CO_2 concentration improved from a preindustrial of ∼280 to 390 ppm right now. The primary supporters of watched CO_2 increment are vehicular emissions, petroleum derivative terminated force plants, deforestation, and chemical processes [12]. Carbonaceous adsorbents show a few focal points, for example, higher protection from water because of their hydrophobicity, high thermal stability, great chemical protection from both alkaline and acidic media, simple planning, tunable pore structure, low energy necessity for recovery, and in particular, low cost. Hence, carbon materials are viewed as the most encouraging adsorbents for CO_2 catch [13].

Partition of N_2 and CO_2 from gaseous petrol (CH_4) is definitely requested so as to use the low quality petroleum gas, for example, biogas. Ozone harming substances (CO_2 and CH_4) add to the global warming. About 60% of the worldwide temperature alteration impact is brought about by the CO2, the vast majority of which be discharged on or after the find expression for gases (normally contains ~70% N_2 and 15% CO_2) of the modern plants. Along these lines, the CO_2 capture/separation from the pipe gas (N_2) is essential as far as possible its discharge near the environment. CH_4 has much higher a global warming potential (GWP) than CO_2. Landfill gas (LFG) is a main wellspring of the CH_4 emission to the air. The N_2 level in the LFG is especially high (~20%) now and again. CH_4 adsorption and CH_4/N_2 separation are fundamental to the decrease of CH_4 emission and redesigning of N_2-polluted LFG. Different advancements have been produced for gas partition/decontamination, for example, cryogenic refining, absorption, membrane separation, and adsorption. Adsorption has received strong interest because of its improbable points of interest: high energy efficiency, simplicity of control, low capital speculation costs. The effect of NOM (Regular Organic Materials) preloading lying on adsorption in GNS (graphene nanosheets), CNTs and GACs exist inspected. Perfect graphene nanosheets (GNS) and graphene oxide nanosheets (GO) were examined, along with single walled carbon nanotubes (SWCNT), multi-walled carbon nanotubes (MWCNT), and two coal-based granular activated carbons, for their effects on the adsorption of phenanthrene (PNT) and trichloroethylene (TCE) (GACs). With all adsorbents on equally equal mass and surface area bases, PNT take-up was higher than TCE. This was attributed to PNT's hydrophobicity. The openness of the organic molecules toward internal areas of the adsorbent, which is influenced by the molecular size of OCs, determines the adsorption limits of PNT and TCE. Due to site competition, NOM preloading, and pore/interstice obstruction, all adsorbents' adsorption limits decreased. It's possible that, among all adsorbents, GO was typically the least affected by the NOM for PNT, even though no pattern of NOM competition with a specific adsorbent for TCE was explored. Additionally, the NOM preloading employed for TCE and the absence of a PNT pattern had a shared affect on SWCNT. The overall results indicated that water quality parameters, adsorbent characteristics, and adsorbate properties will influence the fate and transit of natural pollutants using GNSs and CNTs as nano adsorbents and GACs in various regular frameworks [14].

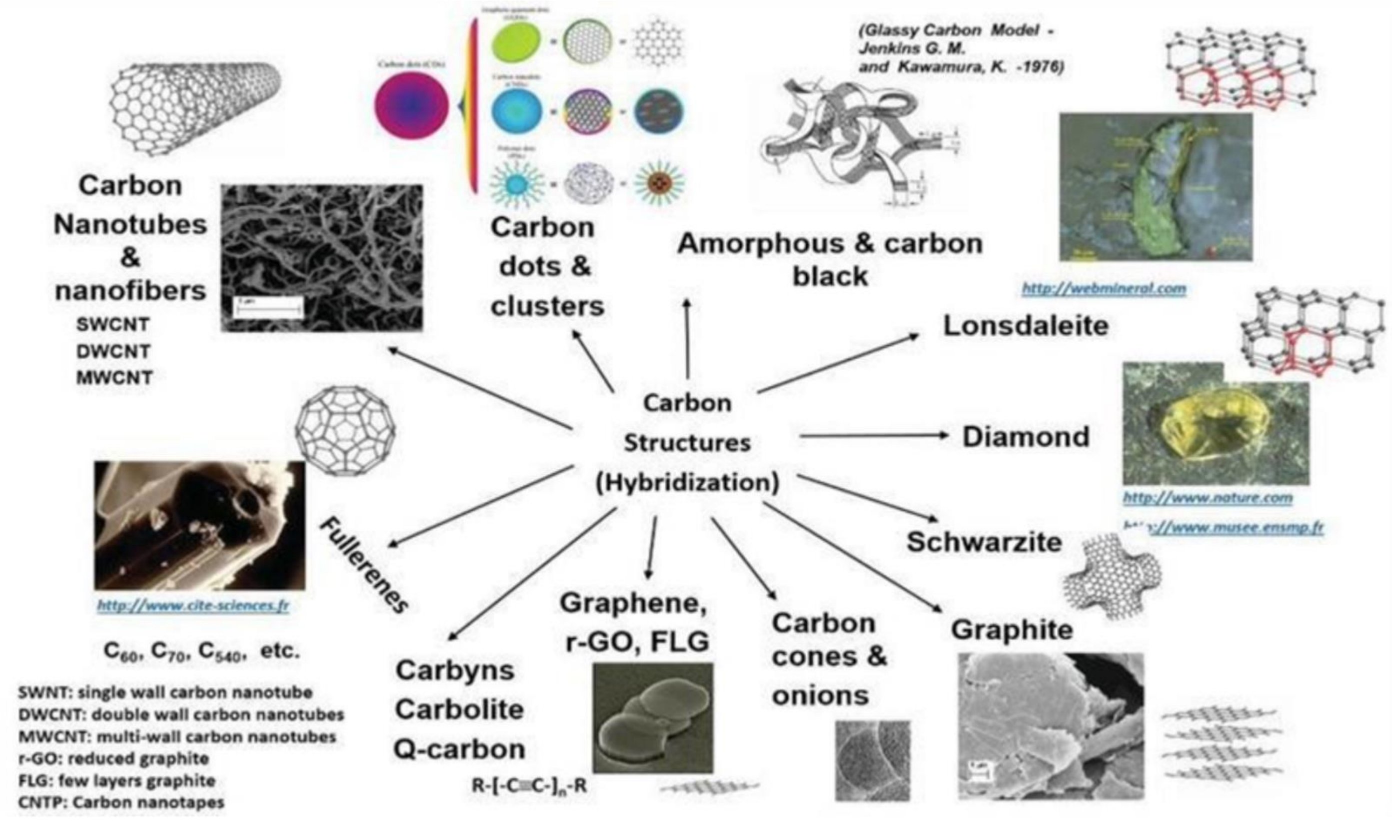


Figure 2.2 Type of carbon structure Length (SWCNT) = 0.2-5 micrometer, length (MWCNT) = SWCNT, Diameter (SWCNT) = 1.2 nanometer, Diameter (MWCNT) = 2 - 25 nanometer. The significant distinction is, single-walled carbon nanotube (SWNT) comprises of a single graphene while a multi-walled carbon nanotube (MWNT) includes grapheme. The structure is a round and hollow cylinder including six-membered carbon rings like graphite shows in figure 3.2.

