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The role of nanotechnology, based on carbon nanotubes in water and wastewater treatment

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ABSTRACT

One of the biggest challenges of the 21st century is the shortage of potable water coupled with increasing water pollution, industrialization and, an ever increasing population. Water is needed to sustain all socio-economic activities which render it vital for life support on earth. Owing to these circumstances, it has become imperatively significant to develop an active method to monitor and control these pollutants in the aquatic environment. Recently, different materials made of carbon nanomaterial have been widely used to construct different types of electrical electrodes to make biosensors and electrochemical sensors. Some of the materials made from carbon nanomaterial s include but not limited to; carbon nanotubes, grapheme, carbon nanohorns, and carbon black. Carbon nanotubes (CNTs) have contributed to the production of active electrochemical sensors/filters as an effective alternative technique in the field of water pollution control. CNT biofilters are generally known to absorb organic and chemical pollutants as a result of their intrinsic characteristics of high flexibility, effective stability, and wide surface area. They also exhibit the quality of electro-oxidation of the adsorbed pollutants which has been attested as potential water and wastewater treatment technology in different laboratory experiments. Active electrochemical CNT has also aided in the stability, sensitivity, and selectivity of filters/sensors. In the field of nanotechnology, CNTs have been discovered to display great water and wastewater treatment potentials due to their superb physiochemical characteristics. The modern technologies that have focused on the utilization of CNTs in the area of water and wastewater treatment technology predominantly used the carbon-based material as membranes or filters, adsorbents, electrodes and catalyst to degrade pollutants in water or wastewater. This study intends to explore and make a general overview of the role of nanotechnology, based on CNTs in water and wastewater treatment.

Keywords: Carbon nanotube filters; Adsorbents; Photocatalysis; Wastewater treatment; Membrane; Electrodes

1. Introduction

Many developing countries are challenged with the bane of water pollution and scarcity. Increasing population concentration and economic growth have greatly contributed to the increased discharge of wastewater. This has further increased the demand for clean water for various purposes [1–3]. Also, given the limited supply of potable water resources, many development stakeholders have applied different measures to treat and reuse wastewater or to reduce the rate of exploitation of the natural freshwater [4,5]. These steps can help to mitigate the challenge

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associated with a limited supply of clean water and treat wastewater effectively [6,7].

Wastewater has been reported by experts to contain different ranges of pollutants [8–12] which when released directly into the environment without effective treatment, pose health threats to humans and aquatic organisms [1,10,13–15] thereby causing environmental degradation [16]. Contaminants are released from both point and nonpoint sources into water bodies [17,18].

Different conventional or traditional methods have been applied to treat wastewater with different constituents of contaminants such as heavy metals, organic pollutants, and emerging pollutants among others [19–21].

However, some of the traditional or conventional wastewater treatment techniques have been noticed to be associated with high operational cost, low efficiency, and high energy usage and production of large volumes of sludge after treatment [8]. Due to the above challenges, some of the contaminants are not effectively removed or degraded in the traditional treatment system. Therefore, more advanced, energy-saving methods, cost-effective, and highly efficient technologies are required to achieve the main purpose of wastewater treatment with less or no challenges [22].

Owing to these circumstances, it has become imperatively significant to develop an active method to monitor and control these pollutants in the environment [8].

Recently, different materials made of carbon nanomaterial have been widely used to construct different types of electrical electrodes to make biosensors and sensors of electrochemical [23,24]. Some of the materials made from carbon nanomaterials include but not limited to; carbon nanotubes [25], grapheme [24], carbon nanohorns [26], and carbon black. Different studies revealed that these materials have enhanced characteristics such as large surface area, affect thermal and electrical conductivity, outstanding catalytic properties, and excellent electron transferability [24,27].

After their discovery in 1991, carbon nanotubes (CNTs) have appealed the attention of many scientific researchers to solve different developmental challenges. In the field of nanotechnology, CNTs have been discovered to display great water and wastewater treatment potentials due to their superb physiochemical characteristics and properties [28].

The modern technologies that have focused on the utilization of CNTs in the area of water and wastewater treatment have predominantly used the carbon-based material as membranes or filters, adsorbents, electrodes, and catalyst to degrade pollutants in water or wastewater [29].

