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Engineering Materials

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Abstract

Nanomaterials can be found in all our products that we use daily. There is a global concern for pollution in our environment a growing need of more sustainable processes. Green nanotechnology was developed to synthesize nanomaterials and reduce the amount of energy used and waste produced. The paper presents a review of the methods of synthesizing green nanomaterials and their application in various fields. Green nanomaterials are synthesized from organic material such as plant and plant waste, bacteria, fungi, etc. The process of synthesizing green nanomaterials takes less energy and produces less pollution than synthesizing nanomaterials chemically. The physical and chemical properties of green nanomaterials enhance their ability to absorb toxins from the environment. More research needs to be conducted to lower the cost of synthesizing green nanomaterials.

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Introduction

Nanomaterials are tiny components found in many products and processes. Nanomaterials are in food and food packaging, pharmaceuticals, water managements, farming, solar cells, recycling industrial waste, and turning diesel soot into carbon nanotubes. Nanomaterials that are synthesized an environmentally friendly way are green nanomaterials. The purpose of this paper is to research the green nanotechnology process and nanomaterials designed to reduce toxins and pollutants in the environment.

The process of producing nanomaterials resulted in high energy use and excessive waste that was harmful for the environment. Research on green nanotechnology began in the 1990s when the Pollution Prevention Act became a law. The law said that industries and companies needed to prevent or reduce pollution at the source of their products. [3]. Research went into producing a method of synthesizing nanomaterials using minimal energy and producing less waste into the environment. The purpose of green nanotechnology is to use renewable resources to produce nanomaterials and products which reduces the amount of pollution that goes into the environment. Green nanomaterials are nanomaterials that are derived from organic material such as plants or fungi. Biomolecule components that come from the organic material are environmentally engineered to form green nanomaterials. The process of forming green nanomaterials is called green nanotechnology. Research in green nanotechnology is important because research has revealed that current nanomaterial production methods produce around 100,000 kg of waste per 1 kg of product [5]. Production of nanomaterials is 1000 times more wasteful than the production of pharmaceuticals and fine chemicals.

The need for green nanotechnology is evident in research comparing the two processes. Chemically producing nanomaterials requires more materials and high temperatures that require higher amounts of energy. Nanotechnology typically requires synthetic reducing agents to produce the nanomaterials. Synthetic reducing agents are harmful to the environment. Nanotechnology also requires stabilizing agents. Nanomaterials that are synthesized chemically need other chemicals and molecules to use as reducing and stabilizing agents [1]. Naturally, extracted components act as the reducing agent and the stabilizing agent. This advantage provides small nanomaterials in larger quantities in a shorter time frame. Current nanomaterial production methods produce around 100,000 kg of waste per 1 kg of product [5]. Production of nanomaterials is 1000 times more wasteful than the production of pharmaceuticals and fine chemicals.

Motivation

I was interested in researching green nanomaterials because nanomaterials are in every aspect of our lives and learning about more environmentally friendly processes to produce everyday products is important to me. Pollution is a growing issue globally. It is interesting to learn about how engineering something so small can produce so much waste and energy. Hopefully, there will be an increasing in using organic materials with green engineering to produce our everyday products.

Applications

The process of synthesizing green nanomaterials takes less energy and produces fewer pollutants when compared to the chemical process of synthesizing nanomaterials [7]. Green nanomaterials use less energy during manufacturing because the process does not need extra chemicals or extreme heat to synthesize. Green nanomaterials have the ability to be recycled after being used. Green nanomaterials are used in manufacturing as catalysts that can produce better efficiency and reduce the toxic waste produced by the manufacturing process [3]. Green nanomaterials are in products in the medical field through pharmaceutical and biomedical fields. Green nanomaterials are found in food packaging products [5].

Nanomaterials are used to remove pollutants and toxins from wastewater. Engineered nanomaterial have large surface areas and high reactivity to contaminants from wastewater or runoff [3]. Using green nanomaterials in water treatment processes is more efficient at detecting and treating contaminants such as bacterial, sediments, and other organic contaminants. For example, nanocellulose is used for removing heavy metal ions, absorbing left over antibiotics, and combines with magnetic nanomaterials to form a super absorbent sponge [5].