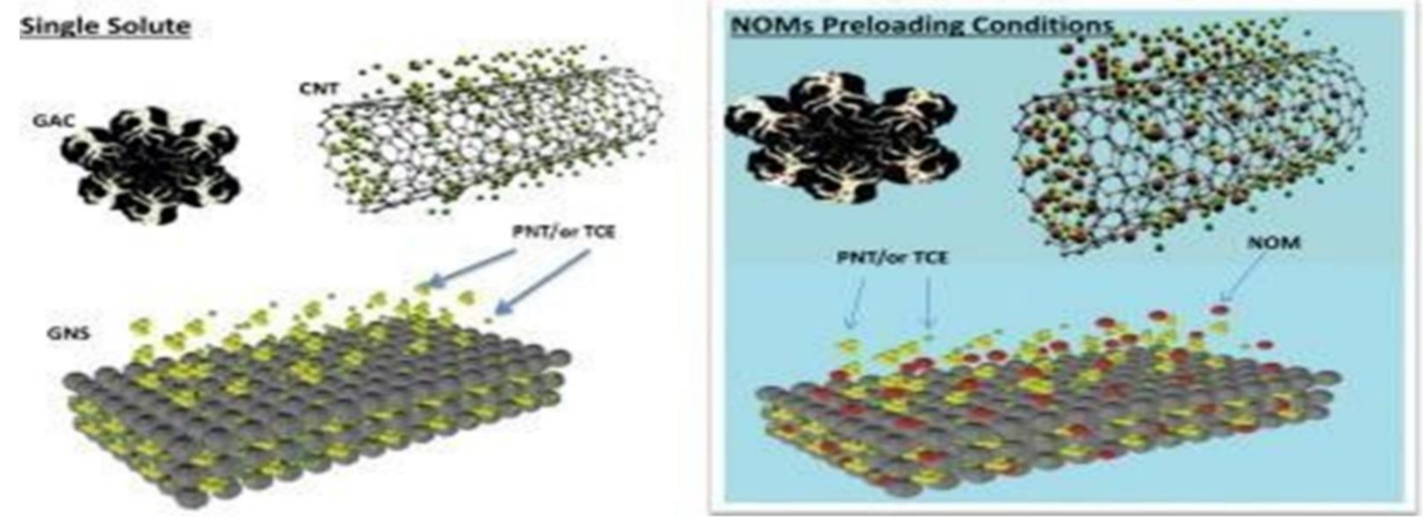


Figure 2.3 Divisions of Parallel Blends.

This figure represents Perfect Adsorbed Arrangement Hypothesis (IAAT) use to assess the division selectivity used for CO_2/CH_4, CH_4/N_2, and CO_2/N_2 paired blends by various pieces with weights as indicated by the ideal adsorbed arrangement theory (IAAT) model, used to foresee the gas blend adsorption conduct in various adsorbents, include mesoporous material. Here, IAAT be utilized toward look at the selectivity of the paired blends (CO_2/CH_4, CH_4/N_2, and CO_2/N_2) on the some as of the test unadulterated part adsorption isotherms [15].

Table 2.1 Types of nanoparticles [1]

Nanoadsorbent Material	**Type of nanoparticles**	**Targets contaminations** **Gases**	**Removal mechanism**
(Carbon nanotubes CNTs)	(MWNTs and SWNTs)	NOX (mixture of NO and NO_2)	As nitrate species move through CNTs, NO is converted to NO_2, which is subsequently adsorbed on the surface of the species.
	(CNTs-APTS), Modified CNTs utilizing 3aminopropylltriethoxysilane (APTS).	CO_2	Because CNTs have numerous amine groups on their surface, they have more chemical sites available for CO_2 adsorption at low temperatures (20-100 degree celcius)

	SWNTs/NaClO	Isopropyl vapor	Chemical adsorption on surface functional groups of the adsorbent and physical adsorption via Vander Waals forces.
	CNTs stored on quartz Filters	VOCs	It completed by pie-pie interactions.
	Si-doped and Boron-doped SWCNTs	CO and CH_3OH gases	Physisorption or chemisorption's, the electronic properties of SWCNT improves essentially the gas adsorption.
Fullerene	Fullerene B40	CO_2	High adsorption capacity for CO_2 by strong chemisorption's.
	Fullerene-like boron nitride Nanocage	N_2O	Adsorption and decomposition of N_2O
Grephene	Grephene oxide(GO)/nanocomposits	CO_2, NH_3, SO_2, H_2S and N_2	Adsorption of gases is controlled by functional groups on the GO surface, and is facilitated by a synergistic interaction between the metal and GO surface.

2.1.2 Degradation by Nanocatalysis

In the current life, indoor air pollution has drawn an overall thought as for the improvement of indoor air quality (IAQ). Interior air contaminants generally contain particulates, carbon oxides (CO and CO_2), volatile organic compounds (VOCs), and nitrogen oxides (NO_x). Among the pollutions, VOCs are apparent specialist indoor poisons which conventionally join trichloroethylene (C_2HC_{l3})[1], $(CH_3)_2CO$, (C_3H_6O), 1-butanol ($C_4H_{10}O$), butyraldehyde (C_4H_8O) [16], m-xylene (C_8H_{10}) , [17] 1, 3-Butadiene (C_4H_6), toluene ($C_6H_5CH_3$), with formaldehyde (CH_2O) [18][[19] VOCs are referred as to include long term effect on human [20]. Likewise, Various VOCs emissions are capable of formation of city fumes cloud and ozone, stratospheric ozone depletion plus the greenhouse effect [21]. With the extending conserns at the indoor air quality, the degradation of VOCs have absolutely control the emission depend of VOCs attempts into the present steady world. Three technique are normally used to manipulate the emission of VOCs, for instance, adsorption by activated carbon [22]. Which transfer pollutants from vaporous phase to solid phase instead of destroying, bio filtration that is slow and no understandable impact and thermal oxidation annihilation [23]. This needs high temperatures of 200˚C - 1200˚C used for compelling movement with exclusive. Removal of VOCs as of indoor air is able to be cultivated use photo catalytic oxidation (PCO), promise and cost effective approach. This lead is a direct result of crafted by highly significantly viable photo catalysts. Improvement of dynamic force structures is pressing for this advancement. TiO_2 is the most usely photo catalyst at present used as a result of the hydrophilic properties of TiO_2 and its functionally to degenerate a wide range of inorganic and organic compounds under irradiation UV or near UV-light [24]. [Nanoparticles size is decay with increase band gap correspondingly nanoparticles size is increase with decrease band gap due to doping according to Home-Rothery rules.]

