Sustainable Wet Processing—An Alternative Source for Detoxifying Supply Chain in Textiles

P. Senthil Kumar and E. Gunasundari

Abstract This chapter discusses the sustainable wet processing techniques and their environmental impacts in the textile industries. Wet processing is a main sector in textile industries, which affects the end product and their quality of textiles. Large amount of water, chemicals and energy are required for various stages of wet processing operation. In this wet processing, Water is used as the solvent for the chemicals and dyes, because of its low price and availability. But, during the process, water gets polluted with chemicals and unspent dye stuffs and gives an end product as effluent. The toxic effluent is not easy to treat or biodegrade and is harmful to humans and animals. This kind of contamination and health problems arises normally in the conventional method of wet processing. So, the alternative methods are necessary to improve the sustainability of the textile wet processing. In the recent time, the new eco-friendly methods have been developed and are preferred mostly instead of conventional methods. Plasma, ultrasonic, laser, biotechnology digital inkjet printing are the new innovated eco-friendly technologies, which provide more advantages to wet processing. In these methods, there are no any harmful chemical, wastewater and mechanical hazards to textiles, etc. This study also clearly discusses the various stages of wet processing operations such as desizing, scouring, bleaching, mercerizing, dyeing, finishing and printing with a new innovated trend and their eco-friendly procedures and technologies on the wet processing.

Keywords Wet processing · Chemicals · Energy and eco-friendly methods

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S.S. Muthu (ed.), *Detox Fashion*, Textile Science and Clothing Technology,
DOI 10.1007/978-981-10-4876-0_2

1 Introduction

Textile industry is the main industrial sector all over the world and is one of the oldest industries. In past few decades, the profit in this sector has extremely high because of the fast fashion trend and increased textile consumption. According to United Nations Commodity Trade Statistics Database, in 2013, the worldwide market was around $772 billion in the textile and apparels exports. China, India, Italy, Pakistan, Bangladesh and Germany were the major exporters in 2013 (Economic Times 2014).

In the wet processing, natural or man-made (synthetic) fibers are used as the raw material in the form of yarn, fabric and garments. Substantial quantity of the energy, water, different types of chemicals and auxiliaries are used for the treatment of fabric. Later, the more amount of polluted effluent is discharged from the process, as it comprises of unfixed dyes and chemical auxiliaries that are dangerous to human health and ecosystem. So, the separate treatment requires for this effluent before the disposal. The discharge of wastewater is depends the production of textiles. For example, every year, over 2.5 billion tons of waste water discharges in the textile industry, when the 54% of the world textile production in China (Anon 2015).

To overcome these problems, the textile industries need to modify the process, technology in environment friendly manner. There, the eco-friendly textile has been produced by the using azo free dyeing, low impact dyeing and bio-processing technique. In 1998, Anastas and Warner was introduced the “green chemistry” concept. The sustainable production of fabric can be achieved by the “green chemistry” concept (Anastas and Warner 1998). The usage of eco-fibers or organic fibers in processing is the key factor to reduce the environmental impacts. Organic cotton corn, bamboo, hemp, soy bean, milk, pineapple fiber, tea, jute fiber, banana leaf fiber, organic wool, and organic silk are the most commonly available eco-friendly fiber. The sustainable chemicals need to replace the toxic chemical to avoid the health and environmental issues. The sustainability can be achieved by the optimizations of water, energy, chemical, chemical substitution, process modification and equipment modification, etc. therefore, a small volume waste only produced by this method. In this chapter, sustainable wet processing, innovations and technology development, eco-friendly dye and fibers has been explained. Various technologies such as plasma, ultrasonic waves, enzyme, digital printing, foam finishing, bio-based dyeing technologies involves in the eco-friendly production.

2 Environmental Impact of Wet Processing

There are several sustainable problems available in the textile wet processing operations. During textile processing, non-biodegradable and eco-unfriendly, extremely chemical-intensive goods are used and the discharged effluents from textile mill containing more amounts of unfixed dyes and the toxic chemicals. The advanced treatments are required for the separation of toxic chemicals from the wastewater however the complete removal of chemicals is not possible. In the recent years, the wet processing operations are performed in the developing or less developed countries. The wastewater released from the wet processing is directly discharged into the environment without any further treatment, which affects the humans and animals. The environment effects of wet processing are clearly explained in the following subdivisions.

2.1 Importance of Water in Textile Wet Processing

In the worldwide, water is the one of an essential natural resource for both humans and industries. They cannot survive without water and have no replacement for it. All around the world, twenty percentage of water has to be consumed by various industries. In the textile industries, a huge quantity of water is required for the textile wet processing operations. This water obtained from different sources like surface water from lakes and rivers and subterranean water from wells. In these operations, water, this is generally consumed as a medium and used as a solvent for the solutions of chemicals. A large quantity of water spent as a cleaning agent during washing and cleaning purpose. For the steam generation also, which is utilized to increase heat in the process bath. From mill to mill, the requirement of water will vary based on the weight of the textile material, equipment type, processing technique and type of dyes and finishing agents during the wet processing. At the end of each process, the more amount of water is consumed for the washing of goods (fabrics). For one kg of fabric material, 50–100 L of water is needed for processing. In 1980, the average water consumption in the textile mill was 150–200 m^3 per ton of finished goods stated by Beckmann and Pflug. 4.3% of the total wet processing costs spent for wastewater treatment and water supply in that same year. Sometimes, water is spent needlessly because of broken or missing valves; hoses left running, circulation of cooling water even though machines, water cooler, and toilets are not working probably (Beckmann and Pflug 1983).

In continuous preparatory processes, the effluents released from desize J-box and caustic washer can be recycled and reused easily through the continuous waste stream. The characteristics of wastewater in wet processing are moderately constant. The wash water discharged from the caustic washer having a caustic substance that influences the elimination of sizing chemicals. However, in the batch operation, the reuse and recycle of wastewater is not easy because of the storage facilities, non-continuous characteristics of wastewater and higher liquor ratios (Smith 1986). A large amount of water used in preparatory process and it has to be reduced by flow reduction and counter current flow. Before dyeing, the necessity to wash off impurities in the textile material using water is to get a good dyeing uniformity. In the dyeing operation, the quantity of water requirement varies with the types of dyeing machinery used. Various low liquor ratio-dyeing machines are manufactured for dyeing fabric to conserve water. In general, the definition for the liquor ratio is the ratio of the quantity of water (in pounds) in the exhaust dye bath to the quantity of fabric material. Compare to the dyeing bath, the large quantity of water is used for washing during dyeing operation. However, in washing, the water used is not affecting the liquor ratio. Therefore, we cannot say that the minimum quantity of water consumed for the dyeing bath. The effectiveness of water wash is enhanced with number of washes using a small quantity of water when compare to the one-time fabric wash with large volume of water. The extra water in the fabric required to eliminate before every wash to avoid contamination of wash water.

