The Utilization of Nanotechnology and Nanomaterials in Chemical Engineering

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Abstract:
Nanotechnology have witnessed application in almost all areas of chemical engineering from Quantum engineering to biosynthesis and biotechnology. It has improved the resonance properties of metals, semiconductors and quantum dots used for sensing and imaging applications. The greatest impact is in the area of biomedicals where neurodegenerative diseases such as cancers, Alzheimer's disease, Parkinson's disease and brain tumors are now addressed with great success. In filtration technology, nanomaterials are now used for onsite dictation and removal of heavy metals. Better performance have been discovered regarding nanomaterials for removing water vapor in the atmosphere as nano-hydroxyapatite can now replace silica gel for water vapour absorption. Even the processes leading up to production of nanomaterials are now modified with microorganisms to synthesize nanomaterials such as silver synthesized via H. Leucopus mediated bioreduction. Materials can now be synthesized down to atomic or molecular level through controlled deposition of the precursor material on the substrate. Size conversion of molecules, surface motif exchanges, ligand technology and polymer technology have witnessed turn around all because of nanotechnology. Organic pollutant known as non-biodegradables, can now be degraded excellently using TiO2 functionalized nanoporous anodized alumina in the presence of UV and visible light. Battery storage capacity have been greatly improved by doping of the electrodes with nanoparticles such that the volume changes during charge and discharge operations are reduced. In the end of this preview, a concise presentation of areas for further research was made to further accelerate research in this area. On battery technology and electrochemistry, a novel ternary composite of graphene, MoS2 nanosheets and a small amount (1wt %) of silver nanoclusters (NCs; MoS2/G/Ag) have been discovered with storage capacity as high as 1308 mAhg¬ 1 (at 5Ag-1 well above the traditional binary system with only MoS2/Ag. Other quantitative results of exploit of nanotechnology are littered in this review.
Keywords: Chemical engineering, Nanomaterials, Nanotechnology, Nanoparticles, Carbon nanotubes

1. Introduction

Nanotechnology is the technology that deals with the study and application of materials (organic and inorganic) that have their sizes in the range of 1-100nm at atomic, molecular and macromolecular levels [1]. One nanoparticle can be obtained by dividing one strand of human hair (about 100µm) into 100,000 parts [1,2]. Major areas of application of nanotechnology include; sustainable energy, catalysis, sensor and medicine, environment, water purification, drug delivery, food and agriculture [2,3-5]]. Nanorods [6,7], nanoclusters [3-14], nanotubes [15,16, 17-19], nanodiamonds [20,21], nanocrystals [22,23], nanocomposites [24,25,26], nanoemulsion [27], and nanopodwers [28] are some of the nanomaterials that have been employed up to this point. Because of new chemical, physical, and biological properties such as electrical conductivity, fluorescence, biocompatibility, elastic strength, ease of scale-up, amenability to modification, and high temperature engineering, nanomaterials have surpassed coarse grain counterparts for mechanical, thermal, electrical, optronics, imaging, and adsorption applications[1,2,5,29]. Some researchers opined that selectivity, robustness, multifunctional properties are resident in nanoparticles to carry out specific tasks such as soil remediation and targeting of malignant cells [23]. Furthermore, nanotechnology has helped improve the ability to prevent, detect and remove environmental contaminants in air, water, and soil in a cost effective and environmentally friendly manner [1].

Nanomaterials (Fig. 1) are currently used in chemical engineering for particle removal, effluent treatment through reductive dechlorination, beta elimination of chlorinated compounds, viruses and bacteriophage removal using zero valent Iron (nZVI) [2,5,30]. Nanocarriers like the mesoporous silicon nanoparticles (MSN) which possess tunable properties are used for drug delivery [7]. Nanomaterials has also been used in the production of dye sensitized solar cells (DSSCs) because of their low cost of fabrication, robust nature, environmental compatibility and simplicity of the fabrication process [2]. Food crisis and growing need for food security has further brought nanotechnology to the limelight, changing how food is produced, processed, packaged and consumed [5]. For instance, smart sensors and delivery systems are used in combating viruses and other crop pathogens [23]. In this review, current developments in nanotechnology were investigated since they are relevant to chemical engineering. Quantum chemistry and solid state fabrication for other applications are covered, as well as photocatalysis and nanopore development, chemical sensing technology and green technology fabrication, battery and electrochemical engineering, biomedical science and pharmaceutical engineering, surface exchange and surface coating engineering, polymer and composite engineering, adsorption and purification technology, biotechnology and biosynthesis, and environmental engineering. Finally, attempts to control nanohazards on individuals, the environment, and ecosystems were highlighted, and interesting topics for additional study were identified in the review to speed research into this promising technology.

