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Mini Review

A MINI REVIEW ON APPLICATION OF TIO_2 NANOPARTICLE IN WOOL TECHNOLOGY

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ABSTRACT

In recent years attention has been towards the development of smart textiles with superior characteristics and enhanced durability. To cater the needs of high sustainable textiles, application of nanotechnology has been introduced in textile industry with promising achievement. Titanium oxide nanoparticle is one such material which could be applicable in textile industry, whose photo-catalytic activities have been widely investigated owning to its high stability and low toxicity. This paper enlists various applicative properties of titanium oxide nanoparticles and its implementation in the textile industry, especially to woollen fibres for advanced applications.

INTRODUCTION

The textile industry is no longer a mere supplier of fabrics, rather it is now evolving as a positive force that can help in the development of the society. Technology has made it possible to manufacture fabrics that have a potential to revolutionize our lives. Today the textile industry seeks innovations which can improve daily life, benefit the industry and health sector and adhere to eco-friendly norms. One such step towards development is development of fabrics that can clean themselves as well as purify water by using nothing but the sun as an energy source. This is possible by application of TiO_2 nanoparticle coating onto the fabric.

Titanium oxide (TiO_2) is a naturally occurring oxide of titanium, also known as Titania. The powdered ore of Titania is white in colour and is widely used as a pigment in paint and food industry after suitable purifications and modifications. The photo catalytic properties of TiO_2 was first discovered by Akira Fujishima in 1967 (Fujishima and Zhang, 2006). In recent years a lot of interest has been shown in the photo-catalytic potential of Titania due to its variant properties. Titania's photo-catalytic potential increases ten folds when used in nanoparticle form due to enhanced surface properties and the several utilities linked to this property in TiO_2 has been illustrated below (Fig. 1). Photo-catalysis is a phenomenon where light acts as a catalyst to drive the reaction forward. In case of TiO_2 nanoparticle the photo catalytic activity is observed under UV spectrum (100nm-400nm) and the UV irradiation causes movement of positive holes and negative electrons, which have oxidising and reducing effects, respectively (Fujishima and Zhang, 2006; Nakajima, *et al.*, 2000). On one hand, holes oxidise water to hydroxyl (OH) ions, which are capable of manipulating configuration of dyes and other organic pollutants; while on the other hand electrons reduce oxygen molecules to superoxide radicles, which decompose harmful microbes, dirt, stains, etc (Ramasundaram, *et al.*, 2016; Pelaeza, *et al.*, 2012).

Thus, the application of TiO_2 nanoparticle onto a fabric, imparts properties such as self-cleaning, anti-aging, UV protection, antimicrobial, etc (Pekakis, *et al.*, 2006; Johnson, *et al.*, 2008; Munafò, *et al.*, 2014). In this article, we shall be focussing on the applications related to wool fibres. Wool, a widely used fibre in the textile industry, is acclaimed as a natural composite fibre with astounding manipulative chemical and physical properties, such as warmth, resiliency, fire-resistance etc. These properties are controlled

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by both chemical composition as well as structural configuration of the fabric (Li, *et al*., 2014; Quagliarini, *et al*., 2012; Behzadnia, *et al*., 2014) (Fig. 2).

However the wool fabric still has a number of limitations; low photo-stability, photo-yellowing, decomposition due to certain insects, microbial susceptibility, etc. (Mura, *et al*., 2015; Montazer and Pakdel, 2010; Periolatto, *et al*., 2013). These problems can be solved to a great extent by TiO_2 immobilization (Yang, 2013; Kubacka, *et al*., 2014; Gelover, *et al*., 2006; Gómez-Ortíz, *et al*., 2013; Lian, *et al*., 2016).

RESULTS AND DISCUSSION

Application of TiO_2 nanoparticles

Titania is a special compound which finds a wide range of applications in various industrial sectors and Table 1 illustrates TiO_2 utilities discovered so far. The properties such as longer shelf-life, self-

