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Application of Carbon Nanotubes (CNTs) for Remediation of Emerging Pollutants - A Review

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ABSTRACT: Nanotechnology is currently an upward trend in diverse fields, and therefore, its application will be reviewed in this paper. One of the nanotechnologies which can be used in environmental remediation is carbon nanotube (CNT). Its excellent mechanical and chemical properties allow it to have better achievement in remediating a wide range of organic and inorganic pollutants. CNT can be categorized into two types: single-walled carbon nanotube and multi-walled carbon nanotube. Due to urbanization, various types of pollutants have been released into the environment in great amounts. For instance, estrogen is the hormone generated and released from animals and humans. However, the overconcentration of estrogen affects the physiology of biological life. Besides, pesticides are frequently used by farmers to increase the fertility of the land for agricultural purposes, while heavy metals are commonly found during anthropogenic activities. Long-term absorption of heavy metals into the body tissues will accumulate toxic effects, leading to body system dysfunction. Hence, CNT technologies, including adsorption, membrane filtration, disinfection, hybrid catalysis, and sensing and monitoring, can be applied to remediate these pollutants. However, the application of nanotechnology and CNT faces several challenges, such as production costs, toxicity, ecological risks, and public acceptance. Application of CNT also has pros and cons, such that the lightweight of the CNT allows them to replace metallic wires, but dealing with nano-sized components makes it challenging.

KEYWORDS: Carbon nanotube (CNT); nanotechnology; remediation; pesticides; heavy metals

1. Introduction

Imagination from humans has allowed the development of nanotechnology to be applied in real life, and this new science, engineering, and technology is conducted at the nanoscale, at which the dimensions are between 1 and 100 nanometers [1]. Environmental pollution is a global concern in developing as well as developed countries, and therefore, it is not only applied in sectors such as chemistry, electricity, and the food industry but also towards environmental remediation technologies. Therefore, the objective of this paper is to study the application of nanotechnology to environmental remediation.

Carbon nanotubes (CNTs) are an emerging nanomaterial that can be used to remediate a variety of organic and inorganic contaminants [2]. CNTs are made of carbon, which is the most notable carbon-based nanomaterial with excellent mechanical properties, high heat and thermal conductivity, and high electrical conductivity [3,4]. Besides, CNT is also equipped with excellent chemical properties, which together allow it to have better achievements in environmental remediation [2]. CNTs can be further divided into two categories, which are single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) [5], where MWCNTs are SWCNTs in bundles. Environmental researchers stated that the applications of CNTs based-products or-technologies can offer many chances and advantages to protect the environment while controlling the emissions of pollutants [6]. In spite of the advantages brought by them, CNTs do have some drawbacks for the environment and human health [6, 7]. Nevertheless, CNT technologies have proved to be able to remediate many kinds of pollutants. Pollutants that normally dissolve in surface water and groundwater can have an impact on water quality and must be removed before entering human bodies. There are several water pollutants listed, such as estrogen, pesticides, and heavy metals, that must be removed before they are used for other purposes that may harm human bodies. The CNTs are then used as an absorbent for pollution treatment and environmental remediation. Absorption is one mechanism of technology that involves the absorption of gas, liquid, and organic pollutants. Other than that, CNTs can also be applied to membrane filtration, disinfection, hybrid catalysis, and sensing and monitoring. Due to its variety of uses, it has generated new environment-friendly products that reduce and control pollutants. Hence, this paper will further discuss the mechanism of carbon nanotubes through adsorption, membrane filtration, disinfection, hybrid catalyst, and also sensing and monitoring that can be applied to remove emerging pollutants such as estrogen, pesticides, and heavy metals.

2. Fate of Pollutant

Air, water, and soil pollution are global issues resulting from human activities during the urbanization and development of a country. The pollutants under discussion include estrogen, which is released by humans and animals, pesticides in agriculture, and heavy metals emitted from anthropogenic stationary sources.

2.1. Estrogen

Estrogen can be classified into two groups, which are natural estrogen and synthetic estrogen [8]. The presence of estrogen will pose threats to the environment, such as the soil, plants, and water resources. By which, estrogens contain compounds that interrupt the endocrine systems of organisms and adversely impact the physiology of biological life.

