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Review

A Review on Carbon Nanoparticles (CNPs): Synthesis, Mechanism of Antimicrobial Action, Applications and Toxicity Effect

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Abstract. CNPs are nanoparticles of carbon in the range of 1nm and 100 nm possessing exceptional physical, biochemical, optical and electrical properties. They may be 0-D, 1-D or 2-D based on their dimensions relevant to nano scale and can be formed by several techniques and processing methods possessed distinguishable properties. They can perform immense antibacterial movements and also retain nano toxicity. The paper discuss various production methods of CNPs and also provide a comprehensive view of their applications in medical field especially and various other fields like energy sectors and environmental protection. The previous paper describes the future outlook of carbon nano devices and that they had become and are still growing as an essential component in most of the fields.

Keywords: carbon nanoparticles, synthesis of CNPs, antimicrobial application, toxicity

Introduction

Carbon (a Latin word means coal) is crucial for living creatures and form the basis of life. Carbon can occur as hard as diamond and as soft as graphite. Carbon nanomaterial's are particles of carbon in nano scale (<100 nm) and these NPs are typically in the range of 10-45 nm with definite surface area of 30-50 m^2/g. CNPs are enticing attention in recent years because of their unique physical, biological, chemical, electrical and optical features and due to these properties, they catch a vast series of applications in many fields. (Nalwa, 2004) Due to their great thermal and electrical conductive properties, they are widely used in thermal management and as electrodes. Moreover, their loose coupling between their layers allow them to be used as a lubricant in various industries such as graphite. Various CNPs such as Fullerene molecules due to their diversity in size and properties are widely used in many areas just like solar cells, drug delivery etc. Several organic and inorganic materials may be coupled to CNPs in nano range via covalent bonds or wander walls' force and referred as functionalization of CNPs and find applications in fuel cells, sensors, photo switches and various nano electronic devices (Gogotsi and Presser, 2013; Bystrzejewski *et al*., 2007).

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CNPs can be categorized on the basis of dimension as there exists different kinds of CNPs having different dimensions. They can be zero dimensional, one dimensional or two dimensional as discussed. 0-DCNPs are those nano materials which possess no dimension other than nano scale. These include, fullerene, onion like carbon, nano diamond etc. 1-DCNPs are those which include one dimension extra than nano scale. These may include carbon nano fibres, carbon nanotubes and others. 2-DCNPs possess two dimensions further from nano scale. These include: Graphene, carbon nano wall and many more. 3-DCNPs are usually made by building blocks of 0, 1 and 2 DCNPs. These may include Graphene sponge and can be in powder form, fibrous or layers and have promising applications in super capacitors (Subramoney, 1998).

This review paper discusses CNPs in a brief and comprehensive manner. This paper helps the readers to demonstrate the categories of CNPs on the basis of dimensions and then synthesis of each particle by various methods and discusses the most suitable method such as CVD for CNTs and PECVD method for carbon nano walls. It is made possible to understand the properties and applications of CNPs involved in various phenomenon of our daily life. It is discovered that CNPs can also be used as an antimicrobial agent in addition to silver CNPs in the previous literature and also demonstrated that in spite of containing the carbon as a main particle, they can also possess toxicity. As CNPs especially CNTs find wide range of promising applications in various fields which are discussed in the last section.

Literature review. The history of CNPs can be traced back to the discoveries of different types of CNPs such as CNTs and graphite and carbon fibres. The idea about graphite sheet tubes reported by (Zou *et al*., 2006). In 1981, a group of researchers published chemical and structural properties of CNPs. In cylinder-shaped carbon fibres, the discovery of nano tubes of carbon can be traced back to 1991, when MWCNTs were firstly introduced by Iijima. Later SWCNTs were also discovered in trying to produce MWCNTs. At the same time, on the day of May 24th, Bethune *et al*. (1993) the US team, also claimed the discovery of CNTs (Monthioux and Kuznetsov, 2006; Iijima, 2002).

After the discovery of CNPs, a tremendous amount of work was done on CNPs due to their high emergence in most of the areas of life especially in recent years because of their exceptional properties and behaviour. In 1991, when Haddon *et al*. (1991) reported that when fullerene (CNP) is doped with various alkali metals, they act as a superconductors. They had also prepared C-60 and C-70 doped alkalis and reported their conductive properties. Similarly, Hebard *et al*. (1991) discovered potassium doped with C-60 as a superconductor (Hebard *et al*., 1991). After few years, Brown *et al*. (1999) discovered that when volume of unit cell was increased, it resulted in elevation and transition of temperature of superconductors of CNPs. This proves the possession of superconductive properties by CNPs such as Fullerene.

Nano diamonds has also been the great attention seeker for most of the recent years. Iakoubovskii *et al*. (2008), by using HRTEM demonstrated large surface area of nanoparticles along with 5 nm diamond grains in cubic lattice structure. By FTIR study, Ji *et al*. (1998), discovered that NDs are perfect water adsorbers and can also adsorb hydrocarbon molecules from the environment sphere. (Iakoubovskii *et al*., 2008; Ji *et al*., 1998). The experimental measurements using microscopy method demonstrated the tensile load strength of CNTs (Yu *et al*., 2014). Similarly, Ruoff *et al*. (1993), demonstrated that under the effect of Vander Waals forces, nano tubes are deformed. Zhou *et al*. (2002) studied and generalized the properties of SWCNTs such as possession of high electrical properties. Dai (2002) discovered that CNTs possess almost three times greater current density than ordinary metal. Moreover, Takesue *et al*. (2006) reported that MWCNTs possess superconductive behaviour 30 times more than SWCNTs. In 2009, Mizuno *et al*. (2009) referred CNTs as practical black body by demonstrating that SWCNTs possess absorbance in between UV and IR wavelengths. (Meyer *et al*., 2007; Bellucci, 2005), studied the single layer Graphene structure by TEM and explained that they possess crystalline structure with only single atom thickness of membranes in ripple form rather than flat. Novoselov *et al*. (2004), showed the Dirac's notation for transportation of electron in Graphene. The dependence on temperature and their intrinsic and extrinsic properties respectively (Xiao *et al*., 2005).