After wet processing operations, the wastewater is discharged into public sewage or on open land along with unfixed dyestuff and chemicals that generally is called it as effluent. The quantity and quality of the effluent differs based on the mixture of chemicals like organic and inorganic pollutants in textile industries. These pollutants present in the wastewater increase biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved salt (TDS), total suspended solid (TSS), pH and decrease the dissolved oxygen (DO) content. The strong color observed in wastewater because of its aesthetic character. These complex mixture of pollutants affecting the aquatic animal forms and as well as the formation bioaccumulation to create toxic environment. So, the quality of water is to be needed to recover using some basic techniques such as filtration, flocculation, clarification, aeration, membrane filtration, etc.

2.2 Energy Consumption

In the textile industry, energy is consumed as fuel (oil, coal, natural gas and LPG) for the boilers to generate steam, as electrical source for cooling and temperature controlled systems, machinery and lighting. During dyeing process, the maximum of the energy has been consumed for heating the dyeing bath. The cellulose fiber can be dyed using lower temperature. However, for polyester more temperature may need for dyeing operation. The temperature requirement for dyeing is based on the type of dyes, fibers and process condition. Different machines such as drying machines, thermosol processes and stentering machines in wet processing are also consuming more energy for running machines (O Ecotextiles 2009). Thermal energy consumption is more in wet processing compare to the electrical energy consumption, which is mainly for heating of water. The energy consumption increased with increasing the water consumption. The energy is conserved by the proper chemical methods, process and machine modification and novel technologies. In steam pipes, energy is wasted by the poor maintenance, improper insulation and leakage in steam pipes. Therefore, proper insulation is important to control the heat losses in the workplace.

2.3 Chemical Utilization

Large amount quantities of chemicals are utilized in various textile industries and are surfactants, lubricants, cleaning agents, defoamers and some specialty chemicals. These chemicals are hazardous to the environment as well as too human because of toxic, carcinogenic, mutagenic properties. So, the offending chemicals are required for wet processing instead these chemicals. For example, in the dyeing and printing process, formaldehyde containing dye fixing agents are used along with dispersive or reactive dyes, which give eye and skin irritation. So, these chemicals should be replaced with the non-formaldehyde based chemicals (Arputharaj et al. 2015). However, the majority of the textile industries are often using the carcinogenic and toxic chemicals even it has health and safety issue between consumer as well as worker who are working in the dyeing industries. Chemicals used for the textile wet processing also harmful when these are left it in wastewater. This wastewater effluent pollutes the land and water bodies. Therefore, it is essential to reduce through chemical substitution the use of chemicals that result in harmful wastes. The chemicals must be reused, recycled for processing when no useful chemical substitutes can be obtained for the toxic chemicals.

3 Textile Wet Processing

In worldwide, Cotton is the most widely utilized natural fiber by various textile industries and have nearly about 40% share of the total global fiber consumption of cotton. The textile material has been processed by using four major steps such as preparatory pretreatment, dyeing, printing and finishing. These are discussed clearly in the following subdivisions.

3.1 Preparatory Pretreatment

Before preparatory pretreatment, first, the yarn materials are going for the sizing process. In the sizing process, the sizing chemical is incorporated into yarn, which is acted as adhesive substance. Sizing agents such as starch, polyvinyl alcohol (PVA), polyvinyl acetate, carboxymethyl cellulose (CMC) and gums are used to improve the properties of the warp yarn, like smoothness, abrasion resistance, and the tensile strength (Jones 1973). Therefore, during the weaving process, it will provide an ability to withstand the mechanical forces.

Then, the singeing operation has to be carried out to remove hairy fiber, lose fiber and protruding fibers on the surface of the woven fabric. This has to be done because; small fiber balls began to form on the surface of the fabric after the several washing of the cloth. Three common techniques are available in the singeing process and classified as gas flame, roller and hot plate techniques. In the gas method, the woven fabric materials are allowed to pass through gas fired burners. In roller method, the heated rotary copper cylinders are used for singeing. Likely, for the hot plate method, the heated plates are used at the speed of 150–250 yards/min.

The untreated textile material, also called as "grey textiles", is treated using different treatment processes and chemicals in the pretreatment department. The pretreatment process includes desizing, scouring, bleaching, and mercerization. In the pretreatment process, Desizing is the first preparatory pretreatment process. It is the process to degrade or solubilize the size fabric material with the help of a desizing agent. The main reason for desizing is that the naturally sizing ingredient such as starch present in the textile, which hinders the impregnation of dyes into fabrics in dyeing and printing processes. Therefore, the removal or conversion of starch into simple water-soluble product is important that may take place either by oxidation or by hydrolysis. In wet processing, three different desizing methods are used for desizing, such as acid desizing, oxidative desizing, and enzyme desizing. For degradation of the sizing materials, hot caustic soda or detergent treatment is also used but this treatment is not that much efficient compare to those treatment methods. Even though the need of water is probably less for the process, starch hydrolysis products have raised the biological oxygen demand (BOD) of the desizing effluent. In general, about 50% of water pollution is caused by high BOD wastewater that was produced during desizing and become unusable (Correia et al. 1994).

Scouring is used to eliminate the natural and add impurities like gums, waxes, lubricants and dirt, etc., from textile fibers and is carried out at high temperature and an alkaline environment. This process can be used to convert these impurities into soluble compound. So, the scouring effluent has excessive COD, BOD, TDS and alkalinity. Non-cellulosic substances such as pectin, wax and proteins from cotton fiber are removed in this process. The conventional scouring of cotton fiber needs a strong alkaline medium with the temperature 120 °C. In scouring bath, reducing agents, wetting agents, sequestering agents and emulsifiers are also applied to increase the effectiveness of the process. For example, if calcium, magnesium and iron present in textile material, soap and detergents (reducing and sequestering agent) are added to precipitate out it and then removed. At high pH, the sequesternants will create strong calcium, magnesium and iron (2+) complexes. Then, the reducing agents are used to reduce iron (3+) to iron (2+). This scouring process may be carried out either continuous or discontinuous manner. Silk material is also scoured with soap/surfactants under mild condition to remove the gummy substance (sericin) (Jones 1973). Sericin substances are also removed by hydrolysis with help of protease enzymes. Greasy matters from wool can also eliminated by the addition of surfactants and emulsifiers. For synthetic fiber, mild scouring is sufficient to remove dust, lubricants, oil, etc., because it will not produce the inherent impurities.