As the occurrence of natural estrogen hormones in a rapidly increasing concentration has threatened the environment, various studies have been conducted to examine the sources that led to the emergence of this pollution issue. The major sources of the emerging estrogen pollution issue are wastewater and sewage treatment plants, as well as effluents discharged from agriculture and aquaculture manure applications [8]. Due to the demand for meat production, steroid hormones have been applied to livestock through the implantation of hormonal growth in beef cattle, which can then enhance the growth of the livestock, promote meat production, and feed efficiency [9]. However, the growth-regulating steroids have adverse effects on the environment. The estrogens are detected in the animals' faces, solid waste from livestock rearing and the agrochemicals used for soil enrichment. In addition, effluents discharged from industry and hospitals are also a problem for the emerging issue [10].

As stated above, animal faces, solid waste, and effluents are the products of the sources of pollutants. The runoff of wastewater, the penetration of contaminants from agricultural sites into the soil, and the effluents from urbanization have resulted in the contamination of surface water and groundwater. However, the estrogens can be removed in the wastewater treatment plants (WWTPs) by biodegradation, adsorption, and advanced oxidation processes to eliminate the physiological effects on human body systems and the negative environmental effects [8].

2.2. Pesticides

Agrochemicals are one of the major sources contributing to the emergence of estrogen compounds, where pesticide is one of the agrochemicals that contribute to environmental issues. The occurrence of pesticides is mainly due to the demand for food production. Pesticides are generally used to ensure an increase in crop yields and production. Pesticides can be found in the atmosphere through particle drift, which is the movement of spray droplets that are produced at the time of pesticide application; vapor drift, which is the movement of fumes after the application of volatile pesticides; and wind erosion of treated soil. Small droplets are easily drifted due to wind compared to larger droplets. Generally, droplet sizes are influenced by the formulation of the pesticides, type of nozzle usage, pressure of the sprayer, and also weather conditions. Meanwhile, vapor drift that can cause pollution and damage to plants and human health generally moves into the atmosphere due to the high air temperature and also the vapor pressure of the pesticides. Besides, pesticide drift can also harm aquatic plants as it contaminates water bodies like ponds and streams.

More than that, water pollution due to pesticides can lead to significant threats not just to aquatic ecosystems but also to drinking water resources. As a result of agricultural application on fields, pesticides can contaminate nearby water bodies, such as from drifted pesticides and soil erosion from treated fields, through drain outflow, baseflow seepage, surface runoff, or even due to accidental spills. Other than that, soil can also be a medium for pesticides to move in the environment. The movement of pesticides in soil can be due to leaching, which is a downward movement passing through cracks and pores that may lead the pesticides to reach ground water. Pesticides can also attach to soil particles as they are transported by wind and water. Furthermore, wind erosion like dust storms can move high amounts of radionuclides, pesticide residues, and heavy metals, which then contaminate the agro-landscapes. Table 1 summarizes the fate and movement of pesticides in the atmosphere, aquatic system, and also in the soil-plant system [11]. The removal of pesticides can be done through WWTPs and constructed wetlands, by physical adsorption, biological degradation, and also through advanced oxidation processes [8].

Table 1. Fate and movement of pesticides in atmosphere, aquatic systems, and soil-plant system [7].

Atmosphere	Aquatic System	Soil-plant System
Application drift	Atmospheric deposition	Leaching
Post-application vapor losses	Surface runoff	Adsorption/desorption
Wind-erosion of pesticide-treated soil	Drainflow	Microbial degradation
	Leaching	Chemical degradation
	Spray drift	Photochemical degradation
	Point sources	Leaf-uptake root

2.3. Heavy Metals

Heavy metal contamination is a common issue that can be seen in every place in the world. However, urbanization has promoted severe issues where sources that have been identified to cause heavy metal pollution have included domestic effluents, pharmaceuticals, agricultural, industrial, and atmospheric sources [12]. Anthropogenic activities such as mining, smelting, and application of agrochemicals have posed threats to the environment. During anthropogenic activities, heavy metal effluents are discharged from the industry into the surface water while the soil water carries the toxic metals and diffuses them into the groundwater, causing water pollution. Heavy metal emissions into the atmosphere are permitted by smelting and mining activities. The types of heavy metals, including mercury, cadmium, lead, zinc, and manganese, have contributed to the greatest extent of heavy metal contamination [13].

Heavy metals are considered pollutants because of their toxicity, even when present at very low concentrations. Heavy metals should not be consumed by any organism due to their toxicity, as long-term exposure results in toxic accumulation inside the body tissues [14]. The accumulation of toxic metals will cause the dysfunction of body systems. As a result, it was concluded that improper heavy metal management can have serious consequences for the environment and biological life [15].