The promising applications of CNPs in electrochemical sensors. Because of unique characteristics and sensitivity of CNPs enable them to be used in sensing instruments. They also discovered that NPs can also be employed as biochemical and electrochemical nano sensors because of their inert properties. Therefore CNPs can be employed as nano sensor and are attracting great attention of researchers. Reinhard Nesper *et al*. (2006) discussed the phenomenon of how CNPs and high magnetic NPs are produced by with carbon coating. They inferred that when metal carbides are decomposed at higher temperature, they produce large range of CNP. Similarly CNTs and CNFs were also produced by Lithium Carbide at low temperature (Nesper *et al*., 2006).

A review paper by SSN Fernando *et al*. (2008) discussed the antimicrobial properties and mechanism of their actions showing that CNPs can be employed as antibiotic drug delivery systems (Seil and Webster, 2012). Similarly a paper by Ong *et al*. (2010) especially focuses on the applications of CNTs in environmental protections such as in removal of air pollution and waste water treatment and in various energy renewable methods. Another paper submitted by Dehdashti *et al*. (2017) describes various applications and employment of CNPs in environmental protection and in many other fields. And demonstrated that CNTs have high potential and thus encourage feasible development. (Thostenson *et al*., 2001) later the applications and implementations of CNPs in analytical chemistry were also demonstrated and further worked on magnetic nano particles with carbon coating through various experimental results.

In short, there is a lot of literature supporting CNPs and their synthesis, properties and usage in tremendous applications (Chou *et al*., 2001).

Synthesis of CNPs. There are different methods to synthesize different kinds of CNPs. 0-DCNPs are synthesized by different techniques than 1-D and 2-D. These methods are described below:

ZERO-DCNPs. ***Fullerene*.** Fullerene also known as bucky ball named after a scientist Lorance and Fuller (2009). These are confined carbon atoms in globular shape containing polyhedral form just like a soccer ball. They can be synthesized by laser vapourization of carbon in inert atmosphere and by Arc Discharge method. Both these methods make tiny amount of fullerene. Other methods to produce bulky amount of fullerene were also suggested such as combustion process and manufacture of C-60 and C-70 from chloroform *via* microwave plasma at lowest pressure argon atom as well as by pyrolysis of naphthalene at 1000 °C. These methods help to produce large amount of fullerene cages with fine aromatic fragrances (Kroto *et al*., 2012).

The crystalline structure of Fullerene is shown in the below Fig. 1a and Fig. 1b.

***Nano diamond*.** Diamond is allotropes of carbon but in harder form. It contains sp^3 bonded carbon atoms in tetrahedron form and is regarded as precious of all gemstones due to its exclusive physical, chemical and electrical insulation qualities. ND possess strong diamonds but its size range is in nm. Two key approaches are used to produce ND. One is conversion from graphite by keeping temperature and pressure high. It is also regarded as 'man made diamond'. The other one is detonation of carbon explosives in a steel vessel under vacuum condition with a negative oxygen balance. Detonation method is widely used but the problem is that diamond produced is impure and impurity is difficult to remove. Later some other methods have been developed such as excessive energy X-ray deflection and electron irradiation method for the creation of pure CNPs at low cost (Hawelek *et al*., 2008).

ONE-DCNPs. ***Carbon nano fibres*.** Carbon nano fibres are made up of Graphene layers in gambled and warped form in 1-D. They show a discrepancy from few to 100 nm. CNFs are synthesized by various methods such as ion beam irradiation, ultrasonic spray pyrolysis and plasma enhanced CVD in which Carbon Nano fibres are produced by catalytic breakdown of hydrocarbn over a nickel catalyst at high temperature for larger scale production. The resulted NFs have diameter of 80 nm and length from several to ten micrometers and have better electrochemical properties shown in Fig. 2 (Xia *et al*., 2005; Harris and Tsang, 1998).

***Carbon nanotubes*.** These are rolled graphite sheets into tube-like form by sp^2 bonding. There are two types of CNTs, one is single wall and other is multi wall CNTs. SWCNT are made of single layer, while MWCNT are made of many layers of Graphene. These have diameter in nano scale but larger length ratio. By Arc Discharge method, SWCNT are made by using Ni or Fe catalyst and shrill anodes with bored holes, while

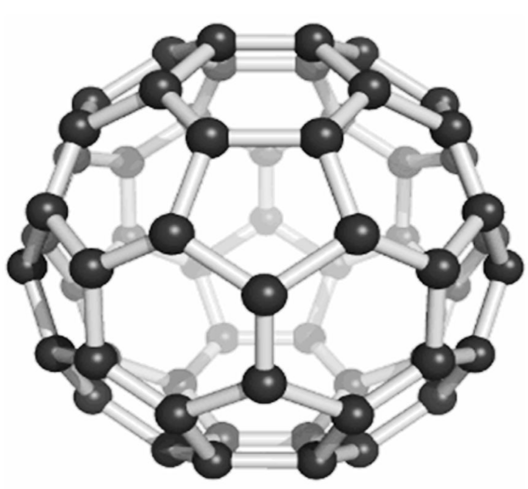

Fig. 1a. Crystal structure of Fullerene (Kroto *et al*., 2012).

