APPLICATIONS OF NANOPARTICLES IN TEXTILES FOR INTERIOR DESIGN

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ABSTRAC

Textiles are a material widely used in interior design and in everyday life. Advances in nanotechnology have achieved a significant impact in the textile industry, resulting in intelligent fiber with great benefits for the user. This investigation aims to review the state of the art applications of nanotechnology in textiles in the field of interior design , as well as its many features. The main properties of these fibers that have allowed other opportunities for the textile industry were also analyzed.

Keywords: *Nanoparticles, silver, zinc oxide nanoparticles, gold nanoparticles, Nano textiles, interior design.*

The textile industry is very important in our country because it has a rich history, not only as a productive sector, but also for its involvement in historical deeds (García-Serrano, 2010). The importance of the Mexican textile industry is such that only in the period between 2011 to 2012 there was an increase in gross value from 14,002,703 pesos to 15,078,276 pesos. In other words, in only one year there was an increase of 7.68% (INEGI, 2013). Today, textiles are one of the most widely used materials within the interior design and technology has not neglected the textile industry through the renovating, merging and creating of innovations that have enabled new features with the introduction of nano metric materials (Quispe-Chejo, 2010).

Nanoscience is the study of the phenomena and manipulation of materials at the atomic, molecular and macromolecular scales, where properties differ significantly from those which are large - scale (European Commission, 2013). Nanotechnology and nanoscience have emerged as opportunities for the application of the development of materials into new products (Tolfree, 2008). This has allowed attention to be focused on the introduction of nanoparticles that are endowed with properties and features that provide users with benefits and solutions to common problems that a conventional textile cannot solve (Wing, 2006). Thus, by means of nanoparticles or nano coatings, they have achieved improved and more complex textiles and hydrophobic and super hydrophobic finishes, self - cleaning and antibacterial properties (Gulrajani, 2013).

Nanoparticles are material of 1 to 100 nm in diameter (El-Drieny et al., 2015). These dimensions give specific properties and behaviors that the macroscale may not have, such as magnetic, optical, mechanical and electrical and quantum behaviors due to its configuration and confinement which allows for continuously or abrupt changes in accordance with its size in the nanoscale (Sayes and Santamaria, 2014). These particles can exist in aggregate form or discreetly and may be hexagonal, spherical, tubular, or irregularly shaped (Gaillet and Rouanet, 2015). It can be considered that research in this area is recent and because of the physical, chemical and biological properties of nanoparticles, it is considered to be an area of opportunity that is still expanding. Nanoparticles have been used in consumer products, construction materials, in the medical, pharmaceutical and agricultural fields, as well as for water remediation technologies, etc. (Filella, 2012).

Although there are the common requirements in most textiles, such as high levels of strength, durability, tear resistance fabric, etc., depending on the application there arises other non-traditional qualities such as flexibility, softness, breathability, optical properties, fire retardants, etc., that are only possible through recent advances in materials (M. Ashby, Ferreira, and Schodek, 2009). It has been reported that silver nanoparticles have been used in products such as cosmetics, disinfectants, medical devices and food packaging (Wasmuth, Rüdel, Düring, and Klawonn, 2016). These nanoparticles have shown antimicrobial activity on cotton fabrics against *Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli* and *Candida albicans* (Bera et al., 2015) and antifungal effects against *Fusarium solani (El-Rafie, Mohamed Shaheen, and Hebeish, 2010).* Other nano-metric compounds such as zinc oxide (ZnO) have been used as blockers of UV light in cosmetics, as well as for its antibacterial properties in the food industry and cotton fabrics (Padmavathy, 2008; Pandurangan and Kim, 2015), giving the textile antibacterial properties and the function of UV (El-Rafie, Shaheen, Mohamed, and Hebeish, 2012) protection. Similarly, nanoparticles of silicon oxide SiO 2 and silver (Ag) are used to provide properties of super hydrophilicity, antibacterial wool (Mura et al., 2015) and super hydrophobicity to cotton fabrics to give best water repellency properties (Xu, Cai, Wang and Ge, 2010). The nanoparticles of titanium oxide (TiO 2) have been used to achieve high hydrophobicity on silk surfaces (F. Chen et al., 2016) and self - cleaning properties of polyester fabrics (Pasqui and Barbucci, 2014) and cotton fabrics (Wijesena, Tissera, Perera, Nalin de Silva, and Amaratunga, 2015) The demand for these materials is increasing. In a publication from 2012, it was estimated that 55 tons of nanoparticles of silver, 3000 tons titanium oxide and 550 tons of zinc oxide (Piccinno, 2012) were produced annually. In general, these particles are used for the production of cosmetics (Katz, Dewan, and Bronaugh, Lu, Huang, Chen, Chiueh, and Shih, 2015; Sierra-Rodero, Fernández-Romero and Gomez-Hens, 2011) , cleaning agents (Nosrati, Olad, and Nofouzi, 2015; Pinho, Rojas, and Mosquera, 2015; Virovska, Paneva, Manolova, Rashkov, and Karashanova, 2016), plastics (. Zanetta et al, 2009), painting (Elhalawany , Mossad, and Zahran, 2014; Herea et al, 2015;. Hu, Pfirman, and Chumanov, 2015), cement (Liu, Li, and Xu, 2015; Shen, Ng, Dong, Ng and Tan, 2016; Soltanian , Khalokakaie, Ataei, and Kazemzadeh, 2015) catalysts (Ahmed, Senthilnathan, Megarajan, and Anbazhagan, 2015; Da Silva Pereira et al, 2015;. Ye, Liu, Lai, Lo, and Lee, 2016), layers for ultraviolet protection (Girigoswami, Viswanathan, Murugesan, and Girigoswami, 2015; Lodeiro, Achterberg, Pampín, Affatati, and El-Shahawi, 2016, Shaheen, El-Naggar, Abdelgawad, and Hebeish), textiles and medical products (Gaillet and Rouanet, 2015 ; Piccinno, 2012).

