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Recent advances with CNT, Nanocellulose and Their Composites in Different Industries

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Abstract: *CNT-based composites and CNT/Nanocellulose composites have attracted the attention of various industrial sectors because of their promising properties. Adsorption, photocatalysis, biosensing, gas sensing, antibacterial, antifungal characteristics, and high strength are all important factors in this application. Packaging serves several purposes in the food industry, including containing a product, preserving, and maintaining the product's integrity and quality, presenting, and identifying the product, and providing benefits to users. Biosensing and gas sensing are also important for food safety purposes. High strength is important in the textile industry. UV-blocking makes these composite unsung heroes in sunscreen- a product of cosmetics industry. Photocatalysis of dye degradation and adsorption of heavy metal make them promising particles in the water treatment industry. Biosensing, Bioimaging, antibacterial, antifungal properties make these composites useful in biomedical industry. These applications of CNT, Nanocellulose and their composites in different industries are the focus of our research.*

Keywords: Carbon Nano Tube; Nanocellulose; Synthesis; Properties; Application.

1. INTRODUCTION

Nanocellulose has dimensions that are no more than one hundred nanometers (nm) in size. The extraction method, the surface characteristics, and the production method can all be used to classify different types of nanocellulose. Nanocelluloses can be broken down into each of these three subtypes. The three types of nanocelluloses that have been mentioned above are cellulose nanofibrils (CNFs) or cellulose nanowhiskers (CNWs), or nanofibrillated cellulose (NFC), nanocrystalline cellulose (NCC) or cellulose nanocrystals (CNCs) or bacterial nanocellulose (BNC) and microbial cellulose. Nanocelluloses can be broken down into each of these three subtypes [1]. In nanocellulose/CNT composites, the nanocellulose exists in the form of nanofibrils and nanocrystals, whilst the CNT exists in the form of single-walled CNTs (SWCNT) and multi-walled CNTs (MWCNT). Cellulose nanoparticles make it facile to achieve a uniform dispersion of CNTs in the aqueous environments. This is indistinguishable to the situation that occurs in composites containing graphene and other forms of carbon, in which the two different types of nanoparticles are linked by non-covalent interactions, such as electrostatic and hydrophobic interactions [2]. The wetting and then the response time of a hybrid electrode material can both be considerably improved with the use of nanocellulose. NFCs are a feasible material for designed biopolymer membranes and their composites in a variety of applications including filtration and biomimetic membranes, which are derived from plant cellulose [3]. The hemicellulose and lignin that make up the matrix of the wood pulp are being used to remove the fibrils. They are mixed by mechanical treatments such as homogenization and grinding in addition to chemical pretreatments in order to soften the stiff structure of the cellulose [4]. They have diameters that range from a few nanometers to several micrometers in length and incorporate both crystalline and amorphous areas of cellulose molecules [5]. Nanocellulose and membranes made of nanocellulose/polymer composites have a broad range of applications, including electrochemical sensing [6]. Chemical processing of cellulose nanofibrils can impart charged (anionic) functional groups such as sulfate, sulfonic, carboxylic, or phosphoric groups onto the NFCs. This can be accomplished by modifying the cellulose nanofibrils. These negatively charged functional groups, known as anionics, have a high oxidation potential. Because of this, they are capable of forming stable colloidal suspensions, which have been successfully utilized to disperse nanoparticles for the sake of the manufacture of functional composites [7]. CNT/nanocellulose composites are finding more and more uses in the field of energy storage [8,9], in addition to transparent electronic devices [7,10], because their appealing aspects can frequently be augmented positively in the composites in which they are employed. Despite this, their electrochemical applications are still harder to decipher [11–13]. Dopamine can now be electrochemically detected by a composite membrane that contains MWCNTs embedded in a highly sulfated nanofibrillar cellulose (SNFC) and Nafion® matrix. This figure represents the membrane in function. Nanocellulose and Nafion ionomers are functionalized there to bring about high surface area emergence. Therefore, they make it possible to control the ion flux in the matrix, in addition to allowing for the stable dispersion of MWCNTs [5,14]. Together with nanocellulose, CNTs that have not undergone any chemical modification and do not contain any further surfactants are deployed as a green dispersant [15,16]. It was possible to disseminate high concentrations of CNTs in a nanocellulose aquatic environment in an effective and reliable manner. In instance, composite fibers comprised of CNT and nanocellulose (1D) [7], films (2D) [15] and aerogels (3D) [17] can be formed from CNT/nanocellulose dispersions without the need for the insertion of any other structural elements. CNT/nanocellulose composite materials, which combine the unique characteristics of nanocellulose with those of CNTs, have been the focus of much research in the fields of flexible energy storage devices and multifunctional sensors [18,19]. Because of the surge in CNT content, it is vital that the application performance of CNT/nanocellulose composite materials associated with high conductivity requirements be optimized. SWCNTs have a higher dispersion efficiency than any other CNTs, and the surface charge density of nanocellulose determines the dispersion limit of nanocellulose to CNTs [20]. It has been demonstrated that there is a sizable amount of room for advancement in the dispersion limit of SWCNTs by the exploitation of TEMPO-mediated and acid hydrolyzed CNCs with a high surface charge density to reach the dispersion limit of 75 percent SWCNTs [15]. It has been reported that SWCNTs/CNF solutions with weight ratios ranging from 4 to 8 for the ratio of SWCNTs to CNF. If the formed SWCNT-CNF films have conductivities that are lower than 710 S/cm, then this demonstrates that the dispersion is not uniform [21] . In order to produce high conductivity SWCNT-nanocellulose materials, it is expected to raise the dispersion limit and make certain that the SWCNTs are dispersed in a fashion that is not only uniform but also stable [20]. So, nanocellulose and CNT have the probable to be utilized in a variety of applications (**Table 1**), including supercapacitors, varactors, biofuel cells, and electrodes for lithium batteries, thermoelectric generators for the conversion of heat to electricity, and the construction of heating elements for use in energy storage [22,23]. Our aim of this study is to give an overview of the industrial application of CNT, Nanocelluloses, and CNT/nanocellulose composites. By this study we assume that the researchers will be concerned with the direct commercial application and conduct the needed study for commercial uses.