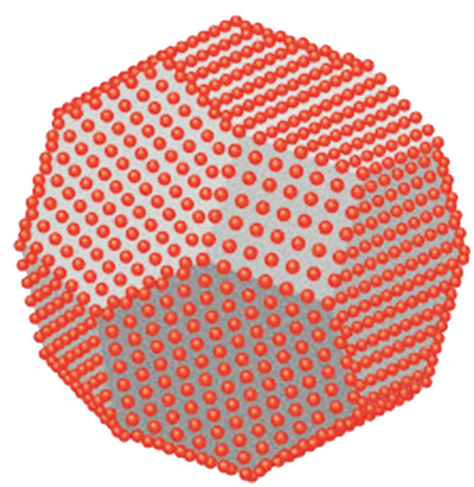

Fig. 1b. Crystal structure of Fullerene (Hawelek *et al*., 2008).

MWCNT by two upright thin rods in a gas mixture of argon and methane using small iron pieces. By Arc Discharge method and Laser Ablation, CNTs are produced in large amount but impurity and high temperature are the drawbacks. Chemical vapour deposition have been successfully using as alternative (Awasthi *et al*., 2005; Popov, 2004).

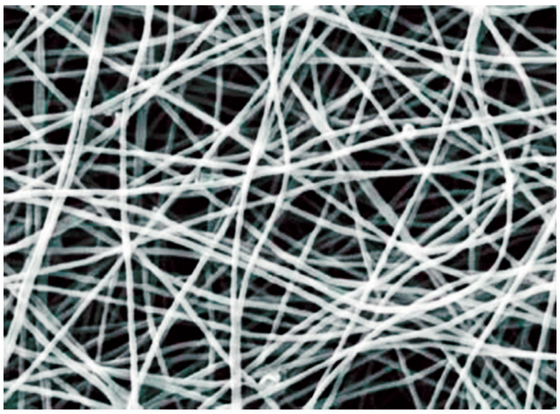

Fig. 2. Structure of carbon nano fibres (Xia *et al*., 2005).

The schematic diagram of MWCNT is shown in Fig. 3.

TWO-DCNPs. *Graphene*. It is a 2-D CNP comprising of thick layer of C atom in sp^2 bonded form. They are building blocks of 1 and 2-D CNTs which is shown in Fig. 4.

They can be synthesized by mechanical and chemical exfoliation and epitaxial growth. Mechanical exfoliation uses 3D Graphene and mined a single sheet called micromechanical cleavage. This produces a high quality samples of Graphene (Seyller *et al*., 2008). In chemical method, reactants are injected to weaken wander Waals forces to form graphite oxide. Then by reduction, Graphene sheet is formed. This method is cheap and rapid. In epitaxial growth, using thermal deposition by epitaxial growth of Graphene on metal carbides by producing the Graphene. It is used to produce large scale production but consequences are high temperature and adsorption energy (Bhuyan *et al*., 2016).

Carbon nano walls. These are Graphene sheets affiliated steeply forming 2-D structure and piercing edges. They are usually formed by microwave PECVD and radio-frequency PECVD and hot water CVD and others. In RFPECVD, they are synthesized without any kind of catalysts, whereas HWCVD provides large scale production. CNTs can be made by a substrate of nickel layered oxidized silicon. In RF, Arc plasma beam with acetylene at 600 °C. Their production had been proved by various spectra and their properties depend upon catalyst and nature of active gas (Mostofizadeh *et al*., 2011; Wu *et al*., 2002) in Fig. 5.

Summary of all methods. Different methods of synthesis of zero, one and two dimensional CNPs are discussed above briefly and demonstrated the most suitable method for their production. Here presents an overview of all the methods for their synthesis which is present in Fig. 6.

Antimicrobial activity of CNPs. Nanotechnology is finding extensive applications in many fields especially in medicine. NPs possess antimicrobial properties and

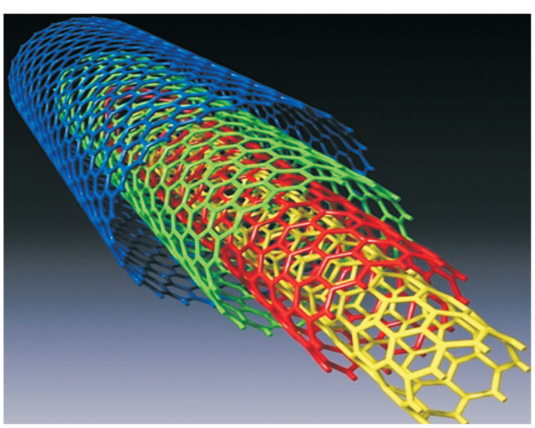

Fig. 3. Multi walled carbon nano tubes (Awasthi *et al*., 2005).

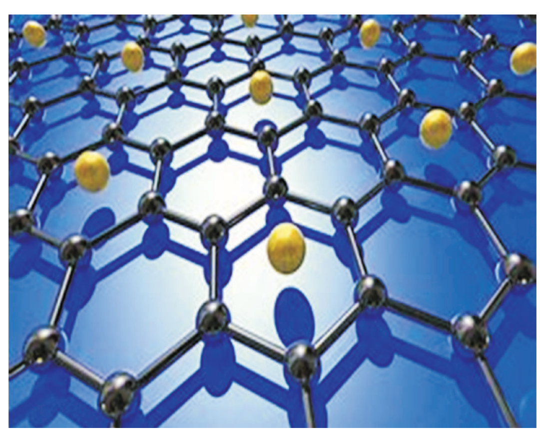

Fig. 4. Crystal structure of graphene (Bhuyan *et al*., 2016).

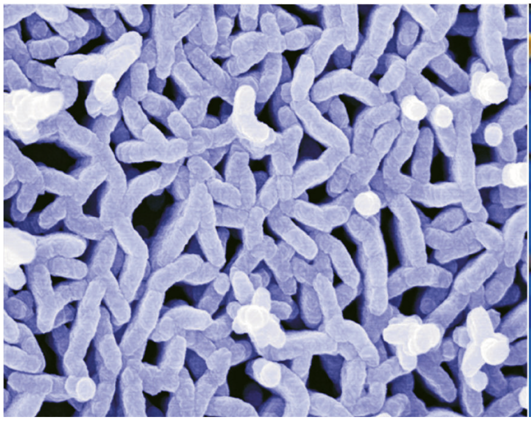

Fig. 5. Structure of carbon nano walls (Wu *et al*., 2002).