The natural colored matters from the textile materials are removed by bleaching process. This process is also used to improve the whiteness level of fabric. Bleaching agents are essential for bleaching process to destroy chromophores, probably breaking one or more double bonds into conjugated system. These bleaching agents are classified into three types and are oxidative, reductive and enzymatic bleaching agents. Comparing all these type agents, oxidative bleaching agents are most commonly used for the process. In the alkali solution, this agent is decomposed to form active oxygen that partly or completely destroys the natural colored matter in fabric material. The oxidative bleaching agents like hydrogen peroxide, sodium hypochlorite and sodium chlorite are most widely used in the decoloration process (Rott and Minke 1999). After scouring, the fabric is allowed to pass through the sodium chlorite bath for impregnation and then the traces of bleach are removed by washing with antichlor ($NaHSO_3$). The sodium chlorite is very successful at pH 4. Compare to the chlorine bleaching; peroxide bleaching is preferred mostly based on the permanent whiteness and environmental point of view. But the peroxide bleaching is comparatively very costly. In general, chlorite is used in the beginning of bleaching. Then, at the time of washing, antichlor ($NaHSO_3$) is replaced by the hydrogen peroxide, which is used in lower concentration. So, after bleaching, the permanent whiteness and economy of bleaching can be ensured.

Finally, before dyeing and printing process, the mercerization process is carried out with a strong caustic alkaline solution for the cotton material to improve the dye absorption capacity, luster, strength/elongation, smoothness, hand, dimensional stability, etc. This process along with a strong alkaline solution under tension forms the permanent swelling and shrinks in the fiber. Then the goods are washed with water to eliminate alkali and then will get a permanent silk-like luster (Osman 2007). Based on the concern of cost and desire result, caustic soda is mostly used for mercerization.

3.2 Dyeing and Printing Process

After the pretreatment process, the fabrics are all set to go for the dyeing process. In general, dyeing is the process of applying colors to fabrics or yarn that can be carried out either for various textile fibers, yarn and fabrics or for a finished product like apparels and garments. Dye solution is prepared by the combination of dye molecules and aqueous medium (water) which can be used for dyeing in neutral, alkaline or acidic environment. The dye molecules are chemically bonded with the textile fibers molecules. There are several stages are there for colorization of the textile fiber using dye molecules and the steps are as follows:

- A migration of dye molecules within the dye bath near fiber.
- Diffusion of dye molecules in the dye bath.
- Absorption of dye molecules from dye bath on the external surface of fiber.
- Diffusion of dye molecule through the interior surface of fiber.
- Then finally dye molecule well bond with fiber and is so called as “fixation” (Cegrra et al. 1992).

There are two types of dyes are available such as dyestuffs and pigments. Dyestuffs are dissolved easily with water or made to dissolve using an additive named as auxiliary chemicals. The reasons for the addition of auxiliary chemicals into the dyeing bath are mainly to govern the movement of the dyes, prevent foaming, leveling of a dye, etc. pigments are not solubilizing with aqueous medium. Therefore, a binding agent is essential to bind the dye with fabric or yarn. In these two types of dyes, dyestuffs are most widely used for dyeing operation.

Dyestuffs are classified into two major classes such as natural and synthetic dyes. Natural dyes are extracted from animals and plants. The most of dyes are produced from the plants like berries, leaves, roots, woods, etc. synthetic fibers are prepared from synthetic resources including earth mineral and petroleum by-products. Synthetic dyes are most commonly used for the dyeing process when compare to the natural dyes. The first class of fiber reactive dyes generally reacts with functional groups of fiber which are acid, basic, direct, reactive and mordant dyes. The second class of dyes are required chemical reaction, which are vat and sulfur dyes and, finally the third class dyes are called as a special dyes such as disperse, solvent and natural dyes.

Direct dyes are directly colored the cellulose fiber with the addition of salts. The discharge of effluents contains unfixed dyes and salts that pollute the environment. These dyes are cheap, different range of bright colors and easy to apply. But, they are not environment friendly. One type of direct dye is azo dyes, which is derived from carcinogenic amines. Later, the last decades of twentieth century, Germany and other European countries were banned some of azo dyes. Sulphur dyeing is carried out for less expensive fibers and garments. It gives only one color, Sculpture Black. Compare to all other types, no heavy metals are added into the dyeing bath during sulphur dyeing. However, the toxic effluents released from the process due to the use of sodium sulphide. The effluent has high pH and unpleasant odor. High quality textiles are to be dyed by these dyes. Alkali and reducing agents are mixed to solubilize these dyes. They are the least environmentally impactful dyes i.e. only 5–20% of dyestuff, oxidizing agent, reducing agents remain in the discharge effluents. However, they are more costly. This reactive dyes also has advantages like multiple colors, bright color and easy to apply. The effluent released from the process also has salts, alkali and unfixed dyes. Therefore, the synthetic dyes are having more advantage but these types of dyeing are non-ecofriendly and produce lots of toxic waste effluent. Reactive and direct dyes are most commonly used for cotton fiber due to the formation of covalent bonding between fiber and dyestuff. However, for the hydrophobic nature of polyester, the same kind of dyes is not used instead of that the insoluble disperse dyes are dyed because of the property difference between the cotton and polyester. Cotton/polyester fibers are dyed using both reactive and disperse dyes. This dyeing process can be carried out in the batch or continuous manner. Beam, package, jet and jig dyeing can be done in batch mode. Pad-batch dyeing is one of the special methods, which is using reactive dye for dyeing of cellulose fibers. In the continuous dyeing, the long length fabrics are passed through the dyeing bath. Steam is applied for the fixation of dyes onto the fabrics. Simultaneously, the excess dyes are washed with the help of water (Shukla

2007). The polyester is processed using disperse dyes at elevated temperature in a batch mode and then, the machine is cooled after dyeing. For the cotton portion, reactive dyes are refilled in machine. Finally, the excess dyes are removed from the fabric by washing or dye-extraction.

