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Nanomaterial Regulation and its Applications in Textile Sector: A Review

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ABSTRACT

The beauty of nano-technology is mainly dependant on the size of the particle. As the size decreases to nano range (1- 300 nm), the surface area of the particle increases and thus imparting the nano-particle the enhanced chemical, physical and biological properties. Nano-technology is an emerging science at present and is the science for the future development. It has got a wide range of scope and applications in the fields of medical science, space science, agriculture, chemical engineering, genomics and so on. As such there is no renowned bodies for its regulations internationally but at a country level some of the developed and developing nations are regulating through its existing institutions. OECD, EU, FDA, Health Canada, etc. are some of the working regulatory bodies in the field of nano-technology. Its application in the field of textile sector is not explored much but it is mainly used for finishing of the fabric or imparting specific properties like anti-microbial, fire resistance, UV protective clothing, etc. by coating the fabric with nano-particles. A huge scope and tremendous gap are existing with respect to its regulation for manufacturing, sell, transportation, storage, handling of nano-products, etc. In future, its application in the field of textile can be explored voraciously.

Keywords: Nano-fibre, Regulatory bodies, Covid-19, Anti-microbial, Stain repellent, Textile

Any product having nano-particles on it, in it or made up of nano-particles (that is in the range of 1-100 nm) at least in any one dimension are considered to be nano-products and the technology involved in making these products are known as nano-technology. However, there is no such hard and fix definitions related to the size of nano-products. In general particles in the size of 0-300 nm are considered to be nano-products. As such there is no exact proof regarding the term 'nano-technology' used by whom but the concept of it was discussed for the first time in a talk entitled 'There's Plenty of Room at the Bottom' by an American Theoretical Physicists Richard Feynman in 1959 (Patra and Gouda, 2013). Since then, the advent of nano-technology started and during 80s and 90s it took a fast lap in the field of science. Nano-technology is an emerging science having diverse application in the fields of medical, engineering, agriculture, space science, chemical engineering, genetics and breeding and so on, with improved properties from the conventional products. As such, there is no internationally renowned bodies for regulations of nano-products but some of the countries constitutes a specific authority or committee to regulate its manufacturing, storage, transport and sell across the world. Nano-technology in textiles has given a wide range of nano-products suitable for properties like fire resistant clothes, antibacterial and antiviral protective or medical apparels, high strength army jackets, uniform and boots, nano-sensors in clothes

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and blankets for cooling or heating effect, etc. This technology is a boon for development of a country in the present and the future era. Now a days, it has been used smartly to synthesize products like masks which can trap the deadly virus like covid-19 (Lin *et al.* 2020). 3D printing with the use of nano-technology has changed the scenario of graphics and textile sectors tremendously (Maver *et al.* 2018). It has also been used in harvesting energy and utilizing the same for generation of electricity. This review is mostly written to emphasize the recent development in application of nano-technology for the synthesis of nano-textiles and other diversified textile products.

Synthesis of nano-materials

As such, nano-materials cannot be obtained easily from nature. Either it has to be synthesized or to be extracted from living organisms. Nano-materials/ particles are synthesized /manufactured or obtained mostly by these approaches (Vollath, 2008; Choi *et al.* 2008):

Top to Bottom or Top Down Approach

In this approach, large molecules are broken down into smaller particles of nano-size while maintain the chemical integrity of the molecule. The nano-sized particle obtained via this approach possess enhanced properties like better conductivity, lustre, penetration into deeper layer and targeted delivery at controlled rate, etc. Top down approach is effective in maintaining the size in real world matrix (meter to nano-scale). Here, the bigger molecules are grounded in ball mill or other devices to get the nano-particles (Ex: Polymeric materials).

Bottom to Top or Bottom Up approach

In this approach, very fine and smaller molecules are aggregated to get the particles of nano-size. Here also, the nano-particles obtained possesses improved properties as mentioned above. By using this approach one can achieve very good precision with respect to the size of the material by maintain its optical and electronic properties. This is done via chemical reaction leading to synthesis of nano-products. Examples of nano-products synthesized via bottom up approach are quantom dots, nano-bars, carbon nano-tubes, nano-formulated pesticides, drugs, etc.

Bio-synthesis

Nano-particles can also be synthesized by living organisms especially microorganisms. Here, the organisms or the microbes possess the capability to synthesize nano-products in situ in very small quantity which can be extracted from them and used as such. These are mostly bio-nano molecules like proteins, lipids, hormones, etc. This approach is very useful in synthesizing bio-sensors.