Table 2.2 Different type of nanostructure oxides

S. No.	**Material oxide (used)**	**Synthesis method**	**Applications**	**Removal defilements (pollutants)**	**Refer Ence**
1.	TiO_2thin film	TiO_2 thin film by RF magnetron sputtering joins with thermal annealing.	Applications, distinctive semiconductor photocatalysts in powder form	Toxic natural contaminations (Dichlorodiphenyltrichloroethane, DDT and, lindane, mechanical synthetic concoctions, for example, polychlorinatedbiphenyls (pcbs), and substances, for example, dioxins)	[25]
2.	TiO_2 nanoparticles	Sol gel method	Impacts of humidity and trace Contaminant	Oxidation rates of Formaldehyde, Toluene, as well as 1-3Butadiene	[26]
3.	TiO_2 thin film	Prepared by Sol gel technique nanostructure TiO_2 thin film	Photocatalytic degradation of vaporous CH_3, CO, toluene, and p- xylene utilizing a TiO2 thin film	Acetone, toluene, with p-xylene	[27]
4.	TiO_2 nanoparticles	Facile and eco-accommodating technique TiO_2 nanoparticle	Biomedical nanotechnology applications	Bacteria, parasite, , actinomycet eses	[28]
5.	TiO_2 nanoparticles	TiO_2 nanoparticles thin film deposited by matrix assisted laser Evaporation	Gas sensor applications	Ethanol and CH_3CO fumes sensing	[29]
6.	TiO_2 thin film	Photocatalytic thin film containing TiO_2 nanoparticles by the layer-by-layer self-collecting method	Photocatalytic properties in oxidation of iodide and decomposition of methyl orange	Oxidation of iodide and decomposition of methyl orange	[20]

7.	TiO$_2$ thin film	TiO$_2$ thin films of N-S doped titanium dioxide (TiO$_2$) be effectively arranged by basic sol-gel method within sight of tetrabutylorthotitanate	Photocatalytic degradation	Tetrabutylorthotitanate, ethanol, thiourea, hydrochloric corrosive, and acetylacetone were bought from Merck Organization and utilized moving along without any more purification.	[84]
8.	V$_2$O$_5$ /BiVO$_4$/TiO$_2$ Nanocomposites	Hydrothermal and adhering method	High Visible-light induced Photo catalytic Activity for degradation of toluene	Decomposition of gaseous toluene	[30]
9.	Activated V$_2$O$_5$ nanotubes	Hydrolysis method	Gas sensing ethanol gas	Sensing ethanol gas	[31]
10.	V$_2$O$_5$ thin films	Spray pyrolysis (SP) technique	NO$_2$ sensor	NO$_2$ sensor	[32]
11.	Mesoporous V$_2$O$_5$ and TiO$_2$ composites	Mesoporous V$_2$O$_5$ and TiO$_2$ composites Mesoporous V$_2$O$_5$ and TiO$_2$ composites be manufactured through a ultrasonic strategy with V$_2$O$_5$ sol like the guest precursor	Enhanced photoactivity for vaporous benzene degradation	Benzene gases degradation	[33]
12.	V$_2$O$_5$ nanowire	Using a basic one- advance aqueous technique utilizing NH$_4$VO$_3$ and oxalic corrosive as precursors	Electrochromic execution , in savvy window and in lithium particle battery, supercapacitor and gas sensors	Gas sensing	[34]
13.	Sodium vanadium oxide (Na$_2$V$_6$O$_{16}$·3H$_2$O) nanobelts	A simple and productive hydrothermal method	Gas sensor materials	1-butanol particles are adsorbed, intraction between the oxygen species and gas atoms may likewise assume a significant role under	[35]
14.	Orthorhombic nanocrystalline V$_2$O$_5$ thin films	Chemical spray pyrolysis (CSP) deposition method	Impact of film thickness on NO$_2$ gas detecting properties	NO$_2$ gas detecting	[36]
15.	V$_2$O$_5$ micro/nano-tubes	CVD (at room temperature)	Gas sensing	Humidity	[37]
16.	V$_2$O$_5$ hollow spheres	Solvothermal (At 370 degree celcius)	Gas sensing	Triethylamine (TEA)	[15]
17.	Nanostructured	PLD (At 350 degree	Gas sensing	NH$_3$	[38]

	V_2O_5	celcius)			
18.	Vanadium oxide/polyvinyl acetate(V_2O_5/PVAC) fibers	Electrospinning (At 200 degree celcius)	Gas sensing	NH_3	[39]
19.	Fe_2O_3activated V2O5 nanotubes	Hydrothermal (At 270 degree celcius)	Gas sensing	Ethanol	[31]
20.	p-type porous silicon (PS)/V_2O_5 nanorods	DC magnetron Sputtering (At 25degree celcius)	Gas sensing	NO_2	[85]
21.	V_2O_5 nanorods	Chemical spray pyrolysis (At 200 degree celcius)	Gas sensing	NO_2	[40]
22.	BiOX (X=Cl, Br,I) nanoparticles	Facile precipitation technique at room temperature	Up-transformation phosphors/BiOBr composites for effective degradation of NO gas	NO gas	[41]
23.	BiOBr-Graphene Nanocomposites	Prepared by an easy solvothermal course with utilizing graphene oxide (GO)	Performance on photocatalytic	Performance on photocatalytic evacuation of vaporous nitrogen monoxide (NO)	[42]
24.	WO_3/g-C3N4(Graphitic carbon nitride)	Synthesized by a dissolvable evaporation and in situ calcination method	Enhanced photocatalytic activity	Photocatalytic movement for natural pollutants	[43]
25.	Calcium-Alginate $(C_{12}H_{14}CaO_{12})n$ -Stabilized Ag and Au nanoparticles	Green Photochemical approach	Catalytic application to 4-nitrophenol Reduction	4-nitrophenol	[44]
26.	Calcium/Aluminum Co-doped zinc oxide	Synthesized by a sol-gel technique. Combined nanoparticle test were utilized to manufacture thick film resistive semiconductor gas sensors for CO_2 detection in air (200 ^{0}C)	CO_2 sensors	CO_2	[45]
27.	Calcium Oxide (CaO)	Cyclical carbonation (of a metal oxide) and calcinations (of the metal carbonate formed)	Separation of carbon dioxide (CO_2) from pipe gas	CO_2	[46]

