2. Literature Review

The review of literature pertaining to the study “Synergistic Effect of Plasma and Cationic Pretreated Polyester/Cotton Fabrics Finished with Metal Oxide Nanocomposites on Multifunctional Properties” is given under the following heads:

2.1. Textile Industry
2.2. Textile Industry in India
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2.4. Polyester/Cotton Blended Fabrics
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2.1. Textile Industry

Textile played a vital role in the evolution of human culture by being at the forefront of both technological and artistic development. The search of textile industry for novel technologies, to achieve the consumer expectation and needs, resulted in various innovative developments. Particularly in the current century, innovative improvements allowed the manufacture of efficient functional and smart textile which are proficient in sensing alterations in ecological surroundings or body functions and responding to these changes. Similarly, consumer thoughts towards hygiene and dynamic lifestyle has fashioned a rapidly increasing market for a broad variety of textile products finished with lots of functional properties, which in turn has inspired an intensive research and development activities.

2.2. Textile Industry in India

Indian textile sector is distinctive, in comparison to the industries of other countries, due to its close association with farming and tradition. The Indian textile industry has the ability to manufacture a wide variety of products appropriate to different market divisions, both domestic and export across the world. The Indian textile industry is tremendously diverse, with the hand-spun and hand-woven textile sector at one end of the spectrum, and the wealth concentrated sophisticated mills sector at the other end of the spectrum. It plays a pivotal role through its contribution to industrial output, employment generation and export earnings of the country. The textile industry contributes 10% of manufacturing production and 2% of India’s GDP, employs 45 million people and accounts for more than 13% share of the country’s total exports basket (Ministry of Textile, 2016). The industry realized export earnings worth US$ 42.2 billion in 2014-15, which increased to around 50 billion US$ in 2015 - 2016 as per the Textile Export Promotion Council (Texprocil). Textile and apparel exports from India are expected to increase to US$ 82 billion by 2021. Recent developments in this field have increased the competition between different manufacturers, and they now toil to come to the forefront of the consumer’s mind, by providing desirable qualities to fabrics such as wrinkle-free, dust-free, stain repellant, antimicrobial, UV resistant, non-inflammable, etc.

2.3. Clothing

Textile and clothing play a major role in the development and industrialization process of countries and their integration into the world economy. Clothing plays a significant role in an individual’s life at all the ages, as it provides a medium of self-expression, a way to conform, and a way to suggest wealth and prestige and an outlet for creative energy (Kaur, 2012). It is a feature of nearly all human societies and it protects one’s body from various climates and toxic chemicals, and gives us a good comfort and appearance. The clothing industry caters to a wide range of end-uses, from disposable
fashion to high-tech protective clothing and the functional profile of clothing is undergoing reforms, driven by advances in textile technology from the military and space industries. Many factors such as social, economical, environmental and physical play an important role in selection of clothing of a person (Das & Alagirusamy, 2010).

2.4. Polyester/Cotton Blended Fabrics

Cost, quality, care and comfort are the significant properties that the customer considers before buying a cloth, all of which are different aspects of comfort. Cotton fabrics are in use for hundreds of years because of the quality, consistency and air permeability (Ravandi & Valizadeh, 2011). There are numerous drawbacks in using pure cotton fabric, which is solved by blending cotton with polyester. Blending the fibers in a fabric seems to be a powerful solution to modify the properties and cost of the materials. The polyester fabric has attained its reputation because of its soft finish and its tendency to easily merge with other cloth materials. Cotton has high moisture retention, and so it absorbs sweat and lets it evaporate; therefore cotton is highly water-vapor permeable or breathable. Polyester has low moisture absorbency and it is not breathable, but is crease resistant; cotton is not. So, when cotton is blended with specific percentage of polyester, we get the finest of both the fabrics, and the finished goods are durable too.

Polyester/cotton fabric is probably the most famous and popular blend. The fibers of polyester and cotton have the largest production volumes globally and will fulfill the demand in apparel and clothing, sportswear, healthcare, medical textile, home textile and other technical fields (Mather & Wardman, 2011). Healthcare textile comprises surgical clothing (surgical gowns, head caps, masks, uniforms, etc.), surgical covers (drapes, coversm, etc.) and beddings (bed spreads, blankets, pillow cases, etc.). The combination of cotton/polyester blend results in a soft, absorbent material with just the correct amount of stretch for manufacturing fabric like sleepwear, undershirts, etc. One of the most important characteristics of the fabric which affects the comfort properties of cloth is the constructional specification (Ravandi & Valizadeh, 2011). There are many ways of making fabrics from textile fibers, among which woven fabrics generally have smoother surface and are flexible, strong and porous which makes them useful in clothing, apparel and technical applications with minimum production costs (Dubrovski, 2010). Hence, the plain woven polyester/cotton blended fabrics were used in this study.

2.5. Functionalization of Textile

Increasing global competition in textile has created many challenges for textile researchers. The rapid growth in technical textile and their end uses had generated many opportunities for the application of innovative finishes. Novel finishes of high added value for apparel fabrics are also greatly appreciated by a more discerning and demanding
consumer market. Textile producers share an intelligent market and have to compete very hard in order to satisfy the consumer. Consumers evaluate products based on a wide assortment of attributes. Even though the basic function of textile is to protect the wearer and provide comfort, development of the information era had created a demand for textile with more advanced functionalities. The advent of synthetic finishing agents, to alter and improve performance and characteristics of textile, besides the awareness and concern about damages caused by microbes, pesticides, UV exposure and pollutants, has amplified the demand for multifunctional textile.

The application of textile in high performance and specialized fields is increasing day-by-day, and clothing is expected to have more functional attributes like antimicrobial, self-cleaning, UV resistance, insect repellent, waterproof, anti-static, wash and wear, flame resistant and smart enough to keep the wearer warmer in winter and cool in summer (Gulrajani & Gupta, 2011; Balazsy & Eastop, 1998). The recent trend in textile finishing is to impart functional properties to textile along with aesthetics and comfort (Damle, et al., 2014). The functional properties were categorized as temporary, durable and permanent, according to the degree of performance of the product. Temporary finish lasts one or more dry cleanings or launderings, and durable finish will go on for the lifetime of the product, and permanent finish exists until the lifespan of the fabric (Collier & Tortora, 2001). The rising demand for multifunctional textile has moved the textile research towards multidisciplinary approach and it is widely used in various fields like apparel and clothing’s, healthcare, medical and various technical fields. The permeation of new functional and smart technologies into other textile sectors is gradually finding a path into mass production of clothing (Kapsali et al., 2008).