3. Mechanism of Technologies

In order to remediate the discussed pollutants, many mechanisms involving CNT technologies can be applied, including through adsorption, membrane filtration, disinfection, hybrid catalyst, and also sensing and monitoring.

3.1. Adsorption

Adsorption techniques have been frequently used in environmental remediation, such as gas adsorption, liquid adsorption, and organic and inorganic pollutant adsorption. It is a process where the adsorbate (present in a gaseous or liquid bulk) adheres to the surface of an adsorbent. Adsorbate does not diffuse into the adsorbent and only sticks to the surface of the adsorbent [16]. This process occurs in the environment naturally and is one of the techniques that are widely applied in the industrial process.

The categorization of CNTs as SWCNTs and MWCNTs has the morphology for both CNTs different, such that SWCNTs have smaller inner and outer diameters than MWCNTs [17]. Different morphologies of CNTs, such as the tube diameter and bundle geometry, will affect the adsorption of atoms or molecules [18]. When performing the adsorption, CNTs with a smaller size, a larger specific surface area, and a unique hollow and layered structure will have a higher capacity of adsorption [6]. Hence, SWCNTs are weaker than MWCNTs in adsorbing the adsorbate. However, the differences in bonding interactions between the molecules of contaminants result in each contaminant having its own adsorption capacity, which means different pollutants have different adsorption capacities. The CNT adsorption mechanisms for organic compounds are bonding interactions between contaminants' molecules, which include electrostatic interaction, hydrophobic interaction, hydrogen bonding interaction, and - bonding interaction [6]. Besides, the various bonding interactions of molecules can affect the electronic and transport properties of nanotubes [19]. In addition, heavy metal adsorption, including electrostatic attraction, surface precipitation, physical adsorption, and complexation, occurs between the metal ions and functional groups of CNTs [6]. Table 2 shows some examples of CNT adsorbents for organic and inorganic pollutants.

Table 2. Example of CNTs adsorbents for organic and inorganic pollutants.

Adsorbents	Pollutants	Remarks	Ref
CNTs	Microcystins (MCs)	- CNTs show higher adsorption affinity to MCs compared to activated carbon - Pore size of CNTs is fit for the molecular dimension of MCs - CNTs with smaller outside diameter could absorb more MCs	[21]
Amorphous Al_2O_3 supported on CNTs	Fluoride	- CNTs with supported Al_2O_3 may attribute to the nano-size Al_2O_3 clusters on CNTs and intrinsic adsorption capacity of CNTs toward fluoride due to having higher adsorption capacity towards fluoride - Broader pH range of pH 5-9 allows adsorption to perform well than that of the activated alumina (pH<6)	[22]
CNTs purified by HNO_3	Lead	- Adsorption capacity of acid-refluxed CNTs is higher than the activated carbon which are 11.2 mg/g and 5.5 mg/g respectively - Surface oxygen-containing functional groups are the most important fact for lead adsorption. Higher adsorption capacity of CNTs at pH=7 may due to the cooperating role of adsorption and precipitation	[23]
Ceria nanoparticles supported on CNTs	Arsenate	- Adsorbent that loaded with As(V) can be efficiently regenerated - Adsorption capacity of CeO_2 - CNTs towards arsenate can be enhanced by the presence of Ca^{2+} and Mg^{2+} ions in water which causing formation of ternary surface complex	[24]
MWCNTs	Polycyclic aromatic hydrocarbons (PAHs)	- Exhibited enhanced surface area, high binding affinity, higher capacity, and excellent thermal stability for PAHs - Under acidic and neutral conditions, the separation of emulsified oil from water are highly efficient	[25]
MWCNTs prepared using composite catalyst Co-Mo/MgO	Asphaltenes or heavy hydrocarbon	- Composites provide high adsorption capacity for asphaltenes removal	[25]
Oxidized MWCNTs	Methyl orange	- When temperature, agitation speed, and initial concentration increased, the adsorption efficiency also increased.	[26]
SWCNT-COOH	Methyl orange	- Factors such as ionic strength, initial concentration, sorbent mass, contact time, and temperature significantly affect the adsorption capabilities.	[26]
SWCNT-NH_2	Malachite Green	- Functional groups of $-NH_2$ are more active to absorb the dye pollutants than -COOH	