As well known, many emerging technologies are not without some limitation of which CNTs are not left out. Some commercially available CNTs are known to have high prices which limit their access and large scale application especially in third world countries [30]. Nonetheless, research and efforts have been advanced to mitigate the cost-limitation by trying to find out more effective CNTs at low cost [23,31]. In consideration of the high potentials CNTs exhibit in wastewater treatment, the material can be redesigned and modified to poses higher efficacy at low cost. This can increase the quantity demanded of the product especially in developing countries [25,26,32]. Furthermore, CNTs can be amalgamated into already existing low-efficient technologies such as traditional techniques to boost and improve the rate of contaminant breakdown and removal in the wastewater treatment system.

2. CNTs as adsorbents: CNTs as adsorbents for removal of organic and inorganic pollutants

Adsorption has become one of the most effective and efficient methods applied in the field of water and wastewater treatment for the removal of organic and inorganic contaminants [34,35]. Different adsorbents such as zeolite [36] resin and activated carbons (ACs) [37], have been utilized in this regard to achieve the purpose of water treatment. Among the common available types of adsorbents widely used for water and wastewater treatment, ACs have demonstrated higher efficacy and advantages of other existing ones which include; chemical stability, higher rate of pollutant removal and heat conductivity [36].

Nonetheless, like other adsorbents, ACs applications in wastewater treatment also have some drawbacks including regeneration problems and slow kinetics of adsorption. In order to address this menace challenge, activated carbon fibers (ACFs) were transformed as the second cycle of carbonaceous adsorbents. The pore spaces with the ACFs have direct and large openings on the exterior of carbon background, which quickens the adsorption rate of contaminants. Therefore ACFs normally have stronger kinetics than ACs. Some researchers have maintained that CNTs may be potential their group or generation of carbonaceous adsorbents [29].

CNTs are carbonaceous materials with a cylindrical shape nanostructure which may exist in a form of single-walled, double-walled and multi-walled nanotubes reliant on the mode of synthesizes [38]. CNTs also present significant number of adsorption points with large surface area, rending it advantageous to hold sustainable surfaces. In the process of application, CNTs need to be stabilized to avoid aggregation that may cause decrease in surface characteristic. Therefore CNTs are sustainable and reliable products applied in the adsorption technique of pollutant degradation [24].

The use CNT as an adsorbent started as early as 1991 then attracted higher attention in the past few years [39]. CNTs target different range of pollutants/compounds with different structures and morphology in wastewater to remove them.

Various aspects of CNT characteristics and performance have been studied to justify their strengths and opportunities. These include solution chemistry (including the ionic capability, solution pH among other) and operation factors such as electrostatic interaction, hydrophobicity, electron donor-acceptor (EDA) interaction and hydrogen bonding [24].

According to Celik et al. [25] CNTs, because of the hydrophobic nature of their outer surfaces, CNTs have attraction to organic chemicals such as naphthalene, pyrene and phenantherene [41] due to their surface hydrophobic characteristics.

Some researchers also focused their investigation into the adsorption process of different polar and nonpolar contaminants onto CNTs and suggested that the effect of hydrophobicity of CNTs was not the most dominant effect or mechanism but concluded that the interaction between anions and cations of various materials could be the leading effect. There also exist variations between the rate of adsorption of phenantherene and tetracene on top of the CNTs due to their consequence of nanoscale curvature [30].

To overcome the challenges of water scarcity in arid and other developing countries, brackish water desalination with electrical power generation has been adopted as one of the best solutions to this problem. However, the available traditional desalinations techniques require high energy consumption rate and require intensive technical know-how. Therefore, different studies, focused on the adoption of adsorption method for water and wastewater treatment as well as saline water desalination. Nonetheless desalination through adsorption technique is also bedeviled with other technical challenges which limit their rate desalination. Based on the above, some researcher like Shi et al. [42] proposed the application modifies plasma CNTs with ultramodern capacity twice-higher than the conventional carbonaceous wastewater and water treatment methods.

These types of modified CNTs simultaneously remove salt as well as organic and inorganic contaminants from water and wastewater. Future tools and equipment for water filtration, treatment and disinfection installed with these types of CNTs are expected to have higher efficiency and capacity [43].

Few years ago, a group of researchers from USA also developed a sponge-like CNTs containing a dash of boron that's exhibits the capability to absorb or removes oil from water. The retrieved oil can be contained in the CNT-sponge can be reused for other purposed or burnt to recycle the product.