2.6. Antimicrobial Textile

The inherent properties of the textile provide room for the growth of microorganisms. Besides, the organic content of the fabric may act as a source of nutrient and further induce the growth of microbes. Humid and warm environment still intensify the problem. Infestation by microbes cause cross infection by pathogens and develop odor, where the fabric is worn next to skin. In addition, staining and performance loss of textile are the results of microbial attack. Basically, with a view to protect the wearer and the textile substrate itself, antimicrobial finish is applied to textile materials. Antimicrobial coatings have been developed for a variety of applications to reduce the proliferation of bacteria and fungi on surfaces. Researches involving antimicrobial coating for textile are gaining attention in the healthcare industry due to the increased risk of healthcare associated infections (Sherine et al., 2015).
One of the first antimicrobial textile finishes, used during the Second World War, was made to prevent cotton textile, such as tents, tarpaulins and vehicle covers from rotting. At this point of time, the main concern was the preservation of textile, and therefore the effects of such finishes on the environment were ignored (Bonin & Elizabeth, 2008). Textile materials with engineered nanoparticles (ENPs) have excellent properties as they are antibacterial, antifungal and protective. The textile industry has recognized the importance and the advantages of ENPs, and so they are one of the fastest developing branches of processing. The disposal of such textile treated with ENPs must be monitored thoroughly (Rezic, 2011).

Antimicrobial agents should be safe for use, and at the same time have broad spectrum biocidal properties, and are highly effective against antibiotic resistant microorganisms that are commonly involved in hospital-acquired infections. In addition, the antimicrobial agents should not permit the development of resistance in microorganisms to the active compound or cause skin sensitization (Ramachandran et al., 2004). Antimicrobial agents are natural or synthetic compounds that stall the growth (bacteriostatic or fungistatic) by blocking protein/lipid synthesis or inhibit the activity of enzyme, all of which are essential for cell survival, or kill (biocidal) the microorganisms by damaging the cell wall (Madigan et al., 2006).

2.6.1. Antimicrobial Finish and Its Importance

Ideal antimicrobial finishing should satisfy a number of requirements in order to achieve the target i.e. functionalized textile products (Hashem et al., 2009). Antimicrobial finishing of fabric prevents detoruous microorganisms and avoids medical and hygienic problems, with protection of textile from undesirable aesthetic changes or damage caused by rotting. Antimicrobial finishes for textile materials is necessary to fulfill the following aim (Gopalakrishnan & Aswini, 2002; Mahltig & Textor, 2008):

- To control microorganisms growth,
- To reduce odor from perspiration, and minimize stains on textile material,
- To reduce the risk of cross infection in hospital,
- To control spread of disease and danger of infection following injury, and
- To control the deterioration of textile, particularly fabrics made from natural fiber caused by mildew.

An antimicrobial finish given on a textile needs to satisfy all requirements besides being efficient against microorganisms and also suitable for processing; durability to laundering, safety to wearer and environmental; and moreover should not harm the textile quality or appearance (Gao & Cransto, 2008). It should have easy method of application and should not cause any deterioration of fabric quality. The finish should be resistant to
the body fluids and disinfectant/sterilization. It must withstand repeated laundering, dry cleaning and exposure to light. The finished fabric should be safe and comfortable to wear and it should not cause any irritation to skin. The antimicrobial agent should be used, according to fiber type, including the composition, structure, surface texture, different chemical and physical approaches (Shahidi & Wiener, 2012).

2.6.2. Mode of Action of Antimicrobial Agents

Antimicrobial agents attack crucial microbial functions with least effects or without disturbing host functions. The mechanisms of various antimicrobial agents are in different ways. These include inhibition of synthesis of cell wall, inhibition of functions of ribosome, inhibition of synthesis of nucleic acid, inhibition of folate metabolism and inhibition of functions of cell membrane and releasing toxic metal ions and possessing abrasive properties which carry about lysis of cells (Kandi & Sabitha, 2015). Metal oxide nanoparticles are of huge concern for use as possible antimicrobial agents, because of their exclusive optical, electronic, and magnetic properties. Irradiation by light with more energy compared to the band gap of the metal oxide generates electron – hole pairs that induce redox reactions. Consequently, electrons in metal oxides jump from the valence band to the conduction band, and the electron (e−) - hole (h+) pairs are formed on the exterior of the photocatalyst. The negative electrons and oxygen formed will combine into O2 −, the positive electric holes and water will generate hydroxyl radicals. Eventually, a range of highly active oxygen species will oxidize organic compounds of the cell to carbon dioxide (CO2) and water (H2O). Thus, metal oxides can decay common organic matters in the air such as odor molecules, bacteria and viruses (Ioan, 2015). To summarize, antimicrobial agents kill microorganisms in following ways:

- Cell wall damage.
- Inhibition of cell wall synthesis,
- Alteration of cell wall permeability,
- Inhibition of the synthesis of proteins and nucleic acids,
- Inhibition of enzyme action,
- Release of reactive oxygen atoms, and
- Interrupting in the repair mechanisms.

2.7. UV Protective Finish

The effective spectrum of the solar radiation reaching the surface of the earth spans from 280 nm to 3000 nm (Reinert et al., 1997), where the wavelength of ultraviolet spectrum lies between 290 nm and 400 nm. The UV radiation is classified into UV-A (320-400nm), UV-B (290-320nm) and UV-C below 290 nm. The harmfulness of the radiation is in the order of UV-C>UVB>UVA, but the UVC radiation does not reach the surface of the
earth as it is filtered by the ozone layer. The energy of the UVA and UVB radiation are parallel to the bond energies of the organic molecules (Saravanan, 2007), thus affecting the organic life forms. The most significant reason for skin cancer is ultraviolet radiation (UV) from sun exposure. Cumulative damages which stimulate DNA damage, gene mutations, immunosuppression, oxidative stress and inflammatory responses were caused due to extreme exposures of UV radiation. In addition to this, UV radiation creates mutations to p53 tumor suppressor genes. These are genes which are involved in the apoptosis of cells that have DNA damage or DNA repair.

There are lots of efforts taken to minimize the UV exposure and textile plays a vital role in protecting humans. When light falls on a textile surface, a part is reflected depending on the surface characteristics of the fabric, a part is absorbed, and a part is transmitted through the fabric, which falls on the skin. The sun-blocking properties of a textile are enhanced when ultraviolet absorber finish, that absorbs ultraviolet radiation and blocks its transmission to the skin, is present.

2.7.1. Mechanism of UV Blocking

Several types of UV stabilizers are available, the most common being benzophenones and phenyl benzotriazoles, which are able to absorb the damaging UV rays of sunlight, (Menezes & Choudhari, 2005). In case of traditional UV blockers, the radiation will be generally absorbed by the organic dyes. Recently, metal oxide nanoparticles found its significant place in the UV protective textile replacing the organic stabilizers. The UV light, falling on the metal oxide nanoparticles, will excite the electrons from the valence band of the metal oxide to the conduction band, thus losing its energy. Also, due to the small size of the nanoparticles, they will be able to effectively scatter the UV radiation shining on them. Hence, metal oxide nanoparticles will enhance the UV-blocking property due to their increased surface area and their ability to absorb the radiation via excitation.