In the printing process, the thick paste and viscous form of dye and pigments are applied to prevent the migration of the dye in the fiber. Water-based ink, plastisol ink and some other pigments are involved in printing using different methods like direct, resist and discharge printing. In the direct printing method, the color pattern is directly printed on the surface of textile fabric. In the resist printing method, initially, a resist paste is applied in the desired printing pattern. Then dye is applied onto the fabric. The resist paste applied parts of fabric are not colored. In the discharge printing, the dye is applied on the fabric after, that a discharge paste is printed on the fabric. The availability of reducing agent in the discharge paste influences the removal of dye from fabric. This type of printing is not eco-friendly nature due the presence of formaldehyde in the discharge paste. Washing is required for this printing to eliminate the by-products. Mostly a rotary screen, flat screen or engraved roll is used for the printing color onto the fabrics (Ramesh Babu et al. 2007). High temperature is required to fix the printing dyes on the fabrics and as well as for drying operation. After printing, the unfixed dyes and pigments are released as effluent using water and some organic solvent just like in dyeing. The presence of toxic chemicals in the wastewater is harmful to the environment, wildlife and humans. So the proper waste treatment is necessary before the discharge into the environment.

3.3 *Finishing Process*

There are two types of processes can be carried out in finishing and are mechanical and chemical methods. The most popular mechanical process is calendaring which is provide the pressure to the fabric between rollers and form a flat and smooth fabric surface. Sharp steel points used for abrading the fabric surface that is called it as ‘napping’. Compressive shrinking process is also used to prevent shrinkage of wet fabric. In the chemical finishing processes, the characteristics of the textile materials are improved by the addition of finishing chemicals. The formaldehyde-based chemicals are widely used such as softeners, dye fixing agents and cross-linking agents. These chemical agents are given easy care and better durability to the textile goods. The disadvantage of the use of formaldehyde-based chemicals may cause the skin rashes, eye irritation. The International agency for Research on Cancer (IARC) reported that these chemicals are ‘carcinogenic to humans’.

In recent year, polymeric finishes have been used for resisting the water, stain and oil. This finishes are having long perfluoroalkyl chains with more than eight fluorinated carbons. The long-chain PFAAs are formed by the degradation of the residual raw materials in the environment, which is harmful to humans and animals. The antimicrobial agents are added to treat the textile fabrics get better the health, disinfection and besides to stop odor formation, Tirclosan was widely used as an antimicrobial agent but nowadays which is ignored due to the poisonousness. Different types of flame retardants also used for the finishing operation. Even if brominated and antimony oxide-based flame retardant are very harmful to humans, they are used for finishing and e.g. Polybrominated diphenyl ethers (PBDE) (Saxena et al. 2017). Thus, the main reason for finishing process can modify the shade of colored fabric and their fastness properties.

4 Recent Sustainable Development and Innovations in the Wet Processing

Nowadays, the textile industries in the various developed countries are facing more challenges due to the globalization process. Recent years, the news technologies and innovations have been developed for solving these problems to produce the sustainable textile material with economical manner. The innovations and developments in textile processing can be possible to substitute in various areas of wet processing such as pretreatment, dyeing and finishing. The sustainable developments are substantial for economy, quality, energy conservation and environmental considerations in the textile wet processing. In textile industries, wet processing is a large and essential sector, which has different methods to affect the appearance and quality of goods. The following innovation production techniques help to improve the sustainability of textile industry.

4.1 Eco-friendly Fibers

Eco-friendly fibers are produced from organic and eco-friendly materials and are classified as follows: organic cotton corn, bamboo, hemp, soy bean, milk, pineapple fiber, tea, jute fiber, banana leaf fiber, organic wool, and organic silk, etc. bamboo can grow well as it uses no pesticides and has a unique anti-bacteria and bacteriostasis bio-agent called “bamboo Kun”. During the fiber production, these agents are closely packed with bamboo cellulose. Even after the several washing, fiber has bamboo Kun, which clears that the bamboo fibers having antibacterial, green and biodegradable properties. Organic cotton is also grown without using pesticides, herbicides or insecticides. A new type of colored cotton is grown for the production of the fibers, which is in the colors of green and brown. The advantage of this fiber is not easily fading, which is environmental and skin friendly.

4.2 Enzymes

The impact on the environment as well as product quality has been greatly benefited through the significant use of enzymes in textile wet processing. It is the one of most effective alternative to the use of hazardous chemicals and dyes in wet processing in the each stage. It will create the toxic free environment and produce the sustainable textile material. In the enzymatic processes, moderate conditions and the lesser energy are sufficient that leads to the reduction of the green house gas emissions from the power stations. The water and chemical consumption also reduced by using enzymes used in the every wet processing operations. The byproduct formation also minimized by the enzymes that offers nontoxic and eco-friendly environment. More than five thousand known enzymes are widely available in the world, in which, only about 75 enzymes are mainly applied in the textile wet processing industries. Hydrolases and oxidoreductase are most important used in textile industries and are classified as cellulases, amylases, proteases, lipases and pectinases. Alpha amylase enzymes effectively reduce starches cellulosic fibers into glucose than the acid desizing in desizing or bio polishing in the pretreatment processing (Saxena et al. 2017). These enzymes are applied to minimize the fiber breakage, effluent load and the consumption of water, energy and chemicals. One drawback of these enzymes is that the increase of BOD content in effluent. Instead of alkaline scouring, alkaline pectinase enzyme-based process is used for cotton fabric under moderate temperature to enhance the uniform dye uptake, less damage and energy saving.

The combination of desizing and scouring operation can be carried out to control fiber loss. For example, the non-cellulosic impurities are separated by the combination of enzyme-based scouring and activator-assisted bleaching in the single bath under moderate temperature. In bleaching, laccase can be used to bleach the coloring substance from wood pulp fiber. Flavonoids are giving the color to the cotton fiber, which is decolorized by the laccase system, and this system creates the stone wash effect to denims. Catalases have been studied for the removal hydrogen peroxide from fabric following bleaching (Saxena et al. 2017). For the removal of hydrogen peroxide from fiber material, the large quantity of water is used for washing to avoid difficulties in dyeing. The catalase enzyme with lesser amount of water eliminates these residual hydrogen peroxides.

