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Emerging Trends in Nanoabsorbents Absorption Applications

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ABSTRACT

Nanoabsorbents are nanoscale particles from organic or inorganic materials that have the high affinity for absorbing substances. Several potential applications of nano absorbents are still in the research and development stage; although very few applications are market-ready and will require both translations from the laboratory to field scale plus appropriate safety testing. This very small size of the nanoparticles results in a high surface area to volume ratio which improves the durability of nanomaterials and absorption ability of nanomaterial for the absorption of moisture and other substances. The use of nanoparticles to manufacture nano absorbents allows such nanomaterials to become multifunctional and produce fabrics with unique functions, as well as antimicrobial, UV-protection, flexible, soft, durable, oleophilic, water absorbent, easy clean, water repellent and anti-odor. Practical functioning of nanotechnology for absorbents requires that the nanomaterials in the form of nanoparticles/foams/sponges etc, be rightly engineered or packaged to aid their applications. The review describes the current use of nanotechnology (nano-absorbents) in the absorption of spills and other substances in the areas of energy, health, food technology, environmental remediation and advanced materials and products.

Keywords: *Nanotechnology, Nanoabsorbents, Applications, Nanoparticles, Absorption.*

1. INTRODUCTION

Nanotechnology is the science of working on matter at the nanoscale to make new and unique materials and products with vast potential to changing society [1]. Nanotechnology, which is one of the new technologies, refers to the design, characterization, development and application of structures of devices, and systems whose size in the nanoscale varies from 1 to 100 nanometers (nm) [1]. At scales of nanometer range, materials can show unique characteristics different from their bulk state [2]. In relation to their size, nanoparticles have huge surface areas to volume ratio, a characteristic that makes them very effective in catalysis, absorption and other processes [1, 3].

According to ObservatoryNano [3] nanoabsorbents are nanoscale particles from organic or inorganic materials that have a high affinity to absorb substances. In recent years, nano-particle materials have been studied for their potential as absorbents [1]. The smaller the size of the nanoparticles, the higher the surface area to volume [1, 4], hence, enhances the durability of fabrics (nanomaterials) and absorption ability of nanomaterial for the absorption of moisture and other substances. The use of nanoparticles to fabricate nanoabsorbents allows such nanomaterial to become multifunctional and produce fabrics with special functions, including antimicrobial, UV-protection, flexible, soft, durable, oleophilic, water absorbent, easy clean, water repellent and anti-odor [5].

Nanoabsorbents have applications in environmental remediation, food technology, health and sanitary also in many other innovative applications. However, many potential nanoabsorbents have already been developed and are commercially available, with many still in the research or developmental stage and expected to be commercialized in the near future; which will require both translations from laboratory to field scale.

2. NANOABSORBENT APPLICATIONS

2.1. Nanoabsorbents in Hygiene Application

Disposable diapers, sanitary napkins and other sanitary products readily available in the market have been made to have increased potential to absorb moisture through the use of superabsorbent polymers (SAPs) and other chemicals for a few decades now [6]. However, superabsorbent polymers also known as ordinary pads can cause rashes even irritation because of the chemicals that don't react well to damp conditions, particularly for use as menstrual pad [7]. These materials are capable of absorbing many times their own weight in liquid; the average diaper can absorb 30 times its own weight in bodily fluids [1, 8]. The material is, however, not biodegradable; in ideal conditions, it can take as long as 500 years for a diaper to degrade [8]. Thus, the prolonged use of commercially available products made of SAPs have been linked to health problems like Toxic Shock Syndrome and other conditions, leading to the ban in tampons (a type of absorbent material) in the 1980s [7, 8]. Hence, these issues created the need to develop a safe alternative to SAPs. According to researchers, a new material – made of electrospun cellulose acetate nanofibers – does not have these drawbacks. In their study the team analyzed the material, and they suggest its use in place of SAPs in female hygiene products [1, 8].

Researchers from the Department of Chemical Engineering, Indian Institute of Technology, Hyderabad, led by Chandra Shekhar Sharma, have developed a material made of cellulose acetate electrospun nanofiber that can be used to make improved sanitary pad between 30% and 60% more absorbent using nanothechnology [7, 8]. The material used in the manufacture of these commercially available sanitary napkins is made up of flat, ribbon-like fibers that are about 30 micrometers thick, while those of nanofibers are about 150 nanometers thick – about 200times thinner. The nanofibers are long and very thin fibers made using a technique called elecrospinning – spinning using electricity [7, 8].