2.8. Self-cleaning Finish

The self-cleaning theory originate from natural observable fact which can be detected on leaves of lotus plant, rice plant, wings of butterfly, scales present in fish, etc (Bixler & Bhushan, 2012). This is due to the super hydrophobic effect, which rolls of the water droplets along with the dirt particles present on the surface. Various efforts have been taken to mimic the nature for creating self-cleaning fabrics. Water repellency can be attained by various compounds, but oil repellency can be attained only with fluorocarbon polymers. Other undesirable properties are often found with repellent finishes and these include problems with static electricity, poor soil removal in aqueous laundering and increased flammability (Schindler & Hauser, 2004).
As an alternative, inorganic compounds can contribute to self-cleaning of the fabrics by a different mechanism. When metal oxides are used as self-cleaning agents, they exhibit a photocatalytic effect and degrade the dirt molecules. Also, when compared to the organic compounds, inorganic compounds are very stable in the different environmental conditions, including laundering and exposure to hot sunlight. Various researches demonstrate the use of metal oxides like TiO₂ and ZnO as effective agents for self-cleaning textile.

### 2.8.1. Mechanism of Self-cleaning Action

The fabric coated with metal dioxide nanoparticles when exposed to light, photons with energy equal to or greater than the band gap of the photocatalyst, stimulate electrons up to the conduction band. The excited electrons inside the crystal configuration react with oxygen atoms in the atmosphere, creating free-radical oxygen. These oxygen atom breakdowns the majority of carbon-based compounds by oxidation-reduction reactions, and also acts as a potent oxidizing agent. In these reactions, the organic compounds (i.e. dirt, pollutants, and microorganisms) are broken down into substance such as carbon dioxide and water.

### 2.9. Nanotechnology

Nanotechnology is a term that is used to describe the science and technology related to the control and manipulation of matter and devices on a scale less than 100 nm in dimension (Gupta et al., 2011). Materials behave differently in nano size when compared to their bulk counterparts. Two primary factors are responsible for this effect: surface effects (causing smooth properties scaling due to the fraction of atoms at the surface) and quantum effects (showing discontinuous behavior due to quantum confinement effects in materials with delocalized electrons) (Roduner, 2006). These factors affect the chemical reactivity of materials, as well as their mechanical, optical, electrical and magnetic properties.

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**Figure 2.1. Classification of Nanomaterials (Gusev & Rempel, 2004)**

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The fraction of the atoms at the surface of the nanoparticles is increased compared to micro particles or bulk. Compared to micro particles, nanoparticles have a very large surface area and high particle number per unit mass. As the material in nanoparticulate form presents a much larger surface area for chemical reactions, reactivity is enhanced roughly 1000-fold. Nano structured materials can be classified into zero dimensional, 1 dimensional, 2 dimensional, and 3 dimensional nanostructures based on the confinement of the atoms.

2.9.1. Nanotechnology in Textile Applications

Nanotechnology has become one of the most important of sectors, drawing intense interest. It is widely felt that it is going to change every aspect of our lives and lead to the generation of new capabilities, new products and new markets. It is thus described as an enabling technology that will pave way for novelty in every stream of technology. Similarly, nanotechnology plays an important role in textile application also (Kathiervelu, 2003). Textile based nano products, starting from nanocomposite fibers, nanofibers to intelligent high performance polymeric nanocoatings are getting their way not only in high performance advanced applications, but nanoparticles are also successfully being used in conventional textile to impart new functionality and improved performance. Due to the large surface area to volume ratio and high surface energy, nanoparticles can give better durability of finish to the fabrics (Wong et al., 2006). Greater repeatability, reliability and robustness are the main advantages of nanotechnology advancements in textile. It is obvious that this coating of nanomaterials results in change in physical and mechanical properties such as strength, air permeability and wetting properties (Xin, 2006). Very low consumption levels of chemicals and energy at very low quantity are the advantages of using metal oxide nanoparticles in textile finishing. Nanoparticle application, during conventional textile processing techniques like finishing, coating and dyeing enhances the product performance manifold and imparts hitherto unachieved functionality. The use of nanotechnology allows textile to become multifunctional and produce fabrics with special functions, including antibacterial, UV-protection, easy-clean, water and stain repellent and anti-odour (Kathiervelu, 2003).

2.10. Metal Oxide Nanoparticles: Importance & Applications in Textile Finishing

Among all the functional materials synthesized on the nanoscale, metal oxides are particularly attractive candidates, from the scientific as well as from the technological point of view. Metal oxide nanoparticles are more stable when compared to their metallic counterparts and organic nanoparticles. The unique characteristics of metal oxides make them the most diverse class of materials, with properties covering almost all aspects of materials science and solid state physics. Certain metal oxides like TiO₂, ZnO, MgO and CuO are recognized by the FDA as non-toxic for the human body. Nanosized particles of
TiO$_2$, ZnO, CuO and Fe$_2$O$_3$ possess photocatalytic ability, UV absorption and photo-oxidizing capacity against chemical and biological species. During the last decade, researches involving metal oxide nanoparticles was intensified, focusing on the production of textile with antibacterial, self-decontaminating and UV-blocking functions (Daoud & Xin, 2004; Sojka-ledakowicz et al., 2008). There are numerous reports in the literature on the multifunctional properties of metal oxide nanoparticles as tabulated in Table 2.1.

<table>
<thead>
<tr>
<th>Functional Properties</th>
<th>Metal oxide nanoparticles</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimicrobial textile</td>
<td>Ag, TiO$_2$, ZnO, CuO, Fe$_2$O$_3$, MgO</td>
<td>Azam, et al., (2012); Wong et al., (2006)</td>
</tr>
<tr>
<td>Self-cleaning textile</td>
<td>TiO$_2$ and ZnO</td>
<td>Mihailovic et al., (2011); Chaudhari et al., (2012)</td>
</tr>
<tr>
<td>UV-blocking textile</td>
<td>TiO$_2$, ZnO</td>
<td>Tsuzuki and Wang (2010); Wong et al., 2006; Kathiervalu, (2003)</td>
</tr>
</tbody>
</table>

2.10.1. Titanium Dioxide (TiO$_2$) Nanoparticles

TiO$_2$ is a semiconductor having high photochemical stability with low cost. Well-dispersed titanium dioxide nanoparticles help in many applications such as pigments, adsorbents and catalytic supports (Vijayalakshmi & Rajendran 2012). Titanium dioxide (TiO$_2$) nanoparticles have unique characteristics like chemical stability, antimicrobial activity, photocatalytic activity, non-toxicity, etc. When TiO$_2$ nanoparticles are exposed to ultraviolet rays, the photon energy generates an electron hole pair on the surface which reacts with hydroxyl ions (OH) adsorbed on the surface to produce hydroxyl radicals (OH). The conduction band electron will reduce oxygen to produce peroxide ions (O$_2^{2-}$), and both hydroxyl radicals and peroxide ions are extremely reactive particles. Thus they can decompose organic compounds upon contact with them (Abidi, et al., 2009). The higher photocatalytic reactivity is mainly attributed to the strong UV absorption, and the photodecomposition efficiency varies according to different illumination conditions (Liu, et al., 2012; Zheng, et al., 2012). It was determined that nano sized titanium dioxide are more efficient at absorbing and scattering UV radiation than the conventional size, and are thus better to provide protection against UV rays.