LDC-nanomaterial	Synthesis methods
Fullerene	Laser vapourization, Arc discharge, Combustion, Microwave plasma pyrolysis, Flat flames
Nano diamond	MPCVD, hot-filament, CVD, pulse laser ablation, electro irradiation, High energy X-ray diffraction
Carbon nano fibres	Traditional vapour growth, catalytic combustion, PECVD, Hot filament-assisted sputtering, ultrasonic spray pyrolysis, Ion beam
Carbon nano tubes	Arc discharge, laser-ablation, CVD, other methods
Graphene	Mechanical exfoliation, epitaxial growth, Chemical exfoliation
Carbon nano walls	MWPECVD, REPECVD, HWCVD, EBEPECVD

Fig. 6. Overview of methods of synthesis (Mostofizadeh *et al*., 2011).

thus can be used as a substitute to antibiotics to overcome the complications due to multidrug resistance in bacteria. The mechanism followed by them is that they accomplish action by contacting cell wall without piercing in cell wall. The bacterial resistance to NPs is much lower than as compared to other antibiotics. CNPs have shown wide action against various bacteria, fungi and mycobacteria. Their low surface to volume ratio and small size also play vital role in increasing its action. Particle size, shape and zeta potential also play vital role in enhancing their action (Chen *et al*., 2013).

CNPs such as graphene, CNTs diamond like carbon have wide antiseptic properties but the mechanism they tracked is fairly complex. Fullerene cause membrane and DNA damage and destroy the energy metabolic pathway. It also creates ROS on surface by exposure to light and increase antibacterial activities. CNTs have stronger influence than fullerene, they perform action by wrapping around bacterial cell. Effectiveness of their action is dependent on diameter, functional group, catalyst, coating and length. CNPs can cause severe damage to structure of their cell wall and membrane and their metabolic mechanism. Graphene cause antibacterial actions by segregating bacteria from environment and it became difficult for bacterial survival. Its actions are dependent upon sheet size, number of layers and nano pores. Whenever CNPs intermingle with bacterial cell reactive oxygen is formed, removal of oxygen and oxidation state also help in increasing their actions. Their antimicrobial accomplishments can be boosted by surface modification of NPs. Addition of various components such as polymers and peptides to CNPs can result in increased activities (Al-Jumaili *et al*., 2017).

Toxicity of CNPs. It is a fact that CNPs due to their inimitable properties are a potential aspirant for a multiplicity of a biomedical applications which are discussed later in the paper. But when these NPs are injected in any biological system, there also rise some kinds of risks which can prove injurious to mankind and environment. The potential study of this fact is known as Nano toxicity. Earlier, some researchers claimed that there is no apparent toxicity of CNPs. However, later some researchers reported significant toxicity of CNMs in cell culture and in vivo animals. The most important CNPs involve CNTs and Graphene. CNTs are 1-D and can be single walled (SWCNT) and MWCNT with 1-2 nm diameter. While Graphene is a 2-D CNP and possess almost similar structure and chemical composition. Here, we will discuss toxicity of CNPs in terms of CNTs and Graphene. Toxicity of NPs depend upon various factors such as shape, concentration and surface properties of CNPs (Nerl *et al*., 2011).

Effect of shape or concentration. It can be demonstrated as follow, when SWCNT and Graphene were exposed to neuronal PC12 cells under similar conditions and cell was evaluated. It was found that with higher concentration, SWCNT were highly toxic than Graphene but with lower concentration, Graphene was found to be more toxic. As CNTs are more fibrous tubes and flexible material, thus they can easily penetrate into cell membrane and then cytoplasm by "Snacking Effect". As snacking effect refers to their shape ability, thus we can conclude that concentration and shape of CNPs play vital role in toxicity of CNMs (Win and Feng, 2005).

Role of surface properties. To understand surface effect on toxicity, it is essential to control other parameters such as size, nature, superficial charge, strength and pureness. When toxicity of SWCNTs-polyethylene glycol (PEG) and Pristine SWCNTs was evaluated by observing mitochondrial function and membrane activity, it was observed that SWCNTs-PEG was little toxic than uncovered SWCNT. Thus it was concluded that external covering of CNPs changes their biophysical interaction with numerous biological system and thus affect their toxicity (Wang *et al*., 2013; Akhavan *et al*., 2012).

By surface modification of CNPs, cellular interaction can be enhanced that results in decreased toxicity while, uncoated CNTs and graphene possess higher toxicity and can be dangerous to biological organisms. CNPs can be coated by single stranded DNA and PEG which result in altered physical properties but have promising applications for cancer therapy, tissues regeneration, Sensors and in biological treatment. But before using coated CNPs in human, further systematic evaluation and study is required to understand their toxic effect, so that they can be proved beneficial. Otherwise, whenever exposed to CNPs, it can result in DNA damage and mutation that can cause cancer. This effect is known as Genotoxicity (Lindberg *et al*., 2009). Still many researchers are working and studying on toxic and genotoxic effect of CNTs and methods to control this effect. A huge amount of work is also available in this perspective (Zhang *et al*., 2014).