The nanofiber material is more comfortable than those of superabsorbent polymers (ordinary pads) and leaves behind fewer residues after use [6]. The nanofiber material also is much smoother in composition, resulting in a thinner and softer product that doesn't need to be changed as often as the regular ordinary pads, making them a less expensive option, less of an environmental impact and be safer for humans than the existing superabsorbent polymers materials [7, 8]. This was confirmed in tests using saline and synthetic urine, the electrospun fiber material was much more absorbent than commercially available products [8]. Nanotechnology has made hygiene products safer to use and dispose, thus promises a positive global health and the environmental impacts.

2.2. Nanoabsorbent Astronaut Undies Neutralizing Odour

Deoest® odour eliminating underwear, developed by a Japanese textile company, Seiren, has promises to magically absorb offensive odours [9]. Also, the sales of odour absorbing underpants originally designed for astronauts are hitting their own progress, as Japan faces record breaking temperature [10].

Fig 1: Deoest® Odour Eliminating Underwear

Goldwin, the company that markets Speedo® swimsuits in Japan, emphasize that its nanotechnology improved MXP® underpants can defuse the smell from four liters of sweat. The underwear comprises a nanotechnology and eucalyptus filled fabric by Toray that is lightweight, sweat absorbent, odor removing, antibacterial, antistatic, flame resistant, and quick drying. This odour eliminating underwear is also water conserving because they require infrequent washing [10]. Koichi Wakata, the first Japanese astronaut to live on the International Space Station, wore a similar pair of prototype odour eliminating underwear in 2009 for a month without laundering and at a pre-landing briefing told the press that he wore it for about a month and his station crew members never complained [10].

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2.3. Silver Based Nanoabsorbent Pads in Food Technology

A research by Ferna´ndez *et al.,* [11] demonstrates that specially designed absorbent materials could be optimized to preserve aseptic conditions during manipulation, leading to feasible applications of a silver based nanotechnology in food technology. This was confirmed in the satisfactory relationship between silver ion release and the antimicrobial efficiency against *Escherichia coli* and *Staphylococcus aureus*.

Silver nanoparticles (AgNPs) were found appropriate to assure high antimicrobial activity [12]. Lok *et al*., [13] have reported that AgNPs carry silver ions chemisorbed in the partially oxidized nanoparticles and AgNPs have been fused into food contact surfaces such as polypropylene, polyethylene, or nylon [14], hence absorbent pads. The AgNPs of elemental silver was produced upon silver reduction by ultra violet (UV) light and heat of silver ions adsorbed during immersion in silver nitrate by electrostatic interactions in the cellulose fibers/absorbent pads, which remain stable in highly absorbent fluff pulp and had effective antibacterial activity in food matrices [11]. Hence, porous structure of the cellulose fibers serves as a nano-reactor and favors the production and stabilization of AgNPs [15]. In a study [16], the absorbent pads containing silver nanoparticles (AgNPs) reduced the level of microbial load in exuded fluids, during storage of meat (beef) in Modified Atmosphere Packaging (MAP). In a similar experiment [17], a more drastic decrease in microbial loads was observed during storage of fresh-cut melon pieces stored on AgNP-containing cellulose pads, with longer microbial lag growth phase.

2.4. Nano-Absorbents Measuring Heavy Metals in Children Food

Iranian researchers at Islamic Azad University in Tabriz Branch, Northeastern Iran, have developed a nano-absorbent which can measure slight amount of heavy metals in children food with high precision and speed by an economical method [18]. Ghorbani-Kalhor*et al.*, [19] successfully applied the magnetic metal-organic frameworks (MOF) nanocomposite to rapidly remove trace amounts of heavy metal ions in baby food samples and pre-concentrated them. Magnetic metal-organic frameworks are porous and can accommodate metal ions. The results of the study showed that the nanoabsorbent can be used to identify and measure heavy metals in different industries both in food industry and oil. Using the product would lead to reducing price of food samples and lessen contamination resulted from toxic solutions [18].

2.5. Nano-Absorbent Material for Broadband Absorbers

Broadband absorbers are essential components of much light detection, energy harvesting, and camouflage schemes [20]. Materials that "perfectly" absorb light already exist but they cannot be controlled to absorb only a selected range of wavelengths, which is a disadvantage for certain applications. These materials are either bulky or use planar films causing problems in cracking and delaminating when bent or heated [20].

Recently, devices that could be more than triple solar cell efficiencies, thin, lightweight shield that block thermal detection; transparent window coatings that keep buildings and cars cool on sunny days have been created [20]. These are potential applications for a thin, flexible, tunable, light-absorbing material, called a near-perfect broadband absorber; absorbs more than 87 percent of near infrared light (1,200 to over 2,200 nm wavelengths), with 98 percent absorption at 1,550 nm, the wavelength for fiber optic communication and can absorb light from every angle [20].This material offers selective, and broadband near-perfect, all-directional absorption, that could be adjusted to distinct parts of the electromagnetic spectrum. The absorber depend on optical phenomena which are collective movements of free electrons (known as surface plasmon resonances), that occur on the surface of metal nanoparticles upon interaction with certain wavelengths of light [21].