4.3 Bio-Based Dyeing

The conventional dyeing processes are hugely affecting the environment even if they can give colorful textiles. The dyes present in the textiles risky to the wearers, workers who are in the industries and environment due to the presence of toxic chemicals such as dioxins and toxic heavy metals and formaldehyde that are carcinogenic in nature. To overcome this problem, novel methods are developed for the synthesis of coloring substance. For this bioprocess, no toxic chemicals require for the biological preparation of dyes. Small quantity of raw material, water and energies are sufficient in this biological process. This dye is named as "natural dyes or "bio-dyes", which are cost-effective, eco-friendly and durable. Generally, natural dyes can be produced from different sources such as plants, animals and microbes.

In the olden days, the natural dyes are used widely which is derived from animals, plants and minerals. In 1895, the first synthetic dye discovered and then followed by various dyes produced. Then, the usage of synthetic dyes is increased vastly due to the good color fastness, suitability and different color choice. Synthetic dyes used in the conventional dyeing process are grouped as direct dye, reactive dye, vat dye and sulphur dye. Then the natural dyes are started to use in the dyeing process owing to eco-friendly environment and may offer health benefits to the wearer. Natural dyes having a combination of chemical mixtures, which will differ, based on the variety, maturity, agro climatic variations. Therefore, the same kind of shade with natural dye is hard to reproduce for every dyeing operation and the similar result is produced under different pH and mineral content. For good color fastness properties, the metals are used along with dye, which is not eco-friendly. Thus, the heavy metals in the dyed fibers are avoided to improve the eco-friendly nature.

Compare to plant and animal-based dyes, microbial-based dyes have some advantages like fast growing nature and commercially standardized. Enzyme or fungi acts as a biocatalyst, which is bioprocessed with precursor in the bioreactor to produce the synthetic dyes. The fungus Basidiomycota is one of the effective biocatalyst, which oxidize the colorless precursor to produce colored bio-dyes in bioreactor. The production of the biocatalyst from the fungal culture is quite cheap and simple (Parisi et al. 2015).

The process of dyeing protein fiber (wool) can be carried out with anionic dyes. First, the dye molecules adsorbed on the surface of the fiber. After the adsorption, the diffusion takes place between dye molecules and fiber. The dye molecules bind with colorless acids in the fiber. Then the colored ions in dyes are displacing the colorless acid. Finally, the colored anions are bonded with reactive group in fiber. This fiber also contains amino group and carboxylic group. Comparing wool, it has a low dye fixation due to the less number of $-NH_2-$, $-COOH-$ group presence. Both anionic and cationic dyes are used for dyeing process. Swelling of fiber is more in water owing to that reason, the dyes diffuses easily inside the fiber (Parisi et al. 2015). Polyester and polyamide fiber are processed in the bio-based dyeing. In these, polyamide has the same dyeing properties and structure of natural fibers.

The bio-based process has been effective technology that increases the selectivity of a reaction and eliminates the downstream processing. Thus, this process is reducing the energy and material waste. The advantages of the eco-friendly biocatalysis are lesser process steps, mild process condition (pH and temperature). The bio-based dyeing process can reduce the production toxic effluents and reduces the greenhouse gases. Generally, the bio-dye is in the form of liquid. However, the conventional method is using the dry powders. This dyeing process can be involved either batch or continuous mode, which is depends on the several factors like size of dyeing bath, the type of material (yarn, fiber, fabric and garment), common type of fiber and final product quality requirement.

4.4 Plasma Technology

Plasma treatment is the interesting water free treatment technology for the wet processing due to its usage and environmental tolerability. In this treatment, less chemicals and energy are enough to produce finished fabrics in a pollution free environment. Plasma is the fourth form matter as well as other three forms of matters includes solid, liquid and gas which was proposed by Sir Williams Crooke in 1879. Plasma is the partially ionized gas comprises of ions and was first discovered by Irving Langmuir in 1929. The atoms, radicals and electrons in plasma can be generated by the addition of external energy, which changes plasma as electrical conductivity to electricity. These effects can modify the fabric surface, which is depending on the type current used, temperature, pressure and the gaseous matter used and type of textile fiber. Cold plasma is used for the fabric treatment under the room temperature even, which has higher electron energy. Another one technique, plasma polymerization that is the process to polymerize the polymeric material onto the fabrics however, it is under development. Electrical discharge techniques are commonly used for the plasma treatment textiles. In this process, the gas is to be ionized in a controlled manner under vacuum conditions. Initially, a vacuum vessel is pumped to reach a low to medium vacuum pressure in the ranges of 10-2 to 10-3 mbar using rotary and root blowers. Then the gas is passed into the vessels via valves and mass flow controllers. Air, oxygen, nitrous oxide, argon and tetrafluoromethane are few of the gases used in processing (Sarita 2016).

The major advantages of such plasma treatments in textile processing are as follows:

- The bulk material properties are not changed by the plasma treatment, only the surface of the treated material affected.
- Due to the entrapment of byproduct, the effluents are not discharged into the environment.
- No hot water and chemicals instead of that O_2/He plasma or Air/He plasma is used for desizing operation.
- The wastewater and their treatment cost reduced due to the waterless treatment.
- The damage of the heat sensitive materials is abridged since the plasma occurs at room temperature.
- All kinds of fabric materials can be processed in this plasma treatment.
- Dyestuff fixation and leveling of dye properties are enhanced by the plasma technology. i.e., The plasma can imparts the anti-felting properties to the wool and improve the dye ability of the natural and synthetic fabric materials.
- No drying process required owing to the non-aqueous plasma treatment.

4.5 Supercritical Fluid Technology

Supercritical fluid technology has been another waterless treatment technology for the wet processing. In this treatment, gases are used instead of water, which is possible of changed into supercritical fluid. High pressure and temperature are required for supercritical fluid to dissolve with dyes. The most commonly usable supercritical fluid is CO_2 owing to their low cost, low viscosities and high diffusion rates, which influence the dyes to diffusion into the fabric. Carbon dioxide gas is converted into the supercritical fluid at low pressure and temperature. It has properties of both liquid and gas. In the dyeing operation, first, the dyestuff is mixed with supercritical liquid with increased temperature and pressure and then the mixture is transferred and diffused into the fabric. CO_2 and excess dyes are easily recycled after the process. When compare to hydrocarbon, carbon dioxide is most widely used as a solvent for the fluorinated compounds due to its solubility.