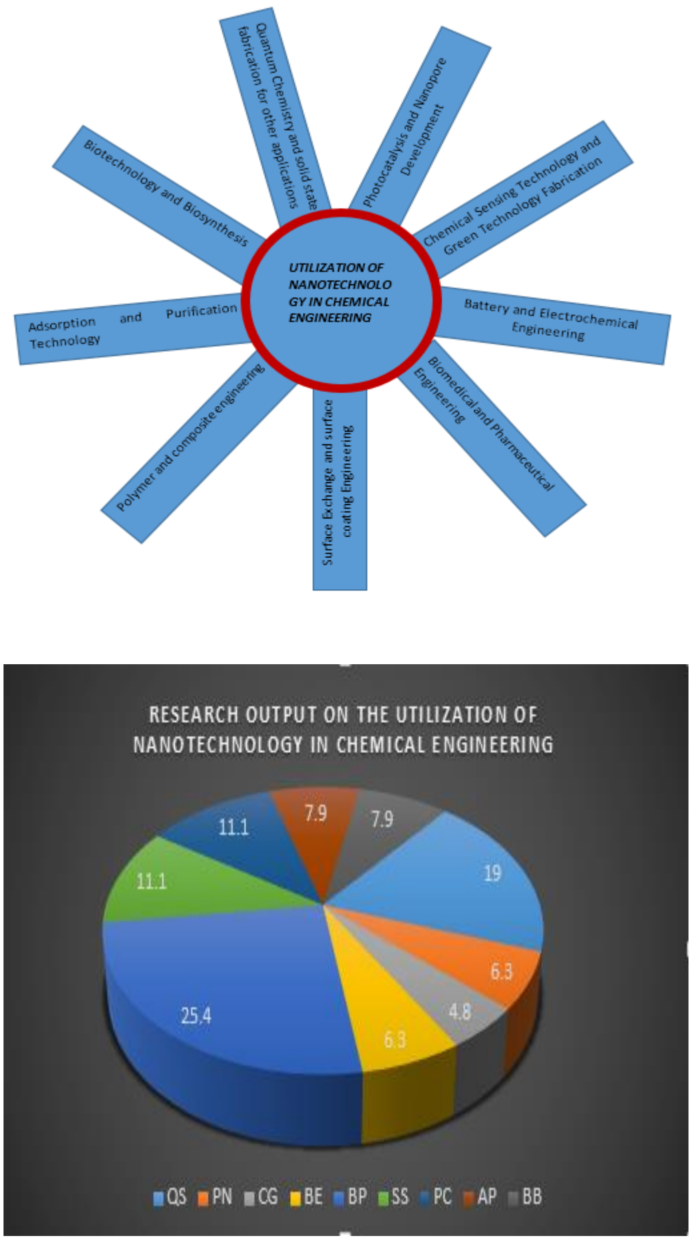

Fig 1:A.) Various Areas of Utilization of Nanotechnology and Nanomaterials in Chemical Engineering. B.) the percentage number of research performed in the identified areas

2. Various Areas Of Application of Nanotechnology and Nanomaterials

2.1 Quantum Chemistry and Solid State Fabrication for other Applications

The resonance properties of metals, metal oxides and quantum dots have been improved by tuning their energy levels via doping and alloying with one another [31]. These have resulted in the development of novel structures such as nanoclusters, nanotubes, and nanocrystals, which promise improved luminescence [8,15,16,17,18]. However, their properties are still not at the level demanded by modern society, necessitating the addition of more metal materials in equimolar or near-equimolar form, such as the high entropy alloys (HEAs). This shows great improvement in Lithium-ion battery system showing several magnitudes of increase in energy than the modern solid electrolyte (LIPON) and almost close to liquid electrolyte [31]. It has been observed that while produced AuAg NCs are identical in size to their monometallic Au equivalent. They display 3.9 times the luminescence increase compared to Au NCs at just 10% molar concentration, with the luminescence emission of AuAg NCs moving from orange to blue.Based on their research, Prajapati et al. [6] opined that Interaction between emitters and their environments can help in engineering the emission characteristics applicable in both photovoltaic and luminescence due to plasmonic, deep level, super-band gap excitation and dipole moment effects [6]. The position of the conduction band (CB) of ZnO and that of the Quantum dots (QDs) must be well adjusted to deliver best results according to fig 2.0 [6]. The CNTs produced via the top-down heating mechanism were found grown following the top-growth mechanism scheme therefore, the solubility of carbon in Iron (SR) was higher at the top than the bottom of the catalyst with the yield of metal Single Wall CNT higher than the semiconductor Single Wall CNT [15]. With the aid of an on chip-method, bridging nanowires (BNWs) were fabricated which is far better than ZnO nanowire arrays (NWA) and syringe nanowires (SNW) showing response and recovery times of 250 and 340ms, about 168 and 144 times faster than NWA and SNW [32]. Elsewhere, multiwall carbon nanotube (MCNTs) dispersion have been improved using the quantum mechanical tunneling giving an enhancement factor as high as 4700 and 670±70 (at high roughness) in paper and glass substrates, respectively [17]. Heat treatment of CNTs have expanded the scope of their application to production of supercapacitors and electronic textile and at a temperature of 9000C, heat treated CNTs become resistant to oxidation and have ID/IG as low as 0.03 as opposed to wet cake material which oxidize at 590oC and ID/IG¬ at 0.36 (see schematic diagram in fig 2.1) [18].