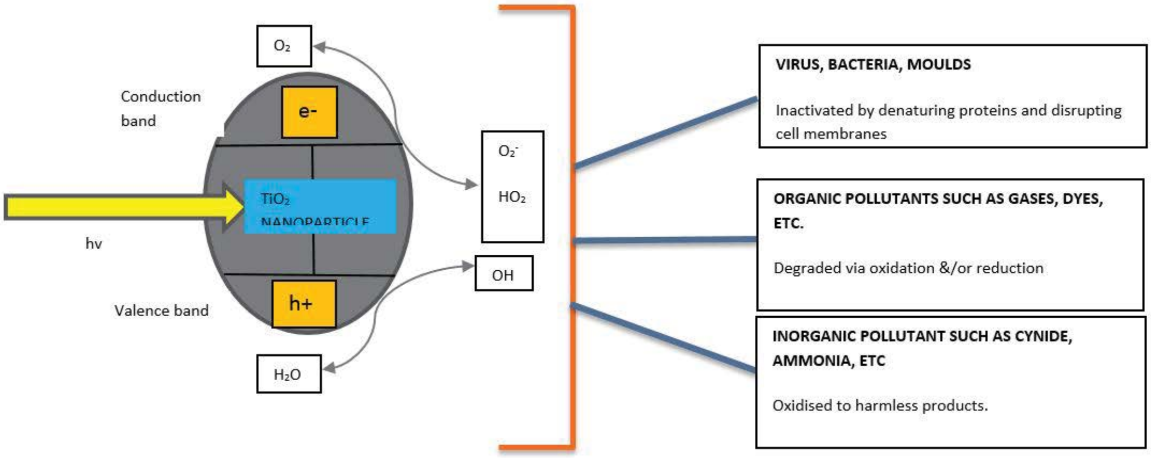

Fig. 1 Utility of the photo catalytic effect of TiO_2.

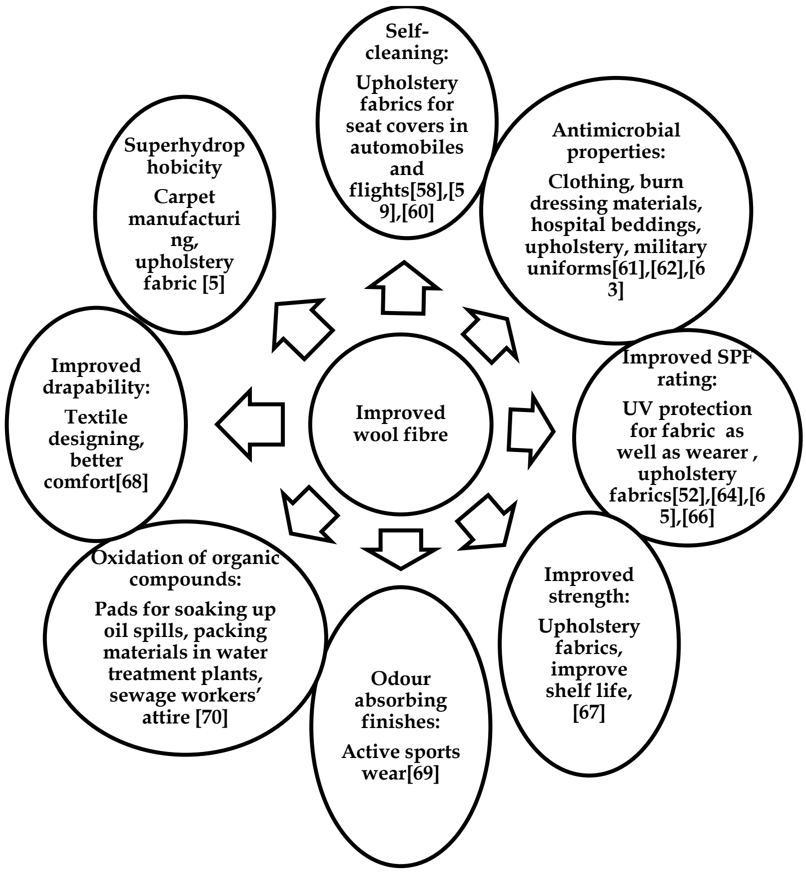

Fig. 2 Represents the various applications of immobilized TiO_2 on wool fiber.