Applications of CNPs. Due to their distinctive physical, electrical and optical characteristics, CNPs found a vast range of applications in biomedical field such as in biosensors, gene, RNA, tissues engineers, drug delivery, regenerative medicine, anti-tumor agent and hyperthermia treatment of cancer (Baughman *et al*., 2002). Their applications in various fields are described below:

CNPs based antibiotic delivery system. Various NPs have potential to act as a medium and carrier for antibiotic drug delivery. CNPs are among of them. Their small size and smaller mass to volume ratio, enhance their antibiotic action and can be employed as drug carrier. To boost their action, antibiotics can be coupled to CNPs. Due to their suitable sizes and shapes, they can be proved valuable for antibacterial chemotherapy, in biological fluids and storage. They also preserve micro biome unlike other antibiotics which adversely affect them (Chen *et al*., 2013; Dastjerdi and Montazer, 2010). Due to progress and synthesis of CNPs, it has become possible to develop novel antimicrobial agents. They exert activity using complex mechanism which depend upon various factors such as size, charge, morphology and surface coatings. Their antimicrobial activities found massive range of applications especially in medical field and industry to provide conventional methods for treatment of infections, as well as in biofilms control (Wang *et al*., 2017).

Efficacy of CNPs and functionalized derivatives in cancer therapy. We know that better CNPs and their derivatives found promising applications in most of the fields' especially biomedical field. Recently, a new type of C derivative, carbon coated metallic NPs (CCMNPs) is attracting great attention for cancer therapy. Due to their exclusive thermal and chemical constancy with magnetic stuffs. As discussed earlier, carbon coating decreases toxicity by providing anti oxidizing layer. This is more stable than MNPs or of oxides. CCMNPs entering in the cell or by attaching to the surface of cell act as constrained heat absorbers and by heating the cancerous cells, collapse them when exposed just before RF energy. Moreover, Panc-1 pancreatic cancerous cells and MCF-7 breast cancer cells are highly destroyed by using the phenomenon. This can be explained as below: When breast cancer cells were exposed to MNs alone, only 37.3% of the cells were destroyed but when exposed to CCMNPs followed by RF treatment, almost 92.8% of MCF-7 cells were demolished successfully. Panc-1 cancer cells by exposing to MNPs show higher resistance than MCF-7 cells. This can be treated by using Multi modal CCMNPs. Thus by using CCMNPs, which destroy cancer cells by absorbing RF energy, some drugs can be produced whose small concentration is enough and thus decreases other adverse effects while successfully controlling cancer cells. There observed 3.5 fold increase in cancerous cellular deaths by using drugs made of CCMNPs (Mahmood *et al*., 2009; Hampel *et al*., 2008) in Fig. 7.

CNPs in renewable energy. Energy consumption has been increasing day by day to meet the needs of life. Thus, to become essential to introduce new technologies for renewable energy sources. CNPs such as CNTs can be used in photovoltaic devices that converts photons absorbed from Sun and produce electricity. Si based photovoltaic devices are costly and less stable so, CNTs can replace them due to their affordable prices and

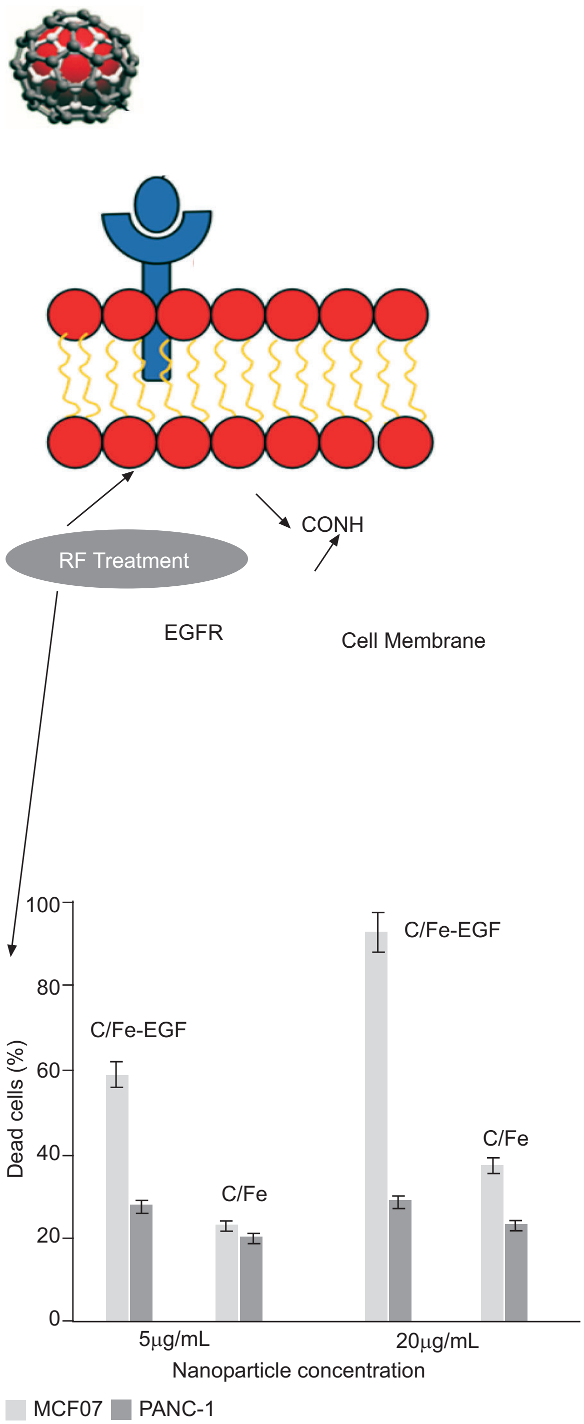

Fig. 7. CCMNPs for RF cancer treatment (Zhang *et al*., 2014).

notable energy transformation. Also energetic superficial area of CNTs in nano scale permits more photons to be absorbed for producing energy and mobility of charges can be increased by delocalized electron. Thus, it become clear that CNTs play an important role in renewable energy especially solar energy consumption. In addition to solar energy (Zhang *et al*., 2013; Dash *et al*., 2006). CNTs can be used as a storage media for hydrogen, as H is relatively clean fuel than conventional fuels, can be used to develop green energy technologies. CNTs because of their affordable prices, recycling process, little density, pore scope nano dissemination plus thermal, chemical constancy can be used to as a medium for hydrogen storage. Studies have shown that hydrogen amount adsorbed is dependent on orientation and array of CNTs. SWCNTs due to their large bulk density have activated carbon and thus enhances volumetric storage at lower temperature and high pressure. There is 30% increase in hydrogen storage capacity when CNPs were doped with transition or alkali metals under room temperature. But unfortunately, CNTs are still far away from meeting DOE target (min 6.5% weight H storage) and thus more efforts and studies are required to use CNPs as storage medium. (Mauter and Elimelech, 2008) (Tibbetts *et al*., 2001).