Power and energy today are heavily reliant on finite resources such as fossil fuels. There is a growing need for an infinite fuel source. Solar energy is a clean energy source owing to its low carbon footprint. The cost of using solar cells compared to current solar panels is significantly lower, however, solar cells are not as efficient due to the lack of understanding of the catalytic reactions [8].

Green nanomaterial applications can be categorized into three different categories, analytical, bioanalytical, and other applications. Analytical applications consist of nanomaterials being used as absorbent materials, as catalyst agents, and as components of sensors [4]. Bioanalytical applications include the using nanomaterials as sensors to detect parts of biological components such as proteins, amino acids, and biomarkers.

1. Definition

Green nanomaterials are nanomaterials that are broken down from organic materials instead of chemically synthesized. Green nanotechnology and green chemistry synthesize nanomaterials by using green solvents, biomolecules, and biopolymers as natural reducing agents [6]. These materials are renewable, biodegradable, economical, and ecofriendly replacements for current nanomaterials being used. These materials increase environmental sustainability and decrease human health risks that come with the use of traditional nanomaterials [3]. Green nanomaterials have a wide range of applications in the real world, such as in medical and pharmaceutical, food and packaging, electrical, oil and gas, and more (Kirsten et al., 2018).

1. The Structure of Atoms

Green nanomaterials derive from different organic material or other chemicals. An example of a green nanomaterial is Chitosan. Chitosan is created by taking chitin and introducing an acetyl function group. Chitosan is a linear polysaccharide that has glucosamine (an amino sugar) and N-acetyl-D-glucosamine (monosaccharide glucose) [9]. Structure of green nanomaterials affects how foreign objects meet the cell surface as well as how foreign objects interact with the cells [9]. For example, Sunil and Jalal (2021) the Chitin compound ChiNCs' rod-shaped structure provides high binding and adhesion that makes it a good candidate for drug carrying in pharmaceuticals.

One the biomolecule is broken down, the nanoproduct is kept in a powder form in a vacuum to keep moisture from entering. Other times, nanomaterials are kept in suspension, but the physical form the nanomaterial is kept in depends on the size of the product. The Nanomaterial measuring technique only produces an equivalent spherical particle diameter, but most nanomaterials have irregular shapes. For example, Sunil and Jalal (2021) determined that the nanoparticle chitin has a rod-like structure provides high binding and adhesion that makes it a good candidate for a drug carrying in pharmaceuticals [9]. Nanomaterials are small with a relatively large specific surface area. Because of nanomaterials, large surface is interactions with its surroundings would be stronger than for bulkier materials.

The structure of green nanomaterials can be sensitive to the processes they are exposed to and how the nanomaterials form. The aspect ratio, the ratio of height and width, of a nanomaterial affects the surface and interfacial properties of a nanomaterial. For example, a higher aspect ratio will enhance the nanomaterials surface and interfacial properties [9]. Different chemical processes can affect different chemical properties and structure of the nanomaterial [9].