2. SYNTHESIS OF CNT/NANOCELLULOSE COMPOSITES

CNT/Nanocellulose composites can be fabricated in different ways (see Fig.2**)**. It is possible to ramp up the oxidation of cellulose nanoparticles by using a chemical called 2,2,6,6-tetramethylpiperidine-1-oxylradical (TEMPO). This is then followed by the establishment of a greater number of anionic carboxyl groups on the surface of the particles, which is related to the dissemination of CNTs by aiding in their distribution [10]. CNTs also have the potential to be functionalized through the exploitation of self-assembling amphiphilic glycosylated proteins. One further approach is to employ Pickering emulsions of nanoparticles in water Pickering emulsions. This would be an alternative method [24,25].

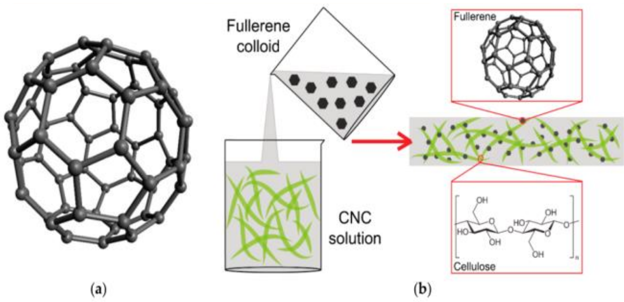

Fig. 1. Three-dimensional nanocellulose/CNT composites synthesis[2]

The conversion of aqueous dispersions into two-dimensional or three-dimensional nanocellulose/CNT composites can be accomplished using a number of processes, some of which include printing, casting, foam forming, vacuum filtering, and centrifugal cast molding (see Fig.1) [2,19,26]. For the fabrication of aerogels and foams, frozen Pickering emulsions of cellulose nanocrystals, SWCNTs, or MWCNTs can be used. After that, the structures of aerogel and foam were generated from them using the freeze-drying method [25]. Nanocellulose was produced through the cultivation of bacteria. In addition to this, as the bacterium grows and develops, it has the ability to produce nanocellulose, which may then be incorporated into the CNTs [11].