CNPs in green nano composites design. As the world grows economically, waste is generated proportionally. Several steps such as recycling process and avoiding waste production are taken. A new technology such as synthesis of green nano composites can be employed to waste treatment. It involves using natural renewable resources and biodegradable polymers as a substitute to non-renewable polymers. But the problem involve is that these polymers retain poor mechanical characteristics and little thermal stability. CNMs can be used as nano reinforcements to extend thermal stability and to improve mechanical properties and durability such as for poly (butylene succinate), increases by 10 °C by implementation of CNTs. Moreover CNPs due to degradation of polymer can be used for reuse and recycling process (Ong *et al*., 2010; Krueger, 2008).

CNPs in removal of pharmaceutical pollutants. Common methods of savage are not enough to remove hazardous chemical constituents from the environment. Increasing population and changing lifestyle causes increase in consumption of pharmaceutical products. These drugs entered in environment and because of higher aqueous solubility, they also accumulated in humans, animals and plants. They are non-degradable and can't be aloof by traditional methods. Some other methods such as advanced oxidation, reverse osmosis and activated carbon can be used as alternative methods. Adsorption method has also proved beneficial for removing it. CNTs can be thus used to remove these products and achieve success by 93%. The removal of amoxicillin and atenolol with 94% efficiency of CNPs were also revealed in various studies (Bina *et al*., 2012).

CNPs in removal of heavy metal and dye. Some heavy metals are crucial for human health but some are toxic and hazardous. These heavy metals don't dispose of from body and mount up in fat muscles, tissues, and cells that can end result in cancer and neurological disorders, kidneys and respirational problems. Instead of mundane methods like chemical and electrical precipitation, CNTs can be used to eradicate them. It had been proven that CNTs can eliminate heavy metals with 85% effectiveness (Ghanizadeh and Asgari, 2009). Dye is toxin in wastewater and even small expanse of it can be proved as dangerous. Various industries uses dye for products making which can be proved perilous for aquatic life and human as well. Beside coagulation, advanced oxidation, CNTs can be instigated to remove dye products from water. Studies have publicized that CNTs can eradicate dye with 89% efficacy (Dehdashti *et al*., 2017).

Other applications of CNPs. CNPs can be used in super capacitors as an electrode material and replaces traditional batteries. CNPs can be employed for purification of waste water, in treatment of Leachate, in removal of petroleum compounds and in many fields of Biotechnology as discussed earlier and many other (Helland *et al*., 2007).

Conclusion

As discussed in the paper, the exclusive and admiring characteristics of CNPs have made them an attraction for most of the researchers and they had been playing important role in various medical and engineering fields such as in transistors, energy storage, DNA, medical cure and in removing ecological pollutants. They are not just limited to carbon nanotubes but also involve various other forms as discussed in above section. They can also play a role of antibiotics due to inimitable properties. It has become clear that CNPs and other Nano devices are becoming more and more essential for future life and can be proved much favorable if wisely handled as they also have nano toxicity (Schrand *et al*., 2009).

Conflict of Interest. The authors declare no conflict of interest.

References

Akhavan, O., Ghaderi, E., Akhavan, A. 2012. Size-dependent genotoxicity of graphene nanoplatelets in human stem cells. *Biomaterials*, **33:** 8017-8025.

Al-Jumaili, A., Alancherry, S., Bazaka, K., Jacob, M.V. 2017. Review on the antimicrobial properties of carbon nanostructures. *Materials*, **10:** 1066.

Awasthi, K., Srivastava, A., Srivastava, O. 2005. Synthesis of carbon nanotubes. *Journal of Nanoscience and Nanotechnology*, **5:** 1616-1636.

Baughman, R.H., Zakhidov, A.A., De Heer, W.A. 2002. Carbon nanotubes the route toward applications. *Science*, **297:** 787-792.

Bellucci, S. 2005. Carbon nanotubes: Physics and applications. *Physica Status Solidi (c)*, **2:** 34-47.

Berl, H.C., Cheng, C., Goode, A.E., Bergin, S.D., Lich, B., Gass, M., Porter, A.E. 2011. Imaging methods for determining uptake and toxicity of carbon nanotubes *in vitro* and *in vivo*. *Nanomedicine*, **6:** 849-865.

Bethune, D., Kiang, C.H., De Vries, M., Gorman, G., Savoy, R., Vazquez, J., Beyers, R. 1993. Cobalt-catalysed growth of carbon nanotubes with single-atomic-layer walls. *Nature*, **363:** 605-607.

Bhuyan, M.S.A., Uddin, M.N., Islam, M.M., Bipasha, F.A., Hossain, S.S. 2016. Synthesis of graphene. *International Nano Letters*, **6:** 65-83.

Bina, B., Amin, M., Rashidi, A., Pourzamani, H. 2012. Benzene and toluene removal by carbon nanotubes from aqueous solution. *Archives of Environmental Protection*, **38:** 3-25.

Brown, C.M., Taga, S., Gogia, B., Kordatos, K., Margadonna, S., Prassides, K., Pattison, P. 1999. Structural and electronic properties of the noncubic superconducting fullerides A4′C 60 (A′ = Ba, Sr). *Physical Review Letters*, **83:** 2258.