A lot of free electrons can be carried by the metal nanoparticles which make them exhibit strong surface plasmon resonance but mainly in visible light, not in the infrared. The engineers perceived that if they could change the number of free electron carriers, the material's surface plasmon resonance would be adjusted to varying wavelengths of light. Therefore, they designed and built an absorber from materials that could be improved, or fixed, to carry a different amount of free electrons: semiconductors [21]. These researchers used a semiconductor (zinc oxide) which has a moderate number of free electrons, and combined it with its metallic version (aluminum-doped zinc oxide) which houses a high number of free electrons [22], not as much as an actual metal, but enough to give it plasmonic properties in the infrared. The materials were deposited one atomic layer at a time on a silicon substrate to form an arrangement of standing nanotubes, each made of alternating concentric rings of zinc oxide and aluminum-doped zinc oxide. The tubes were 1,730 nm tall, 650 to 770 nm in diameter, and spaced less than a hundred nanometers apart. The nanotube arrangement was then transferred from the silicon substrate to a thin, elastic polymer or any type of substrate and can be scaled up to make large surface area devices, like broadband absorbers for large windows [20].

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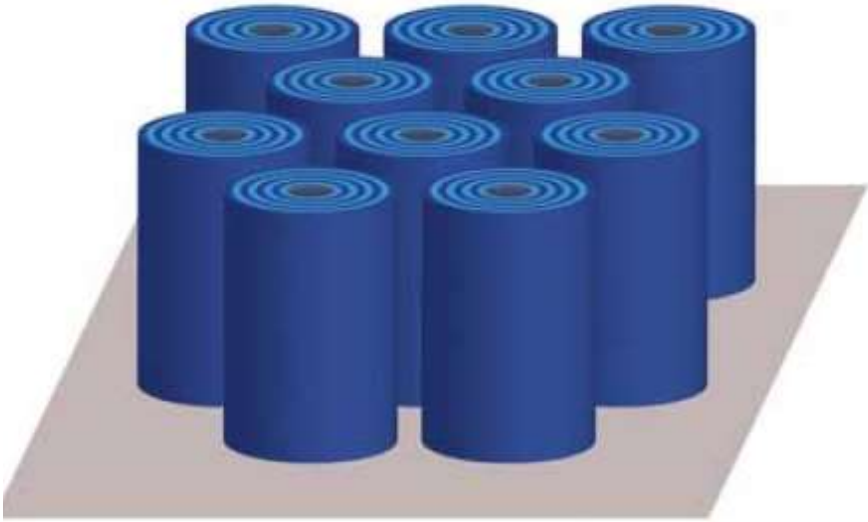

Fig 2: This is a schematic of the nanotube array. (Image: UC San Diego Jacobs School of Engineering)

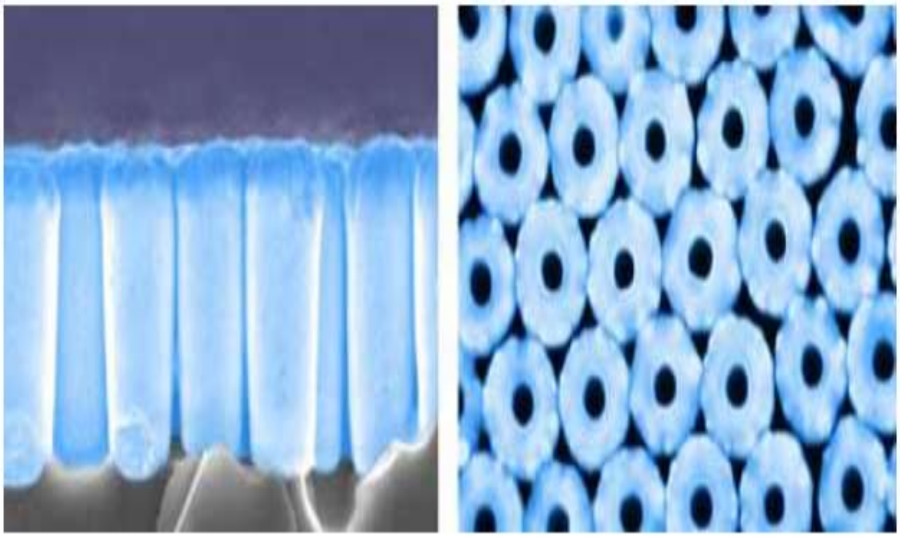

Fig 3: SEM images of a nanotube array: side view (left) and top view (right). (Image: UC San Diego Jacobs School of Engineering

The technology is still at the developmental stage. A lot of works are ongoing to discover different materials, geometries and designs to develop absorbers that work at varying wavelengths of light for various applications. The synthetic strategies presented here are universal and can be applied to other nanoparticle systems.