28.	Au-CeO_2 nanocomposite Film	By using molecular beam epitaxy (MBE), the CeO_2 thin film was preserved. At a high temperature, Au was injected into the film while it was developing, followed by high temperature strengthening to form highly defined Au nanoclusters.	Plasmonic Gas Detecting: H_2, NO_2, and CO	H_2, NO_2, and CO	[47]
29.	CeO_2 nanoparticles	Hydrothermally and used as redox mediator for the manufacture of proficient ethanol chemi-sensor.	Chemo-sensor and photograph catalyst	Ethanol sensor CeO_2 nanoparticles likewise performed well as a photograph impetus by productive corruption of amido black and acridine orange	[48]
30.	CeO_2 Nanoparticles	Green and Chemical Synthesized	Photocatalytic Degradation of indoor vaporous toxin acetaldehyde and contrasted and ordinary artificially combined CeO_2 nanoparticles (NH_3 and NaOH)	Acetaldehyde, NH_3 and NaOH	[49]
31.	Magnetic Nanoscaled Fe_3O_4/CeO_2 Composite	Prepared by the impregnation method	Heterogeneous Catalyst used for degradation of 4-Chlorophenol	4-chlorophenol	[50]
32.	CeO_2 doped ZnO flower-like nanostructure	Synthesized by means of an extremely quick microwave helped technique utilizing zinc acetatedihydrate and ceriumnitrate as starting materials and water as solvent.	Sensor	Ethanol in nearness of CO and CH_4	[51]
33.	Pt/CeO_2 Model Catalysts	Performed a synchrotron radiation photoelectron spectroscopy (SR-PES) concentrate lying on the system of SO_2 deterioration on Pt/CeO_2 (111) form impetuses arranged on Cu (111). Resonant photoemission spectroscopy (RPES) be applied to screen change of the cerium oxidation state. Adsorption of SO_2 at 150 K on Pt/CeO_2	SO_2 decomposition	SO_2	[52]

		(111)/Cu(111) yields surface sulfites ($SO_3{}^{2-}$) on ceria and upstanding standing sub-atomic (SO_2) lying on Pt alongside hints of nuclear sulfur. Incomplete decay and desorption of the adsorbed species as SO_2 happen somewhere in the range of 150 and 300 K.			
34.	MnO_2 thin films	Chemical spray pyrolysis Technique	Acetaldehyde sensing property	Acetaldehyde	[53]
35.	Sputtered grown Pd decorated MnO_2 nanowalls	Responsive sputtering was used to deposit vertically adjustable, highly ordered Pd adorned MnO_2 nanowalls directly on a porous anodic alumina (AAO).	Highly sensitive and selective hydrogen gas sensor , electronic with reactant properties	Gas sensor	[54]
36.	MnO_2 coated cellulose nanofibers hybrid	Energy-efficient synthetic method	Removal of methylene blue ($C_{16}H_{18}Cln_3S$)	Methylene blue	[55]
37.	MnO_2 nanorods	Hydrothermal method	Gas sensing Properties	Ethanol	[56]
38.	Hybrid Cross- Linked olyaniline- WO_3 nanocomposite thin Film	Fabricated using vacuum thermal evaporation technique	Gas sensing	NO_x	[57]
39.	WO_3 nanorod based thin films	WO_3 nanorod based thin films were saved by means of beat laser testimony onto conductometric transducers utilizing the most brief frequency (193 nm) arf excimer laser	Ethanol and H_2 sensing	Ethanol and H_2	[58]
40.	WO_3	Prepared by a colloidal chemical method,	Gas sensing	NO_2	[59]

41.	MWCNTs-WO_3 nanoparticles	Terpineol is used to combine, hydrothermally synthesised WO_3 nps and commercial MWCNTs to create the sticky gel of the MWCNTs-WO_3 NPs hybrid.	Multi-walled carbon nanotubes and tungsten trioxide nanoparticles (mwcnts-WO_3 NPs) of the cross type have been synthesised and developed into an adaptive nitrogen dioxide (NO_2) sensor on a polyethylene terephthalate (PET) substrate.	NO_2	[60]
42.	Macroporous WO_3 Thin Films and Role of the Hosted Cr Isolated Centers and Pt-nanoclusters	Macro porous WO_3 films by modified opal structure be incorporated by one-advance method, which includes the self- get together of the round templating operators and the concurrent sol gel buildup of the semiconductor alkoxide antecedent. Change metal doping, meant to upgrade the WO3 electrical reaction, was done with including Cr (III) plus Pt (IV) focuses in the oxide framework.	NH_3 sensing	NH_3	[61]
43.	WO_3·H_2O nanosheets presence of Au	Synthesized tungsten oxide (WO_3•H_2O) nanosheets by an facile and effrctive aqueous process	Gas sensing applications	Toluene gas	[62]
44.	Nano- photocatalyst WO_3-TiO_2 and C_3N_4 composite	Hybrid photocatalyst WO3-TiO_2-g-C_3N_4 by robust stabilities as well as versatile properties has been synthesized through facile hydrothermal technique	Photo degradation of aspirin (acetylsalicylate) and caffeine (methyl- theobromine) ,Expulsion of acetylsalicylate and methyl-theobromine	Acetylsalicylate and methyl-theobromine	[63]
45.	Au–WO_3 nanoplatelets hybrids	WO_3 nanoplatelets finished with Au NPs were set up by laser ablation in liqids (LAL) with subsequent aging and anneling treatments	Performance for detecting ethanol vapor	Ethanol vapor	[64]

46.	Nanocrystalline Zn_2SnO_4 microcubes	Hydrothermally synthesized	Photocatalytic removal of NO and HCHO	NO and HCHO	[65]
47.	Ce-doped ZnO thin-film	CeO_2-doped ZnO meager film gas sensors by various Ce/Zn proportions contain manufactured through plunge covering strategy, beginning from zinc acetic acid derivation dehydrate, cerium nitrate hyxahydrate ($Ce(NO_3)_3.6H_2O$) and anhydrous ethanol.	Gas-detecting properties	Acetone, benzene and alcohol	[66]
48.	Zinc Oxide thimn film nanoparticle	Using basic wet concoction approach and afterward the movies were strengthened at 450°C into air climate for 2H	Low temperature LPG sensing properties	LPG gas	[67]
49.	ZnO nanoparticles	Synthesized in enormous amount by means of straight forward aqueous procedure utilizing the fluid blends of zinc chloride and ammonium Hydroxide	Photocatalyst and CH_3, CO sensor	Acetone	[68]
50.	ZnO Thin-Film	ZnO thin film developed RF Sputtering	NO_2 gas sensing	NO_2	[69]
51.	ZnO thin films	Sol–gel method at 500 C utilize zinc acetate acid derivation, 2-methoxyethanol, plus monoethanolamine like precursors	NH_3sensing properties of gas-sensing devices	NH_3	[70]
52.	Electro deposited Mesoporous ZnO thin Films	Prepared by electrochemical Deposition	Photocatalysts for the degradation of dye pollutants	Dye pollutants	[71]