Apart from that, the geometric structure of CNTs would also affect its mechanisms, which are carrier localization and charge distribution. A bundle of CNTs will result in stronger molecule adsorption on the surface or inside of the nanotube, which is much stronger than just an individual tube [19]. Figure 1 shows the surface structure and adsorption sites for CNT in bundles [19]. CNTs in bundles have two kinds of adsorption sites: external sites (exterior and groove) and internal sites (interior and interstitial) [18,20]. According to the study done by Zhao et al. (2002), the adsorption ability and charge transferred for SWCNT are weak and small, whilst the adoption ability for CNT in bundles is high in interstitial and groove sites, which means the interior site is slightly more energetic than the exterior site. Hence, it can be concluded that the molecule's absorption can be enhanced by increasing the number of nanotubes used [19].

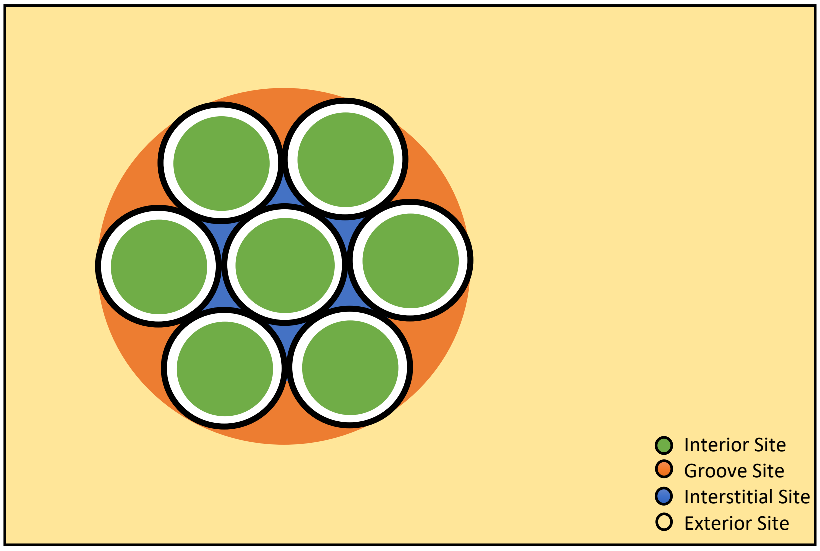

Figure 1. Surface structure of CNTs in bundle.

3.2. Membrane Filtration

In order to control quality of water to the extent that water is safe to drink, there are several methods have been used in water treatment or water purification system which one of them is membrane filtration technologies such as microfiltration, nanofiltration, forward osmosis and reverse osmosis [27]. CNT membrane is totally different from adsorption as it involves the filtration process which traps the contaminants from wastewater when it passes through the membrane [28]. CNTs are chosen to made membrane filtration due to several reasons such as having strong antimicrobial activity, tunable pore size and higher water flux than other porous materials [27].

To form an active adsorption layer, CNTs are combined with the membrane materials, which is also known as the general CNT membrane, where membrane materials with CNTs will trap contaminants from wastewater, including heavy metals and organic pollutants. Moreover, CNTs will not be released into the effluent as they are part of the membrane materials. There is another CNT filter named the electrochemical CNT filter where the CNT is combined with the anodic filter to degrade the organic pollutants and deactivate the bacterium. The mechanism obtained from this type of membrane filter is electrochemical oxidation degradation, where the organic pollutants are oxidized due to the loss of electrons when in contact with the anode filter [6]. They are highly recommended to be used in water desalination and water treatment plants due to their high efficiency in removing pollutants [28].

CNT membranes can be categorized into two groups according to their fabrication methods: (1) freestanding CNT membranes (vertically aligned CNT (VA-CNT) membranes and buckypaper CNT membranes), which is a membrane with drastically fast water flux suitable for water desalination and water and wastewater treatment applications (anti-biofouling membranes); and (2) composited CNT membranes (mixed-matrix CNT membranes, CNTs as the intermediate layer and CNTs coated on the membrane surface or support) [29,30], which is a combination of various traditional CNT membrane materials and their use in water desalination, oil-water separation, and removal of organic and inorganic pollutants. Figure 2 summarizes the development of CNT membrane types for water treatment [27]. The aligned

SWCNT and functionalized SWNT are expected to become the new trends for water purification.