Table 1. Various applications of TiO_2 nanoparticles

S. no.	Properties	Sector	Example	Ref
1	Self-Cleaning	Environment	Poly(vinyl dine fluoride) is used as a cross linker to immobilize TiO_2 by melting at 160°C on the steel Mesh.SM helps to remove organic dyes from the flow of wastewater.	[2], [3], [4], [5]
			TiO_2/H_2O_2 nanocomposite are used for the removal of the heavy metal from waste water.	[6]
			The bulk insertion of TiO_2 in various materials (cements, ceramics etc.) related to building industry helps in degradation of organic and inorganic pollutant in gas phase.	[5], [7], [8], [9]
		Construction	Self-cleaning and anti-fogging glass is prepared due to the micro constructed composition of TiO_2 at hydrophilic and oleophilic phases. Sometimes PEG and its composites are used a cross linker agent. Used in bulbs commonly.	[10], [11], [12], [17]
			TiO_2 coating on the surface of lime stones protect heritage for several year.	[6], [14], [15],
			TiO_2 addition in water based acrylic paint enhance its long lasting power and mechanical properties to cure the cracks etc.	[16], [17]
		Marine Hydrology	TiO_2 coated Ti mesh works as oil separating device due to their superoleophobicity	[18]
		Food	Simultaneous Implication of UV radiation and TiO_2 on sludge at high temperature helps in controlled removal of PAHs through the process of degradation.	[19]
		Textile	Incorporation of TiO_2 along with casein and other sensitizing agent in the different fabrics (e.g. cotton) protects the garments from organic stains.	[20], [21], [22]
2	Anti UV property and anti-aging	Textile	Attachment of TiO_2 nanoparticles with clothes to improve the anti-UV absorption and improve the life of material.	[23], [24]
3	Antimicrobial properties	Health	In rural areas, coliforms are removed from the water by using TiO_2 coating on any substance, also could be used for anti-microbial agent towards pathogenic microbes.	[25], [26], [47]
		Construction	$Ca(OH)_2$ and TiO_2 mixture was coated on the limestone, prevents the growth of fungus.	[27]
		Food	In the presence of high pressure, TiO2 nanoparticle can be easily transported from polyvinyl-Chitosan biofilm or other packing material) to food stimuli (e.g olive oil) which helps to protect from biodegradation.	[28]
		Health	Coating of tio_2 on the biomedical device basically prevents the transmission of various infectious diseases during the diagnosis period. Titanium based material could be used for space closure in bialveolar dental protrusion.	[29], [30]
4	Odour Removal	Health	Degrade the H_2S and other unpleasant odour bearing gas in NO_2,SO_2 and CO_2	[31]

cleaning, UV protection and antimicrobial properties are much sought after to improve quality of life as well as create products that are sustainable and environment friendly (Visai, *et al*., 2011; Chaitanya, *et al*., 2017; Ao and Lee, 2005).

The main reasons for the wide acceptance of TiO_2 nanoparticles as a coating material its safety and non-toxicity to the fabric as well as to the skin, durability, ease of application, stability, no degradation on repetitive wash cycles, and the scope for manipulations in its photo catalytic properties by modifying reaction conditions. (Tung and Daoud, 2009; Pakdel, *et al*., 2013; Zhang, *et al*., 2014; Li, *et al*., 2010; Behzadnia, *et al*., 2015; Euvananont, *et al*., 2008) Moreover, it has been reported that it is possible to shift active region from UV range to visible light (Behzadnia, *et al*., 2015). It is also applicable to a wide range of surfaces. In textile industry, it is used extensively due to its high compatibility with fabrics and low cost of production (Wang, *et al*., 1997;

Table 2. Represents various techniques available for TiO_2 immobilization

Immobilization Techniques	Immobilizing agent	Conditions	Advantages	Disadvantages	Reference
Sol gel method	Succinyl anhydride	Room temperature	One step, easy and homogeneity at atomic level ,High adhesion of TiO_2	Shrinkage, low durability, Deterioration of carrier gas	[32],[33],[34]
Hydrothermal method	Tetrabutyl titanate and ammonium chloride	Low temperature Presence of water in the system		More energy Requirement	[35],[20],[36]
Sono-synthesis		One step process in very optimum pressure and low temp(70°C-80°C)	Rapid, simple and inexpensive, Absence of toxic substances	No bond formation causes low adhesive nature	[37],[38],[39]
Self -assembly	poly (sodium 4-styrene-sulfonate) (PSS)	Electrostatic deposition	Less energy consumption, Easy and uniform distribution	Absence of covalent bond	[23]
Direct method		Lowering the pH at room temp		No bond formation	[40],
Grafting	Citric Acid		Most uniform deposition No degradation of carrier gas	May produce toxic waste	[41],[42]
Sputtering		Deposition of source material at a temperature lower than evaporation	Fast process	No bond formation only van dar waal and mechanical interaction Less adhesive	[43]
Plasma treatment	Inert gas worked as a carrier gas	Occur at the room temp	Fast and one step process Strong adhesion	More energy consumption	[44],[45],[46]

Spasiano, *et al*., 2015; Kim, *et al*., 2016; Guan, 2005; Licciulli, *et al*., 2011).