53.	ZnO nanoparticles	Ozone gas sensors lying on adaptable substrate by Ti/Pt cathodes have been created by normal photolithography plus femtosecond laser removal forms below similar conditions. ZnO nanoparticles stored by drop covering strategy have been utilized as delicate dainty film material with 280 nm thickness because of their great qualities on gas identification.	Ozone flexible sensors	Ozone	[72]
54.	ZnO thin films	ZnO detecting film stored on Au covered crystals has been created utilizing an indigenously evolved surface plasmon resonance (SPR) estimation arrangement	Carbon monoxide (CO) optical gas sensor	CO and others NH_3, CO_2, NO_x, LPG, H_2	[73]
55.	ZnO thin films	ZnO thin film was set up by responsive RF spittring lying on thermally oxidized Si used for gas detecting applications.	VOC sensing applications	Acetone, Isopropanol and ethanol	[74]
56.	Al-doped ZnO	Al-doped ZnO (AZO) nanoparticles have been readied utilizing an adjusted sol–gel procedure. The as prepared AZO nanoparticles were annealed at 400 ◦C	Highly sensitive CO gas sensors	CO gas	[75]
57.	In_2O_3–ZnO composite films	The substance of ZnO in In_2O_3–ZnO film was constrained by modifying the Zn^{2+} /In^{3+} molar proportion (r) during the film planning. With appropriate measure of ZnO fused into the In_2O_3 films, the reactions of the composite films to nox at operation temperatures below 200◦C were greatly improved	NO_x gas sensors	NO_x	[76]

Specific Factors of this table

Most useful nanomaterials are to be explaining on the following specific factors: The most useful nanomaterials for detection of air pollutions are TiO_2, ZnO and SnO_2. The TiO_2 is most promising materials used acts as a photocatalyst in figure 3.4. Pure TiO2 show three phases as Anatase, Brookite and Rutile structure utilizing amorphous titania as a type of starting materials. While anatase nanoparticles were made using acidic acid, phase-pure rutile and brookite nanoparticles were made with hydrochloric acid at a range of concentrations and hydrothermal treatment at considerable temperatures with the right reactants.

TiO_2 anatase utilized a role in energy and environmental research because of its effective photoactivity, high stability, low cost and safety to the environmental and people. TiO_2 is that absorb only UV light to its high band gap of 3.2eV. The structure of TiO_2 has basically three crystal structures anatase (tetragonal), rutile (tertragonal), beookite (orthorhombic). Rutile phase transform above 600^oC while anatase structures forms at lower temperature. It is used in products as paints and coating, including glases and enamaels, plastic, paper, inks, fibers, foods, pharmaceuticals and cosmatics mostly used for toothpastes.

It has also been noted that hydrogen peroxide-based TiO_2 metal synthesis promotes the creation of TiO_2 nanorods. A cleaned Ti metal plate might be placed in a 50 mL solution of 30 percent H_2O_2 at 353K for 72 hours to get the TiO_2. It was treated with substance had been proven to achieve success toward a wide range of microorganisms along with protozoa algae, fungi, bacteria and viruses. The level of effectiveness depends upon the material was prepared and it has been doped with different substances to improve its antimicrobial capabilities.

Titanium dioxide (TiO_2) nanomaterials are uitilized in a wide range of applications for example, photocatalysis, separations, sensors, paints, and solar cells with dye sensitization. TiO_2 nanoparticles' material characteristics depend on their crystal structure, size, and shape. As a result, they could be very dependent on the synthesis procedure. Anatase, brookite, and rutile are the three primary phases of titanium dioxide. Rutile is the stable phase of TiO_2 in bulk, however most solution-phase production techniques for TiO_2 favour the anatase structure. Surface energy and precursor chemistry are the two main influences seen in these observations. An important component of total energy is surface energy, and it has been noted that anatase has lower surface energy than rutile and brookite. Anatase nanoparticles phase shift into rutile nanoparticles at a crossover size of about 30 nm, which surface energy believes to be accurate. Titanium (IV) isopropoxide and acetic acid are typically used to create phase-pure anatase nanoparticles with diameters ranging from 6 to 30 nm. When stronger acids are used, brookite nanoparticles usually make only a minor portion of the final output. Amorphous titania was used as the starting material to create phase-pure brookite particles (0.3–1 m), which were then hydrothermally treated with NaOH. The procedure involves the synthesis of sodium titanate, which eventually transforms into pure TiO_2 with the brookite structure. Thermolysis of $TiCl_4$ in aqueous HCl solution has been used to explain how brookite nanoparticles of 5–10 nm are made.

This property takes into consideration the oxidation various molecules, which including the pollutants with inside the air and on the surface, in addition to the formation of hydroxyl and oxygen radicals from water and oxygen with inside the air. The titanium oxides concrete show to correctly remove nitrogen oxides is well as common volatile organic compounds (VOCs) which include benzene, toluene, and ethyl benzene. To dispose of nitrogen oxides entirely, a multi-step procedure is needed. The procedure, consistent with the Czestochowa paper, starts with the reaction

$$NO + 2OH^- \longrightarrow NO_2 + H_2O$$

This cycle manner alone doesn't eliminate nitrogen oxides however alternatively changes nitrogen monoxide to some other risky and harmful compound, nitrogen dioxide, which allows a second reaction to occur

$$NO_2 + OH^- \longrightarrow NO_3^- + H^+$$

This reaction really eliminates the residual nitrogen dioxide and changes it to nitrate particles ions, which at the point of structure nitric acid, HNO_3, with the ionized hydrogen.

The TiO_2 is an amazing innovative and consolidated an energy proficient light source with a TiO_2 (titanium dioxide) covering coating to well help in the removal of airborne bacteria, mold, viruses, fungi, smoke and household odors [10].

Au-Pt co-catalyst saw more 100 multiple times more active than in order to make of a customary material used for trichloroethylene (TCE) decomposition. Similarly ZnO photocatalyst is as of now being created and is needed to have two functions to identify and moderate impurities [77].