2.6. Nanotechnology-Based Absorbent Materials for Environmental Remediation

Numerous solutions for dealing with the problem of oil spills which include use of microorganisms to digest the oil, mechanical means (skimmers, booms, pumps, and mechanical separators etc), sorbents to remove oil from water through adsorption and/or absorption and use of chemical dispersants like detergents etc., have been proposed [23]. Although the application of nanotechnology for oil spill cleanup is still in its emerging stage, using engineered nanoabsorbent materials is a better option than conventional techniques as it leads to better efficiency and response. The higher efficiency of nanomaterials can be credited to their increased surface area and higher reactivity as well as the prospects of *in situ* treatment [23]. For this application, nanoabsorbent materials are mainly determined by their sorption capacity, selectivity for organic solvents and oil, rate of sorption, tailored surface chemistry etc. The nanoporous sorbents, namely thermally exfoliated graphite oxide (TEGO), carbon fluorinated (CF) functionalized aerogels and carbon nanotube (CNT) sponges have outstanding oil absorption capacities [23].

Nanoabsorbents selectively absorb oil from water-oil mixtures because of their unique combination of superhydrophobic and superoleophilic properties but the conventional sorbents based on polypropylene, silicon-coated glass fibers, raw cotton etc. can absorb both water and organic solvents [24]. An additional feature of nanoabsorbents is that they are robust, highly flexible and

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capable of tolerating a number of large strain compressive cycles without affecting their properties which makes them highly useful for recovery of oil as well as renewal and reuse of the material [23].
Practical effectiveness of nanotechnology for oil spill remediation requires that the nanomaterials in the form of nanoparticles/foams/sponges etc, be suitably engineered or packaged to facilitate their application [23].

2.6.1. Examples of Engineered Nanoabsorbent Materials for Proper Oil Spill Remediation

Thermally exfoliated graphite oxide (TEGO): TEGO is a powdery material that is contained in large porous sacks made from polypropylene or polyethylene fabric or porous film. On the other hand, TEGO can be co-treated with a polymer binder in the form of a foam sheet. The open cell structure of the foam allows the TEGO surfaces to make contact with the oil. The advantage of this system is that the absorbent system can be rolled for storage [23].

Hydrophobic CF functionalized aerogels*:* These are powdery materials that may be incorporated into devices. Here, aerogels are incorporated into solid support like fiberglass, alumina, coon, wool carbon foam etc. The incorporation is done by dipping the solid support in either the powdered aerogel, or in slurry of the aerogel in a solvent, or by any other coating technique [23].

Nanowire Membranes: Massachusetts Institute of Technology (MIT) researchers has developed super-hydrophobic nanowire membranes for the selective absorption of oil from an oil-water mixture [25]. These super-hydrophobic nanowire membranes are free-standing membranes comprising inorganic nanowires that can absorb oil up to 20 times their weight. By using these super-hydrophobic nanowire membranes, MIT has recently created an automatic oil-absorbing robot called Sea-swarm which is capable of navigating the surface of the ocean to collect surface oil and process it on site.This prototype robot has a conveyor belt covered with the oil absorbing nano-wire membrane which rotates when moving along the surface of water, and selectively absorbs the water to do the cleaning job. These automatic robots use very little energy (as low as about 100 watts), can run for weeks and have the capacity to clean up several gallons of oil per hour [25].

Cotton Absorbent Pads and Filter Papers: This is a low-cost, raw cotton waste, which is a remarkable oil absorbing material that is biodegradable in nature. It can soak up oil up to 40 times its weight. Professor S. Ramkumar of The Institute of Environmental and Human Health (TIEHH), Texas Tech University has developed value added cotton absorbent pads using nonwoven materials and nanotechnology; recently, he chemically treated the raw cotton which enhances its oil absorbing capabilities to soak the oil up to 70 times its weight [23].

3. CONCLUSION

This article provides current trends of usefulness of nanoabsorbents (nanotechnology product) in absorption of spills and other substances, in the areas of energy, health, food technology, environmental remediation and advanced materials and products. It is quite evident from the foregoing exposition that nanoabsorbents have enormous potential to provide innovative solutions by virtue of their unique structures, superior properties and outstanding performances. However, for their successful placement as commercially viable technologies, there is need to carry out thorough studies on the engineering aspects, environmental issues, scalability and economic effectiveness.

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