In Supercritical dyeing processes, the fabric sample is covered around a perforated stainless tube that is placed inside the autoclave. At the bottom of the vessel, the dyes powder is placed and closed tightly. In which, the gaseous CO_2 is continuously purged and preheated. Then CO_2 is compressed with aid of optimum working temperature and pressure. For 1 h, the same pressure is maintained and after that, the pressure is reduced to recycle CO_2 and dyes. Finally, the dry textile sample is removed from the vessel (Sarita 2016). The main advantages of CO_2 used in this treatment are inert, easy to handle, recover and reuse, availability, low cost, no waste generation and as well as eco-friendly. For example, in the dyeing process, the supercritical carbon is used as the medium instead of water for the polyester and polyamide using pure disperse dyes. This process is the effluent-free dyeing process. The major advantages of this technique are short dye cycle, waterless dyeing, effective leveling and no drying step.

4.6 Digital Ink-Jet Printing

Digital ink-jet printing has been established to replace the conventional process in the textile industry. Apart from having few advantages like prototyping, small run printing, customization and experimentation, this printing also does not fail to be within the budget. This digital ink-jet printing has better properties such color fastness and pattern quality that can be used for all type of the fabric materials. The advantages this technique are lesser energy and water consumption, higher dye fixation rate, no cleaning and washing required for equipment's and no wasted inks and dyes. In digital ink-jet printing, ink is directly sprayed on the surface of textiles with the help of nozzles without contact, which generally named as the non-contact technology. This printing process can be used to make different color designs using design data from the computer file without the need of any screens or running of heavy-duty machinery. However, it is not possible to get same shade and color what you see on screen. In the inkjet printing, a printing head releases more number of tiny drops of different color ink on textile substrate. These drops are combined to produce the photo-quality image. The quantity of drops ejected from printing head is depends on the nozzle size, the actual print head principle. After printing, heat/steam is applied for curing the ink. In the digital printing process, different kind dye inks are used such as disperse dye, acid dyes, reactive dyes, pigment ink, latex ink based on each type of fabric includes cotton, polyester, nylon, silk, etc. (Ibrahim 2012).

Disperse ink is widely used as a water-soluble ink which produce bright color to the textile. It is only worked with polyester and polyester/natural fibers printing. Both direct method and transfer methods are carried out to print the fiber using this ink. In the direct method, disperse dye ink is directly applied to print on the textile. In the transfer method, initially, this ink is printed on a roll of paper. After drying that, the paper is pressed on the textile material with help of calendaring roller. Then heat applies to vaporize the ink and then permanently absorbed on the textile (polyester and polyester/natural fiber). Transfer method is better than the direct method.

Acid dye ink is apt natural fiber like wool, silk, albumen fiber and as well as for polyamide textile, nylon and nylon/elastane and is having good color fixation and saturation properties. Medium to low viscous inks is used for piezo electric print heads. In digital printing, Reactive dyes are chemically bonded with textile. Only, medium viscous inks are suit for piezo print heads. Both types of inks is directly printed on the textile. After the printing, the unfixed dyes and ink-receptive coating are washed off using water. High heat and water are essential for these dyes (Eccles 2016).

Pigment inks are used mainly for direct printing of textile rolls and garments. Heat pressing is required for binding of pigment on textile later printing. These inks are commonly used for polyester, viscose, and leather cotton (Eccles 2016).

Latex-capable natural and synthetic material can be printed by using latex ink in digital printer which gives bright color. It is odorless and solvent free ink (Eccles 2016).

4.7 Ultrasonic Waves

Ultrasonic technology has been interesting technique in the textile wet processing. It can able to utilize and modify the wet processing. This ultrasonic wave have been used all wet processing operations to reduce the process time, minimize the usage of auxiliaries and improve the quality of the textile material. This technique used in the process is more eco-friendly. The main advantages of the ultrasound are and lesser processing time. The frequencies of ultrasonic waves range from 20 to 500 kHz. These frequencies are inaudible to human ear. The ultrasonic waves can be used in different part of fabric processing such as desizing, scouring, bleaching, dyeing and as well as for washing. Ultrasonic desizing is the energy saving method as compare to the conventional sizing and desizing. It can degrade the starch but not degrade the fiber. It gives better whiteness and wet ability. The scouring of wool in the neutral and very light alkali bath reduces fiber damage. 20 kHz frequency is sufficient for the peroxide bleaching of cotton fiber. It has been found that bleaching rate increased to increase the degree of whiteness as compared to the conventional bleaching. During dyeing, cotton uses the direct dye; the polyamide and acetate fiber use the disperse dye; wool uses the acid dyes. Ultrasound is more useful to the water insoluble dye to hydrophobic fibers. The dyeing is depends on the frequency of ultrasound. 20 kHz ultrasound is enough to make cavitations (Sarita 2016; Ibrahim 2012). The advantages of this method are lower consumption of energy, chemicals and time as well as lesser processing cost.

4.8 Innovations in the Machinery

Many advanced machineries have developed for textile wet processing. Water, energy and chemical consumption for the wet processing has reduced by these machineries. In the batch processing of fabric, low liquor ratio processing has to be carried out with lesser amount of water using the advanced machineries. This process not only reduces the water consumption and also save energy and chemicals as well as reduce the amount of effluents. These machineries are equipped with microprocessor-based controllers that minimize the carbon dioxide emission and energy consumption. Likewise, chemical consumptions in wet processing have reduced by the installation of an automated chemical dispensing system with processing machineries. Compare the batch processing, continuous processing have been often used in the textile industry. Continuous bleaching and dyeing ranges (CBRs) are equipped with prewasher, comi steamer, dosing system with automatic control, effective washing unit and dryers. This type of processing reduces the water, energy, space and operational cost.

In the dyeing process, high efficiency padder, vaccum application of dues and various dye application systems have been used for minimize the environmental impact of the dyeing process. Waterless dyeing technology has also introduced in the dyeing process. In this type, instead of water, air is used that reduces the liquor ratio and as well as effluent production. The dyed textile is not to go for drying owing to non-aqueous treatment. Therefore, energy consumption for processing also reduced. Knits and Closed HTHP jiggers have been developed for the dyeing of PET fibres using ultralow liquor ratio of 1:2 (Saxena et al. 2017). The usage of insulated steam pipes and machineries as well as heat exchangers conserve energy and create the less hot environment to the worker and effluent.

