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Mini Review

Nanopolymer: Overview, Innovation and Applications

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Abstract

In this review, we have tried to highlight some nano polymers innovations in the recent time frame. We have mentioned various approaches for novel nano polymeric materials and their new age applications in the context of industries, biomedical research and environmental sustainability.

Keywords: Nanopolymers; Environment; Nanocellulose; Fabrication; Composites

Background

Over the years, continuous innovative advancement has been observed in the field of polymer technology. Lot many researchers have gained a wide attraction in recent years to characterized, designed, and fabricates number of novel polymer, biopolymer and nano biopolymer sophisticated materials mainly due to the benefits related to environmental sustainability which is need of hours in the green planet earth. The current review article highlights recent development and innovations in the area of polymer, biopolymer and nano biopolymer composites, such as synthesis, characterization, and application of such sophisticated novel composites in the polymer and related industries. Living organisms produced nano biopolymers (nanocellulose, nano starch, nano chitin, nano silk, etc.) and microbial nano biopolymers, having received widely scientific and engineering interests in recent decades due to their extensive availability, sustainability as well as biocompatibility and biodegradability. Compare with petroleum-based polymers, biopolymers are sustainable and biodegradable. Chemical, mechanical, and microbial methods are generally used to fabricate nano biopolymers from nature. Nano biopolymers can be processed via solution casting, vacuum filtration and freeze drying [1-4] while most microbial nano biopolymers, polyesters can be processed using polymer processing equipment, like extruder, injection molding, etc. [5]. Nanopolymers have been synthesized using various methods. Eco-friendly, fully biodegradable microstructured polymeric nanoparticles systems are widely in demand, as biomedicine specially in tissue engineering and regenerative medicine [6-9], targeted controlled delivery to particular organs/tissues, carriers of DNA in gene therapy and in their ability to deliver proteins, peptides and genes through an oral route of administration [10,11], biocompatibility with tissue and cells [12,13], to improve bioavailability, and bioactivity of various pharmaceutically active compound used in various ailments [14,15] biodegradable and smart packaging [16-19], environment protection such as global spill accidents, water quality [20,21] etc. To improve the current growth of the bio-economy and green chemistry, the use of bio-derived polymers and chemicals could also be considered [22].

In recent years, the use of polymeric nanofibers has gained great importance in biomedical and biotechnological applications such as tissue engineering, controlled release systems, wound dressings, medical implants, composites for dental applications and biosensors. The electrospinning method is the most preferred production method because it allows the production of nanofibers with different materials Polymeric nanofibers are promising drug delivery systems, especially in terms of their applications as controlled release systems to achieve localized drug delivery [23]. Biologically active dendrimers can be useful for combination therapy for conjugated drugs, and for improvement of the therapeutic index, and 'personalized nanomedicine' [24-27]. The delivery of sncRNAs molecules by biodegradable, biocompatible and nontoxic biopolymers including chitosan, cyclodextrins, poly-l-lysine, dextran, poly (lactic co-glycolic acid), polyglutamic acid, hyaluronic acid and gelatin [28]. Nanocellulose polymers have played a vital role in biomedical applications and biomedical engineering as a whole and made possible with 3D bio-ink printing. This achievement has made it easy for skin grafting, organ transplants and cancer screening and treatment. The many available thermoplastics are being replaced with cellulose from wood, pulp and plants, some of the cellulose polymers covered in this paper are Nanocellulose (CNF), nanofibers (CNC), Bacterial cellulose and many more cellulose polymers. 3D structures of numerous advantages like flexibility, improved mechanical strength, controlled biodegradability and user-specific have made it possible to transplant, regenerate and cushion any loopholes in the medical field. The materials are also unique. Its ability to produce and regenerate tissues and organ structures has opened further studies in this field [29-43].

Fabrication and Characterization of Eco-Friendly Microstructured Polymeric Nanoparticles Systems in the Recent Times

Kustiyah et al. [44] made an attempt to create transparent conductive high cellulose-based paper by a facile process using chemicals and sonication methods to obtain cellulose nanofibril from sorghum stems waste which are eco-friendly and can be used as a substitute for glass coating in the display industry. Meindrawan et al. [45] explored an edible coating based polymeric bio nanocomposite of gelatin and ZnO nanoparticles to improve the quality of the broiler chicken fillet during storage. Saragih et al. [46] studies, cellulose nanofiber has been isolated using the steam explosion method from lignin and hemicellulose of pseudo-stem of abaca (Musa textilis). Oktaviani et al. [47] synthesized the bacterial cellulose-co-polyacrylamide by radiation-induced graft polymerization using gamma rays with the simultaneous technique. Nano biopolymers and nanomaterials such as SFNPs, SFNCs, POSS, ZCPs, and nickel hydroxide nanosheet have shown their roles in NF-transport. There are many different techniques for the fabrication of nanoparticle-containing NF membranes, including electrospun membranes, nanosheet membranes, layer by layer assembly and hollow fiber spinning which are used in combination with these techniques [48]. Novel nano polymers has many forensic applications such as drug detection, toxicology, fingerprints, document examination, DNA analysis, sensors, and trackers have benefitted by utilizing these novel polymers. It integrates the use of nanoparticles, quantum dots, nanochips, nanotubes, nanofibers, and nanorods to multiply the results of tracing, detection, and analysis in forensic investigation. Nanomaterials are widely utilized for commercial purposes such as fabrics, cosmetics, sunscreen, dental fillers, semiconductors, smart packaging materials, actuators, and target nutrient and drug delivery, 3D nano systems, self-assembled structures, and more complex heterogeneous nanostructures will be seen in the near future [49]. Advancements in the material science have emerged as an extraordinary area that combines various analytical techniques like TEM, SEM, XRD, AFM, NMR, FTIR, LC/MS, GC/MS, MS/MS to detect and analyze nano evidence [50].