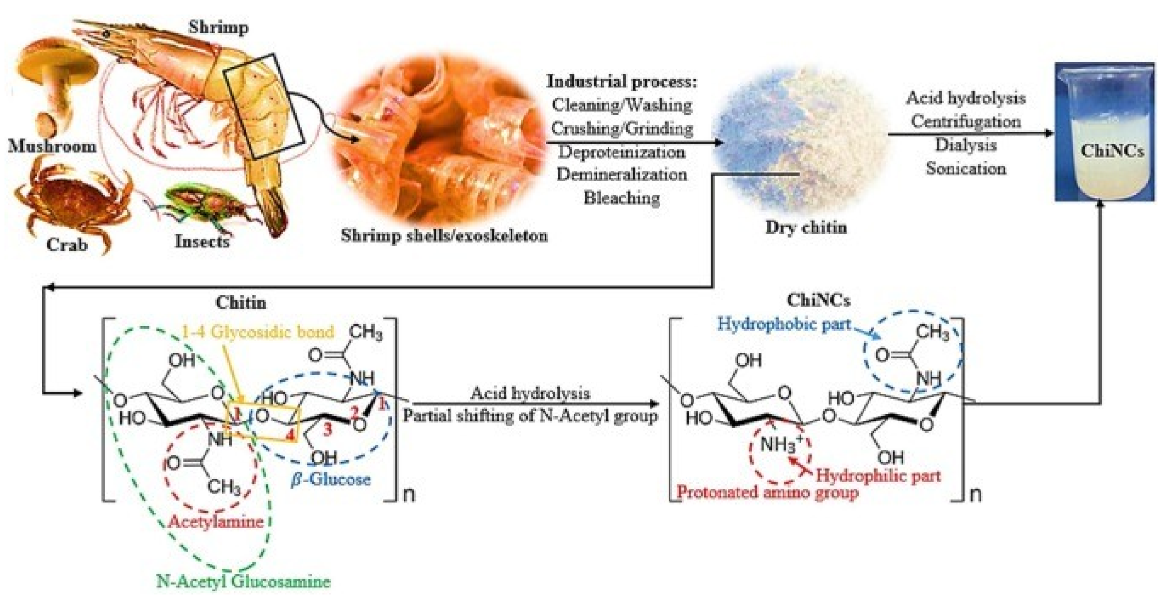

Figure 1: Chitin Structure [8]

2.Pollution Prevention and Greener Technologies

2.1 Wastewater and Air Pollution Management

Nanomaterials synthesized from organic material that are used for wastewater and air pollution treatment have a high specific surface area, adjustable pore size, surface reactivity, etc., have significantly higher rates of pollution absorption than chemically actuated nanoparticles that have limited surface-active sites and needs activation energy. Yunes et at. (2018) research how different nano-absorbents worked [10]. Some of the nano-absorbents they worked on being carbon based, metal-based, and polymeric based [10].