4.9 Recycling and Reuse of Process Inputs

Recycle and reuse of process input in wet processing can minimize the cost of process and as well as the environmental impact. Treatment of textile effluents can recovered the process inputs and reduces the colors and COD content using advanced membrane processes such as microfiltration, ultrafiltration, Nano filtration, reverse osmosis, adsorption and ion exchange processes. A small number of chemicals from the waste effluents are only recovered and reused. Alkali containing mercerizing wash liquor can be used for scouring and bleaching operations. A large quantity of water can be used for wet processing. So the recovery and reuse of water can reduces the environmental pollution and quantity of effluents and rises supplement water resources (Saxena et al. 2017).

4.10 Electrochemical Dyeing

The vat and Sulphur dyeing processes are having both reducing and oxidized step. Dyes used in the process are water insoluble, which made into water-soluble form by the addition reducing agents and alkali. These reducing agents are producing the non-regenerable oxidized byproduct. These conventional dyeing processes are non-ecofriendly in nature because of the discharge of waste effluent from dyeing. Electrochemical method is an alternative technique to overcome those problems from the conventional dyeing process but still in the laboratory stage (Sarita 2016).

4.11 Foam Finishing

In foam finishing process, air is widely used instead of water in the form of dispersion foam, which leads to the energy conservation. The mechanical air blowing process using excess stirring and the mixture of chemical or dyes and foaming agents' forms foam mechanically. Foam is coated on the surface of the fabric and then this foam-coated fabric is placed between the squeeze rolls to collapse the foam and uniformly distributed the chemical or dye on the fabrics. Blow ratio chosen the relative proportion of air and liquid phase. The significant parameters for the foaming are density, diameter and foam stability need to remain constant. In general, the foam density for foam finishing operation is in the range of 0.14 g/cct–0.07 g/cc and 0.33–0.20 g/cc for foam printing. The foam density is used in process is mainly based on the fabric weight which increased by increasing the fabric weight. Bubble diameter used in the foam processing is in the range of 0.0001–2.0 mm (Sarita 2016). When comparing the large size bubbles, smaller size bubbles are more stable. This technique is applied for fabric preparation, printing, dyeing, softening water, oil repellent finish, DP finish, soil-release finish, and mercerization, etc.

5 Detoxifying Supply Chain

In the 2011, Greenpeace (non-governmental environmental organization) reported that the textile industries in china releasing hazardous chemicals into rivers. The organization wrote the open letter to the multinational fashion brands to “detox” their manufacturing process. The main of the goal of the organization is to remove 11 most toxic chemicals from the manufacturing process by 2020 and communicate clearly about the outsourced production suppliers of the companies (Ethical fashion form 2013). In 2011, the detox campaign was launched for presenting the dirty laundry report about the usage of toxic chemicals in textile industries like China and Mexico. Based on the report, Greenpeace conduct test for toxic chemicals across 20 global brands. The toxic chemicals from the industry like nonylphenolethoxylates (NPEs) in textile that is very toxic and durable chemical (Ethical fashion form 2013). They have ability to contaminate the water bodies and food chain. The needs of the Detox campaign are

- Major fashion brands to accept the zero chemical discharge
- Brands and supplier transparency across their manufacturing process
- Consumer’s conversation with the brands and government to restrict the import and sales of the toxic chemical containing goods.

Stakeholders from chemical and fashion industries have to be dedicated to following international regulations for the production the toxic free cloth. The non-government organization states the whole supply chain try to meet the environmental demand. For the sustainable production and configuration with Greenpeace DETOX commitment, comprehensive services, training and workshop must to conduct. Apparel brands and supplier have joined to remove all hormone-disrupting, toxic and persistent chemical from the products and processes. In the Greenpeace campaign, the top brands and retailer are working for achieving a “Zero discharge of hazardous chemicals” (ZDHC) in textile supply chain by the year 2020. The motive of this ZDHC is to create a Joint Roadmap for eliminating the 11 toxic chemicals and helping the member companies to replace the greener chemicals in manufacturing process. The current consumers are expecting safety standards and liable production processes to protect the environment and product from harmful chemicals.

A chemical management system is implemented to verify and monitor process that is interconnected to the manufacture, distribution and sale of product. The process is economical owing to the lesser consumption of water and energy for the treatment of waste.

Experts conduct full inspection of the supply chain and then give the clear solution to the textile and footwear industries. The main aim of this service is to diminish the negative environment impact compliance and increase compliance that is associated with the industrial operation and practices. The services are as followed:

- Provide proper flexible module-based training to hazardous substance, chemical and environment management, action plan workshop.
- Monitoring of wastewater for hazardous substance based on the guideline of ZDHC's wastewater and DETOX commitment.
- Give Manufacturing restricted substance list (MRSL) compliance to the input chemical inventory.
- Supplier audits according to Zero discharge of hazardous chemicals chemical management system (ZDHC CMS).
- Product testing based on the standards, regulations and DETOX commitment.
- Water efficiency program, risk assessment for Continuous Improvement through.
- A customized chemical management audits for evaluating the procurement and the raw materials and chemicals storage.
- Verification audits for the control and disposal of pollutants and validate corrective action (Sharma 2016).

These are the services helpful to improve the performance of the supply chains in textile industries.

5.1 Supply Chain Management

A supply chain is a network between a company and their supplier to produce an end product and deliver to customer. System of organization, people, activities, information, and resources are involved in the supply chain. The supply chain management improves the supply chain. Supply chain management (SCM) is management of raw materials, information and finance as they move in the way from supplier to manufacturer to wholesaler to retailer to consumer. It is important to the company success as well as the customer satisfaction. The goal of the supply chain management (SCM) is waste reduction, time compression, flexible response and unit cost reduction.

The flow of the supply chain management is classified into three types and is product flow, information flow and finances flow. The product flow comprises a smooth flow of textiles from suppliers to customer besides service needs. The quicker material flow is essential for the enterprise simultaneously it minimize the cash cycle. Information flow includes the request for quotation, transmitting order and updating of delivery status updates. The financial flow is also called as money flow, which consists of the payment schedule, credit terms, and consignment arrangements. The management of all three flows is important to attain an efficient and effective supply chain (https://en.wikipedia.org/wiki/Supply_chain_management).

Advantages of supply chain management are explained as follows:

- Improves better customer services and relationship.
- Reduces warehouse and transportation costs.
- Reduces direct and indirect costs.

- Makes well delivery mechanism for products and services in demand with minimum delay.
- Develops the productivity and business functions.
- Helps to achieve shipping of the right products to the right place at the right time.
- Improves inventory management and support the successful execution of just-in-time stock models.
- Supports companies to reduce waste, driving cost and attaining efficiency in the supply chain process.
- Assists companies in adjusting to the challenges globalization, expanding consumer expectations and economic upheavals.