Many research papers have focused on the examination of the antimicrobial properties of TiO$_2$ modified textile materials, since a powerful oxidizing effect of TiO$_2$ upon the light irradiation leads to the destruction of a broad spectrum of microorganisms, such as bacteria, viruses and fungi. These examinations were carried out by studying the
antibacterial efficiency of textile materials against gram-negative bacteria *E. coli* (Montazer & Seifollahzadeh, 2011), Gram-positive bacterium *S. aureus* (Daoud, et al., 2005; Ibrahim et al., 2010), airborne bacteria, fungi (Kiwi & Pulgarin, 2010) and bacteria isolated from the active sludge (Wu, et al., 2009). Titanium oxide nanoparticles appear in the form of black hexagonal crystals. Titanium dioxide, also known as titanium (IV) oxide or titania, is the naturally occurring oxide of titanium with chemical formula of TiO$_2$. It is a white odorless solid powder, insoluble in water, with density of 4.23 g/cm$^3$ (Rutile) to 3.78 g/cm$^3$ (Anatase). Titanium dioxide is the most widely used white pigment because of its brightness and very high refractive index (Azonano, 2013).

2.10.2. Zinc Oxide (ZnO) Nanoparticles

Zinc oxide is an inorganic compound with the formula ZnO. ZnO is a white powder that is odorless, insoluble in water but soluble at favorable condition (0.16 mg/100 ml (30 °C), with density 5.606 g/cm$^3$ and refractive index of 2.004. It has boiling point of 2360 °C and melting point of 1975 °C (decomposes). ZnO is a semiconductor, having strong room temperature luminescence, wide band gap, high electron mobility and good transparency. During recent years, low-temperature wet chemical methods have received more and more attention and already been commonly used to grow ZnO nanostructures. There are mainly three common approaches in chemical growth at low temperature, i.e., the hydrothermal (Le et al., 2005) chemical bath deposition (CBD) (Vayssieres, 2003) and electrochemical deposition (Hames et al., 2010).

For textile applications, zinc oxide is not only biologically compatible, but also nanostructured ZnO coatings are more air-permeable and efficient as UV-blockers compared with their bulk counterparts (Yadav et al., 2006). Hydrothermally grown ZnO nanoparticles in SiO$_2$-coated cotton fabric showed excellent UV-blocking properties (Mao et al., 2009). Zinc oxide nanowires were grown on cotton fabric by Ates & Unalan, (2012) to impart self-cleaning, super hydrophobic and ultraviolet (UV) blocking properties. ZnO is more stable and has a longer life than organic-based disinfectants or antimicrobial agents. This is particularly important for harsh conditions such as high temperatures and/or pressures occur during product manufacturing, storage and transportation (Hewitt et al., 2001). Nanoscale (20-100 nm) ZnO can be employed as a safe physical sunscreen because it scatters and reflects UV in sunlight. The antibacterial activity depends on surface area and concentration, while crystalline structure and particle shape have little effect. The antibacterial activity increases with increasing particle concentration and decreasing particle size. Possible mechanisms of antibacterial action by ZnO nanoparticles include disruption of cell wall and membrane integrity, generation of ROS and free radicals (Zhang et al., 2009).
2.10.3. Copper Oxide (CuO) Nanoparticles

Copper nanoparticles have unique optical, catalytic and chemical properties specific to the nano level. The synthesis of copper nanoparticles with controllable sizes, shapes and surface properties is vital for exploring copper based nanomaterials for different industrial applications. Cu and CuO nanoparticles have been synthesized through different methods such as thermal oxidation, simple hydrolysis, hydrothermal, solvothermal, microwave-hydrothermal thermal decomposition and sonochemical reactions (Wang et al., 2002; Meng et al., 2011). Among various techniques, the hydrothermal method of producing metal oxide nanomaterials is unique and economical. Copper oxide with silver nanoparticles can be exploited in medicine for burn treatment, dental materials, coating stainless steel materials, textile fabrics, water treatment, sunscreen lotions, etc., as copper oxide exhibit low toxicity to human cells, high thermal stability and low volatility (Duran et al., 2007).

CuO nanoparticles are an effective killing agent against broad spectrum gram-negative and gram-positive bacteria (Azam et al., 2012) including antibiotic-resistant strains. Copper oxide nanoparticles interact with the building elements of bacterial membrane and cause damage to the cell. The TEM analysis and EDAX study confirmed the incorporation of CuO nanoparticles into the membrane, which was recognized by formation of pits on the cell surface. Perelshtein et al. (2009) reported that in the case of the CuO-coated fabric, the antibacterial effect detected was due to the generation of reactive oxygen species that are responsible for damaging the bacteria's cells. CuO nanoparticles resulted in the leakage of reducing sugars and proteins and induced the respiratory chain dehydrogenases into inactive state, suggesting that CuO nanoparticles were able to destroy the permeability of the bacterial membranes. Copper oxide nanoparticle is a brownish-black powder, 40nm, with 99% purity and 6.3-6.49 g/cm³ density and melting point of 1326 °C.