Adsorption can be described as a process in which contaminants are absorbed on a solid surface from a solution. Adsorption process usually happens under physicals mechanism however; sometimes partial chemical bonding also takes place during adsorption [44].

3. Catalysts or catalyst support; CNTs in photocatalysis

The usage of CNTs has proven to be superb catalyst-supporter due to their operational and morphological tendencies which include; wide specific surface area of over 150 m^2/g [51].

The adsorption of chemicals prior to the breakdown of contaminants by heterogeneous catalysis is most suitable with the Langmuir–Hinshelwood mechanism [26].

In this case, the wide specific area characteristic of CNTs put them in the advantageous side of greater adsorption rate of aqueous pollutants.

CNTs could also be modeled with hydroxyl and carbonyl moieties through acidic treatment then further transformed to upgrade the adsorption capacity for some specific elements such as the degradation of contaminants with high toxicity levels.

Also, the regular surface structure of CNTs mitigate the challenge associated with mass transfer of reaction agents from aqueous solution to the surface functional points on the catalyst.

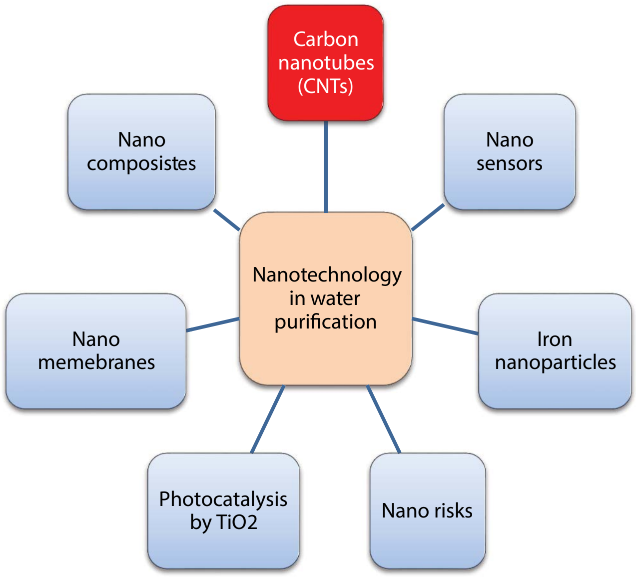

Fig. 1. Major nanotechnologies used in water and wastewater treatment. *Source*: Adapted from Kunduru et al. [33].

CNTs also possess resilient and much more durable characteristic which renders them with proper thermal stability function and can be utilized in extreme conditions.

3.1. CNTs application in photocatalysis

Photocatalysis is derived from two Greek word which is "photo" (light) and "catalysis" (decomposition). Therefore, photocatalysis basically means decomposition or breakdown of chemical compound with the use of light. Scientists have not come to a general consensus for the definition of the term "photocatalysis". However a more general understanding of the term in academia is that, photocatalysis can be described as process of stimulating compounds through the use of ultraviolet rays (UV) or solar energy. Photocatalysts alter the rate chemical reaction without interference in the chemical development process. Unlike the conventional thermal catalysts which are activated though heat energy; the photocatalysts are stimulated through the means of light energy.

Nanophotocatalysts are usually applied in the field of water and wastewater treatment methods due to their excellent chemical and physical characteristics.

The topic of photocatalysis has gained much attention in the breakdown of organic contaminants for many years [52]. Globally recognized conventional photocatalysts include CdS, TiO_2, Fe_2O_3 and ZnO among others. These photocatalysis are also classified as semiconductors which possess some demerits like other semiconductors. TiO_2, ZnO and CdS are disadvantaged with; inability to harvest the array of solar-light, possess photocorrosion characteristic and minimize photostability and activity respectively.

Due to their superb electrical, surface optical and resilient features, CNTs are best form of alternative building blocks in crossbreed catalysts and enhance the activities of photocatalysts. Some CNTs are classified under metallic or semiconductors based on their chirality and diameter.