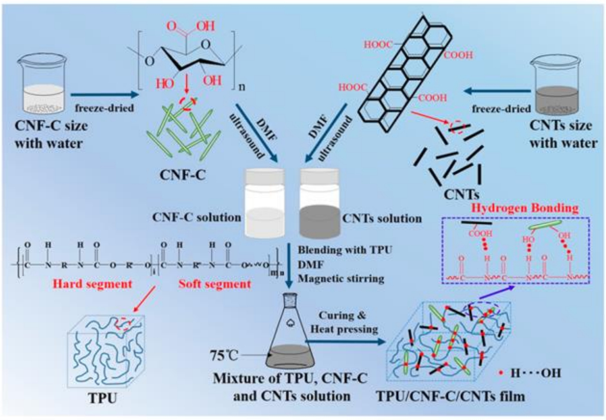

Fig. 2. Fabrication of CNT/Nanocellulose composites [27]

Films made of composite nanocellulose and SWCNT have the capacity to convey solar radiation energy; depending on their thickness, they can be translucent or semitransparent [28]. In terms of selecting the properties of nanocellulose/CNT composites to the requirements of specific applications, it is possible to incorporate atoms, molecules, and nanoparticles into the material. For instance, the addition of Ag nanoparticles to the surface of MWCNTs caused changes in the electrical behavior of CNT-based films grown on a microbial nanocellulose membrane [29]. CNTs that have been coated with polypyrrole can be integrated into CNC aerogels that have been chemically cross-linked. They have the potential to generate chemicals that could be used in flexible three-dimensional supercapacitors [30]. Combining cellulose acetate, chitosan, and SWCNTs with Fe_3O_4 and TiO_2 in electrospun nanofibers has the ability to execute the adsorption and photocatalytic reduction of Cr^{6+}, As^{5+}, methylene blue, and Congo red from aqueous solutions [31]. Generally, to synthesize CNT/nanocellulose composite both CNT and nanocellulose should be made individually. CNTs could be synthesized by Chemical vapor deposition or in situ polymerization method. Nanocellulose can be prepared by mechanical, enzymatic, or chemical methods. The CNTs will be introduced into the solution of nanocellulose by mixing. The composite can be formed by casting the solution of nanocellulose, CNTs, and monomer onto a substrate, or by electrospinning the solution (see fig. 3). Moreover, post treatment of the composite can be done by addition of a crosslinking agent and drying extra solvent to improve the mechanical properties [27].

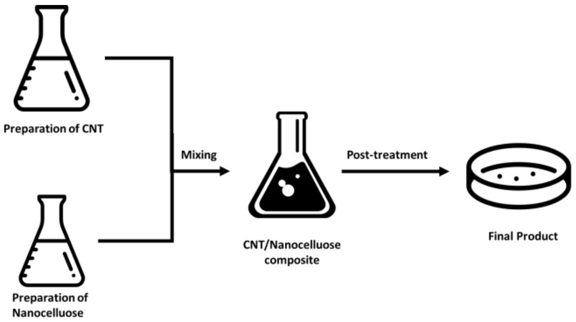

Fig. 3. A general mechanism for fabrication of CNT/Nanocellulose composite.