2.10.4. Iron Oxide (Fe₂O₃) Nanoparticles

Fe₂O₃ nanoparticles are found naturally in the environment (Karlsson et al., 2008). Various methods such as synthesis by water-in-oil microemulsion system, co-precipitation, polyl method, flow-injection synthesis, thermal decomposition, hydrothermal synthesis, micro emulsion and sonochemical synthesis can be employed in their fabrication (Laurent et al., 2008). In addition, these nanoparticles can also be prepared by the other methods such as electrochemical synthesis (Cabrera et al., 2008), laser pyrolysis techniques, microorganism or bacterial synthesis (especially the magnetotactic bacteria and iron reducing bacteria) (Bharde et al., 2008), etc.
Several authors have reported the synthesis of iron oxide NPs by hydrothermal method (Hu et al., 2007). Iron oxide nanoparticles can be used as a potential nano adsorbent for textile dyeing effluent treatment. Due to the high surface area, good absorbing capacity and a nature of catalyst, the synthesized iron oxide nanoparticles was used in the decolorization of textile dyeing industry effluent (Rajan et al., 2015). Azam et al. (2012) reported that the Fe₂O₃ nanoparticles exhibited excellent antimicrobial activities against both gram positive and gram negative bacterium. Fe₂O₃ are visible light active photocatalyst and they possess excellent self-cleaning properties. The crystallographic system of iron oxide is cubic or tetrahedral with density of 4.87(g/cm³), hardness of 5 and Curie temperature 820-986 K (Cornell & Schwartman, 2003).

### 2.10.5. Aluminium Oxide (Al₂O₃) Nanoparticles

Alumina nanoparticles are thermodynamically stable particles over a wide temperature range. They are corundum like structure with oxygen atoms adopting hexagonal close packing with alumina ions filling two thirds of the octahedral sites in the lattice (Sadiq et al., 2009). Murdock et al. (2008) have observed that the particle behavior was also influenced by particle size, shape and surface charge. Alumina is a white oxide with several phases such as gamma, delta, theta and alpha. In general, alumina has many interesting properties like high hardness, high stability, high insulation and transparency. Alumina is also widely used in the fire retard, catalyst, insulator, surface protective coating and composite materials (Keyvani et al., 2010).

Alumina can exist in several crystalline phases, which all revert to the most stable hexagonal alpha phase at elevated temperatures (Blanda et al., 2013). The large specific surface area, energy density and high reactivity of Al₂O₃ nanoparticles make them unique combustible additives in propellant formulations for significantly higher and faster energy release. As one of the widely studied and used nanomaterials, Al₂O₃ nanoparticles have been applied in catalysis, structural ceramics for reinforcement, polymer modification, functionalization of textile, heat transfer fluids and waste water treatment. There have been very few studies available in the literature on the interaction of the Al₂O₃ nanoparticles with microbes.

### 2.10.6. Magnesium Oxide (MgO) Nanoparticles

MgO is used in many applications such as catalysis, toxic waste remediation, paint, superconducting products, refractory materials and adsorbents, additive in heavy fuel oils, antibacterial activities against food borne pathogens, etc. MgO can be synthesized by thermal treatment of magnesium hydroxide / carbonate, sol-gel method, sonication method and flame spray pyrolysis method (Ozturk et al., 2012). MgO is an important material, which is used in many applications like catalysis, toxic waste
remediation, paint, superconducting products, refractory materials and adsorbents, additive in heavy fuel oils, reflecting and anti-reflecting coatings, superconducting and ferroelectric thin films as the substrate and antibacterial activities against food borne pathogens (Mageshwari et al., 2013; Mastuli et al., 2012).

An et al. (2011) found that high MgO nanoparticle concentrations resulted in greater bacterial inactivation. Many reports have indicated that MgO nanoparticles have better activity towards gram-positive bacteria than towards gram-negative bacteria (Tang & Lv, 2014). The reason is probably due to the difference in cell membrane structure. The cell wall of gram-positive bacteria (E. coli) consists primarily of thin layers of lipid A, lipopolysaccharide and peptidoglycan, but that of gram-negative bacteria S.aureus consists of only a peptidoglycan layer. Magnesium oxide nanoparticle is a white powder, 30-50nm, with 99.9% purity and 3.58 g/cm³ density, melting point of 2852 °C and boiling point 3600°C (Azonano, 2013).

2.10.7. Evaluating the Safety of Metal Oxide Nanoparticle Coated Functional Textile

The increasing production and use of metal oxide nanoparticles in numerous applications lead to adverse effects on health (Galdiero et al., 2011). Several studies have demonstrated nanoparticle toxicity and increased cytotoxic potential of these materials. However, a better understanding of the biological mechanisms of cytotoxicity and/or genotoxicity is necessary (Ingle et al., 2014). The fact that the clothing worn can play a critical role in the transfer of dangerous pathogens is indisputable. This is particularly true if the effectiveness has been proven beyond all doubt, i.e., on the basis of practical tests carried out by a neutral body. On the other hand, the term ‘antibacterial’ inevitably raises questions amongst wearers as to the skin compatibility of antimicrobial textile worn next to the skin. The user of the textile products can therefore expect them to be safe in use and not to pose a health risk. For this reason, validated test methods have been developed to objectively assess the biological safety of textile with antimicrobial activity on scientific basis. The basis for the biological safety tests for textile is the EN ISO 10993 and by this test skin irritation potential was tested. A classic test to determine the irritation potential of a substance is the Draize test, in which the substance to be tested is dripped on to the conjunctiva of a laboratory animal’s eye in order to identify any potential irritants. The scientifically recognized hen’s egg test on the chorioallantoic membrane (CAM) is an alternative to the animal test. This has been validated among others by the European Centre for Validation of Alternative Methods. It is possible to determine the irritation potential of substances which could be released from the textile material just as accurately by observing the blood vessels of the treated egg as using the animal test. The hen’s egg test on the chorioallantoic membrane (HET-CAM) therefore offers decisive additional security regarding the use of antimicrobial textile (Hipler & Elsner, 2006).
2.10.8. Synthesis of Metal Oxides

The synthesis of nanoparticles involves two main approaches namely, top-down and bottom-up methods. Top-down approach implies successive cutting of a bulk material to obtain nano size particle. Top-down approaches seek to create nano scale devices by breaking down larger particles. This approach often uses the traditional workshop or micro fabrication methods where externally controlled tools are used to cut, mil and shape materials into the desired shape and order. Ball milling, sputtering and micro patterning techniques such as inject printing and photolithography belong to this category. Bottom-up approach refers to the build-up of a material from the bottom, i.e., atom by atom, molecule by molecule and cluster by cluster. Bottom-up approaches produce more uniform and homogenous nanoparticles when compared to top down approaches. Solution-gel process, chemical precipitation, hydrothermal and solvothermal methods fall under this category. Commonly used nanoparticle synthesis methods are described below.

Co-precipitation methods: This involves dissolving a salt precursor (chloride, nitrate, etc.) in water (or other solvent) to precipitate the oxo-hydroxide form with the help of a base. Very often, control of size and chemical homogeneity in the case of mixed-metal oxides are difficult to achieve. However, the use of surfactants, sonochemical methods and high-gravity reactive precipitation appear as novel and viable alternatives to optimize the resulting solid’s morphological characteristics (Dsouza & Richards 2007; Chen et al., 2002).