Table 1
Overview of types of nanomaterials applied for water and wastewater technologies

Nanomaterial	Properties		Applications	Novel approaches	Reference
	Positive	Negative			
Nanoadsorbents	High specific surface, higher adsorption rates, and small footprint	Expensive production inputs	Point-of-use, removal of organics, heavy metals, bacteria		[45]
Membranes and membrane processes	Reliable, largely automated process	Comparative high energy demand	All fields of water and wastewater treatment processes		[46]
Nanometals and nanometal oxides	Short intraparticle diffusion distance compressible, abrasion resistant, magnetic Photocatalytic (WO_3, TiO_2)	Less reusable	Removal of heavy metals (arsenic) and radionuclides, media filters, slurry reactors, powders, pellets		[24]
Nanoadsorbents					
Polymeric nanoadsorbents (Dendrimers)	Bifunctional (inner shell adsorbs organics, outer branches adsorb heavy metals), reusable	Complex multistage production process	Removal of organics and heavy metals	Biodegradable, biocompatible, nontoxic bioadsorbent (combination of chitosan and dendrites)	[24]
Zeolites	Controlled release of nanosilver, bactericidal	Reduced active surface through immobilization of nanosilver particles	Disinfection processes	Nanozeolites by laser induced fragmentation	[36]
Carbon nanotubes	Highly assessable sorption sides, bactericidal, reusable	High production costs, possibly health risk	Point-of-use, heavily degradable contaminants (pharmaceuticals, antibiotics)	Ultralong carbon nanotubes with extremely high specific salt adsorption	[24]
Nanometals and nanometal oxides					
Nano zero-valent iron	Highly reactive	Stabilization is required (surface modification)	Groundwater remediation (chlorinated hydrocarbon, perchlorates)	Entrapment in polymeric matrices for stabilization	[47]
Nanosilver and nano-TiO_2	Bactericidal, low human toxicity nano-TiO_2: high chemical stability, very long life time	Nanosilver, limited durability nano-TiO_2, requires ultraviolet activation	Point-of-use water disinfection, antibiofouling surfaces, decontamination of organic compounds, remote areas	TiO_2 modification for activation by visible light, TiO_2 nanotubes	[48]
Magnetic nanoparticles	Simple recovery by magnetic field	Stabilization is required	Groundwater remediation	Forward osmosis	[27]

(*Continued*)

Table 1 Continued

Nanomaterial	Properties		Applications	Novel approaches	Reference
	Positive	Negative			
Nanomembranes					
Self-assembling membranes	Homogeneous nanopores, tailor-made membranes	Small quantities available (laboratory scale)	Ultrafiltration	Process scale up	[46]
Aquaporin-based membranes	High ionic selectivity and permeability	Mechanical weakness	Low pressure desalination	Stabilization processes (surface imprinting, embedding in polymers)	[40]
Nanofiltration membranes	Charge-based repulsion, relative low pressure, high selectivity	Membrane blocking (concentration polarization)	Reduction of hardness, color, odor, heavy metals	Sea water desalination	[49]

Source: Adapted from Gehrke et al. [50].

Furthermore, CNTs possess large capacity for storing electrons which was also estimated that carbon atoms single walled CNTs can store significant number of electrons [53]. As CNTs come into contact with nanoparticles of TiO_2, they initiate the transfer of electrons to the CNT surface from the conducting band of TiO_2. In other words, CNTs are affinitive to and store photogenerated electrons and hinder the re-amalgamation of holes and electrons. Thereafter these electrons can be transferred to different electron acceptor which breakdown and minimize organic pollutant in water or wastewater.

Current research has showed successful combination of CNTs with TiO_2 nanoparticles as composites in the degradation and oxidation of some pollutants. These two composites (CNT/TiO_2) have been applied in some studies to breakdown and oxidize phenol. This was achieved mainly due to the minimized charge recombination which is a reflection of the fact that, reduced intensity of photoluminescence and single-walled carbon nanotubes (SWCNT) improved the photocatalytic activity of TiO_2 better than multi-walled carbon nanotubes (MWCNT) due to additional individual connection between SWCNT and the TiO_2 nanoparticle surface [43,54].

Some researchers have also revealed that CNTs can also act as photosensitizers.

Then insert the photo-electrons into the conducting band of TiO_2 due to their semiconductor characteristics [55].

Also, combining CdS with CNTs have the potential to inhibit the photocorrosion feature associated with CdS applications only. This can be attributed to the fact that, CdS responsive-transparent photocatalyst. The CdS/CNT combination improves the adsorption capacity by capturing and stabilizing CdS and reducing the agents in the aqueous solution [41].

Photocatalysis is an advanced stage of oxidation process which is applied in the areas of water and wastewater treatment to remove microbial pathogen and micropollutants. It has been reliably reported in different articles that majority of organic contaminants can be broken-down by heterogeneous photocatalysis [56,57].