3. PROPERTIES OF CNT/NANOCELLULOSE

The electrical and mechanical properties of conductive film formed of CNTs and nanocellulose (NFC) are extraordinary. CNT/Nanocellulose composites offer unique features. Conductivity of the sandwich-shaped CNT/NFC/CNT film was 90.8 Scm^{-1} when the CNT loading quantity was 19.2 wt percent, and its tensile strength was 60.8 MPa [32]. The thermal stability, mechanical strength, and water resistance of modified CNT/nanocellulose, such as CNC stabilized CNTs, are significantly improved. Polyvinyl alcohol (PVA) and polyacrylic acid are both included in this CNT-nanocellulose-PAA. After surface coating of the PANI shell, the PANI@CNT-CNC/PVA-PAA specific surface area, nanofibrous membranes exhibit porosity, electroconductivity of 0.44 Sm^{-1} and tensile strength of 54.8 MPa [33]. Cellulose nanocrystal/CNT exhibit large electric conductivity, high tensile strength, and fatigue resistance characteristics [34]. CNT can show UV-blocking property [35]. Nanocellulose-based films' ability to absorb ultraviolet light was caused by the presence of lignin, hemicellulose, quantum dots, ZnO NPs, TiO_2 NPs, and ethyl cellulose NPs that were either loaded with conventional chemical sunscreens or bio-based filters [36,37]. The band gap can be attributed to the transition of an electron from the valance band to the conduction band. This transition is responsible for the absorption of ultraviolet radiation. There is some uncertainty regarding whether CNTs are metallic or semiconducting. The chiral vector, Ch = (na1 + ma2) = (n,m), is the primary parameter that is responsible for determining the electronic characteristics of CNTs. This formula assumes that n and m are integers and that a1 and a2 are the real space unit vectors of the graphene sheet. The graphene sheet's wrapping pattern is specified by the Ck value. When (n-m) is a multiple of 3, a simple theory leads to a crossing of bands at the Fermi energy, which implies that CNT is metallic or that it is expected to be a semiconductor instead. There are finite band gaps in the zigzag SWNTs [38]. At a nanocellulose concentration of 9 ppm, the other study found that a tremendous energy bandgap of 1.32 eV could be attained [39].

4. APPLICATIONS OF CNT NANOCELLOULOSE

CNT/Nanocellulose composites can be utilized in several industries (see Fig. 4) for their various potential in industrial purposes.

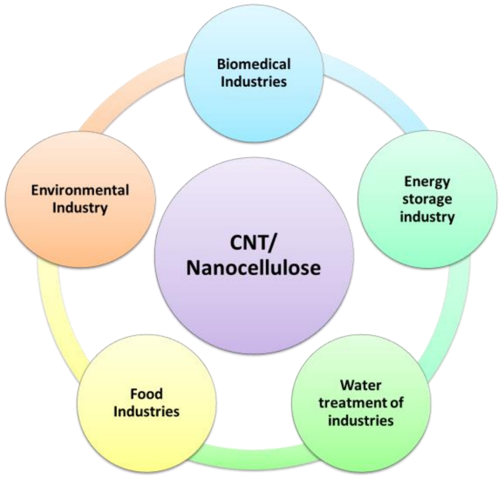

Fig. 4. The potential of CNT/Nanocellulose composites in miscellaneous industries.

4.1 Biomedical Industries

Nanocellulose and nanocarbon have several potential applications in the medical field. The composites of these have application in both radical scavenging and photothermal ablation to remove pathogenic bacteria. Along with these they have anticancer activity. These nanomaterials can show photodynamic and combined chemophotothermal therapy to be useful as anticancer agent. They are also feasible in drug delivery, wound dressings, biosensors, and tissue engineering. The presence of nanocellulose and nanocarbons in hybrid materials promoted the osteogenic differentiation and growth of individual bone marrow mesenchymal stem cells. In vitro, they were able to stimulate the outgrowth of neuritis from rat dorsal root ganglions. Additionally, they stimulated neuron regeneration in rats while the animals were still alive. In addition to this, they exhibited an antibacterial action, enhanced wound healing in vivo in mice, and influenced the proliferation of human dermal fibroblasts and mouse subcutaneous L929 fibroblasts. Therefore, the use of these materials holds promise for the engineering of bone, neural, and vascular tissue, as well as for the development of enhanced wound dressings and patches for the heart [2]. Nanocellulose and CNT composites, which can be employed electrochemically, have the designed to spot oxygen metabolites of ATP [40] by using techniques based on electrochemistry. They are able to sense pressure and temperature using a technology based on thermoelectricity and piezo resistance [41], pressure [18], strain, human motion [42]; humidity, human breath [43]. CNT/nanocellulose composites are used in the drug delivery process. Nanocellulose/CNT dispersions can kill cancer cells even in the absence of anticancer drugs. The TEMPO-oxidized cellulose, AgNPs, and CNTs that go into the construction of thermoelectric-based sensor make it possible for the device to concurrently sense temperature and pressure. Pumping hybrid fillers comprised of CNTs and carbon nanowires into porous electrospun thermoplastic polyurethane membranes allowed for the fabrication of advanced flexible strain sensors that can control the movements of the human body. Wet spinning in an aligned direction was used to manufacture cellulose nanofibers derived from tunicates, which were then homogeneously composited with SWCNTs to produce versatile wearable textile sensors. These sensors can be used, for example, for gas detection [2]. SWCNT-SNC nanocomposite films can be applied as monitors for respiratory-related disorders by monitoring breathing. This monitoring is based on the humidity sensitivity of sulfated nanocellulose (SNC), which allows the films to detect changes in humidity [20].