Bystrzejewski, M., Lange, H., Huczko, A., Elim, H., Ji, W. 2007. Study of the optical limiting properties of carbon-encapsulated magnetic nanoparticles. *Chemical Physics Letters*, **444:** 113-117.

Chen, H., Wang, B., Gao, D., Guan, M., Zheng, L., Ouyang, H., Feng, W. 2013. Broad-spectrum antibacterial activity of carbon nanotubes to human gut bacteria. *Small*, **9:** 2735-2746.

Chou, T.W., Thostenson, E.T., Ren, Z. 2001. Recent advancements in carbon nanotubes and their composites: a review: *Composities Sciences and Technology*, **61:** 1899-1912.

Dai, H. 2002. Carbon nanotubes: opportunities and challenges. *Surface Science*, **500:** 218-241.

Dash, R., Chmiola, J., Yushin, G., Gogotsi, Y., Laudisio, G., Singer, J., Kucheyev, S. 2006. Titanium carbide derived nanoporous carbon for energy-related applications. *Carbon*, **44:** 2489-2497.

Dastjerdi, R., Montazer, M. 2010. A review on the application of inorganic nano-structured materials in the modification of textiles: focus on anti-microbial properties. *Colloids and Surfaces B: Biointerfaces*, **79:** 5-18.

Dehdashti, B., Pourzamani, H., Amin, M., Mokhtari, M., Babaei, F. 2017. A review of the performance of carbon nanotubes in reducing environmental pollution. *Journal of Environmental of Health Sciences and Development*, **2:** 300-311.

Fernando, M.M., Stevens, C.R., Walsh, E.C., DeJager, P.L., Goyette, P., Plenge, R.M., Rioux, J.D. 2008. Defining the role of the MHC in autoimmunity: a review and pooled analysis. *PLoS Genetics*, **4:** e1000024.

Ghanizadeh, G., Asgari, G. 2009. Removal of methylene blue dye from synthetic wastewater with bone char. *Iranian Journal of Health and Environment*, **2:** 104-113.

Gogotsi, Y., Presser, V. 2013. *Carbon Nanomaterials*: 2nd edition, pp. 529, CRC press.

Haddon, R., Hebard, A., Rosseinsky, M., Murphy, D., Duclos, S., Lyons, K., Kortan, A. 1991. Conducting films of C60 and C70 by alkali-metal doping. *Nature*, **350:** 320-322.

Hampel, S., Kunze, D., Haase, D., Krämer, K., Rauschenbach, M., Ritschel, M., Hoffmann, V. 2008. Carbon nanotubes filled with a chemo-therapeutic agent: a nanocarrier mediates inhibition of tumor cell growth.

Harris, P., Tsang, S. 1998. A simple technique for the synthesis of filled carbon nanoparticles. *Chemical Physics Letters*, **293:** 53-58.

Hawelek, L., Brodka, A., Dore, J.C., Honkimaki, V., Tomita, S., Burian, A. 2008. Structural studies of nanodiamond by high-energy X-ray diffraction. *Diamond and Related Materials*, **17:** 1186-1193.

Hebard, A., Rosseinky, M., Haddon, R., Murphy, D., Glarum, S., Palstra, T., Karton, A. 1991. Potassium-doped C60. *Nature*, **350:** 600-601.

Helland, A., Wick, P., Koehler, A., Schmid, K., Som, C. 2007. Reviewing the environmental and human health knowledge base of carbon nanotubes. *Environmental Health Perspectives*, **115:** 1125-1131.

Iakoubovskii, K., Mitsuishi, K., Furuya, K. 2008. High-resolution electron microscopy of detonation nanodiamond. *Nanotechnology*, **19:** 155705.

Iijima, S. 2002. Carbon nanotubes: past, present, and future. *Physica B: Condensed Matter*, **323:** 1-5.

Ji, S., Jiang, T., Xu, K., Li, S. 1998. FTIR study of the adsorption of water on ultradispersed diamond powder surface. *Applied Surface Science*, **133:** 231-238.

Kroto, H.W., Fischer, J.E., Cox, D. 2012. *The Fullerenes: Newnes*, e Book ISBN: 9780080984728.

Krueger, A. 2008. New carbon materials: biological applications of functionalized nanodiamond materials. *Chemistry-A European Journal*, **14:** 1382-1390.

Lindberg, H.K., Falck, G.C.M., Suhonen, S., Vippola, M., Vanhala, E., Catalán, J., Norppa, H. 2009. Genotoxicity of nanomaterials: DNA damage and micronuclei induced by carbon nanotubes and graphite nanofibres in human bronchial epithelial cells in vitro. *Toxicology Letters*, **186:** 166-173.

Lorance, L., Fuller, R.B. 2009. *Becoming Bucky Fuller*: MIT Press.

Mahmood, M., Karmakar, A., Fejleh, A., Mocan, T., Iancu, C., Mocan, L., Li, Z. 2009. Synergistic enhancement of cancer therapy using a combination of carbon nanotubes and anti-tumor drug. *Nano Medicine*, **4:** 883-893.

Mauter, M.S., Elimelech, M. 2008. Environmental applications of carbon-based nanomaterials. *Environmental Science and Technology*, **42:** 5843-5859.

Meyer, J.C., Geim, A., Katsnelson, M., Novoselov, K., Obergfell, D., Roth, S., Zettle, A. 2007. On the roughness of single-and bi-layer graphene membrances. *Solid State Communications*, **143:** 101-109.

Mizuno, K., Ishii, J., Kishida, H., Hayamizu, Y., Yasuda, S., Futaba, D.N., Hata, K. 2009. A black body absorber from vertically aligned single-walled carbon nanotubes. *Proceedings of the National Academy of Sciences*, **106:** 6044-6047.

Mostofizadeh, A., Li, Y., Song, B., Huang, Y. 2011. Synthesis, properties, and applications of low-dimensional carbon-related nanomaterials. *Journal of Nanomaterials*, p. 16.