3.2. CNTs application in moisturized-air oxidation

Moist air oxidation has been defined as a continuous process whereby the oxygen in air is used to degrade suspended particles or dissolved organic pollutants in water or wastewater. This method has been applied in the field of water purification for over six decades. However, this method is challenged with high cost and limited operation reactions which hampers its wider application in purifying wastewater from industrial sources. Several studies have reported that, in order to address the above limitation, an active catalyst in moist air oxidation should be applied to reduce cost and improve the operating efficiency [58].

Due to the excellent characteristics, CNTs have been discovered to as one of the best catalyst that transform wet air oxidation process in degrading toxic and organisms in contaminants from wastewater [59].

In other studies too, CNTs been combined with pd, Ru and pt as catalysts in wet air oxidation process to oxidize aniline and phenol among other pollutants wherein successful outcomes were achieved [24,60].

4. Membranes: CNT membranes for water purification

The application of membrane technology has attracted the attention of many researchers for several decades which also cover nanofiltration, reverse osmosis, ultrafiltration, and microfiltration, among other membrane techniques employed in the field of water and waste water treatment. Membranes made from polymers have also gained wide application treatment plants for their merits which include but not limited to, mechanical and chemical stability. Nonetheless, polymer membranes are limited by their hydrophobic high rate of organic foulants adsorption. In addition, the irreversibility of adsorbed inorganic

Table 2
Types of nanomaterials and their features

Types of nanomaterials			Feature	Source
SWCNT	MWCNT	Double-walled carbon nanotubes	Untreated	[32,34,63,64]
Oxidized SWCNTs	Alkali-activated MWCNTs		Treated	[65,66]
	MWCNTs activated with KOH		Treated	[67]
	Carboxylated multi-walled carbon nanotubes		Treated	[45,67]
	Pristine and hydroxylated MWCNTs		Treated	[45]
	Chitosan/Fe_2O_3/MWCNTs		CNTs based nanocomposite	[27]
	Calcium alginate/MWCNTs		CNTs based nanocomposite	[27]
	MWCNTs/$CoFe_2O_4$		CNTs based nanocomposite	[68]

Source: Adapted from Madhura et al. [69].

and organic elements on surface of the membrane could contribute to fouling and flux-diminish [29,61].

Researches have proven that CNT can cause high fluidability under relatively low mechanical pressure [24].

Due to their intrinsic mechanical and chemical strengths including strong antimicrobial activity and proper flux, CNTs exhibit higher potential of substance separation and filtration than other related materials [61].

4.1. CNT filters as anti-microbial materials

Due to increasing urbanization, industrialization coupled with increasing population concentration, water pollution levels are concurrently increasing globally with their adverse impact on human health and the ecology. The threat imposed on human health by water pollution due to the presence of disease causing agents such as bacteria has been addressed by previous studies [62]. Hence, the degradation and removal of these bacteria and other microorganism wastewater and drinking water is very paramount for ensuring sustainable livelihood [16].

The special group of CNTs popularly known as SWCNTs has been known to possess higher antimicrobial functions [45,53].

Furthermore, SWCNT and MWCNT filters exhibit great bacterial retention and high virus-related microorganisms removal at relatively low pressure respectively [24,27].

In another studies, through the application of external electric field, CNT filters removed virus at significantly high rate as a result of better viral particle transport [54]. Elsewhere, when silver nanoparticles [47] and silver nanowires [49] were respectively combined and used with CNTs it led to improved antibacterial activity of the CNT filters which were prepared through simple filtration. Based on the above, it is clear that CNT filter exhibit some potential over other traditional filters. They can be cleaned severally through simple autoclaving and ultrasonication processes

4.2. CNTs as additives for anti-fouling membranes

Membranes sometimes do go under fouling based on the connection between foulant and surface of the membrane which also depend on characteristics of the two materials. One of the best methods applied to control fouling of membrane surface chemistry is tuning [43,70].

In order to improve the surface characteristics of the membrane one most commonly applied technique is to improve its surface hydrophilicity to make strong in resisting fouling. This can simple be achieved to the fact that most organic foulants are hydrophobic in nature. Even though CNTs are intrinsically known to be hydrophobic, they can simply converted to hydrophobic through acid modification method.

Celik et al. [25], reported that CNT blended polysulfone membrane polyethersulfone membrane have improved anti-fouling characteristic because of their hydrophilic carboxylic groups they belong to [30].