4.2 Energy storage industry

By dispersing CNTs into nanocellulosic matrices, hybrid nanocomposites with functional properties using carbon nanomaterials can be fabricated. The high density of negatively charged functional groups on the nanocellulose is responsible for electrode application [44]. Because of its one-of-a-kind characteristics, such as an increased surface area, a rapid electrochemical reaction, a good adsorption capacity, improved chemical stability, considerable electrical conductivity, and enhanced mechanical strength, MWCNT is the material of choice among scientists. Cellulose is a natural biopolymer that is not only biocompatible but also sustainable, abundant, and unbounded in supply. Because of this, it is anticipated that a nanocomposite composed of functionalized MWCNT and NCs will demonstrate electrodes that are robust, flexible, and effective while also possessing superior electrochemical performance and mechanical integrity for the detection of certain analytes [13]. The most application areas for nanocellulose-based composites in the field of energy storage are fuel cells, batteries, supercapacitors, and other electrochemical storage devices. Because of their high electrical conductivity, superior specific surface area, and easy access to electrolytes, graphene derivatives, activated carbons, and CNTs are the most promising candidates for use as energy storage electrodes. It has been reported that energy storage candidates based on nanocellulose-based devices have rapid charge discharge capacity, high specific power, and specific energy with lasting stability; these devices are also more environmentally friendly than commercial ones thanks to the fact that they are compatible with renewable sources and are regarded as potential energy generators of the future. In the future, there will be a variety of different energy storage technologies, such as batteries, supercapacitors, and fuel cells, that make use of materials derived from nanocellulose [45]**.** To manufacture electrode materials, nanocarbon and conductive polymer can be combined with nanofibrillated cellulose (NFC) and bacterial cellulose (BC), and these combinations give electrodes enhanced flexibility and mechanical robustness while sustaining their capacitances in supercapacitors. A procedure including in-situ polymerization and filtering was employed to bring about the preparation of a flexible BC/RGO/PPy composite film [46]. A consistent and stable solution was formed by mixing cellulose nanofiber with CNT and relying on electrostatic repulsion in between two materials. This solution was then employed as an electrode in super capacitors [47]**.** It is possible to employ a composite material that is made up of MFCs, a thin layer of Si, and CNTs in a Li-ion battery, where the process for functionalization is plasma-enhanced CVD and CNT/Si is the precursor [48]**.** Si-coated CNT/ nanocellulose paper (Si-nanopaper) can be employed as the Lithium-Ion Battery electrode. For this electrode, the cell was constructed using Li metal foil, Si-nanopaper, and a Celgard 2250 separator that had been soaked in electrolyte (LiPF6 in ethylene carbonate/diethyl carbonate). The high stability of the Si-nanopaper can be assigned to the CNT/nanocellulose paper [49]. The CNT/cellulose composite can reduce electromagnetic wave interference, limit unwanted reactions, avoid crosstalk, and suppress noise in electronic circuits. MWCNTs reinforced with cellulose fibers prepared by electrospinning MWCNT-loaded cellulose acetate (CA) solutions were used. Electrospinning technology has been used here to combine cellulose and MWCNTs, in order to fabricate core–sheath MWNT-cellulose having a cable structure with a conductive core and an insulating sheath [50]. A study found that increasing the amount of CNTs added to cellulose increased the thermal stability and conductivity of the composite material. This was due to the positive interaction that existed between cellulose and the MWCNT. A study has been done to construct smart MWCNT coated with cellulose fibers using a dip-coating procedure to investigate the sensing capacity of the nanotubes as well as their stability in response to various other environmental stimuli. The MWCNT/cellulose fibers exhibit high conductivity and superior sensitivity to the many stimuli that come from the outside world [51].