The natural thinness and wavelength-independent absorption up to (99%) at a nanometric state of a 15nm absorber layer were combined with the broad band absorption properties of a graphene absorber (single atomic layer of graphite). This gave rise to disordered nanotexturing with sub-wavelength sized metal nanostructures [33].

. Moreover, Interconnection technology has gotten high popularity in the electronic industry because of the need to restrict the amount of hazardous waste generated through electrical and electronic equipment for instance, lead [16]. Hence, the emergence of new alternatives like sintered silver are being considered [16]. Furthermore, ZnO film normally show photo-responsivity but ZnO nanostructures have become attractive as it has high responsivity due to its large surface to volume ratio [32]. Through aggregate induced emission (AIE) the window size of Au(I)-SG@SiO¬2 was found to lie between 8.6 and 9.04Å aiding greater luminescence [34]. Finally, the sol-gel approach, which involves replacing Ca2+ ions in the molecule with Sr+ ions, has addressed the constraints of thermostability and mechanical strength associated with hydroxyapatite [35]. Details are provided in Fig.2.

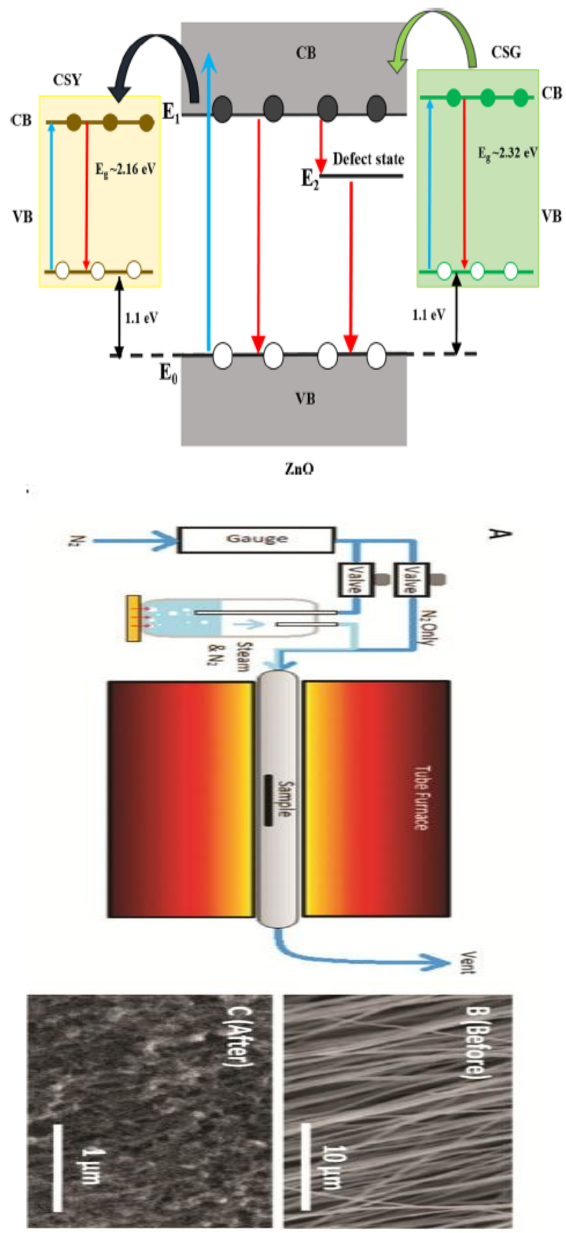

Fig. 2. Schematic of the energy band diagram and alignment of ZnO with CdSe quantum dots (CSG and CSY[6]. Fig 2.1.(A) Schematic diagram of the set up used to steam treat the samples (B) Typical SEM micrograph of the CNT loaded fibres (C) same fibres after purification [18].