Different functional groups applied on CNT surface including hydrophilic isophthaloyl chloride groups and amphilic-polymer groups with protein resistance capability have been demonstrated by [70] and [34], respectively.

Studies have also shown that membranes developed with lager breadth CNTs were stronger in foul control than membranes constructed with smaller size CNTs which can be attributed to the efficacy of a large-size CNT to eliminate bigger organic contaminants from water or wastewater [41].

4.3. Aligned CNT membranes for future seawater desalination

In the era of global crises of potable water supply and usage brackish water desalination is receiving greater application due to its contribution in the provision of fresh water for domestic, agricultural, commercial and industrial purposes. Most, modern desalination technologies depend on reverse osmosis polymer-membranes to screen out suspended particles and dissolved minerals (salt). The operation mechanism of the desalination technique basically operates under high energy supply and pressure.

Previously, it was estimated and speculated through mathematical calculation and empirical experiments that water carries many orders of magnitude faster in CNTs than other traditional porous materials [71].

This high flux can be associated to the internal walls of the CNTs which are hydrophobic and smooth in nature.

Within the water and CNTs interface-interaction hydrogen bonds are produced and bring forth vaporized condition serving as a border between the nonpolar CNT wall and the range of water molecules.

Hence, the aligned CNT membrane walls have the propensity to serve as high-flux desalination membranes.

To fully understand the concept of aligned CNT membranes, through catalytic chemical vapor deposition created sub-2-nm aligned nanotube membranes. Theses group of nanotube-based membranes exhibited higher efficacy of water absorbency than conventional available polycarbonate membranes [30].

Also, in another studies, lager-diameter and perpendicular aligned CNT membranes were designed and created by [38,46].

5. Electrodes; CNT electrodes for microbial fuel cell

As water crises continue to be a development constraint worldwide, different sustainable approaches to curb this challenge are been investigated into [54,72]. Different method of wastewater treatment has been in implementation to encourage water reuse, avoid water pollution and subsequently reduce the dependence on the natural fresh water [4,16,56,73,74]. As a sustainable technique in field of wastewater treatment, microbial fuel cell (MFC) has become one of the most commonly employed biological treatment method which has gained wide research attention and industrial application [75]. MFC is a wastewater treatment system with internal electrical power generation efficiency through the utilization of microorganisms. The operation of MFCs, pollutant removal and electricity generation depend on the environmental and performance conditions which surrounds it activities. Some of these conditions include temperature, pH, chemical oxygen demand (COD), electrode material and microbial specie type [83,84].

Within the anode of the MFCs, the microorganisms that transport electrons to the electrodes known as the exoelectrogens–microorganisms degrades the organic pollutants in the wastewater.

The anode pole best operates when its material has powerful conductivity, large specific area for the attachment and growth of the microbial community and high catalytic activity.

Until recently, carbon-based materials including carbon foam, carbon paper and carbon cloth among others are utilized in in the manufacturing process of several MFCs-anode poles but are challenged with little electro-catalytic activity for reactions in the electrode microbial community.

Therefore, CNTs possessing higher conductivity surface area can a potential source of anode-material however; they also have cellular toxicity which can lead to cell death rending it ineffective for direct application.

A practical solution to the above limitation is the coating of CNT surface with conductive polymers including polypyrrole [85] and polyaniline [83] to utilize as anode-material to improve the charge transferability.

In addition, to improve the surface characteristics of CNTs and make them biocompatible, surface oxidation process can be used for the modification.

Yue et al. used oxidized MWCNT as anode modified with microsized MFC through oxidation method [55].

Within the cathode of MF, oxygen usually accepts electrons as the most sustainable and dependable medium electron acceptor. Nonetheless the operation of MFC is sometimes threatened by weak oxygen reactions under harmonious activity. Therefore CNT-cathodes can enable the transfer of electrons and improve oxygen reduction due to their shape and size [34].

Hence, it can be concluded that based on the excellent properties of CNTs and their superb electrical characteristics, it renders is potential MFC electrodes for future-large scale application.

6. Working principles of electrochemical CNT filters for water and wastewater treatment

Electrochemically active (EA) CNT filter were produced as an improved technique for water and wastewater treatment during the past decade. CNT filters are used to adsorb organic and inorganic pollutants mainly due to their large specific surface area, great elasticity and resilient chemical stability [28].