4.3 Water treatment of industries

At the nanoscale, cellulose offers exceptional mechanical and chemical capabilities, in addition to a high aspect ratio and a huge surface area. In the membrane reinforcement, these are to be anticipated. These characteristics contribute to an increase in the membranes' longevity and endurance in the field of water purification. Since nanocellulose is the biopolymer found in the greatest abundance on Earth, its use in the production of membranes is likely to continue to be favored. In addition, the various surface modification procedures are compared to acquire an understanding of the practicality, both technically and economically, of using nanocellulose membranes for water purification. The shape of the nanocellulose plays a role in adsorption, which in turn affects the removal of pollutants. Nanocellulose fibrils have a linear structure, and the formation of aggregates often takes place through a combination of intramolecular and intermolecular hydrogen bonding. In most cases, nanocellulose possesses a powerful attraction for both it and for substances that contain hydroxyl groups. Considering this fact, it is well knowledge that nanocellulose can readily agglomerate in the absence of the appropriate drying method. The hornification process is the name given to this event [52]. It is possible for adsorbents to undergo change because of the interaction between the contaminant and the adsorbent. It is preferable to use the charged surface of adsorbents while removing dyes and heavy metals. In a typical scenario, the positively charged heavy metals and dyes can be successfully removed from the environment by using a negatively charged adsorbent. As oils have both hydrophobic and oleophilic properties, it is usual practice to give nanocellulose a low surface energy by employing either physical or chemical means. This is done in order to increase the oil adsorption capacity of the nanocellulose [53]. When it comes to methylene blue, the adsorption capacity of unfunctionalized nanocellulose is significantly lower than that of functionalized nanocellulose [54]. The speeds at which dyes degrade are dependent on several parameters including pH, temperature, and others. Because it is made from resources that can be replenished, the nanocellulose Food packaging variety of aerogel is seen as being friendlier to the environment than the other types of aerogel [55]. Long-term contact with the dye found in water sources can cause respiratory difficulties, skin irritation, and an increased chance of developing cancer. Because dyes do not break down in natural processes, water that has been contaminated by them is difficult to treat. These dyes might have an aromatic structure, and they might have cationic, anionic, or non-ionic properties, depending on the dye. The extraction of cationic dyes was accomplished using anionic functionalized NCs as the catalyst. Extraction of anionic dyes is possible with the use of positively functionalized NC. Jin et al. provide evidence that cationized CNCs are effective in removing anionic dyes. The production of cationic CNCs involves a series of oxidations using sodium periodate, followed by a reaction with ethylenediamine [56]. When making a Pd/GO/BNC membrane, it is necessary to include GO flakes into the BNC matrix as it is growing; this is done to complete the manufacturing process. The development of PdNPs in situ on GO flake has been done. The layered structure of Pd/GO/BNC, which produces nano capillaries across the membrane, enhances the contact between organic dye pollutants and PdNPs that are anchored on the GO flakes. This allows the organic dye contaminants to be removed more effectively. The packing of GO flakes within the BNC fibers can be seen in the cross-sectional SEM picture of the Pd/GO/BNC film. This results in the formation of a laminated structure that has a thickness of around 7 micrometers [57]. CNF membranes with a graphene oxide (GO) composites can be used for the purification of water [58].

4.4 Food Industries

It is conceivable that the CNT composite may prove useful for a diverse assortment of applications inside the food industry. The following are some applications that are examples of those that fit under this category; however, this list is not exhaustive: It is impossible to ignore the fact that the CNT is present in fruit since its participation in the ripening process is very necessary. Composites that are made up of nanocellulose and nanocarbon have the potential to have the ability to restrict the growth of germs, and these composites could have this capability. There is also the chance that these composites have antimicrobial activity. Antibacterial activity and antifungal activity are both examples of antimicrobial activity because they both work to inhibit the growth of microorganisms in the environments in which they are active. Antimicrobial activity can be distinguished from other types of biological activity by its competence to inhibit the development of microorganisms. There are numerous different subtypes of antimicrobial activity that may be further differentiated. Compounds that can display this behavior have the potential to be beneficial in the context of packaging. Composites of nanocellulose and nanocarbon have the potential to be beneficial because of their capacity to display this behavior. This sort of component takes a clear and simple approach to discussing the issue of food packaging. In food industry the molecules of interest (composites of nanocellulose and nanocarbon) can be used in food packaging [2].