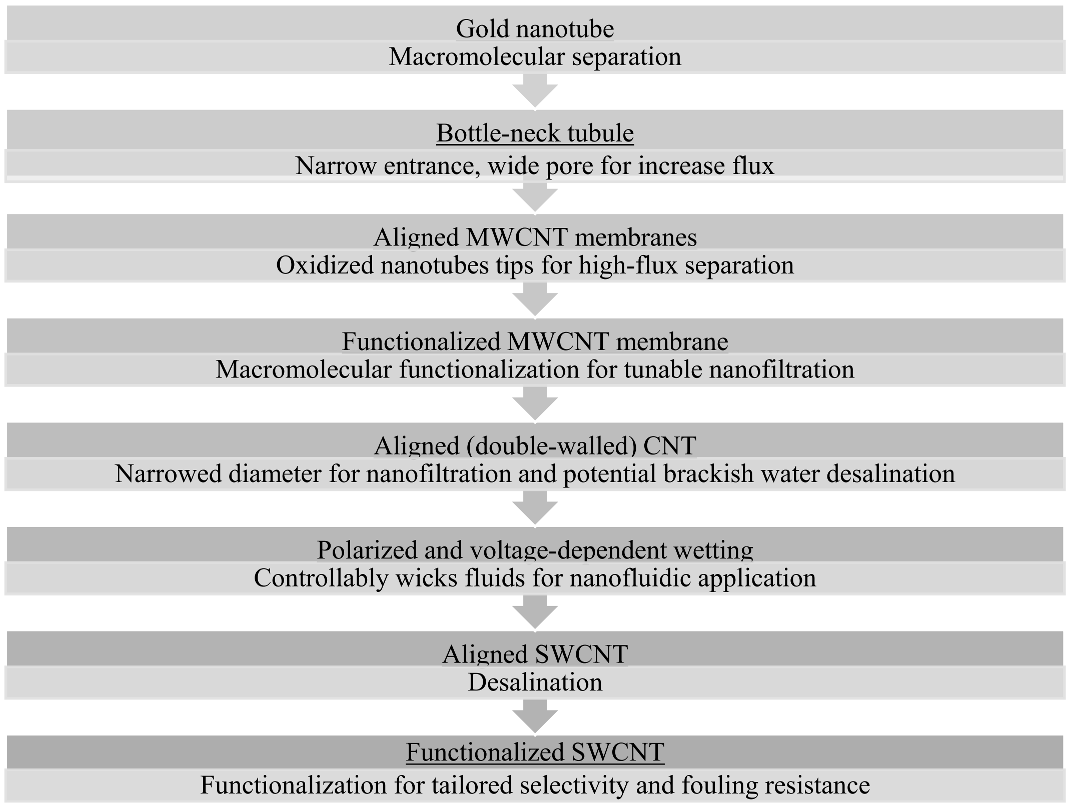

Figure 2. Evolution and types of CNT membranes for water treatment purpose [27].

3.3. Disinfection

Other than desalination, CNT membrane has also been used for removing disinfection by-products. As mentioned previosly, the application of CNTs in membrane technology has inactivated the bacterium [6]. The cell wall and membrane of the bacterium can be interrupted by the CNTs which then penetrate the cell body, thus, causing the damage to the DNA and protein dysfunction. Besides, there is also generation of secondary products (reaction oxygen species (ROS)) that will cause damage to the cell body [31]. Their ability of antibacterial are affected by their shape and size. Such adhesions of short CNTs onto the surface of the cell will cause the disruption of cell wall and leakage of the intracellular components [6,31,32].

Whilst, the long CNT will wrap the whole cell body. The chemical reactions that occur between the cell wall and the functional groups of CNTs will then produce ROS, which cause damage to the DNA and the oxidation of protein [32], where cell membrane damage and the leakage of intracellular contents are the mechanisms of CNTs to achieve the antibacterial effects [31]. The production of ROS and oxidation stress are also counted as another mechanism of the ability of CNTs to inactivate microbial cells where the harmful ROS is produced once the CNTs enter the body of bacteria.

3.4. Hybrid Catalysis

Hybrid catalysis offers the customization of synthetic catalyst and screening and is both cost-effective and environmentally friendly. There are several challenges that have arisen in hybrid catalysis that the presence of CNTs is capable of resolving. Catalysis can be divided into three categories: (1) photocatalysis, (2) catalytic wet air oxidation (CWAO) and (3) bio-catalysis.