Nalwa, H.S. 2004. *Encyclopedia of Nanoscience and Nanotechnology*, Vol. 10, American Scientific Publishers.

Nerl, H.C., Cheng, C., Goode, A.E., Bergin, S.D., Lich, B., Gass, M., Porter, A.E. 2011. Imaging methods for determining uptake and toxicity of carbon nanotubes *in vitro* and *in vivo*. Nanomedicine, **6:** 849-865.

Nesper, R., Ivantchenko, A., Krumeich, F. 2006. Synthesis and characterization of carbon-based nanoparticles and highly magnetic nanoparticles with carbon coatings. *Advanced Functional Materials*, **16:** 296-305.

Novoselov, K.S., Geim, A.K., Morozov, S.V., Jiang, D.E., Zhang, Y., Dubonos, S.V., Firsov, A.A. 2004. Electric field effect in atomically thin carbon films. *Science*, **306:** 666-669.

Ong, Y.T., Ahmad, A.L., Zein, S.H. S., Tan, S.H. 2010. A review on carbon nanotubes in an environmental protection and green engineering perspective. *Brazilian Journal of Chemical Engineering*, **27:** 227-242.

Popov, V.N. 2004. Carbon nanotubes: properties and application. *Materials Science and Engineering: R: Reports*, **43:** 61-102.

Ruoff, R., Tse, D.S., Malhotra, R., Lorents, D.C. 1993. Solubility of fullerence (C60) in a variety of solvents. *The Journal of Physical Chemistry*, **97:** 3379-3383.

Schrand, A.M., Hens, S.A.C., Shenderova, O.A. 2009. Nanodiamond particles: properties and perspectives for bio-applications. *Critical Reviews in Solid State and Materials Sciences*, **34:** 18-74.

Seil, J.T., Webster, T.J. 2012. Antimicrobial applications of nanotechnology: methods and literature. *International Journal of Nanomedicine*, **7:** 2767.

Seyller, T., Bostwick, A., Emtsev, K., Horn, K., Ley, L., McChesney, J., Speck, F. 2008. Epitaxial graphene: a new material. *Physica Status Solidi (b)*, **245:** 1436-1446.

Subramoney, S. 1998. Novel nanocarbons-structure, properties, and potential applications. *Advanced Materials*, **10:** 1157-1171.

Takesue, I., Haruyama, J., Kobayashi, N., Chiashi, S., Maruyama, S., Sugai, T., Shinohara, H. 2006. Superconductivity in entirely end-bonded multi-walled carbon nanotubes. *Physical Review Letters*, **96:** 057001.

Thostenson, E.T., Ren, Z., Chou, T.W. 2001. Advances in the science and technology of carbon nanotubes and their composites: a review. *Composites Science and Technology*, **61:** 1899-1912.

Tibbetts, G.G., Meisner, G.P., Olk, C.H. 2001. Hydrogen storage capacity of carbon nanotubes, filaments, and vapor-grown fibers. *Carbon*, **39:** 2291-2301.

Wang, L., Hu, C., Shao, L. 2017. The antimicrobial activity of nanoparticles: present situation and prospects for the future. *International Journal of Nanomedicine*, **12:** 1227.

Wang, A., Pu, K., Dong, B., Liu, Y., Zhang, L., Zhang, Z., Zhu, Y. 2013. Role of surface charge and oxidative stress in cytotoxicity and genotoxicity of graphene oxide towards human lung fibroblast cells. *Journal of Applied Toxicology*, **33:** 1156-1164.

Win, K.Y., Feng, S.-S. 2005. Effects of particle size and surface coating on cellular uptake of polymeric nanoparticles for oral delivery of anticancer drugs. *Biomaterials*, **26:** 2713-2722.

Wu, Y., Qiao, P., Chong, T., Shen, Z. 2002. Carbon nanowalls grown by microwave plasma enhanced chemical vapor deposition. *Advanced Materials*, **14:** 64-67.

Xia, W., Su, D., Birkner, A., Ruppel, L., Wang, Y., Wöll, C., Brandl, W. 2005. Chemical vapor deposition and synthesis on carbon nanofibres: sintering of ferrocene-derived supported iron nanoparticles and the catalytic growth of secondary carbon nanofibers. *Chemistry of Materials*, **17:** 5737-5742.

Xiao, J., Gama, B., Gillespie Jr., J. 2005. An analytical molecular structural mechanics model for the mechanical properties of carbon nanotubes. *International Journal of Solids and Structures*, **42:** 3075-3092.

Yu, J.-G., Zhao, X.-H., Yang, H., Chen, X.-H., Yang, Q., Yu, L.-Y., Chen, X.-Q. 2014. Aqueous adsorption and removal of organic contaminants by carbon nanotubes. *Science of the Total Environment*, **482:** 241-251.

Zhang, Y., Petibone, D., Xu, Y., Mahmood, M., Karmakar, A., Casciano, D., Biris, A.S. 2014. Toxicity and efficacy of carbon nanotubes and graphene: the utility of carbon-based nanoparticles in nanomedicine. *Drug Metabolism Reviews*, **46:** 232-246.

Zhang, Q., Uchaker, E., Candelaria, S.L., Cao, G. 2013. Nanomaterials for energy conversion and storage. *Chemical Society Reviews*, **42:** 3127-3171.

Zhou, O., Shimoda, H. Gao, B., Oh, S., Fleming, L., Yue, G 2002. Materials science of carbonnanotubes: fabrication, integration and properties of macroscopic structures of carbon nanotubes. *Accounts of Chemical Research*, **35:** 1045-1053.

Zou, G., Zhang, D., Dong, C., Li, H., Xiong, K., Fei, L., Qian, Y. 2006. Carbon nanofibres: synthesis, characterization, and electrochemical properties. *Carbon*, **44:** 828-832.