4.5 Environmental Industry

Nanocomposites are showing promising photocatalytic activities. In the process of CO_2 reduction, the nanocomposite of Cu-Cu_xO, CNT, and BC might be used as an electrode. This composite was made by reducing the amount of CNT/BC composites used in the manufacturing process. This electrode had shown encouraging efficiency in the lowering of CO_2 levels. Over a period of twenty hours, this electrode can maintain its tolerance in ECR-CO_2. As a result, it draws the attention of the current research age. After then, it was developed to serve as a catalytic support for CNT/nanocellulose composites. In particular, the results of this research will give a novel design for ECR-CO_2 with improved charge transport qualities, decreased contact resistance, increased current density, and improved CO_2 electro reduction efficacy. Because of the drop in CO_2 levels, the composite of CNT/nanocellulose has come into focus and shown its viability for use in environmental contexts. This application will contribute to the clean environment sector as well as the decrease of the greenhouse impact [2] [59,60].

Table 1. Application of CNT/Nanocellulose composites in different industries

CNT/Nanocellulose nanomaterials	Application	Industry	Ref
nanocellulose/ nanocarbon composites	Radical scavenger, Biosensors, Chemophotothermal therapy	Biomedical industries	[2]
cellulose nanofiber/CNT	Electrode in supercapacitors	Energy Storage Industry	[47]
Nanocellulose/ nanocarbon composites	Packaging, Drug Delivery, Microbial infections, construction of fire retardants	Food Industry	[2]
CNT/Bacterial Cellulose (BC)	Catalyst, electrodes	Environmental Industry	[59]

5. CHALLENGES OF CNT/NANOCELLULOSE UTILIZATION

A fascinating new class of materials with several potential uses is CNT and nanocellulose composites. Before these materials can be extensively used, however, several concerns still need to be overcome. Due to their tiny size and large surface area, nanocellulose and CNTs are both challenging to equally scatter in a matrix material. Poor mechanical characteristics and other issues may result from this [34]. To impart the better characteristics of the nanoparticles to the composite, it is essential to provide strong interfacial bonding between the CNT/nanocellulose and the matrix material. Reduced mechanical strength and higher vulnerability to failure may be caused by weak bonding [36]. Large-scale manufacturing of superior CNT and nanocellulose composites may be difficult and expensive. To make these composites economically feasible, mass manufacturing methods must be devised [61]. Because CNTs have the potential to emit tiny airborne particles, handling and processing them raises questions concerning occupational health and safety. To safeguard employees throughout the production process, the proper safety rules and safeguards must be put in place [62]. Environmental effects might result from CNT and nanocellulose composite manufacture and disposal. Throughout their entire cycle, it is crucial to evaluate any possible environmental effects and implement sustainable procedures. It is important to look at the long-term stability and toughness of CNT and nanocellulose composites, particularly when they are subjected to environmental variables including temperature changes, humidity, and UV radiation [63]. The usage of CNT and nanocellulose composites may need adherence to certain laws and norms, as with the use of any novel materials. They may need the creation of new testing and safety procedures due to their unique features [64].

6. CONCLUSION

Depending on their chemistry, CNTs and nano cellulose can perform a wide variety of useful functions. These functions include the production of composites, aerogels, papers, films, or fibers. CNTs and nano cellulose each fall into a unique category of their own, including SWCNT and MWCNT of carbon nano tube and cellulose nanofibers, cellulose nanocrystals, and bacterial nanocellulose. The top-down and bottom-up synthesis processes both allow for the conversion of nano cellulose into a variety of different forms. CNT/nano cellulose composites are attractive materials due to the unique qualities that they possess. Some of these properties include a high surface to volume ratio, high mechanical strength, thermal property, conductivity, photodynamic activity, and adsorption and filtering capacity. They have a significant impact on a variety of commercial sectors, including the biomedical sector, the energy storage sector, the water treatment sector, the environmental sector, the food sector, and others.

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