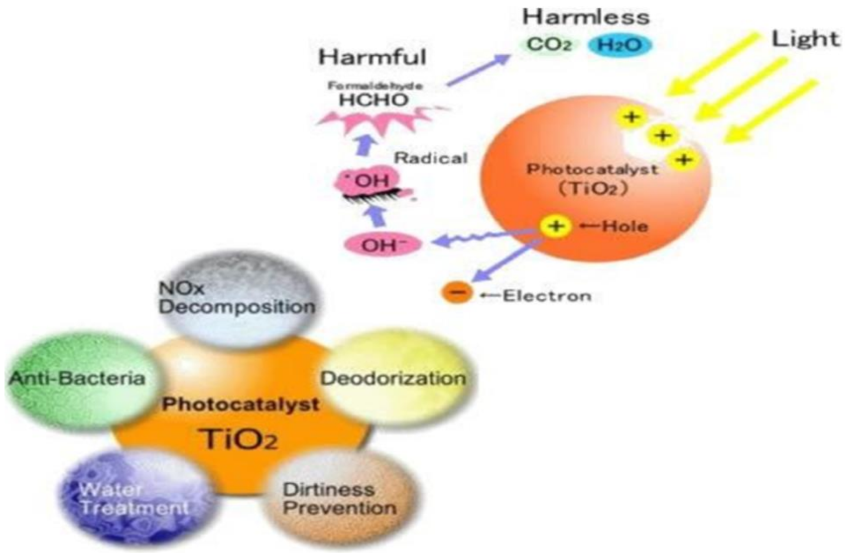


Figure 2.4 TiO_2 Photocatalyst

2.1.3 Filtration/Separation by nanofilters

The ejection of filtration and filtration-associated development to observe the improvement of the phase inversion technique for the produce of polymeric membranes layers, in the 1960s, lead to the affiliation of three film separation processes: reverse osmosis, ultrafiltration and, more recently microfiltration. These activities accept The separation spectrum as of the typical decrease factor acknowledgement reason of standard filtration of around 0.01 mm (10 m) to the best specific solids, an aggregation of nanometers in size, and connect the separation of big molecules from solution The precise size ranges will vary from source to source, but it is generally accepted that microfiltration includes sizes from 10 m to 0.1 m, while ultrafiltration includes sizes from 0.1 m to 0.005 m (5 nm) with regard to discrete particles or Molecular Weight Cutoff (MWCO) data of 300,000 to as low as 300 Daltons for broken dissolved materials. Reverse osmosis, clearly, was future to hold the little sodium chloride molecule, which recommended passing nothing other than excepting for water [78].

The important difference among nanofiltration and inverse osmosis be that the last hold monovalent salts, (for instance, NaCl), while nanofiltration award them to pass, and a short time later holds divalent salts, for instance, Na2S [86].

The membrane thin film layer separation process method referred to as nanofiltration is basically a liquid phase one, even as separates a range of inorganic and organic substance as of plan in a liquid – generally, but by means of no means, totally, water. This is achieved by means of scattering through a layer, under pressure differential which might be extensive now no longer precisely people humans for turn processing, but essentially extra incredible than those for ultra-filtration. It changed into the development of a thin film complex layer that give the genuine impetus to nanofiltration as fairly technique, and it's incrediable development as of that factor ahead forward is to an incredible region an after effect of its remarkable capacity to confine and fractionate ionic and sensibly low nuclear weight organic species. The membrane layers be essential to closer to the presentation of nanofiltration system. They are created in plate and casing configuration, winding injury, cylindrical. In figure 3.5 shows an SEM perspective on Ahlstrom's Disruptor nanofiltration layer. 34 Component Filtration Separation October 2008, 34 Element fine and blank fiber positions, considering opportunity of material, include cellulose derivatives and synthetic polymers, as of inorganic materials, ceramic especially, and as per natural/inorganic hybrids [78].

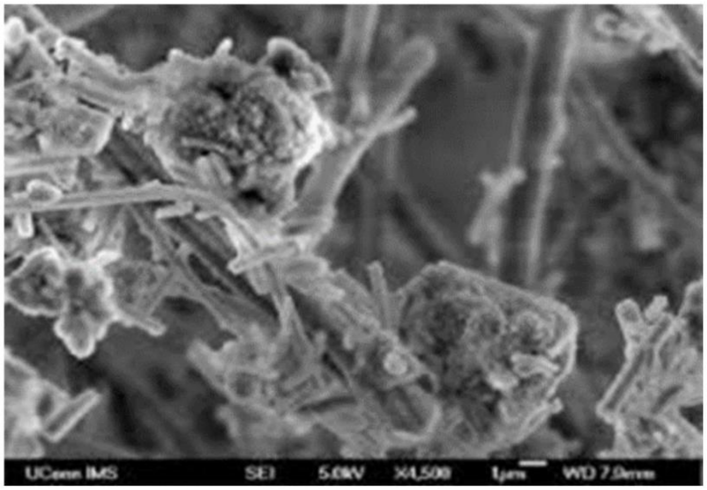


Figure 2.5 A SEM perspective on Ahistrom's gure disruptor nanofiltration membrane [78].