2.2 Photocatalysis and Nanopore Development

Photocatalysis has to do with the utility of nanoparticles as catalyst in carrying out reactions that are dependent on light. The leading nanoparticles in this area is the titanium dioxide and nanoporous anodized alumina which two can be used to effectively degrade stubborn organic pollutant [36,25]. The silver NCs were birthed due to the polydispersed nature of ordinary silver nanoparticles (NPs) [3]. They have particle size less than 2nm and exhibit different physicochemical properties such as Highest Occupied Molecular Orbit-Lower Unoccupied Molecular Orbit (HOMO-LUMO) transition, quantized charging and strong photoluminescence, among others [3]. These properties coupled with the ultra-fine nature of Ag NCs, have made them common place in the industry [3]. According to Anjugam and coworkers reaction have continued to trail the discharge of dyes like azo dyes into water as they are potentially non-biodegradable and carcinogenic [36]. When released into water bodies would cause harm to aquatic organisms and by extension humans and hence the need to be degraded through nanoparticles mediated photocatalysis [36]. The study further confirmed that r-Ag NCs and Ag+ combine to lead to cytotoxicity (reduced metabolic and energy activities in the algae cells), however, as the chlorophyll content decreased, the algae was healed [3]. It was found that TiO2 coated noble metal will shift the absorption of Ag and Au doped TiO2 to 3.05eV and 2.99eV as against bare TiO2 at 3.16eV leading to efficient removal of dye contaminant by as high as 85% [36]. Moreover, dyes can be dealt with effectively by sinusoidal pulse anodization (SPA). The entire process's effectiveness depends on relative position between the resonance band of the TiO2-NAA-µQVs and the absorbance band of the model organics [25]. The photostability and the structural stability of TiO2 was improved by light confinement and hence ensured effective and efficient removal of organic pollutant [25].

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2.4 Chemical Sensing Technology and Green Technology Fabrication

ZnO has played important role in handling gas sensing problems. This may be due to the consistency in the development of its nanostructures namely; nanowires, nanodisks, nanoleaves, all possessing high surface to volume ratio [37]. Biosensing research have accelerated in recent times with the rise in cases of Pancreatic cancer which has shown to contain high concentration of trypsin up to 84.4µg/mL and urine sample higher than normal (115 – 350ng/mL) [38]. Other nanomaterials include carbon nanotubes used to fabricate cathode arrays for sending and receiving electric signals [37]. In order to study the effect of size of the nanostructure in its gas sensing capabilities, a general formula is normally developed for ZnO ethanol gas sensing which was formed by ethanol molecules reacting with oxygen ions and taking surface depletion into account [37]. It has been discovered that increase in temperature increases the sensing ability of the NPs at the expense of decreasing gas concentration to be detected [37]. Moreover, a novel biosensor using interferometric reflectance spectroscopy (IRS) method to detect trypsin has been developed [38]. This method is well suited for different target and also it is contactless [38]. This method used a film which interfered white light to produce partial beam of light for the charge-coupled device (CCD) detector thus producing a considerably wide gap for reaction time and pH in the presence and absence of trypsin [38]. Hence, it beats its counterparts, quantum dots and nanoclusters in terms of cost speed and reproducibility [38].

2.5 Battery and Electrochemical Engineering

Battery technology and electrochemistry have led to the fabrication and optimization of energy storage systems such as the popular Lithium ion battery. This has greatly augmented conventional electricity but has been faced with volume changes and decrease in capacity after long use [25]. Although, carbon-metal fluoride is greatly sought after because of their high-energy density, however, it has shown draw backs in conductivity and storage due to large volume changes during the period of charging and discharging [39].

On the other hand, graphite has been considered a good option for Li+ battery manufacture but for its reduced capacity due to LiC6 stoichiometry, attention has shifted to MoS2 [11](Fig. 3). The large separation between the layered sheets of sulphur in MoS2 called exfoliation has improved its capacity up to 950mAh-1 at a current of 50mAg-1 for at least 100 cycles [11]. Also, adding graphene to the transition metal alcogenide has improved conductivity and capacity fading [11]. The structure of the L+ battery anode has been shown to strongly depend on the structure of the material especially its thickness [11]. Hence, MoS2/graphene composite should have their layer increased by hydrothermal synthesis or reflux methods [11]. A recent method called ferrocene/cobaltocene based methods are used to synthesize C-Fe-LiF/C-Co-LiF with excellent cycling stability producing a capacity of 220mAhg¬ 1 for 24hrs and 50 cycles of operation [39]. In addition, a novel ternary composite of graphene, MoS2 nanosheets and a small amount (1wt %) of silver nanoclusters (NCs; MoS2/G/Ag) have been discovered with storage capacity as high as 1308 mAhg¬ 1 (at 5Ag-1 well above the traditional binary system with only MoS2/Ag [11]. Furthermore, the immobilization of S by Ag, the association of Li+ with Ag and increase in the distance between the graphene sheets improves the capacity of Lithium Ion Battery (LIB) up to ~1400 mAhg-1 at only 0.1Ag-1 [11]. Recent research have shown the possibility to produce sequential growth of nanostructures of N-doped carbon-MoS2 due to the synergy of the dual surfactants, complexing effect between amine groups and Mo species, hydrogen bonding interaction among aminophenol resols, cysteine and sodium molybilate hydrate (Na2MoO4.2H2O) (see fig 2.3) [25]. This will lead to long cycle as high as 1308 mAhg-1 and very high columbic efficiency of (>98.13%) [25]. Impedance test carried out on ZnO-TiO2 used in N C-MoS2 offered the least total charge transfer resistance, confirming it enhanced high evolution reaction (HER) kinetics [40].