With regard to textiles, applications of nanotechnology have led to the emergence of a new term: smart textiles. Smart textiles are grouped into five main areas: adaptive systems, transfer systems, smart clothes, transponder systems, micro technology and nanotechnology (Tolfree, 2008). The intelligent textile term derives from the term intelligent material. A smart material is defined as a highly engineered material that responds to environmental stimuli (Addington, 2005). This term was defined in Japan in 1989 (L. Van Langenhove, Hertleer, C. Catrysse, M., Puers, R., Van Egmond, H., Matthijs, D., 2004). A smart textile is one that is able to identify environmental stimuli, react and adapt to them through integration of features in the structure of the textile. Stimuli and responses can be electrical, thermal, chemical, magnetic or other origin (L. Van Langenhove, Hertleer, C., 2004).

It has been observed that the demand for smart fabrics for indoor, outdoor, sports and work has increased remarkably. Only from 1995 to 2011, global growth was 70% in technical textiles, with sales reaching 133 billion US dollars (Gugliuzza and Drioli, 2013).

Undoubtedly, one of the main impacts of the textiles can be appreciated in its aesthetic use for interior decoration. From this point of view, the profession of interior design has been seen as an aesthetic practice to provide an interior space for a client (Hayles, 2015). Thus, the spaces must meet the personal needs, and have functional characteristics. The spaces are designed and trained with the most appropriate materials and technology that must be in line with social, physiological and psychological terms to meet user needs while performing their function in the light of fundamental aesthetic principles (Fitoz, 2015). Thus, it has been related to fashion and luxury design in small spaces. Recently this practice has also focused on providing a space with a healthy and sustainable environment for individuals to live, work or play in (Hayles, 2015). In order to achieve these objectives, textiles have important applications in interior design, among which include textiles that have properties for repelling stains and having a cleaning effect, similar to the lotus or wings of some insects, or antibacterial textiles (MF Ashby, Bréchet, Cebon, and Salvo, 2004).

For all the above, this investigation is intended to review the state of the art application of nanotechnology in textiles in the field of interior design , as well as its many features. As a result of this investigation, nanotechnology types used in textiles are described, the main features that provide different types of nanoparticles to the fibers are discussed, as well as different types of fibers that have been used are explained. This allows a framework to compare the benefits nano textiles can provide, including self-cleaning, hydrophobicity, antimicrobial resistance to ultraviolet rays, fire retardants, among others. Since this is an expanding field, textile fibers that were analyzed included both commercial products and those that are still under investigation but which promise short - term marketing in terms of their properties.

METHODOLOGY

This investigation is exploratory in nature, where 91 sources of information that included articles published in international journals and books were considered. Through this investigation the different types of particles used for functionalizing textiles, uses and benefits thereof were classified. Possible applications that these textiles have for interior design were also discussed. Finally, the results of tests that were conducted on hydrophobicity on commercial textiles are included. Thus, a state of art use of nanoparticles in textiles for interior design was developed.