Measurements of Nano-particles/materials

Once synthesized, nano-products are to be characterized for the properties desired or measured for its size confirmation. It is must to measure the size of the particle, since most of the properties of nano-particles, researchers are finding or incorporating in some instruments or design are based on size of the particles. As size of the particle decreases the surface area tends to increase which are responsible for some properties at the nano-scale. Nano-particles are characterized by a wide variety of techniques like microscopic techniques (Ex: Transmission electron microscopy (TEM), scanning electron microscopy (SEM), atomic force microscopy (AFM), etc.), spectroscopic and photonic techniques like Fourier-transform infrared spectroscopy (FTIR), powder X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), nuclear magnetic resonance (NMR), dynamic light scattering (DLS), and matrix assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF-MS), etc. Each technique has its own advantages and disadvantages or limitations in measurements. Among these techniques, DLS method is more simple, cheap, reliable and easy to operate. In fact, it gives the averaged value for the measured nano-particles diameter (Brar and Verma, 2011).

Regulatory bodies for Nano-products

After synthesis and characterization of nano-products, it is must to ensure safety to the consumers and also to the persons involved in its handling. Throughout the world, there is no such international bodies looking after the manufacture, sell, storage and transportation of nano-products. However, some of the countries are maintaining its rules and regulations for commercialization of nano-products within the existing bodies which measures or control food, pesticides, cosmetics and drug sectors, etc. In the United States of America, Food and Drug Administration (FDA), and Department of Toxic Substances Control (DTSC) within the California Environmental Protection Agency) look after the regulations of nano-products and nano-materials (Bawa, 2013). In Australia, there are seven different bodies regulating nano-technology and the use of nano-materials in commercial products. These are National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Food Standards Australia New Zealand (FSANZ), Therapeutic Goods Administration (TGA), Australian Pesticides and Veterinary Medicines Authority (APVMA), Worksafe Australia, Australian Competition and Consumer Commission (ACCC) and Australian Government Department of the Environment (AGDE). These bodies are responsible for regulation of chemicals, food, drugs, pesticides and other consumable and non-consumable products of nano-nature. They regulate sell, storage, packaging, and handling of nano-products and provide guidelines for safety at work place. They also look on the environmental impact associated with the use of these nano-materials (Jagadish and Barnard, 2020; Ludlow *et al.* 2007). Belgium, France, Denmark, and Sweden have established national registries of nano-materials. In addition, the European Commission (EU) requested the Europeach Chemicals Agency (ECHA) to create a European Union Observatory for Nano-materials (EUON) that aims at collecting publicly available information on the safety and markets of nano-materials and nano-technology. The European Union is implementing a new Classification, Labelling and Packaging (CLP) Regulation for nano-products (Chau *et al.* 2007). Health Canada has established a Working Definition of Nano-materials, where it "considers any manufactured product, material, substance, ingredient, device, system or structure to be nano-material if it is at or within the nano-scale (1–100 nm) in at least one spatial dimension, or is smaller or larger than the nano-scale in all spatial dimensions and exhibits one or more nano-scale phenomena". Health Canada advises manufacturers to consult with the responsible regulatory authority during the early development process to identify and assess the product's risks and properties. In Taiwan, regulations and certifications of nano-products are done by Nano-Mark system under the guidance of Taiwan Nano-technology Industry Development Association (TANIDA). In India, the Department of Science and Technology, and the Government of India have created a group to regulate nano-technology and draft a set of guidelines creating a three-tiered governance framework which has been implemented to assist policy makers in developing a pathway for regulation of nano-products (Adholeya *et al.* 2017). USA, Japan, Canada and Australia are the leading countries with respects to regulations of the nano-products.

Looking at the risk associated with nano-materials, most of the developed countries have become members of international organizations like Organization for Economic Co-operation and Development the Working Party on Manufactured Nano-materials (OECD WPMN), Registration, Evaluation, Authorization and Restriction of Chemicals Annex (REACH Annex), International Organization for Standardization / Technical Committee 229 (ISO/TC 229), etc. Nano-material standardization work and test guidelines are regulated by these international organizations. They also ensure safety related to manufacturing, sell, storage, transportation and use of nano-products. Working Party on Manufactured Nano-materials (WPMN) was launched by OECD in 2006 and are presently involved in preparation and implementation of OECD test guidelines for manufactured nano-materials. The ISO/TC 229 are working on standards for nano-technologies and defines and regulates the guidelines related to measurement and characterization, terminology and nomenclature, materials specifications, and health safety and the environment. ISO and IEC are the internationally accepted standards for many products. Recently, these standards have been revealed for nano-technologies (ISO/TC 229) and nano-technologies standardization for electronic products and electrical system (IEC/TC 113). In fact, ISO/TS 80004-1:2010 defines nano-technology as *"Application of scientific knowledge to manipulate and control matter in the nano-scale in order to make use of size- and structure-dependent properties and phenomena, as distinct from those associated with individual atoms or molecules or with bulk materials"*. ISO/TS 27687:2008 defines the size of nano-particles as in the range of 1 nm-100 nm (Haydon and Eng, 2012). In addition to above regulatory bodies, Korean government regulates various nano-products in the market with information about the safety evaluation of nano-products through Korea Research Institute of Standards and Science (KRISS) and Korea REACH (AzoNano, 2019).