2.6 Polymer and Composite Engineering

The environmental pollutions associated with polymer materials are now being circumvented by shift to bio-based polymers [41]. Of all the bioplastics in existence poly (lactic acid) or polylactide (PLA) are highly promising in terms of renewability, biodegradability, biocompatibility, good thermal and mechanical properties [42]. It has been discovered that the factors which play role in the degradation of PLA are those that increase the hydrolysis of the same [43]. Hopefully, there exists several options to improve the qualities of bioplastics namely; addition of specialty items and bio-polymeriztaion of different biopolymers [42]. Moreover, nanoemulsions are generally difficult to manufacture and thermodynamically unstable, hence using polymer as an oil [27]. Properties of PLA can be improved by mixing it with ZnO and epoxy functional styrene-acrylate oligomeric CE from molecular to thermal properties [18]. Particularly, molecular weight will be two-fold higher by adding treated ZnO NPs to PLA up to 40wt% whilst crystallization rate and crystalline properties will be improved by adding just 0.5-1% phenylphosphonic acid Zn as a

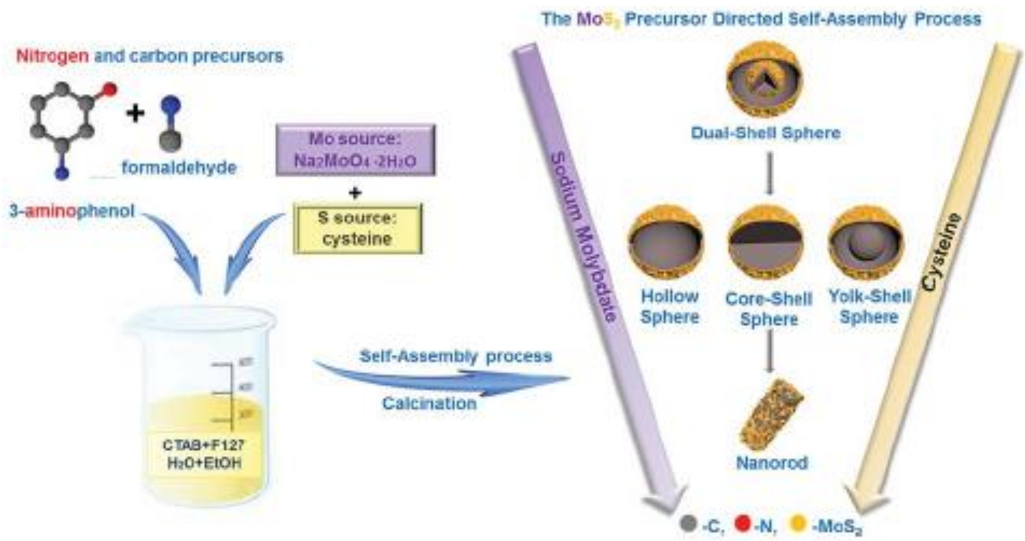

Fig 3. Schematic illustration of NC-MoS2 nanocomposites with variable structures [25]

nucleating agent [18]. Moreover, researchers have found an innovative way of dealing with the drawbacks in polylactic acid (PLA) polymer by mixing the pristine PLA with silica based cloisite material (CLO30B-EBS) coated with ELPPF [5]. This has a tensile strength from 3800-5200 MPa greater than neat PLA [5]. Similarly, hydrolytic degradation of PLA in silanized ZnO has been investigated using phosphate buffer solution (PBS) for about 10months [14]. At the end of 10month aging in the buffer PBS the pristine PLA degraded while the sample containing 3wt% of modified ZnO maintained a tough aspect at 37oC [14]. Analysis on the molecular weight using the size exclusion chromatography revealed that pristine PLA can degrade up to 80% of its original value while its ZnO doped counterpart can degrade up to 55% of their original molecular masses [14]. The result of dynamic light scattering (DLS) showed increasing in Z-average size of the particles showing a mega shift for curcumin loading, positive shift for cyclosporine loading and none for prednisolone loading due to hydroxyl group present in cyclosporine and curcumin, respectively [27].
Furthermore, hydrogen storage can be improved by the use of CNTs activated with any of N,P,B and S but particularly N because of its similarity to carbon atoms [19]. Raman Spectroscopy study indicates defects increment as temperature increased from 500 to 900oC with ID/IG ratio increasing from 1.2 at 500oC to 1.38 at 900oC and hence storage capacity of 2wt% at 900oC [19].