Types of nanometric materials used in textiles

Nanotechnology as an emerging science deals with nanometric dimensions. Nano is a prefix derived from the Greek word meaning *νανο ς* tiny, dwarf, small (M. Ashby et al., 2009). This prefix is used in the international system (IS) units to indicate a factor 10-9 (ie, multiply something by 0.000000001, or billionth of something). Generally, you could define nanotechnology as the manufacture of materials, structures, devices and functional systems through control and assembly of matter at the nanometer scale. ISO defines a nano-object as a material with at least one external dimension in the nanoscale, in the range of 1 nm to 100 nm. If there are three external dimensions in the nanoscale, the conditions for being a nanoparticle are given (ISO 2008). Nanotechnology as a science has tried to solve many problems of everyday life. Textiles have been no exception.

A fabric or fiber is each filament arranged in bundles, in the composition of yarns and fabrics, whether, artificial, plant or animal minerals. Etymologically the word textile, from Latin "*textilis*" and derivative "*texere*" meaning knitting, is defined as all fabrics, framed or woven, used as raw material (Diaz, 2013)

Therefore a nanotextil can be defined as textiles which are formed by some material which external dimensions or structures are on the nano-scale and allow for the obtaining of different structures of the same material at a larger scale with the same features.

Types of intelligent textiles with applications of nanoparticles

Textiles electro-active. Electronic textiles are also called e-textiles. These kinds of textiles have strong demand in transportation, communication, aerospace, military, biomedical and the sports industry. Incorporating electro-active materials can convert electrical energy into mechanical energy to allow biomimetic movements (Gugliuzza and Drioli, 2013; Jinlian, 2011). In general, these materials act according to melting or glass transition temperature (Jinlian, Harper, Guoqiang, and Samuel, 2012).

Memory shape membranes. There are other materials with high potential for application in textiles. The basic function of this type of textile is that is temporarily deformed and then returns to its original shape under the influence of external indicators of temperature, pH, light or chemicals (Gugliuzza and Drioli, 2013). These kinds of textiles have emphasized aesthetic aspects of interior fabrics, detecting and reacting to temperature changes in the prescribed form (Chan Vili, 2007).

Intelligent gels. The use of smart gels as sensitive membranes in textiles is a particular area of application in clothing for adjusting temperature, regulating permeability, antibacterial covering and for the capture of odor, or release of nutrients or drugs (Gugliuzza and Drioli, 2013; Jinlian et al, 2012).

Self-cleaning textiles. These durable textiles are able to preserve their duties after being washed or cleaned, while offering resistance to dirt and chemicals. For this reason, they have created a self-cleaning cover capable of removing organic and inorganic contaminants by two different mechanisms, either the contact angle between droplets of moisture, or by photo catalysis (M. Ashby et al, 2009; Gugliuzza and Drioli, 2013). Self-cleaning is the first mechanism, which is based on the hydrophobicity of natural surfaces, but artificial surfaces can be made hydrophilic by photo catalysis (Nosrati et al., 2015).

Antimicrobial textiles. Antimicrobial agents are used to prevent undesirable effects on textiles: degradation in coloring, pigmentation , and fiber damage; odor and increased potential health risk. For this purpose inorganic nanoparticles have been used with great potential for antimicrobial application (Dastjerdi and Montazer, 2010).

Types of treatments for textiles

Nano layers. There has been a major scientific effort to modify the surfaces after treatment which are capable of changing or confer different properties to textiles. These treatments include the formation of micro and nano layers. These treatments can be developed through various approaches (Alongi, Carosio, and Malucelli, 2014):

- **Absorption of nano particles:** This method is the immersion of the textile in a suspension of aqueous nano particles to promote their absorption on the surface of the fiber.

- **Assembly layer by layer.** This process is an evolutionary process of the absorption of particles. It consists of building a film step by step through electrostatic interactions until you get what is known as poli electric multilayers.
- **Sol-gel and dual cured process.** This method is the synthesis of new materials with a high degree of homogeneity at a molecular level (Dastjerdi and Montazer, 2010). It is based on a synthetic route between two steps in a reaction called hydrolysis or condensation. With regard to the field of textiles, this process has received special attention on the development of smart textiles which protect from or inhibit microbial development and ultraviolet radiation. In parallel, the evolution of the sol-gel process has led to the dual cured process, which is used to prepare organic and inorganic protective layers through a photo polymerization reaction followed by a thermal treatment to promote the formation of phases of silica.
- **Plasma treatments.** The cold plasma technique is a surface treatment thru which small functional groups and macromolecular compounds can be linked to different substances. This technique does not modify or alter the properties the bulk properties of the treated material. Through this process there can be a) impregnating of the structure surface and / or its function in the presence of non polymerizable gases such as N_2, H_2, O_2, Ar, NH_3, CO_2 , etc.; b) performing a deposition of thin particles on the surface of the material; c) performing a polymerization process just when the plasma is activated on the surface d) performing an induced polymerization by low pressure plasma.
- **Deposit of bio macro molecules.** The possibility of using “green” retardant systems to replace traditional chemicals continues. Systems based on the isolation of proteins, caseins, and nucleic acids have been used.