Applications of Nano-technology

Nano-technology has immense application in the field of medical science, space science, chemical engineering, and energy sectors. In agricultural science, applications of nano-technology are still not explored much and find its uses in controlled delivery nano-pesticide and nano-fertilizer. Besides these, it also finds its uses in textile sectors and bio-sensors. There are a variety of products manufactured through nano-technology using nan-materials. Some of the currently used nano-products and nano-materials are summarised in Table 1 (Park and Yeo, 2016).

In synthesizing these nano-materials and nano-products, a large number of industries or companies are involved. Some of these industries or companies involved in manufacturing nano-products across the world are listed in Table 2.

Once the nano-materials are synthesized, they are either coated on the fabric or are incorporated in the fabric or yarn to make desired textile products. Nano-fibres are also made via chemical bath or electrostatic adhesion. Textile material maybe yarn, dyed fabric, clothes, composites, etc. In the textile sector, commonly used nano-particles or nano-materials are gold, carbon, silver, titanium oxide, copper and its complex compounds for imparting the desired properties. These properties may be anti-microbial, sensors, flame retardant, stain, wrinkle and shrink resistance, high tensile strength, highly conductive, luminescence, super-magnetic, energy conservation, cooling effect, water repellent, self-cleaning, etc. (Haydon and Eng, 2012). Antimicrobial clothing or fabrics are associated with anti-odour, anti-fungal, anti-bacterial. By imparting these properties, the textile materials become free of traditional care of storing at appropriate place, frequent washing, wrinkle, odour, etc. Researchers have used nano-particles for making nano-textile either coating the yarn, fabric, and composites, etc. or by incorporating and blending the nano-fibres into other fabrics to get the nano-products. Some of the representative work on nano-textiles has been listed in Table 3.

There are many more applications of nano-technology in the fields of textile have been explored worldwide and yet to be explored. Nano-sensors used on fabrics helps in tracking and provides protection from germs by keeping you alert. Now a days, masks are made up of incorporating nano-particles into it and aiding in protecting even from deadly virus like covid-19. Looking at the present covid-19 pandemic, the recent application is synthesis of masks suitable for trapping the virus through high surface area to volume ratio and small pore size (Chowdhury *et al.* 2020).

Table 1: Nano-products and nano-materials in usage

Sl. No.	Nano-particles/ materials	Products used
1	Ag, Fe, and Carbon nanotubes	Air humidifiers, refrigerators, and washing machines
2	Ag, Au, SiO_2, TiO_2, ZnO, and carbon nanotubes	Agriculture (Seedling germination agents, pesticides, fertilizers, effluent treatment and water purification, water retention)
3	ZnO, TiO_2, and Fe_2O_3	Paints, ceramics, glass, cement, pigments, adhesives, rubbers, plastics, sealants, foods, batteries, ferrites, lubricants, ointments, fire retardants, and first-aid tapes
4	Ag, activated carbon, TiO_2	Spray based air cleaner, Ozone and UV-treatment in water filters
5	Ag, SiO_2, and TiO_2	Coating on textile with paints, polish, liquid spray, etc.
6	Jute charcoal, bamboo charcoal, Teflon, fullerene, Ag, Au, TiO_2	Textile for UV protection and anti-microbial clothes
7	Ag, Au, SiO_2, and ZnO	Electronics (microchip, semi-conductors, computers), and cooling liquids
8	Au, Ag, Pt, Cu, and fullerenes	Cosmetics (sunscreen, lotion, lipstick, face powder, soap, spray, liquid gel) and medical services (anti-fungal, anti-bacterial, sanitizers, etc.)