2.7 Adsorption and Purification Technology

This area has witnessed great improvement in the dawn of nanotechnology as impurities even at nanoscale level can now be removed with the aid of nanomaterials. Ions like Fe2+ ions having grave effects on aquatics and humans, have been removed by different methods namely; membrane technology, chemical precipitation, coagulation, ion exchange and electrolytic reduction [44]. As good as these methods sounds, they all have their drawbacks: long operation time, low capacity for removal and low thermal and mechanical stability. Adsorption remains the best option because of its efficient, easy, cost effective and ecofriendly [44]. With these recent developments, chemical spills by oil or heavy metals which led to disastrous consequences such as the case in Gulf of Mexico can now be remedied [45]. This has can be achieved by use of materials possessing high affinity for the pollutants and having large surface area and also one that can be easily regenerated via desorption [45].
Carbon flakes and fibers was developed by some authors and was used to achieve efficient removal of impurities [45,46]. Silica nanoparticles (SNPs) have been synthesized by sol gel method and used to successfully remove Fe2+ ions being about 15nm to 90nm in size with an absorption efficiency of 99% in just 20minutes [44]. Researchers have also shown that when iron NPs are coupled unto graphene oxide, there will be increased surface area and coercivity up to 93m2/g and 216KG, respectively for 3.2wt% of Fe with a maximum operating time of 216hrs [45]. Until now carbon fibers have been formulated in different forms like immobilized multiwalled carbon nanotubes (MWCNTs) and its oxidized counterpart are used to remove nanosized impurities with great efficiency [46]. Recently, the production of hierarchical carbon nanomaterial based on a carbon fiber (CF)-carbon nanotubes (CNT)-carbon(graphite oxide) sponge (GO) all deposited on commercially available CFs has been studied with a transparency of 30% on Rhodamine B after 10 filtration [46]. To overcome this drawback which leads to excessive water up take polyhedral oligomeric silesquioxanes (or POSS reagents) can be employed leading to increased glass transition temperature and decrease water up take [45]. In comparison with silica gel under the same experimental condition GoHAP-

1 (10nm) showed a higher activity, hence, GoHAPTM can replace silica gel for rapid reduction of relative humidity [29].in addition, the amount of water adsorbed on 10nm nano-HAP was 5 times larger than that on 40nm nano-HAP for the same water activity [29].

2.8 Biotechnology and Biosynthesis

Biotechnology has opened a new avenue for production of nanomaterials which are environmentally sustainable as against the traditional physical and chemical approaches [4]. The combination of green chemistry (low emission processes) and white biotechnology (using living cells like yeast, mold, algae, and bacteria) has been shown to significantly revitalize the nanotechnology industry . This is possible through the use of microorganisms like bacteria, microalgae, yeast, and mold microbial nanomaterials like silicified frustules, calcified coccoliths, magnetosomes, bacterial nanocellulose, and exopolysaccharide [4,47]. In their review, Verma et al (2019) said that the usage of plants in nanoformulation is due to their availability and wide variety of metabolites, such as vitamins, antioxidants, and nucleotides [47]. Microbial nanomaterials synthesized include; nanoparticles and bacterial nanowires [4]. The advantages of these materials includes; well defined chemical composition, size, and morphology, obtained at mild physico-chemical condition, easy handling, easy cultivation, easy scale-up and tunable characteristics [4]. Biotechnological techniques based on genetic engineering and recombinant technologies can be used to manufacture metal nanoparticles such as (CdSeZn, Cu, CuO, ZnO, Ag, PrGd, CdCs, and FeCo) that have never been chemically synthesized [4,23,547-49]. Bacteria have been utilized to produce inorganic nanomaterials (mainly selenium, gold, and silver nanoparticles) throughout the previous decade. Interesting qualities that may be used in the manufacture of voltammetry sensoristic devices, third generation biosensors for diagnostic applications such as cell imaging, and applications has been discovered [4,50]. The drawbacks that has limited the use of biosynthesis for nanoparticles production can be addressed by selection of appropriate microbial strains, optimization of culturing conditions and use of genetic engineering tools [4]. Bimetallic nanoparticles can also be synthesized using plant synthesis thus producing core-shell structure eg. gold core-silver shell nanoparticles using cashew nut and west indies mahogany [48]. During synthesis of metal nanoparticle from plant source, there must be an activation period, when the metal ions are converted to zero valent state from their mono or divalent oxidation states so that nucleation can proceed from there [48]. Novelty is seen in the synthesis of metal NPs using essential oil such as nutmeg oil because of their relative safe status, wide acceptance, ease of exploitation and cost effectiveness [48].