From the standpoint of applications, nanowires, nanotubes and spherical nanoparticles have been detected. These nanomaterials have applications in curtains, tablecloths, upholstery, carpets, bedding, medical uniforms, and in the aerospace and military industry (Table 1).

Table 1. Different types of nanoparticles used in the textile sector.

Nanoparticle	Fiber	Characteristcs	Application in interior design	source
Nanowires Silver (silver nanowires)	Cotton	High electrical conductivity, UV light resistant, antibacterial, superhydrophobicity	curtains Table linen Upholstery	(Nateghi y Shateri-Khalilabad, 2015)
Nanopartículas Titanium dioxide	Cotton Wool	Semiconductor, photocatalytic, Antibacterial, self - cleaning surface	Rugs upholstrey	(Bozzi, Yuranova, y Kiwi, 2005; Clouser, Samia, Navok, Alred, y Burda, 2008; Montazer, 2011; Nosrati et al., 2015)
Copper Nanoparticles	Nylon	Antifungal and antimicrobial	Cushions Curtains	(Komeily-Nia, Montazer, y Latifi, 2013)
Gold Nanoparticles	Wool	Resistant to ultraviolet light and stable colors	Upholstery Rugs Bedding	(Johnston y Lucas, 2011)
Silver Nanoparticles	Cotton Polyester Polyamide Silk Nylon other synthetics	Antibacterial activity, antifungal	Bedding rugs curtains	(Dubas, Kumlangdudsana, y Potiyaraj, 2006; Durán, Marcato, De Souza, Alves, y Esposito, 2007; Lee, Yeo, y Jeong, 2003; Sataev et al., 2014)
Nanoparticles of titanium dioxide and silicon oxide	Polyester Cotton	Excellent optical properties, thermal stability surface, long lifetime, low toxicity and UV protection.	Making furniture, curtains, carpets, car interior decoration and thread	(Erdem, Cireli, y Erdogan, 2009; Fakin, Stana Kleinschek, Kurečič, y Ojstršek, 2014; Hashemikia y Montazer, 2012)
Nano aluminum oxide	Polyester	Superior mechanical strength, high load capacity and wear resistance	applications in aerospace, automotive, naval and other industries	(Sun, Yang, y Li, 2008a, 2008b)
Silver nanoparticles with chitosan	Cotton	Antibacterial and comfortable	Applications in medical scrubs	(Abdel-Mohsen et al., 2012)
Zinc oxide, titanium dioxide, and silver nanoparticles	Cotton Wool	Antibacterial	Children´s clothing, textiles and clothing wear applications, medical applications	(Becheri, 2008; Selvam et al., 2012)

NANOPARTICLES MOST OFTEN USED IN TEXTILE DESIGN

Silver nanoparticles-Silver is one of the most widely used antibacterial and therapeutic agents because their mechanism of action acts with about 650 species of bacteria, while the rest of antibiotics may have a more limited spectrum of healing, around only 5 to 10 species of bacteria (Sataev et al., 2014). This material has wide applications because of its low toxicity to human cells (Dastjerdi and Montazer, 2010).

Titanium dioxide nanoparticles- These nanoparticles are a very attractive, multifunctional material due to its high stability and its potential for application in self - cleaning, as an antibacterial agent and for protection against ultraviolet light (Dastjerdi and Montazer, 2010; McIntyre, 2012).

Zinc oxide nanoparticles-This material has been used as an antibacterial agent in cotton fabrics (Dastjerdi and Montazer, 2010). It is characterized by optical, electrical, dermatologic and antibacterial properties (F. Zhang, Yang, J., 2009).

Silicon oxide nanoparticles- This material is mainly used as a fire retardant (Erdem et al., 2009).

BENEFITS OF NANOTEXTILES

Nanotextiles provide solutions to various problems to which users are faced with the use of conventional textiles. Some of the benefits nanotextiles have are (Roya Dastjerdi, 2010):

- To prevent uncontrolled and unwanted reproduction of microbes that can lead to serious health problems while using textiles.
- Decrease in degradation or less or no discoloration.
- Avoidance of the production of unpleasant odors.
- Reduce potential health risks.
- To maintain adequate moisture and temperature.
- Prevent dust or dirt.
- Prevent stains on textiles due to food spills liquids.
- Avoid mites in textiles.