TiO_2 modifications and immobilisation onto woollen fabric

As mentioned earlier, wool is a photo-sensitive fibre and UV light, in particular, has a negative effect on the stability of the fibre. Immobilizing TiO_2 (coating the nanoparticle) on to the surface of the fabric helps solve these problems as well as improves the mechanical strength of the fabric (Ghoranneviss, *et al*., 2011; Kan and Yuen, 2007; Kan and Yuen, 2006; Chi-wai, *et al*., 2003; Chatterjee, *et al*., 2016). Table 2 illustrates various modifications and conditions used for immobilizing TiO_2 onto woollen fabric (Ferrari, *et al*., 2015; Carneiro, *et al*., 2012; Salthammer and Fuhrmann, 2007; Banerjee, *et al*., 2014; Karaca and Tasdemir, 2014).

Post application of TiO_2 nanoparticle coating properties such as improved strength, crease resistance, self-cleaning, UV protection, resistance against microbial decay, etc. have been achieved. Thus the newly improved fibre finds a greater deal of applications in diverse fields (Zhang, *et al*., 2014; Xu, *et al*., 2016; Kale, *et al*., 2016; Liu, *et al*., 2012).

CONCLUSION

Among the wide range of options available in nanoparticle applications, Titanium dioxide and its composites have gained most attention mainly due to their high chemical stability, ease of availability, low cost and non-toxicity. It significantly enhances the characteristics of wool fabric but does not alter any intrinsic property, mainly draping ability and resilience. Wool is a multifunctional fibre which comes in a range of diameters and fabrication techniques that makes it a widely sought after fibre for clothing manufacture, household fabrics as well as technical textiles. The application of TiO_2 nano-coating not only elevates the existing properties of the fibres but also imparts certain beneficial properties such as self-cleaning and odour. Overall outcome of such a modification would be the development of smart textiles with superior performance and enhanced comfort.

REFERENCES

Ao, C.H. and Lee, S.C. (2005). Indoor air purification by photocatalyst TiO_2 immobilized on an activated carbon filter installed in an air cleaner. *Chem. Eng. Sci*. 60 : 103-109.

Banerjee, S., Pillai, S.C., Falaras, P., O'Shea, K.E., Byrne, J.A. and Dionysiou, D.D. (2014). New insights into the mechanism of visible light photocatalysis. *J. Phys. Chem. Lett*. 5 : 2543-2554.

Behzadnia A. Montazer M. Rashidi A. Rad MM. Rapid sonosynthesis of N-doped Nano TiO_2 on wool fabric at low temperature: Introducing self-cleaning, hydrophilicity, antibacterial/antifungal properties with low alkali solubility, yellowness and cytotoxicity. Photochem. Photobiol 2014, vol. 90, no. 6, pp. 1224–1233.

Behzadnia, A., Montazer, M. and Rad, M.M. (2015). Simultaneous sonosynthesis and sonofabrication of N-doped ZnO/TiO<inf>2</inf> core-shell nanocomposite on wool fabric: Introducing various properties specially nano photo bleaching. *Ultrason. Sonochem*. 27 : 10-21.

Behzadnia, A., Montazer, M., Rashidi, A. and Rad, M.M. (2014). Sonosynthesis of nano TiO_2 on wool using titanium isopropoxide or butoxide in acidic media producing multifunctional fabric. *Ultrason. Sonochem*. 21 : 1815-1826.

Carneiro, C., Vieira, R., Mendes, A.M. and Magalhães, A.F. (2012). Nanocomposite acrylic paint with self-cleaning action. *J. Coatings Technol. Res*. 9 : 687-693.

Chaitanya, N., Arshad, A.M., Praveen, K.R.K., Prashant, C., Bailwad, S. and Navin, P. (2017). Space closure in bialveolar dental protrusion cases - A comparative combination method. *Asian J Pharm Clin Res.* 10 : 106-109.

Chatterjee, A., Nishanthini, D., Sandhiya, N. and Abraham J. (2016). Biosynthesis of titanium dioxide nanoparticles using vigna radiata. *Asian J Pharm Clin Res.* 9 : 1295-1300.

Chi-wai, K., Kwong, C., Chun-wah, M.Y., Hom, H. and Kong, H. (2003). Surface characterization of low-temperature plasma treated wool fibre. *Autex Res. J*. 3 : 194-205.

Euvananont, C., Junin, C., Inpor, K., Limthongkul, P. and Thanachayanont, C. (2008). TiO_2 optical coating layers for self-cleaning applications. *Ceram. Int*. 34 : 1067-1071.