5.2 *Supply Chain Decision*

The decisions for supply chain management can be generally divided into three levels such as strategic, tactical, and operational.

5.2.1 Strategic Decision

Company management creates high-level strategic supply chain decisions, which is related to entire organizations. The strategic decisions are closely connected to the corporative strategy and guide supply chain policies from a design perspective. These comprise product development, customers, suppliers, and logistics. In the company, senior management has to define a strategic method for the manufacturing and selling of product to their consumers. When product cycle mature or product sales decline, management needs to take strategic decision to develop and introduce new forms of existing products into the market. A company has to recognize consumers for their products and services at the strategic level. They have to identify the key customer segments where company marketing and advertising will be targeted, when management takes strategic decisions on the products to manufacture. Manufacturing decision explain requirement of manufacturing infrastructure and technology. The company management needs to create strategic decision on in what way product to be manufactured. The manufacturing decision requires new manufacturing facilities to be built or to improve production. With respect to suppliers, the company needs to decide on the strategic supply chain policies. Minimize the purchasing spend for a company that can be related to increase profit and the number of decisions can be made to get that result. The logistics function is important to the success of the supply chain. Order fulfillment is a significant part of the supply chain and company management has to make the strategic decisions on the logistics network. The performance of the supply chain is depends on the design and operation of the network (Murray 2016).

5.2.2 Operational Decision

Operational decisions are made at the business locations that affect in what way product are developed, sold, moved and manufactured. They give awareness to the strategic and tactical decisions that have been approved in a company. A framework inside the company's supply chain operations is created by these higher-level decisions. These decisions make sure that the product efficiently moves along the supply chain and achieving the maximum cost benefit. The local plant management has to define an operational decision for keeping certain products in stock to confirm that manufacturing is to be continued. The local management is important to define the operational decision to negotiate with supplier for them to make a product with better to confirm the quality of the finished product. Even though strategic and tactical decisions are made to get the highest efficiency with low cost, the day-to-day operations of supply chain need that local management makes hundreds of operational decisions. These decisions are made in the framework that created by the strategic and tactical processes however that not made in isolation (Murray 2016).

5.2.3 Tactical Decision

Tactical decision made to focus on adopting measures, which will produce cost benefit for a company. These decisions enclose the extent of the supply chain for a whole company and creating real benefits for the company. Company management may be made strategic decisions on the number and location of manufacturing places to be operated. However, tactical decisions are made on how to produce product within the budget and made on adopting of manufacturing methodologies like just-in-time. These decisions made to reduce material wastage in a company still cannot distribute to other manufacturing plants. Tactical decision may be needed to use a third party logistics company in country where transportation costs are high. At a tactical level, management needs to work in strategic guidelines to detect and negotiate terms, which will understand the maximum cost benefits across a company. A tactical decision has to make for developing the particular product (Murray 2016).

5.3 Challenges and Solutions in Sustainable Wet Processing

During the wet processing in the textile industries, several problems have been occurred in each stage of wet processing such as preparation, dyeing and finishing that affect the quality of fabric material and effluents discharge. The water and chemicals are very important for the textile processing and are a significant part of production costs. Water is flowing through different supply sources that have impurities in some amount. The impurity level is based on the supply source and the contaminants comprises of heavy metals, calcium, magnesium, aluminum, chlorine, dissolved salt, oil and grease etc., which influence the poor wet processing operations that also damage the machineries used. The problem occurred by these impurities in the water in the wet processing operation such as

- The poor removal starch sizes during desizing.
- Irregular absorbency after scouring and tendency of fabric material to attract soil.
- Reduction of surfactants solubility and rate of dissolution.
- Fiber degradation, decrease of whiteness, loss of fiber strength occurred during the catalytic decomposition of hydrogen peroxide.
- In dyeing, inconsistent shade and spots because of uneven washing off.
- Reduction in the wet fastness and foaming.
- Corrosion of machinery.

Therefore, the proper water treatment is necessary and the addition of suitable sequestrants during wet processing operation also to overcome these problems.

For each stages of wet processing, more amounts of chemicals are spent to improve the quality of textile material and also improve the processing operations. The production cost increased by increasing the chemical consumption. For saving the production cost, recycle and reuse of chemicals are essential. The usage the chemicals in the textile processing can affect the effluents that released from each stage of operations that increases risks the agricultural pollution, disrupt the aquatic ecosystem and hazardous to the humans. Thus, the lesser dangerous chemicals or bio-based dyes/chemicals can be used instead of the potentially hazardous and carcinogenic chemicals/dye to improve sustainability of the wet processing operation. The certain of chemical substitutions have been explained as follows:

- The biological oxygen demand in the effluent can be reduced by the substitution of formic acid for acetic acid.
- Chlorine can be used instead peroxide compounds in bleaching to remove the significant quantity of activated carbon absorbable organohalogen and trichloromethane compounds.
- The sodium hydroxide or sodium carbonate buffer can be substituted for trisodium phosphate to eliminate the phosphate pollution. This trisodium is mainly used in the fixation of high temperature reactive dyes. The effluent discharged after dyeing may have lesser salt content so the pollution of the rivers can be controlled (Schlaeppi 1998).
- Synthetics dyes can be replaced by bio based dyes and natural extracts to reduce the toxicity of the effluents.

6 Conclusion

In this chapter, the sustainable wet processing operation has been discussed with the recent innovations and techniques such as plasma technology, supercritical fluid technology, ultrasonic waves, and digital ink-jet printing and so on. But, the new techniques are still facing challenges even in the laboratory level which requires further development and improvement to make it as an effective substitute to the conventional processing. The production of natural and bio-based dyes and chemicals are essential for the sustainable wet processing to control the environmental problems. The developing countries are in need to concentrate on the installation of the proper waste treatment units, and disposal. Thus, the governments need to impose the regulations for the textile industries to produce sustainable textile materials. The main aim of the textile industries is to achieve the zero discharge of hazardous chemicals that prevent the humans and aquatic life of environment. Thus, the manufacturer, retailer and consumer are essential to be conscious about environmental problems and need to produce the toxic free products.

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http://www.springer.com/978-981-10-4875-3

Detox Fashion
Sustainable Chemistry and Wet Processing
Muthu, S.S. (Ed.)
2018, VII, 137 p. 29 illus., 12 illus. in color., Hardcover
ISBN: 978-981-10-4875-3