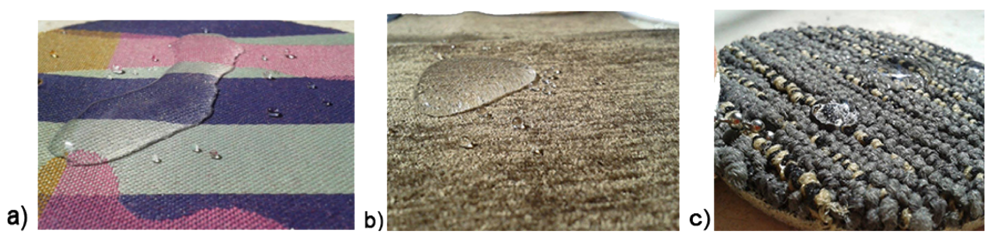
However, obtaining these benefits in textiles faces the challenge of cost and reproducibility of the fibers at an industrial level. However, currently they are existing varieties of nanotechnology textiles with built – in services for users for interior decoration. From the standpoint of marketing textiles with nanometric properties, there are significant attempts being made around the world. The U.S. company Nano-Tex has developed and patented many fabrics such as Nano -Care®, Nano-Dry ®, Nano-Pel-TM, and Nano-TouchTM which rely primarily on hydrophobic properties like the lotus effect (Gasman, 2006; Tolfree, 2008). Nano Care and Nano Dry fabrics offer anti-wrinkle cotton fabrics (Sawhney et al., 2008). In the same vein, the company Nano-Pel has developed technology with stain resistance and oil repellence that uses the concept of surface energy and develops hydrophilic fabrics that are complemented by other attributes such as breathability, softness and comfort (Sawhney et al., 2008).

In this sense we can highlight the Aitex company, which was established in 1985 as an initiative of the Spanish government in Valencia. This is one of the companies engaged in the development of nanotextiles. It is now a center dedicated to research, innovation and advanced technical services in the area of textiles. For this company, the purpose of the application of nanotechnology is to create an outstanding performance in everyday items:

clothing, fabrics for home furnishings and interiors, industrial fabrics, etc. Some of these innovations include the benefits of self - cleaning fabrics, virus and bacteria repellency, fire retardants, temperature regulation, odor, even up to properties such as color change. This allows the use of nanomaterials in textiles for interior upholstery furniture such as chairs, sofas, curtains, tablecloths or wall coverings (Aixtex, 2015).

The company Aitex provided this research group a sample of fabrics with hydrophobic properties. Such fabrics were analyzed for the purpose of verifying the functional properties they have. Figure 1 shows a) the hydrophobicity test developed for use in a textile table linen, b) test to a carpet fiber and c) test to an upholstery textile. As can be seen, water is unable to penetrate the fiber.

Figure 1. Hydrophobicity in textiles.



CHALLENGES OF USING NANOPARTICLES

Finally, it is important to note that the evaluation of the toxicological effects of particles continues to be essential, as it has found evidence of a possible interaction of silver nanoparticles with the kidneys, lungs, bone marrow, brain, skin, spleen, eyes, muscles, blood, small intestine, stomach, lungs, bladder, prostate, tongue, teeth, salivary glands, thyroid, parathyroid, heart, pancreas and duodenum (Gaillet and Rouanet, 2015). However, it is important to note that this interaction will not necessarily be linked to disease. Nanoparticles can be used in a controlled dose for diagnostic imaging (Lo, Wu, and Wu, 2015; Luo et al, 2015; Stone et al, 2015; F. Zhang et al, 2016.), Controlled drug release for various diseases (Agiotis et al, 2016. X. Chen Yao, Wang, Chen, and Chen, 2015), treatment of infections (Allaker and Memarzadeh, 2014; Baelo et al, 2015;. d'Angelo et al. , 2015) and tissue repair (Albrecht, Evans, and Raston, 2006; Jayaraman et al .; Raftery, Tierney, Curtin, Cryan, and O'Brien, 2015).

CONCLUSIONS

Currently, there are several enhanced textiles with nanoparticles that could be used within interior design with the ability to solve the most common problems that decrease the life of textile fibers. In addition, it should be noted that research in the area of nanotextiles still has many development opportunities that will allow through the interdisciplinary work of materials science, production processes of textiles and interior designers can provide better user comfort and a longer life time for decoration products, as one of the major causes of wear of the fibers are UV light, microbes, bacteria and fungi. However, one of the main challenges is still assessing the toxicological effects of different nanoparticles used for this purpose.

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