Ferrari, A., Pini, M., Neri, P. and Bondioli, F. (2015). Nano-TiO_2 coatings for limestone: Which sustainability for cultural heritage?. *Coatings*. 5 : 232-245.

Fujishima, A. and Zhang, X. (2006). Titanium dioxide photocatalysis: Present situation and future approaches. *Comptes Rendus Chimie*. 9 : 750-760.

Gelover, S., Gómez, L.A., Reyes, K. and Teresa, L.M. (2006). A practical demonstration of water disinfection using TiO_2 films and sunlight. *Water Res*. 40 : 3274-3280.

Ghoranneviss, M., Shahidi, S., Anvari, A., Motaghi, Z., Wiener, J. and Šlamborová, I. (2011). Influence of plasma sputtering treatment on natural dyeing and antibacterial activity of wool fabrics. *Prog. Org. Coatings*. 70 : 388-393.

Gómez-Ortíz, N., Rosa-García, D.S., González-Gómez, W., Soria-Castro, M., Quintana, P. and Oskam G. (2013). Antifungal coatings based on $Ca(OH)_2$ mixed with ZnO/TiO_2 nanomaterials for protection of limestone monuments. *ACS Appl. Mater. Interfaces*. 5 : 1556-565.

Guan, K. (2005). Relationship between photocatalytic activity, hydrophilicity and self-cleaning effect of TiO_2/SiO_2 films. *Surf. Coatings Technol*. 191 : 155-160.

Johnson, T.A., Jain, N., Joshi, H.C. and Prasad, S. (2008). Agricultural and agro-processing wastes as low-cost adsorbents for metal removal from wastewater: A review. *Journal of Scientific and Industrial Research*. 67 : 647-658.

Kale, B.M., Wiener, J., Militky, J., Rwawiire, S., Mishra, R. and Jacob, K.I. (2016). Coating of cellulose-TiO_2 nanoparticles on cotton fabric for durable photocatalytic self-cleaning and stiffness. *Carbohydr. Polym*. 150 : 107-113.

Kan, C. and Yuen, C.M. (2007). Plasma technology in wool. *Text. Prog*. 39 : 121-187.

Kan, C.W. and Yuen, C.W.M. (2006). Surface characterization of low temperature plasma-treated wool fibre. *J. Mater. Process. Technol*. 178 : 52-60.

Karaca, G. and Tasdemir Y. (2014). Migration of PAHs in food industry sludge to the air during removal by UV and TiO_2. Sci. *Total Environ*. 356-361.

Kim, S.M., In, I. and Park, S.Y. (2016). Study of photo-induced hydrophilicity and self-cleaning property of glass surfaces immobilized with TiO_2 nanoparticles using catechol chemistry. *Surf. Coatings Technol*. 294 : 75-82.

Kubacka, A., Diez, M.S., Rojo, D., Bargiela, R., Ciordia, S. and Zapico, I. (2014). Understanding the antimicrobial mechanism of TiO_2-based nanocomposite films in a pathogenic bacterium. *Sci Rep*. 4 : 4134.

Li, J., Yu, H., Sun, Q., Liu, Y., Cui, Y. and Lu, Y. (2010). Growth of TiO_2 coating on wood surface using controlled hydrothermal method at low temperatures. *Appl. Surf. Sci*. 256 : 5046-5050.

Li, Q., Zong, L., Li, C. and Yang, J. (2014). Reprint of photocatalytic reduction of CO_2 on MgO/TiO_2 nanotube films. *Appl. Surf. Sci*. 319 : 16-20.

Lian, Z., Zhang, Y. and Zhao, Y. (2016). Nano-TiO_2 particles and high hydrostatic pressure treatment for improving functionality of polyvinyl alcohol and chitosan composite films and nano-TiO_2 migration from film matrix in food simulants. *Innov. Food Sci. Emerg. Technol*. 33 : 145-153.

Licciulli, A., Calia, A., Lettieri, M., Diso, D., Masieri, M. and Franza, S. (2011). Photocatalytic TiO_2 coatings on limestone. *J. Sol-Gel Sci. Technol*. 60 : 437-444.

Liu, J., Wang, Q. and Fan, X.R. (2012). Layer-by-layer self-assembly of TiO_2 sol on wool to improve its anti-ultraviolet and anti-ageing properties. *J. Sol-Gel Sci. Technol*. 62 : 338-343.