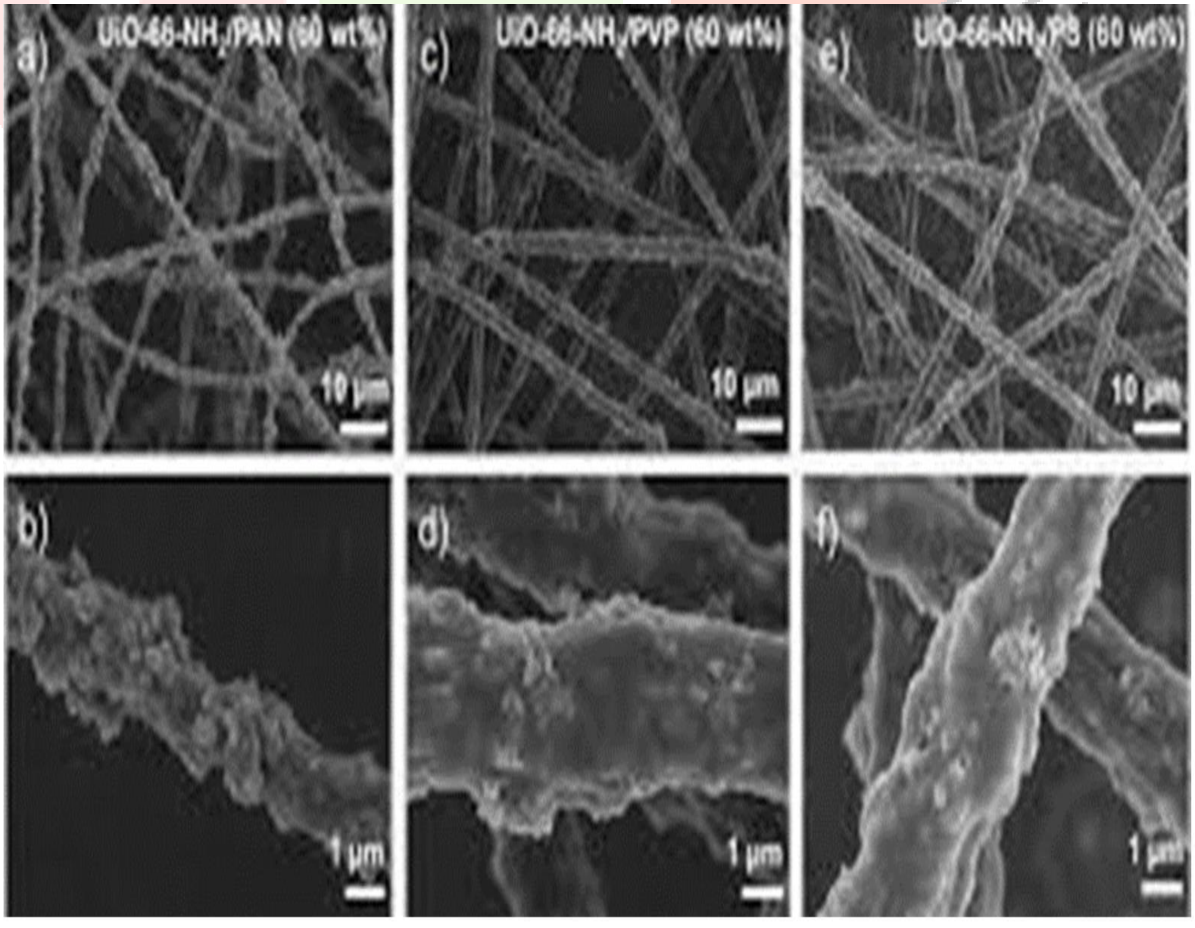


Figure 2.6 SEM pictures of (a, b) UiO-66-NH_2/Dish MOFilter, (c, d) UiO-66-NH_2/PVP MOFilter and (e, f) UiO-66-NH_2/PS MOFilter. All the filters are loaded with 60 wt % MOF [78].

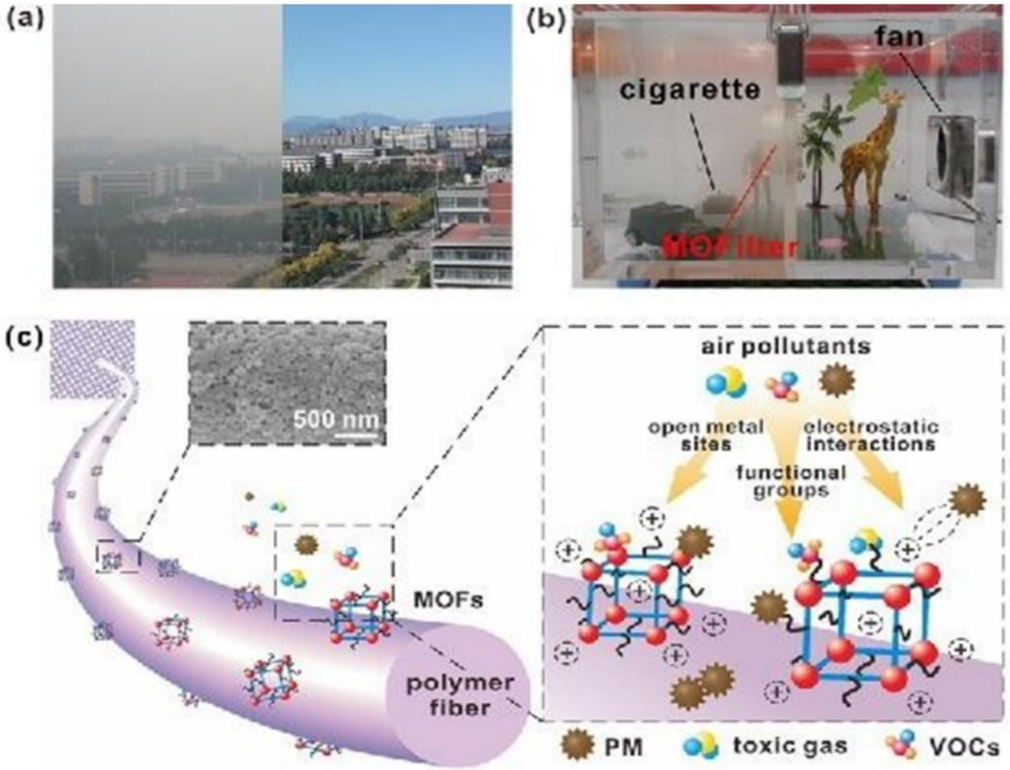


Figure 2.7 (a) Photographs of the grounds of the Beijing institute of Technology during a polluted and a clear day. (b) Exhibition of the molecule filtration ability of the MOFilter in the recreated dirtied environment. (c) Proposed capture instrument of the MOFilter for air poisons. Inset is the SEM picture of the outside of the MOF/polymer composite fiber [79].

2.2 Air pollution prevention with the help of nanotechnology

Nanotechnology can be used to address air pollution in a number of ways. One involves using vaporous reactions to make advantage of nano-catalysts with increased extended surface area. Catalysts function via chemical reactions that transform toxic gases from modern vegetation and automobiles into pure, harmless gases. A nanofiber catalyst composed of manganese oxide is now being used to remove VOCs from mechanical smokestacks [87].

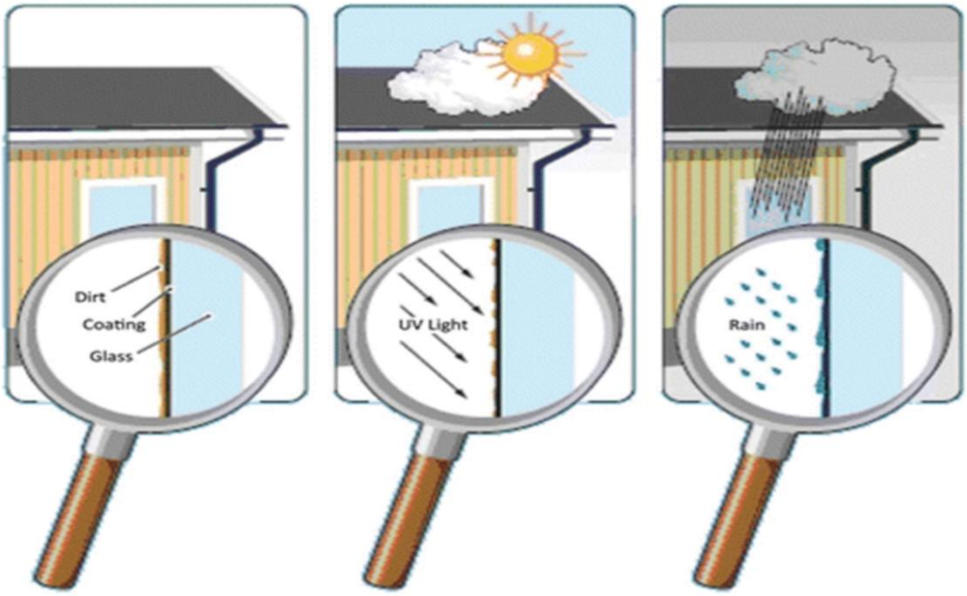
Another philosophy makes use of nanostructure membrane layers which have pores little to isolate methane or carbon dioxide from exhaust [88]. The materials that were filtered through still posed a problem for disposal because just dumping rubbish on the ground has no benefit. Japanese researchers experimented with the idea of gathering accumulation filtered from diesel fuel pollutants and recycling it into CNT manufacture material in 2006 [89]. In order to fundamentally change the filtered waste into the channel, the single-walled CNT filter is made from the diesel soot using laser vaporisation.