Sol-gel processing: The method prepares metal oxides via hydrolysis of precursors, usually alkoxides in alcoholic solution, resulting in the corresponding oxo-hydroxide. Condensation of molecules by aqving off water leads to the formation of a network of the metal hydroxide. Hydroxyl-species undergo polymerization by condensation and form a dense porous gel. Appropriate drying and calcinations lead to ultrafine porous oxides (Interrante & Smith, 1997).

Microemulsion technique: Microemulsion or direct/inverse micelles represent an approach based on the formation of micro/nano-reaction vessels under a ternary mixture containing water, a surfactant and oil. Metal precursors on water will precede precipitation as oxo-hydroxides within the aqueous droplets, typically leading to mono dispersed materials with size limited by the surfactant-hydroxide contact (Uskokovic & Drofenik, 2005).

Template/Surface derivative methods: Template techniques are common to some of the previous mentioned methods and use two types of tools: soft-templates (surfactants) and hard-templates (porous solids as carbon or silica). Template and
surface mediated nanoparticles precursors have been used to synthesize self-assembly systems (Dsouza & Richards, 2007). Gas-solid transformation methods with broad use in the context of ultrafine oxide powder synthesis are restricted to chemical vapor deposition (CVD) and pulsed laser deposition (PLD).

**Chemical Vapor Deposition:** There are a number of CVD processes used for the formation of nanoparticles among which we can highlight the classical (thermally activated/pyrolytic), metal organic, plasma-assisted and photo CVD methodologies (Ohring, 1992). The advantages of this methodology consist of producing uniform, pure and reproduce nanoparticles and films although it requires a careful initial setting up of the experimental parameters.

**Multiple-pulsed laser deposition:** The process heats a target sample (4000 K) and leads to instantaneous evaporation, ionization and decomposition, with subsequent mixing of desired atoms. The gaseous entities formed absorb radiation energy from subsequent pulses and acquire kinetic energy perpendicularly to the target to be deposited in a substrate generally heated to allow crystalline growth (Hubler, 1992).

**Hydrothermal method:** In this case, metal complexes are decomposed thermically either by boiling in an inert atmosphere or using an autoclave with the help of pressure. A suitable surfactant agent is usually added to the reaction media to control particle size growth and limit agglomeration. Hydrothermal synthesis in supercritical water has advantages for synthesis of multi metal oxide compounds because the reaction rate is enhanced by more than 103 times under the conventional hydrothermal conditions owing to the low dielectric constant (<10) as well as products with high crystallinity (Adschiri et al., 2000, Hakuta et al., 2003). The particle size of metal oxide depends on the hydrolysis rate and solubility of the metal oxide. The production of various metal oxide particles such as TiO₂ (Imai et al., 2009), Al₂O₃ (Sato et al., 2008), Fe₂O₃ (Xu & Teja, 2008) and ZnO (Ohara et al., 2008) has been demonstrated by hydrothermal batch and flow reaction systems. The main advantage of the hydrothermal method is the homogeneity of the nanoparticles produced. Hence, this method was adopted for the current research.

### 2.11. Nanocomposites

Nanocomposite materials are engineered materials prepared from two or more essential nanomaterials that remain detached and distinct on a macroscopic altitude while forming a single component. Nanocomposites can be fashioned with several metal oxides having various compositions. Nanocomposites exhibit excellent properties by synergistically combining the effects of individual nanoparticles. There are lots of attempts to blend metal oxides with different properties and coat them on to the fabric. Wang et al.
(2003) reported the hydrothermal preparation for CeO$_2$/ZnO composite nanostructure, by using Zn (NO$_3$)$_2$·6H$_2$O, Ce (NO$_3$)$_3$·6H$_2$O and hexa methylene tetramine on Si substrate. CeO$_2$/ZnO composite nanostructure may find potential application in the selective detection of CO. Nylon fiber filled with ZnO nanoparticles can provide UV shielding function and reduce static electricity of nylon fiber. A composite fiber with nanoparticles of TiO$_2$/MgO can provide self-sterilizing function (Babi, 2006). In a composite providing multifunctional activity, i.e., the use of silver nanoparticles could improve the application of alginate and chitosan in the wound dressing market by merging both the antibacterial activity and biodegradability (Sreenivasan, 2006).

TiO$_2$/SiO$_2$ nanocomposites were coated on to cotton textile material by a dip-pad-dry-cure process. Photocatalytic activity of the treated cotton fabrics was demonstrated to be higher when compared to pure TiO$_2$ treated cotton fabrics in a typical photocatalytic test using a model compound of Neolan Blue 2G dye. (Kaihong Qi et al., 2007). Zhang et al. (2012) reported on carbon coated Fe$_3$O$_4$ composites with pine-leaf hierarchical structures having excellent electrical, chemical and magnetic properties. These properties not only depend on the composition but also on the morphology of the nanomaterials. Several researchers are giving serious consideration to the preparation of metal oxide nanocomposite due to its wide range of application in engineering and technology.

2.11.1. Preparation Methods of Nanocomposites

There are several types of synthetic routes for the synthesis of nanocomposites, among which are impregnations, polymeric precursor, CVD, ball milling and sol-gel synthesis (Rahim et al., 2011). More than one method can be combined in different stages of the formation of nanocomposites, such as solvothermal and hydrothermal coprecipitation. or they can be combined with the reduction of metal through the use of a reducing agent. The method of wet impregnation can be used when one of the components of the composite, such as a silica matrix, is previously available. The synthesis of nanocomposite processes generally used to fabricate nanoparticles and nanocomposite preparations are enlisted by Prabu & Anbarasan, (2012).

Vapor-phase synthesis: In vapor-phase synthesis the nanoparticles of metals, alloys or compounds are formed in the gaseous phase through evaporation and condensation of atoms and molecules at controlled temperature. The process involves hydrolysis of gaseous metallic chlorides under the influence of water which leads to a high temperature reaction zone. In the process of condensation, convective gas flow plays an important role. Nanoparticles are formed when vapors cool down in the condensation zone (Rajput, 2015). Inert gas condensation, plasma-based synthesis, flame based synthesis and spray pyrolysis techniques fall under vapour-phase synthesis.
**Solution processing:** Solution processing remains much attractive for researchers due to its simplicity and ability to form encapsulated and composite nanoparticles with control over shape and size at room temperature. A major advantage, from commercial perspective, is that it is possible to process the production of tonnage quantities of powders by this route. Solution processing can be further classified in the following categories: Solution-gelation (sol-gel) process, solution precipitation and water-oil microemulsion method (Hussain et al., 2006).