3.4.1. Photocatalysis

Photocatalysis is a photoreaction that is accelerated by light or photons in the presence of a catalyst. Photocatalysis will need to improve its catalyst ability in response to visible light and reduce the electron-hole pairs with induced photons during photocatalytic recombination [6]. The CNT-based photocatalytic composites can be synthesized with two methods. The first method is through the synthetization of nanoparticles that are connected to the CNT via covalent (organic or bio-molecular linkers) and non-covalent interactions. The second method is through electrochemical deposition using the CNTs as the templates [33]. Through this method, a uniform composite nanomaterial can be obtained and, therefore, CNT is chosen as the suitable applicant in the photocatalysis process [28].

3.4.2. Catalytic Wet Air Oxidation (CWAO)

The ability of CWAO to degrade toxic and non-biodegradable contaminants through the basis of wet air oxidation (WAO) makes it one of the most cost-effective and eco-friendly processes [28]. The CWAO is efficient in removing organic compounds such as carbon dioxide (CO_2), hydrogen oxide or hydrogen polyoxide and other final products produced during the oxidation process, by which the WAO is widely applied in wastewater treatment systems [34]. However, its operating conditions and maintenance fees are too stringent and expensive, putting an end to the possibility of using them in treatment systems [35]. Nonetheless, the presence of CNT as the catalyst added to the WAO, forming CWAO, has greatly increased the possibility of using it in treatment systems. The surface chemistry of CNTs gives better catalytic performance of the CNTs for different applications [28]. There is no difference in mechanisms between WAO and CWAO except the addition of the catalyst into the oxidation process.

The enhancement in various sectors of the WAO due to the addition of catalyst, such as the operation conditions becoming easier, the reaction rates having improved, and thus reaction times becoming shorter, which promotes the application of CWAO in remediating pollutants. CWAO can be categorized into homogeneous and heterogeneous CWAO based on the difference in catalyst used. There are three further categories for heterogenous CWAO, which are non-noble metal catalyst, noble metal catalyst, and carbon catalyst [35]. The carbon catalyst was introduced in recent years and forms CNT-based WAO. Because of their unique thermal stabilities and chemical properties, carbon nanotubes (CNTs) are gaining more attention than other catalysts. The heteroatoms such as oxygen, nitrogen, and sulfur have high reactivity with the carbon surface. Table 3 summarizes the common heteroatoms introduced on the carbon surface, as well as their mechanisms for tuning the properties of CNTs [36]. The addition of a CNT catalyst such as in the MWCNT will greatly support the removal of total organic carbon (TOC) and other contaminants due to their pore structure, large specific area, and food stability. Thus, removal of TOC can reach 80% through the application of MWCNTs [37].

3.4.3. Bio-catalysis

Bio-catalysis is part of biotechnology that converts organic compounds into other products with a minimum of waste through the utilization of enzymes as the catalyst. The enzymes are fragile and prone to denature if the conditions such as pH and temperature are not suitable for their survival [38]. CNTs are used in bio-catalysis to immobilize enzymes and improve their catalytic stability, selectivity, and reusability [38,39]. For example, the immobilization of lipase on CNT can be done through adsorption to synthesis ester in a non-aqueous medium [39]. However, the enzyme immobilization on CNT is still facing certain difficulties, such as enzyme structural perturbation (covalent linking), leaching (physical adsorption), and low cost-efficiencies, which affect its opportunity to be widely utilized in the treatment of wastewater and water [39,40].

Table 3. Common heteroatoms and their mechanisms in tuning CNTs properties [36].

Heteroatoms	Mechanisms
Oxygen-containing surface groups	- Using nitric acid as reagent - Efficiency of oxidation treatment is depending on the method used, treatment duration, ratio of CNT/oxidant, and the concentration of acid used - Abundant oxygenated groups are generated on the carbon surface to remove amorphous carbon and metal impurities - Liquid-phase oxidation can be performed in a Soxhlet extractor or boiling the CNTs in nitric acid
Nitrogen-containing surface groups	- Nitrogen atoms can easily incorporate with carbon structure due to the similarity of nitrogen and carbon atoms' sizes - In order to incorporate nitrogen onto the carbon structure, in-site (during synthesis) or ex-situ (post-treatment) approaches can be used - Ammonia or nitrogen-containing carbon precursors, such as urea, melamine, polyacrylonitriles, polyvinylpyridine, and quinoline-containing pitch can be used in post-treatment to treat carbon materials
Sulfonic acid surface groups	- CNTs can achieve strongly acidic properties by incorporation of sulfonic acid groups - Oxidation with sulphuric acid or a mixture of sulfuric acid/nitric acid by hydrothermal methods is routinely used