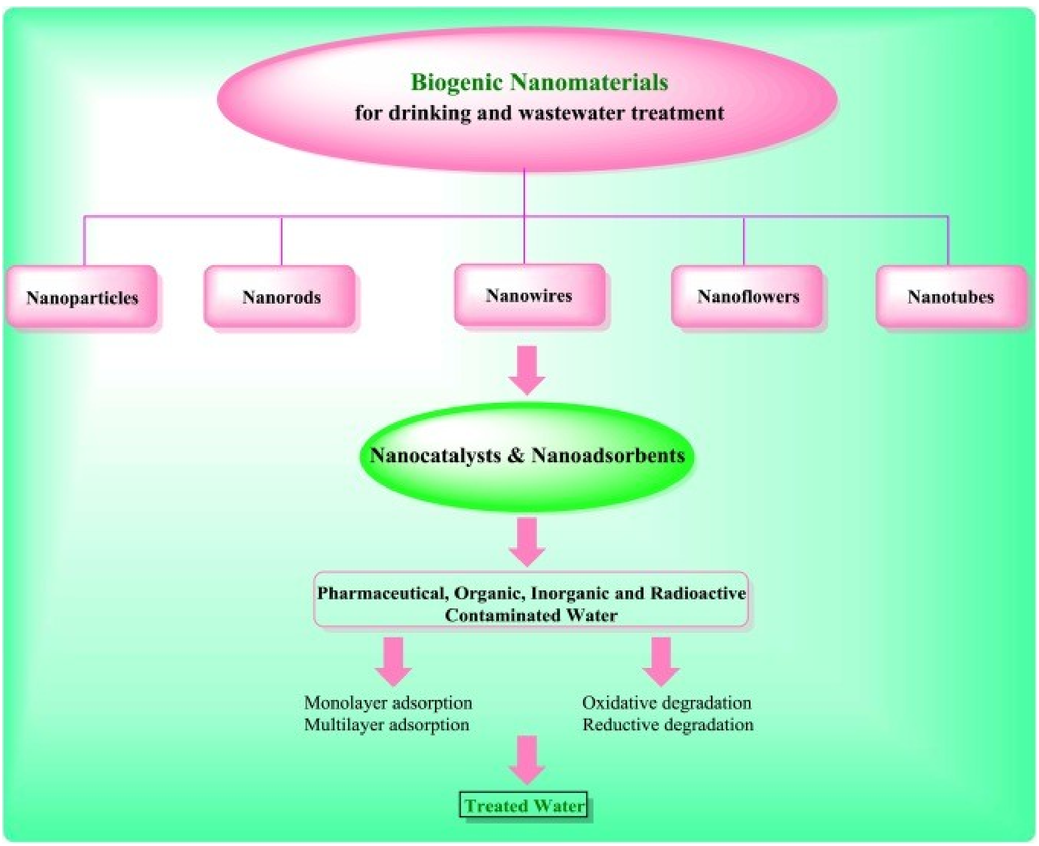

Figure 2:Application of nanomaterials to wastewater treatment [6]

2.1.1 Carbon-Based Nano-Absorbents

Carbon based absorbents used in wastewater and air pollution are carbon nanotubes. Carbon nanotubes are the favored carbon-based absorbent because of their high specific surface area. The two types of carbon nanotubes are single-walled and multiwalled. There are four different sites on carbon nanotubes that can absorb different pollutants: hollow internal sites in the inner nanotubes, interstitial channels, which are found between the nanotubes, the outside surface, and grooves that are found on the outer surface of the nanotubes. Carbon nanotubes contain antimicrobial properties that fight bacteria, such as E. coli and Salmonella as well as viruses. Disinfectants used in the average household have chlorination and ozonation that produces a toxic chemical oxidation. Carbon nanotubes disinfection process only produces nontoxic byproducts, which is a significant advantage over household disinfectants.

2.1.2 Metal-Based Nano-Absorbents

Metal-based nanoparticles are used to absorb heavy metals like arsenic, lead, mercury, copper, chromium, nickel, and radionuclides [10]. Examples of metal-based nanoparticles are iron oxide and titanium dioxide. Metal-based nanomaterials are cheap to manufacture and have high absorption, easy separation, and regeneration. Removing heavy metals using metal-based nanomaterials is a two-step process [10]. First, the nanomaterial has fast absorption of the metal ions around the outer surface of the nanomaterial. Then, diffusion happens along the pores of the wall of the outer surface. Metal-based nanoparticles are typically in powder form and are used for industrial purposes. For example, iron-oxide is used to absorb heavy metals that are found in soils. Nano iron hydroxide is used for absorbing arsenic from waste and drinking water.

2.1.3 Polymeric Based Nano-Absorbents

Dendrimers are polymeric based nanoproducts which were used for removing heavy metals by absorption by hydrogen bonding, hydrophobic effect, and electrostatic interactions [10]. Dendrimers are star-shaped macromolecules with a central core, an interior dendritic structure, and an exterior surface with functional groups. Zeolites are a type of polymeric based nanomaterial. Zeolite are used in water treatment systems to inhibit the growth of microbes and absorption, and work to remove emissions from fossil fuel combustion. These methods of using polymeric based nanomaterials are more cost effective, easily accessible, and have a higher efficiency of eliminating pollutants for wastewater treatment when compared to the traditional treatment systems

3. Chemical Properties

3.1 Reactivity and stability

Green-fabricated nanomaterials are fabricated to react with hazardous material to reduce and change the material to be nonhazardous. Green fabricated iron material reacts with toxic arsenic to produce a nontoxic material [4]. Green nanomaterials are also used as environmentally friendly catalysts to speed up reactions.

3.2 Composition

Composition of green nanomaterials are simple compounds. Many green solvents that go into fabricating green nanomaterials, such as supercritical carbon dioxide and supercritical water, are nonflammable and nontoxic. These green solvents have unique properties such as low viscosity, high diffusivity, and near zero surface tension [4]. A common solvent that is used to break down biomolecules is water.