Table 2: Industries or companies involved in manufacturing nano-products across the world

Sl. No.	Companies/ Industries	Products made	References
1	Auto Fibre Craft Powders, India	Ag-NPs powder	NanoWerk (2020)
2	Nanoshel, India	Nanotubes, SWCNT's, MWCNT's, nanoparticles	NanoWerk (2020)
3	Adano Technologies, India	Graphene and carbon nanotubes	NanoWerk (2020)
4	Advanced Nano Tech Lab, India	Coating products	NanoWerk (2020)
5	Agilent, 454 Life Sciences, US Genomics, Nanomix (USA)	Biosensors, nanotube chemical sensors, nanopore sequencing, etc.	Mazzola, L. (2003)
6	NanoMateria and AngstroMedica (USA), pSiMedica (UK)	Medical devices (Tissue engineering)	Mazzola, L. (2003)
7	Advanced Nano Products Co., Ltd, South Korea	Metallic nano-powder	AzoNano, (2019)
8	Nano Co., South Korea	Manufactures and regenerates Selective Catalytic Reduction (SCR) catalysts	AzoNano, (2019)
9	ABC Nanotech, South Korea	nanomaterials that create high value-added propositions	AzoNano, (2019)
10	Nano Technology Inc., South Korea	Pulsed wire evaporation system to produce nano-powder, magnetic pulsed compaction system to compact nano-powder, Metal/Ceramic nano-powder: Al, Cu, Fe, Ag, Sn, W, Zn, Cu-Ni Alloy, CuO, ZnO, SnO_2 Nano Fiber: Al_2O_3, Fe_2O_3 Nano Lubricant	AzoNano, (2019)
11	NTbase, South Korea	Nano-powders	AzoNano, (2019)
12	Hitachi high Technologies, London, UK	Electron-beam lithography	Mazzola, L. (2003)
13	Imago Scientific Instruments, USA	Microscope	Mazzola, L. (2003)
14	Dendritic Nanotechnologies, USA	Dendrimers	Mazzola, L. (2003)
15	Evident Technologies, Quantum Dot, Nanosphere, USA	Semi-conductors, quantum dots, detection systems, etc.	Mazzola, L. (2003)

Table 3: Area explored on nano-textiles across the world

Sl. No.	Areas explored	Properties	References
1	Fire resistance	Nano-particle coatings are done layer by layer to impart insulation from heat	ACS (2011)
2	Filtration	Nano-fibres and nano-composite polymers are used in chemisorption processes	Berger, M. (2006); Schoen *et al.* 2010; Schaefer *et al.* 2007
3	Electronics	Metal nanoparticles and polymeric materials are coated on fabrics to imparts electrical conductivity	Mattana *et al.* 2011; Orecchini *et al.* 2010
4	Light generation	CdO nano-particles are imparted on tagging fabrics for detection through infrared light	Saranya *et al.* 2020
5	Medical	Drugs in nano-capsules are coated on medical dressings to aid in wound healing at a controlled manner	Zhou *et al.* 2010; Hofer *et al.* 2003
6	Anti-shrink fabrics	Keratin nano-powders have been used on fabrics to increase the strength of fabric and thus reducing shrinkage	Cardamone & Martin (2008)
7	Tensile strength	Carbon fullerenes and nanotubes are used in polymeric matrix to impart high strength to composites and fabrics	Kumar *et al.* 2010; Jain, R. (2006)
8	Self-cleaning/spill or stain resistance	Polymeric nano-filaments are grown on fabric through gas coating procedure to impart high contact angle surface on fabric which aids in water or spill repellency.	Zimmermann *et al.* 2008; Xue *et al.* 2010; Wong *et al.* 2006
9	Anti-odour/anti-bacterial	Ag nanoparticles are used on textiles through wet chemical reduction	Parson *et al.* 2005; Stover, D. (2007); Ki *et al.* 2007; Beringer, J. (2006).
10	Thermal insulation	Insulation from thermal properties were obtained on fabric by incorporation of aerogels on nonwoven fabric	Buratti *et al.*, 2016; Dowson *et al.* 2011
11	Protection from UV light	Titanium oxide nanoparticles are coated on textile fabrics to block UV light	Sojka *et al.* 2011; Yang *et al.* 2004

Limitations and Challenges to Nanotechnology

Any technology which produces a product must be safe to living organisms, and do not impart any health hazards or toxic load on to the environment. Production of nano-materials needs advanced equipment and highly skilled brain. While spraying the nano-particles on fabric during coating or handling the nano-particles at any stage of production, one must ensure safety first, since it is highly dispersible, driftable and penetrative material. Nano-textiles must be made available to consumer only after generating the data on human safety and its toxicological impact on disposal. Though, regulatory bodies are taking care of these during standardization process but still it needs more scanning and precautionary steps in handling nano-particles and nano-products.

CONCLUSION

Traditional textile fabrics/materials are prone to degradation due to microbial attack, UV light, Water stagnation, heat exposure, etc. But due to the advent of the technology like nano-technology, it is possible to a greater extent to retard these lacunae in textile sectors. However, regulation of these nano-textile product is still a challenge to the research community. There is a need for holistic and unified international approach towards the handling and future research work related to nano-technology as it is nano.

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