Montazer, M. and Pakdel, E. (2010). Reducing photo yellowing of wool using nano TiO_2. *Photochemistry and Photobiology*. 86 : 255-260.

Munafò, P., Quagliarini, E., Goffredo, G.B., Bondioli, F. and Licciulli, A. (2014). Durability of nano-engineered TiO_2 self-cleaning treatments on limestone. *Constr. Build. Mater*. 65 : 218-231.

Mura, S., Greppi, G., Malfatti, L., Lasio, B., Sanna, V. and Mura, M.E. (2015). Multifunctionalization of wool fabrics through nanoparticles: A chemical route towards smart textiles. *J. Colloid Interface Sci*. 456 : 85-92.

Nakajima, A., Koizumi, S.I., Watanabe, T. and Hashimoto, T. (2000). Photoinduced amphiphilic surface on polycrystalline anatase TiO_2 thin films. *Langmuir*. 16 : 7048-7050.

Pakdel, E., Daoud, W.A. and Wang, X. (2013). Self-cleaning and superhydrophilic wool by TiO 2 / SiO 2 nanocomposite. *Applied surface science*. 275 : 397-402.

Pekakis, P.A., Xekoukoulotakis, N.P. and Mantzavinos, D. (2006). Treatment of textile dyehouse wastewater by TiO_2 photocatalysis. *Water Res*. 40 : 1276-1286.

Pelaeza, M., Nolan, N.T., Pillai, S.C., Seery, M.K., Falaras, P. and Kontos, A.G. (2012). A review on the visible light active titanium dioxide photocatalysts for environmental applications. *Applied Catalysis B: Environmental*. 125 : 331-349.

Periolatto, M., Ferrero, F., Vineis, C. and Rombaldoni, F. (2013). Multifunctional finishing of wool fabrics by chitosan UV-grafting: An approach. *Carbohydr. Polym*. 98 : 624-629.

Quagliarini, E., Bondioli, F., Goffredo, G.B., Cordoni, C. and Munafò, P. (2012). Self-cleaning and de-polluting stone surfaces: TiO_2 nanoparticles for limestone. *Constr. Build. Mater*. 37 : 51-57.

Ramasundaram, S., Seid, M.G., Cho, J.W., Kim, E., Chung, Y.C. and Cho, K. (2016). Highly reusable TiO_2 nanoparticle photocatalyst by direct immobilization on steel mesh via PVDF coating, electrospraying, and thermal fixation. *Chem. Eng. J*. 306 : 344-351.

Salthammer, T. and Fuhrmann, F. (2007). Photocatalytic surface reactions on indoor wall paint. *Environ. Sci. Technol*. 41 : 6573-6578.

Spasiano, D., Marotta, R., Malato, S., Fernandez-Ibañez, P. and Somma, D.I. (2015). Solar photocatalysis: Materials, reactors, some commercial, and pre-industrialized applications. A comprehensive approach. *Applied Catalysis B: Environmental*. 90-123.

Tung, W.S. and Daoud, W.A. (2009). Photocatalytic self-cleaning keratins: A feasibility study. *Acta Biomater*. 5 : 50-56.

Visai, L., Nardo, D.L., Punta, C., Melone, L., Cigada, A. and Imbriani, M. (2011). Titanium oxide antibacterial surfaces in biomedical devices. *Int J Artif Organs*. 34(9) : 929-946.

Wang, R., Hashimoto, K., Fujishima, A., Chikuni, M., Kojima, E. and Kitamura, A. (1997). Light-induced amphiphilic surfaces. *Nature*. 431-432.

Xu, Q., Fan, Q., Ma, J. and Yan, Z. (2016). Facile synthesis of casein-based TiO_2 nanocomposite for self-cleaning and high covering coatings: Insights from TiO_2 dosage. *Prog. Org. Coatings*. 99 : 223-229.

Yang, Z.D. (2013). Application of titanium dioxide nanoparticles on textile modification. *Adv. Mater. Res*. 901-905.

Zhang, H., Yan, H. and Mao, N. (2014). Functional modification with nanoparticles and simultaneously dyeing of wool fibres in a one-pot hydrothermal process. *Ind. Eng. Chem. Res*. 53 : 2030-2041.

Zhang, H., Yang, Z., Zhang, X. and Mao, N. (2014). Photocatalytic effects of wool fibers modified with solely TiO_2 nanoparticles and N-doped TiO_2 nanoparticles by using hydrothermal method. *Chem. Eng. J*. 254 : 106-114.