**Solid-state synthesis (Ball milling):** Solid-state synthesis, or mechano-synthesis, consists of high energy ball milling in order to blend one or more crystalline compound (Suryanarayana, 2004). Mechanical synthesis procedure is usually followed by industrial community due to high processing capacity and being economically cheaper even though it lacks control over morphology. High-energy ball milling is a powder processing method in which powder particles go through a repeated process of cold welding, fracturing and re-welding. These processes are repeated several thousands of times during the mechanical milling operations, resulting in crystallite dimension diminish with processing milling point in time and consistent distributed particles in the metal matrix. The milling may be wet or dry, depending upon the phase change requirements during the milling process. The milling time may extend to several hours to minimize the size of milled nanoparticles below 100 nm, and the properties obtained are the functions of milling time.

Milling velocity has a significant responsibility in the progression of mechanical milling. The privileged the speed the higher is the velocity of energy transfer to the powder, and lower is the milling time to attain the preferred size. In 2013, Aboraia, reported that in Al-Al₂O₃ nanocomposite preparation system, three sets of powders with three different milling speeds (200, 300 and 400) were studied. However, there is a frontier to the utmost velocity that can be used. At higher speeds, the balls are liable to attach to the walls of the vial and consequently are incompetent of transferring energy to the powder particles. Next to higher speeds, the warmth of the system may possibly increase and may increase the speed of the transformation process and results in crystallization of the amorphous phase. Accordingly, the highest speed selected should be lower than this critical value. From Al-Al₂O₃ nanocomposite system, it is found that 300 rpm milling rotation speed is the proper milling speed to achieve the desired size, and it is used in Al-Al₂O₃-ZrO₂ system. The crystallite size decreases due to the local deformation from milling, which, accelerating the work hardening of the matrix and increase the grain refinement. High energy ball milling was chosen for the current research work, because it is simple, economical and can be easily scaled up.
Additionally, it is a very energy efficient and clean process. In general, the environmental benefits of plasma treatment can be summarized as: i) Reduced amount of chemicals needed in conventional processing, ii) Better exhaustion of chemicals from the bath, iii) Reduced BOD/COD of effluent, iv) Shortening of the wet processing time, v) Decrease in needed wet processing temperature, and vi) Energy savings (Radetic et al., 2007).

2.12.1.1. Effects of Plasma Treatment of Textile

Textile materials subjected to plasma treatments undergo major chemical and physical transformations, including chemical changes in surface layers, changes in surface layer structure and changes in physical properties of surface layers. In the plasma treatment of fibers and polymers, energetic particles and photons generated in the plasma interact strongly with the substrate surface, usually via free-radical chemistry. Plasma creates a high density of free radicals by disassociating molecules through electron collisions and photochemical processes. This causes disruption of the chemical bonds in the fiber polymer surface which results in formation of new chemical species. Four major effects on surfaces, which are surface cleaning, ablation or etching, cross-linking of near surface molecules and modification of surface chemical structure are normally observed (Shishoo, 2007). Both the surface chemistry and surface topography are affected and the specific surface area of fibers is significantly increased. Plasma treatment on fiber and polymer surfaces results in the formation of new functional groups such as -OH, -COOH which affect fabric wettability as well as facilitate graft polymerization which, in turn, affects liquid repellence of treated textile and nonwovens (Shishoo, 2007). Also, the wax and oil impurities, which are present as a continuous covering on the cotton fiber surface, are also broken down and hence their solubility will be increased (Matthews et al., 2004). Hydrophilic properties of the polyester/cotton blended textile have been found to be improved after the treatment with atmospheric pressure plasma (Kale et al., 2011). Plasma etching can change the surface contact angles such as hydrophilic to hydrophobic or vice-versa, the argon plasma etching has reported to enhance contact angle from 52 degrees to 68 degrees (Zia et al., 2015).

2.12.1.2. Atmospheric Pressure Plasma System for Textile Applications

The atmospheric pressure plasma (APP) technologies seem to be quite attractive alternative for the textile industry. The APP technology offers several advantages over low pressure systems, like working at atmospheric pressure, continuous processing of material and possibility of integration with the existing textile processing set up. Atmospheric plasma is a cost-competitive and alternative method to low-pressure plasma and wet chemical treatments, avoiding the need for expensive vacuum equipment and allowing continuous and uniform processing of fiber surface (Jia et al., 2011). There are various power sources available for generation of plasma, among which DC air plasma is...
a very economical process. DC atmospheric air plasma the plasma is formed by applying a DC potential between two electrodes. DC atmospheric plasma techniques is potentially a very useful and effective way to obtain surface etching, chain scission, polymerization, cross linking, development of functional groups, surface roughness, etc., of temperature sensitive materials such as fabrics (Cera et al., 2010). Recent research on plasma generated at atmospheric pressure demonstrated excellent results for stability, uniformity and workability in surface modification of textile and many other types of material (Skundric et al., 2007; Morent, 2008). It was found that the plasma exposure not only increased the wettability, oxygen concentration and roughness of the polyester fiber surface, but the water wicking, antistatic property, detergency and dyeability were also successfully enhanced (Gotoh & Yasukawa, 2011).

2.12.2. Cationization Process

Cationization is a process of pretreatment of textile materials to enhance its functional properties. Cationic sites are introduced by cationization process using different cationic agents based on the need of the particular functional property. Mostly all cationized fabrics are much more positively charged, and therefore, show better adsorption of metal ions, nanoparticles, anionic dyes, etc., (Pal et al., 2009). Binding of cationic surfactant during the treatment leads to the change of fabric surface charge. Cationization is mainly carried out to improve affinity towards anionic substances, such as metal ions, dyes in conventional textile processing and unfixed dyes in effluent treatment. Wetting, transport of water molecule and retention of liquids in porous of textile materials are complex phenomena of fabric. It mainly depends on fiber surface morphology and geometry of fabric pores. Changes of fiber surface morphology, structure of fiber pores and chemical composition can modify fabric hydrophilic characteristics. On cationic modification of fabrics, water retention value is minimally reduced. Cationization occurs mainly on primary hydroxyl groups of C-6 atom of cotton cellulose, and hence certain number of functional groups is blocked for water molecules. The surface of fibers in water is negatively charged due to dissociation of functional groups and adsorption of ions from the water, inducing formation of electrolytes. Apart from dissociation of functional hydroxyl group (–OH and – COOH), carboxy groups from oxidation of aldehyde also contribute negative charge to the surface of cotton.

This process on fabric not only increases absorbency but imparts ionic crosslinking for fabric but also provide wrinkle resistance, stain repellency and other functional property (Hashem et al., 2003). The presence of cationized groups on cellculolitic or polyester materials also imparts antimicrobial properties. The metal oxide nanoparticle coatings to the cationized surface of the textile is a new approach for producing textile material, having multifunctional properties, which includes UV blocking,
antibacterial, antifungal, flame retardant, self-cleaning properties, etc. Modifying cotton fibers with cationic charges prior to coating of metal oxide nanoparticles is an attractive route to improving the adsorption of nanoparticle to the fabric (Kim & Choi, 2014).