Some authors have successfully produced mesoporous carbon nanotubes (Fig. 4) for supercapacitor applications via direct activation of raw corn silk fibers in a single step. This is followed by pre-carbonization of corn silk fibers followed by chemical activation, and hydrothermal carbonization and then chemical activation (see fig 2.7) [51].

Recently, nanoparticles have been used to limit the development of microorganisms involved in fruit deterioration, resulting in 0% growth for fungus at 50,70,75, and 100ppm of silver and 4.9 to 6% mean weight loss over four weeks [23]. Carbon dots may be found in a variety of foods, including eggs, orange juice, garlic, cotton, oats, coriander, leaves, onion, grape juice, and apple juice [50]. That using banana stem has shown quantum yield up to 48% by hydrothermal route and cell viability of about 95% and 85% at only 0.5mg/mL and 1mg/mL, respectively after 24hrs [50]. Silver nanoparticles (Ag NPs) are now been synthesized by green approach using Helvella Leucopus which can be applied for fungi growth inhibition in fruits [49].

2.9 Environmental and Health Risk Impact of Nanotechnology and the way forward

As wonderful and promising nanomaterials may sound, scientists and health practitioners are continually worried about its impact on health, judging that it may impact negatively just as far as it does some great jobs. To address the threat posed by nanotechology and nanomaterialsVerma and coworkers advocated risk assessment, risk management, communication and planning as indispensable for evaluating and containing risk associated with nanomaterials [47]. So, in as much as nanotechnology and materials presents an answer to majority of human problems basically because of their very small size they can also harm greatly if not well tracked throughout their life cycle.

2.10 Identified areas for further Research

From this review, some important areas for further research have been identified to further accelerate the drive of nanotechnology application in chemical engineering. On their part, Prajapati and coworkers (2020) pointed out clearly that the CB of CSG is above that of ZnO and as such electrons excited to the CB of CSG may fall into the CB of ZnO and not vice versa [6]. However, the CB of CSY is lower that of ZnO hence electrons excited to the CB of ZnO may fall into the CB of CSY thereby depleting the population of electrons in the CB of ZnO. So, the challenge is aligning the CB of QDs and ZnO [6].

In the same vein, silanized ZnO polylactide was shown by Benali et al (2015) to have an excellent hydrolytic resistant properties, however, further studies could be carried out to identify the toxicity level of silanized ZnO for use in packaging of food materials [43]. King and coworkers (2015) used surfactant sodium dodecylbenzenesulphonate (SDBS) to functionalize CNT surface morphology, however in a way of further research, effect of other surfactant on the morphological properties of CNTs can also be investigated [18].

Furthermore, Preparation and characterization of strontium fluorapatite nanoparticles by sol-gel method was carried out by Kamael and Fathi (2018) but the authors did not evaluate the impact of addition of strontium substitution and hence opens a knowledge gap for further study. Based on the work done by Liu and coworkers (2019), it is recommended that the method of induced cooperative assembly of MoS_2 precursors (Cysteine