3.5. Sensing and Monitoring

The demand for freshwater promotes the application of the biosensor to sense and monitor polluted water, as contaminated water introduces many pollutants. A biosensor is applied in water quality monitoring with the aim of toxic and bacteria detection [41]. The advent of CNTs has promoted the incorporation of CNTs into monitoring and sensing techniques due to their properties such as large specific surface area, excellent electrical conductivity, and superior mechanical strength [6]. The basic concept of a biosensor consists of two parts, which are the biological element and the transducer. The biological elements can be used to detect the presence of a substance while the transducer is the main stage of the biosensor which converts the information received from the biological elements into a signal to proceed to the next stage [41,42].

4. Challenges in Carbon Nanotube Applications

Even though CNTs are well-known in various sectors and have excellent potential in environmental remediation, there are still several obstacles that block the application of CNTs widely in industry and daily life.

4.1. Manufacturing Costs

The production cost of CNTs is one of the obstacles which blocked the chance for CNTs to be apply in the industrial application. Although the global CNT production has been increased in recent years, the CNT production and consumption have been continuously decreased from 1000 USD/kg to less than 50 USD/kg which failed to meet the expected annual production growth rate from year 2013 to 2018 [43]. However, it is still unaffordable for the company to apply CNTs in industry [6].

4.2. Toxicity and Environmental Risks

Other than that, CNTs have potential ecological risks for the environment and may impose risks on human health. The morphology and action mechanisms will affect the toxicity of CNTs [6]. Generally, raw CNTs pose a greater threat to the environment and human health as they are more toxic than functionalized CNTs [20], where CNTs have a risk of causing carcinogenicity and lung tumors [44]. Besides, CNTs can induce toxic effects on different organisms, such as earthworms and zooplankton [45]. However, there is still a lack of information and precautions about the potential effects on humans and the environment.

4.3. Public Acceptance

On the other hand, the development of technology is mostly based on public acceptance. Without public acceptance, the development of CNTs in environmental remediation will be difficult [6]. However, there are various aspects that lead to the public's less support. For instance, the limitations of CNTs' industrial applications are still unknown and there are no safety guidelines for CNTs to check whether which or what kinds of CNTs will affect their toxicity. Besides, exposure to CNTs may have risks for human health where the exposed workers may be affected by hypoxemia and lung disease after coming into contact with chemical paste that contains undefined nanoparticles [46]. Therefore, guidelines and risk assessment of CNTs should be developed to ensure the applications of CNTs in environmental remediation can be accepted by the public.

4.4. Advantages and disadvantages

Hence, CNT can be seen as an excellent technology that can help in remediating the environment. However, they do have their drawbacks. Table 4 lists the advantages and disadvantages of CNTs [7].

Table 4. Advantages and disadvantages of CNTs

Advantages	Disadvantages
- Excellent to replace the metallic wires due to their lightweight and are extremely small in sizes	- The working of CNTs is not easy to understand even all research have been done through
- The production of CNTs needs many kinds of resources but the production of CNTs only requires small amount of the resources to manufacture	- It is difficult to work with the nano size of CNTs
- Able to function in extreme temperature which mean they are resistant to temperature	- The operation condition to produce nanotubes are relatively expensive
- Enhance the conductive mechanical properties of composites	- This new technology will take sometimes to replace the old technology as they still need further investigation to study their potential effects on human and environment
- Application of nanotubes in hybrid catalyst decrease the reaction time and operation conditions	- At the rate of technology has been becoming obsolete it may be a gamble to bet on this technology

5. Conclusions

The application of CNTs in environmental remediation is very useful through various mechanisms such as adsorptive, membrane filtration, disinfection, hybrid catalyst, and also sensing and monitoring. To treat different types of pollutants, the CNTs are required to either be oxidized or synthesized into different forms so that they can employ their function. Nevertheless, the production costs, toxicity, ecological risks, and public acceptance have blocked its way to protecting the environment and controlling pollution. It is believed that CNTs can have safety guidelines and risk assessments to assess the safety of using CNTs, which can promote and enhance the application of CNTs in the near future.

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Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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