At present nano polymer degradation possesses a great challenge of high societal importance for which an experimental lacking exists. A closed graphene liquid cells in combination with fluorescent dyes can be used to detect the release of particular contents, with efficient screening of events, utilizing atomic force microscopy followed by electron microscopy. Such approaches can be used including chemical and physical triggers for the controlled break down of polymeric materials into primary building blocks to facilitate the transition towards a circular economy [51,52]. Qiang et al. [53] prepared a novel polymeric precursor with Zr-C-Si-N main chain structure was synthesized through a two-step method which shows an excellent moldable property, oxygen-free compositions and high Zr content of PZCS make it an ideal precursor for the preparation of UHTCs matrixes and fibers. Zhang X, et al. [54] were successfully prepared high-temperature resistant polycarbonates with different BHPF contents by a melt-polycondensation method with BPA, DPC, and BHPF. This discovery has tremendous application potential in high temperature resistant plastic industry. Zhang et al. [55] worked on bio-based N-heterocyclic poly (aryl ether ketone) with a high biomass content and superior properties prepared from two derivatives of guaiacol and 2,5-furandicarboxylic acid. Curcuma longa (Turmeric) embedded super macroporous cryogel discs used as a natural ligand for hazardous metal ions removal from aqueous and synthetic wastewater [56]. Godiya et al. [57] recently reported the cost-effective techniques for removal of bisphenol-A, with reasonably advanced efficiencies to address existing problems of bisphenol A-contaminated wastewater treatment.

Zhai et al. [58] rapidly prepared silica gel composite corks (Cosiae-SP and Cosiae-VP) by immersing corks of different tree species in silicone mucilage via the respiration impregnation method. Silica aerogel was immobilized in the cork cells to form a layered network structure with holes. Kalali et al. [59] developed a novel Wood Polymer Composite (WPC) flame retardant system using APP and Phytic Acid-Modified Layered Double Hydroxides (Ph-LDH) as raw materials. Cinausero et al. [60] studied the synergistic effect of nano-oxide and Ammonium Polyphosphate (APP) with polymers such as Polystyrene (PS) and Polymethylmethacrylate (PMMA). Manfredi's group [61] fabricated some composites with mod-acrylic acid and UPR as substrates, and jute, flax, sisal and glass as reinforcements, and compared the FR of these composites. Laoutid et al. [62] summarized the flame retardant properties of polymer composites obtained by adding nano-fillers to a polymer matrix and accounted for the flame-retardant mechanisms of various nano-fillers. Baysal's group [63] prepared vinyl monomer–wood composites by treating sapwood with a mixture of 1 wt% borax and boric acid (1:1). The vinyl monomer–wood composites were prepared by using styrene, methyl methacrylate and a mixture of styrene and methyl methacrylate (50:50). The FR of the composite was evaluated using the combustion weight loss method. Fernandes et al. [64] introduced decabromodiphenyl combined with antimony trioxide as an additive to UPR to improve the FR of Sisal–Polyester (SSP) composites. Jones et al. [65] compared extruded polystyrene foam with rice husk/mycelium biological plate and found that the biomass system is expected to have better flame retardancy due to the presence of carbonaceous coke and embedded silica in the combustion process [65, 66]. For myoglobin recognition from aqueous solutions and human plasma with high adsorption capacity and selectivity in binding capacity the molecular imprinted supermacroporous cryogels technique can be used [67]. Functional 3-D nanofibrous scaffolds produced by electrospinning have immense prospective in a wide spectrum of biomedical research, viz. drug/gene delivery, tissue engineering and wound dressing [68]. Tolnaftate and tolnaftate- graphene composite loaded polyacrylate nanofibers can be potential used as dressing materials/scaffolds for efficient care of dermatophytosis [69,70]. Ying et al. [71] also studied the preparation of Straw Magnesium Cement (SMC) from rice straw, another bio-based isolation material.

Future Outlook

The integration and development of lignin processing, deconstruction, and synthetic polymer chemistry could prove crucial to yield commercial, biobased products such as adhesives, packaging plastics, biomedical devices, and stimuli-responsive materials [64] Fabrication and characterization of eco-friendly microstructured polymeric nanoparticles systems becomes more demanding and complex. It finds applications in various field including Environment and biomedical research. A viable and promising strategy for the use of biodegradable polymeric nanoparticulate drug delivery systems in biopharmaceutical industry and green chemistry with ecofriendly biological entities can help in minimizing harmful impacts on human health. Polymeric Nanoparticulate Drug Delivery Systems (PNDDS) can increase the bioavailability, solubility and permeability of many potent drugs and also reduce the drug dosage frequency. PNDDS can be used to exploit for many biological drugs that have poor aqueous solubility, permeability and less bioavailability in future to overcome these problems.

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