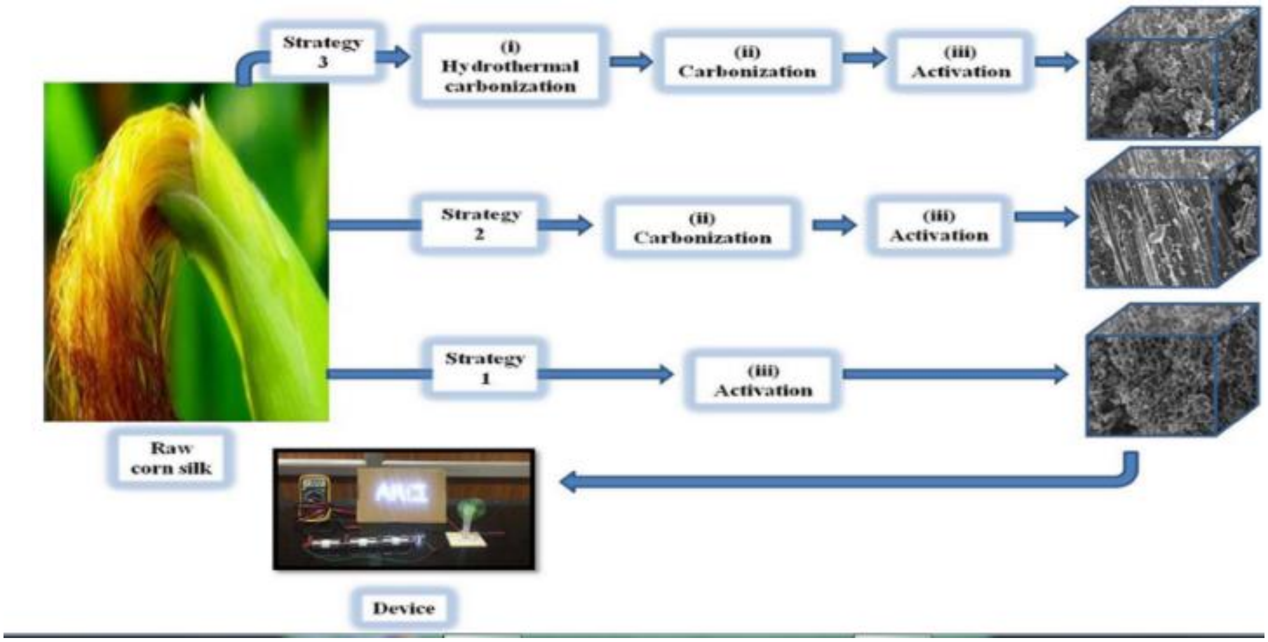

Fig 4. Schematic illustration of strategies involved in the synthesis of porous carbons from corn silk fibres [51]

and Na2MoO4.2H2O) can be tried out on other metal Sulphides [25]. The electrocatalytic potentials of ZnO/TiO2 hybrid as designed by Ibrahim and coworkers (2020) can further be harnessed by changing the ratio of combination of ZnO and TiO2 both for doped and undoped states [40].

Moreover, Cynamine 5.5 dye showed a good cell viability as confirmed by Lam et al (2016), however, other biomolecules probes can be exploited in conjunction with SPIONs to ensure better cell viability and improved imaging properties [24]. Based on Pada and coworkers' study, other morphological shaped nanodrug delivery vehicles can as well be studied to check their toxicity, cellular uptake and delivery capabilities [7].

Efforts should be channeled towards the functionalization of metal NCs so as to improve its targeting property and clearance from the body [14]. Also, more should be done to figure out the effects of functionalities of metal NCs on their targeting, biodistribution and toxicity in the complicated biological set-up [14]. Although metal NCs can be functionalized with double-stranded DNA and poly-thymine single-stranded DNA, more studies are needed here to unravel their physicochemical properties [14]. Although, nanodiamonds (ND) has been shown to be an answer to cellular imaging due to its photostability, ease of internalization by the cells and functionalization. However, its application and superiority in drug delivery over other NPs is yet to be verified [21].

In their own right, Aivazi and coauthors proposed further studies on both surface treat and non-surface treat comparing osteoblast cells with L929 cells [26]. Although the detection accuracy of the PEI-GA-PEI functionalized NAA-GIFs is very poor compared to conventional sensing protocol, further research can be carried out to improve its detection accuracy through structural engineering [30]. It was equally advocated that more work should be done in understanding how the interleaf co-exists with the composite and whether the crack can be caused to propagate within the reinforcing region [52].

It is well known fact that silica adsorbs water in ambient air more slowly but efficiently. On the other hand, nano-HAP is known to be rapid in absorption but gets saturated real quick. Therefore, these two qualities can be harnessed to produce an adsorbent which will adsorb water vapour rapidly and for longer period without saturation [29]. Further research could be done in the area of cost effective porous carbons using other activating agents like ZnCl2, H3PO4, K2CO3,NaOH etc. with other agro-wastes like fruit and vegetable husks to produce high capacity supercapacitors [51]. Finally, AgNPs have been shown to possess some antifugi potential, however, its safety in food storage application should be evaluated [49].

3. Conclusion

This review focused on the utilization of nanotechology and nanomaterials in chemical engineering. The work ranged from the utility of nanomaterials in quantum chemistry up to biotechnology and biosynthesis. Nanotechnology remains the best technology to have been invented by mankind having its secret hidden in ultra small size of nanomaterials. This makes it very useful in catalysis, disease diagnosis, disease and drug life cycle monitoring, and administering therapeutic intervention to target sites. In as much as they are useful in many areas of human endeavors, they can still be very dangerous because of their ulltrasmall size. For instance, deep down in the human tissues it may be retained and that could lead to grave consequences. Moreover, they may miss their target in an event of poor luminescence of molecular probes thereby hitting health cells. Therefore, as much we revel in the wonder of this technology, we must never forget its potential to harm us and our environment.

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