The US Environmental Protection Agency's (US EPA) SITE programme has found that one semiconductor photo catalyst is useful for water remediation [90]. In comparison to the typical structure of TiO_2 powder, the surface of TiO2 fundamental catalysts that can utilise nanotubes has proven to be consistently productive at disposing of the material [27]. ZnO is thought to have two purposes, specifically to detect and remove pollutants. During testing at the research centre, a ZnO photocatalyst was primarily employed to identify and remove 4-chlorocatechol [80].

2.3 Environmentally friendly materials

A substance or material that is ecologically friendly can be created using nanotechnology, replacing several hazardous materials that are currently used. For instance, LCD computer screens have replaced cathode ray tubes (CRTs), which contain specific toxic elements, because they are more energy efficient and less harmful. Additionally, LCDs use less energy and don't contain lead compared to CRT computer displays. The use of CNTs in PC displays may also have a lessening impact on the environment by eliminating toxic heavy metals, reducing material and importance requirements substantially, and boosting performance in accordance with customer requirements. Field emission displays (FEDs) are a common form of show technology that utilise CNTs.

Additionally, the incorporation of nanotechnology could result in a composite material with improved mechanical and other qualities. This is taking into account the way that nanotechnology may create structures that are lighter and smaller without lowering the quality of their existing qualities. The benefits of this movement include competitive power, reduced system costs, complete substitution, and consequently reduced environmental effect. Examples of environmentally friendly materials that can be produced using nanotechnology include self-cleaning glass, biodegradable plastics that use polymers with an atomic structure that is no longer difficult to degrade, and nanocrystalline composite materials that can replace lithium-graphite electrodes in battery-operated devices without causing harm. Active Glass, a company from Pilkington, is an example of a glass item with self-cleaning capabilities that has been widely made available with inside the market. Figure demonstrates how Pilkington Activate works for cleaning glass.



Coating is activated by UV light

After installation the special coating needs 5 to 7 days of exposure to daylight to activate fully.

Organic dirt is broken down

The coating breaks down organic dirt and by doing so, reduces the adherence of inorganic dirt.

Rain washes dirt away

Water droplets spread out to form a 'sheet', dirt particulates on the surface are picked up by water and washed off glass

Figure 2.8.The self-cleaning mechanism of glass Pilkington Activate [7].

Figure 3.8 delineates how one self-cleaning glass Pilkington Activate works.The glasses have a sheet (coating) organized of remarkable TiO_2 nanocrystal. Exactly while introduced to light, the glass is reacting in two distinct manners. To start with, the glass separates every organic molecule that is on the glass's surface, deposits. Second, when it rains, the movements of the water effortlessly determine the solid pollution throughout the glass surface. TiO_2 is applied as a thin coating with a thickness of 2–20 nm in this object using high-temperature gas-phase deposition. In order to provide the best photocatalytic action and transparency, the film thickness is crucial.

The surface coating has a hydrophilic quality (contact angle with water is 20°, which is lower than the 40° contact angle between differentiated and normal soda-lime glass at the same time). At the point when strong contaminations are saved at the glass surface, the contact edge surface expands then reductions once more because of light. Photochemical responses, which require oxygen, are mind boggling and include various items between the radicals. TiO_2 is simply going about as an impetus and isn't devoured during the response. The response will bring about the decay of natural issue into CO_2. Simultaneously the equal time, the contact area surface is decrease similar due to irradiation (between 20° to 15°). After light, strong poisons resolve all the other handily smooth clean as of the glass surface by rain.

Water be able to be spread efficiently by forming a coating lying on the surface of the glass [7].

2.4 Gas detection

Titanium dioxide (TiO_2) based sensors include functional used for estimating numerous gases as well as oxygen, carbon monoxide, hydrogen, nitrous/nitric oxide, water fume and hydrocarbon gases. Tatiana sensors are especially attractive reducing gas sensors since their reaction is influenced toward a lesser degree by humidity than to facilitate of the normal SnO_2 sensors [10]. The gas detecting attributes of WO_3 have been very much consideration in view of its excessive sensitivity to different gases because the work led through Akiyama et al. who found out that resistive-type gas sensors using WO_3 are highly sensitive to NO and NO_2. The particle size impact has likewise been accounted for WO_3-based gas sensors [81].

Conclusion

The use of nanoparticles allows for the detection of numerous airborne contaminants. Nanoparticles can remove airborne pollutants through adsorption, oxidation, and filtering processes. When applying the adsorption removal method, nanoparticles may adsorb the highest quantity of air contaminants to their enormous surface area. Another method is to detect some poisons, such as VOCs, and control air pollution by using nanostructure layers. Nanotechnology can be utilised to prevent the creation or arrangement of pollutants or contaminants by developing an environmentally benign substance or material to substitute regularly used harmful materials and lowering environmental contamination.. Toluene, 1, 3-butadiene, and formaldehyde's oxidation rates were studied in relation to the effect of stickiness using a photocatalytic (mostly TiO_2 based) reactor component. According to research, the lockdown decreased pollution levels and increased air quality from "bad" to "excellent" class from before to after the lockdown.Nanomaterials such as TiO_2, V_2O_5, FeO, MnO_2, ZnO, CeO_2 CaO, $CaCO_3$, WO_3, C_3N_4 and so forth are utilized in air pollutants control. A few matals like Ti, V, Mo, Pt, Rh, Ag, Bi, Cr, Grapheme, Hg, Au, In, Sn, Pb, Fe, W, are also utilized in air pollution control.

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[82] *DTE Staff Published*: Wednesday 08 May 2019, M. Hasan/D. Tribune, N. noushad ,Stud ent at Keyi Sahib Training College, Karimbam, Taliparamba, Kannur, Hindstan Times, Gurugram, B. Meets, J. Friedman, S. Alam.

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