2.12.2.1. Cationic Agents

Numerous chemicals have been reviewed that can be used to provide cationic sites in the textile material. Pretreatment of fabric can be done by using commercial cationic agents namely Sintegal V7conc, chromatech 9414, polyvinylamine chloride, Polyamino chlorohydrins quaternary ammonium compound etc. Modification of fiber with glycidal trimethyl ammonium chloride, N,N-dimethylaze-tidinium chloride, N-methyl acrylamide, chloro propionyl chloride, polymer PL, polypeichlorohydrin acrylamides, 3-chloro-2-hydroxypropyl trimethyl ammonium chloride and nicotinyl thioglycollate has been tried, and some of them yielded encouraging results which have previously been patented (Shahin, 2015).

CHPTAC (3-chloro-2-hydroxy propyl trimethyl ammonium chloride) is a quite low-priced chemical compound which is potentially a high-quality cationic agent for the alteration of fibers (Liu et al. 2007; Montazer et al., 2007). Cationized cotton was prepared by CHPTAC to create cationic sites on the surface of textile materials. The cationic modification of cellulose usually goes by the etherification with a 2-hydroxy-3-(trimethyl ammonium) propyl group, which can be attained by the reaction of the biopolymer and 2, 3-epoxy propyl trimethyl ammonium chloride (EPTAC). EPTAC, however, is an unstable and lethal reagent that cannot be used in industrial applications. An alternative is the use of CHPTAC. CHPTAC and its derivatives are the only family of compounds that can be obtained cost-effectively and in pure and stable forms for cellulose modification. Use of CHPTAC as a cationization mediator is reviewed with importance on safety, bulk scale applications, price and performance compared to conventional method of finishing of cotton. Utilization of CHPTAC includes practical methods of cationization and promising improvements upon existing procedures. CHPTAC reduces the cost of waste water treatment and subsequently decreases the environmental pollution (Hauser et al., 2001). Cationized cotton fabric in finishing of metal oxide nanoparticle is an environmentally friendly approach to increase the utilization of metal oxide by the fabric.

The addition of cationic agents to fabric is performed, using standardized techniques, for achieving good adhesion of nanoparticles to the textile materials to improve the quality of the finished product. The most demanded functional properties are application of nanoparticles for achieving antimicrobial activity, UV property, etc., into textile materials (Hebeish et al., 2009).
2.13. Textile Finishing

The main objective of the textile finishing is to deliver textile materials fit for their end uses. Textile finishing is one of the most significant areas in manufacturing process that is capable of producing textiles with novel aesthetic and intelligent properties (Walters, et al., 2005). To enable the textile material to encounter the functional performances during its usage, it is essential to impart finishing of any type (Mather & Wardman, 2011). Finishing is done on textile to modify the appearance, features or performance of the fabric (Nirupama, 2007). Finishing stands as the face of processing industry and value addiction arises from finishing procedure, which is one of the crucial features influencing the marketability of the fabric (Trivedi & Archana, 2014). Finishes assist to enhance the appearance of the fabric, make it appropriate for specific end uses and can be applied on fabric either chemically or mechanically or by combining both the methods (Tomasono, 1992). The flexibility of textile fibers suggests various ways for functional finishes that can facilitate their own form of functionality, revise existing properties of fibers or create new benefits that are unique. Functional textile materials with multiple properties are the future expectations of the international textile and apparel industry. The foremost application of these textile will be in the field of functional garments where the buyer is demanding more and more comfort, easy care, health and hygiene. The customers also expect protection against mechanical, thermal, chemical and biological attacks. Such complex expectations can only be met by developing new, advanced and innovative technologies for finishing of textile products (Gulrajani & Gupta, 2011).

2.14. Finishing Methodologies

Finishing is a technique done to textile materials to confer the ultimate performance characteristics requisite to it. Functional properties can be incorporated either by modifying the characteristics of the polymer or by adding additives before spinning in the fiber stage or during construction phase of fiber, yarn, fabric or finally in finishing stage. Finishing applications used to impart antimicrobial, UV resistant, fire retardant and self-cleaning finishes employ simple dip-dry method, pad-dry-cure method, exhaust method, spraying method, enzyme immobilization, layer-by-layer assembly, nano coatings by nanosols, chemical vapor deposition, polymer dispersions, physical vapor disposition, atomic layer deposition and plasma coating (Gulrajani & Gupta, 2011; Mahltig et al., 2005). Imparting functional qualities is inevitable to produce textile for technical applications as well as to fabricate ordinary textile with great product variation. Unique finishes adding high value to textile are greatly appreciated in consumer market (Paul, 2014). The most common methods used for finishing is pad-dry-cure method.
**Pad-dry-cure method:** Other methods mentioned above are not ideally suited for this research work, because of the possibility of the application of the nanoparticles into the interstices of the fabric. Pad-dry-cure method was widely used for the textile finishing because it is durable compared to other methods (Kathirvelu et al., 2008) and it also ensures the uniform distribution of the materials on the fabric surface. This instrument can be used in both continuous and semi-continuous methods of chemical/dye application to fabrics. 100% wet pick up can be maintained in the padding process, which gives uniform finish to the fabrics (Hossain & Rahman, 2015). A padding mangle is used to apply nanomaterials in the form of a suspension. A binder is also used in the suspension to bind the nanomaterials on to the fabric surface. When the fabric is fed to the nip of the padding rollers, the pressure of the nip helps the material suspension to be pressed on to the fabric surface. The treated fabric is then dried and then cured at a required temperature to ensure the fixation. The functional properties, that can be imparted to textile by this method, may include antimicrobial, UV protection and self-cleaning.

### 2.15. Summary

The textile industry in developed countries is confronting the world’s marketing conditions and competitive challenges which are driving towards the development of advanced, highly functional textile and textile with higher added value. Multifunctional textile with properties like antimicrobial activity, UV resistance, self-cleaning, etc., incorporated into one textile found an important place in the advancing research trend. On the other hand, advancements in nanotechnology are gaining momentum on a faster scale. Incorporating nanomaterials into the textile will greatly fuel the textile industry to meet the consumer demands. Nano sized particles have a larger surface area, and hence have higher efficiency than larger size particles. However, preventing nanoparticles from aggregation is the key to achieve the desired performance. In order to increase surface energy and poor adhesion of the coatings, it is necessary to improve some of the surface properties of the fabrics without changing the bulk properties. Plasma surface treatments and cationic modification of surfaces can be the solution to the adhesion problems. By combining the advantages of the advancements in textile industry and nanotechnology, high value textile can be produced.