3.3 Porosity

Nanoproducts with high porosity and a large surface area are commonly used for water treatment. Porous green nanomaterials have properties such as high surface are, tunable acidity, controlled micropores, active site access, and stability [7]. Nanomaterial membranes have cylindrical sized pores that are 1-10 angstrom, which is 0.1 nanometer, that pass through the membrane at a 90 degree angle. Nanomaterials can be constructed to have high porosity to absorb hazardous or toxic material from polluted resources. For example, Mahmoud et al. (2021) researched green fabricated amorphous iron that was manufactured to remove arsenic from polluted resources. The arsenic was uniformly absorbed on iron's surface area.

4. Green Nanotechnology (Green synthesis)

The purpose of green synthesis is to use renewable energy, minimize waste, and use minimize energy consumption. Green nanotechnology utilizes organic material for the active bio-component with low heating and nontoxic solvents. Water is a common solvent in green synthesis. Biomolecules are extracted from plants to produce biomolecules that have reducing, capping, and stabilizing agents for the nanomaterial [6]. Nanomaterials are stored in powder form in a vacuum to prevent moister from entering.

Green nanomaterials are prepared through green synthesis, also known as green chemistry. Green chemistry follows a set of principles that reduces the product of hazardous materials during the design, manufacturing, and implementation stages of chemical products [2]. Green nanomaterials are manufactured by using green solvents, biomolecules, and biopolymers as natural reducing agents. Plant, micro-organisms, and other biomolecules are used in creating green nanomaterials. An example of a natural reducing agent is microorganisms, enzymes present in microorganisms break down substrate to form green nanomaterials [3].

Figure 3: Basic green synthesis process (a) bacteria, (b) yeast, (c) algae, (d) fungi, (e)bacteria, (f) plants [3]

5. Future Analysis

Future research is needed to better understand the physical, chemical, and mechanical properties of nanomaterials in general. For example, there needs to be more information on the metrics of green nanomaterials, such as surface area, size, etc., to perform things such as risk assessments. Since green nanomaterials are relatively inexpensive, this technology may be able to help developing nations have access to clean drinking water and clean air.

Green nanomaterials can have a potentially positive impact of agriculture. Development in nanomaterials in agriculture can improve soil quality, plant health, and increase crop productivity. While green nanomaterials themselves are biocompatible and renewable resources, the process to formulate green nanomaterials are not as renewable. Nanomaterials are synthesized using chemical, physical, and biological techniques, which can be expensive and form environmental toxicity and create carcinogens [2]. More research is needed to produce more efficient, environmentally friendly, and cost-effective green nanotechnology processes.

Figure 4: Outlook of Green nanotechnology [2]

6. Cost Analysis

Nanomaterials are widely used in the industry and in consumer products. Consumption of all types of nanomaterials has a global market of $10 billion in 2020 and the market is projected to continuously grow [3]. Increase in green nanotechnology involves investing money into technical devices, research, filtration devices for water waste management, etc. The cost of manufacturing some nanomaterials through current nanotechnology can be cheaper than producing nanomaterials through more environmentally friendly nanotechnology. For example, a study done by Piyal et al., stated that producing super paramagnetic iron-oxide nanomaterials through assisted microwave chemical processes has a production cost of around USD 160 per 10 grams [8]. Through green synthesis, iron nanomaterials that are extracted from plant extract costs between 250-500 USD per 10 grams.

Summary

Green nanotechnology is the synthesis of nanomaterials using renewable resources and environmentally friendly procedures to reduce the amount or waste created and the amount of energy used. Green nanomaterials are broken down from organic materials like plants, bacteria, fungi, etc. Green nanomaterials have specific properties that help absorb pollution in various areas. Many green nanomaterials have large surface areas and high absorption to absorb toxic materials from water, air, soil. Green nanotechnology and green nanomaterials are relatively inexpensive. With more research, this technology may be able to provide clean water and cleaner air to developing countries as well as reduce the overall pollution that effects everyone all over the world.

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