EA-CNT filters also generate extra value by eletro-oxidizing the trapped pollutants which has been justified as excellent water and wastewater treatment method in other studies [23].

The linking of CNT filter with electrochemical process has widened the scope of CNT application in wastewater and water treatment. The merging of the two distinct aspect of chemistry has helped in the large application of; corrosion control, electroanalytical sensors, separation, electroplating as well as environment protection among others. The environment application of this technology covers batteries, sensing of environmental compounds and water purification which been reviewed and reported in earlier studies [86]

Existing research also experimented and revealed that CNT filters are effective in eliminating aquatic organic contaminants such as pharmaceuticals, phenol, salts, azo dyes, viruses and perfluorinated chemicals from water and wastewater.

Also, the combination of CNT with electrochemistry has the potential to minimized fouling of filters by biological function inactivation and on-site foulant destruction.

Actually, CNT-filters contain uncountable tubes that are connected with each other through van der Waals forces of attraction which give rise to high specific surface area that has the potential to absorb biological and chemical pollutants.

The general mechanism for the electrochemical filtration include hydrodynamically enhanced mass transfer, temperature-dependent physical adsorption or desorption, and voltage-dependent direct electron transfer [86].

Electrochemical oxidation process for organic pollutant uses lesser time compared to the traditional biological water and wastewater treatment technologies. Also, complex contaminants that escape other treatment methods are further electrochemically oxidized through CNT filters.

7. Conclusion and recommendation

CNTs designed and modeled based on nanomaterials poses numerous benefits over other traditional materials in the areas of water and wastewater treatment as well as other environmental application.

The limitations of the conventional nano-based materials have led to search for other alternatives which are cost effective and high efficient in water purification technology. One of such sustainable and viable techniques is the integration of CNT into other commonly available water and waste water treatment technologies.

In order to totally utilize the operation potential of CNTs, macroscopic manipulation and Surface modification are usually applied to enhance the surface, chemical, physical and electrical characteristics of the material.

In as much as more efforts have been implored to highlight the advantage of utilizing CNTs in water purification, it is equally important to take note of its limitation to put into consideration during large scale application. As reliably reported by expects in its research, CNTs operate more appropriately at point of usage applications (POU). As filters made of CNTs have the potential to remove different categories of inorganic or organic contaminants they thus, have the propensity to replace traditional decontamination and adsorbents agents in POU system. Hence great precautions should be observed to curb the infiltration ability of CNTs into potable water.

The application of some simulated pollutants including dyes and phenol have been discussed for CNT-catalytic activities, therefore, more attention should also be geared towards biodegradation of other potential chemicals which are applied in complement with CNT-catalysts. Their degradation as well as modification process should be studied further to fully understand the dynamics that are associated with them.

In all, the following conclusions can be made from the above comments on the role of nanotechnology, based on CNTs in water and wastewater treatment.

CNTs have the potential to active remove microbes by adsorbing and killing of microorganisms. The excellent filtration capability of CNTs are rooted in their intrinsic characteristics such great antifouling activity, higher physical strength and high porosity rate. However, CNTs are still being limited by high industrial cost, control challenges associated with aligning of CNTs and operationalization.

Predictability of CNT adsorption capacity via simulation of molecules is an easy to evaluate it potential in that aspect. Therefore, CNTs have been proven to be more effective in adsorbing contaminants than activated carbon. This could be attributed to their simple regeneration, greater adsorption selectivity and mechanical strength.

CNTs also serve as one of best alternatives support for catalyst due to their high adsorption capacity, high electrical current generation and high mechanical strength.

CNTs used as composites with catalysts such as TiO_2 can improve photoactivity and result in obtaining efficient charge.

The potential leakage associated with CNT devices should be vigilantly examined before the real-world application due to the cytotoxicity they have been proven to contain.

Much scientific experimentation are currently running in different institutions around the globe with the motive of finding long-lasting, cheaper, eco-friendly and quality nano-based products for water wastewater purification. Some studies have demonstrated the successful and effective application of CNT-based nano-materials for water treatment that meet the international standard of WHO guidelines for potable drinking water. As earlier discussed, extra investigations need to be carried out to emerging risks associated with CNTs in water and wastewater treatment. In the light of this development, some expects have envisioned that CNTs as nanotechnologies will soon be seen acting a vibrant and vital role in water stressed regions by supplying quality and affordable water.

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