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Review Article

APPLICATIONS OF GREEN CHEMISTRY PRINCIPLES IN TEXTILE WET PROCESSING

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ABSTRACT

The conventional finishing and dyeing processes practiced in the textile industry have a huge impact on the environment and human health. This impact is due to the use of toxic chemicals, huge amounts of water usage, discharge of the effluents generated by the textile industry in the water bodies, inefficient treatment of the discharged, water, atmospheric emissions and high energy consumption. The aim of the present study is to discuss the applications of green chemistry principles in eco-friendly textile wet-treatment processes. This paper discusses the use of enzymes (biochemical approach) and physical treatment processes like ultraviolet radiation, plasma, and ozone technology. In case of dyeing it discusses the use of natural dyes and technologies like Air Dye, ultrasonic, microwave, plasma, supercritical CO_2, electrochemical and Nano-DyeTM.

Keywords: Textile wet processing, Green chemistry, sustainability, natural dyes.

1. INTRODUCTION

Chemistry has an important role to play in every aspect of modern life, from clothing, food, medicines, fuels, cleaners, personal care and agriculture etc. One of the major applications of chemistry is in the textile industry where it plays a crucial role in manufacturing of fibres followed by different finishing operations carried out on fibres, yarns or fabrics. The Textile industry involves long manufacturing and wet-processing stages. The manufacturing stages of the textile industry involve yarn, fabric and garment manufacturing and their wet processing [1]. The natural fibres/fabrics (cotton, wool, silk), modified cellulosic fibres (rayon, cellulose acetate) and synthetic fibres (nylon, polyester, acrylic) undergo many finishing treatments. These finishing treatments change the appearance, handle and the performance of the fibre, yarn and fabrics. The textile wet-processing industry is based on various pre-processing, processing (dyeing and printing) and post-processing stages that consume a significant amount of water, dyes, chemicals and energy. All these treatments are important to ensure optimal performance and to impart desired visual effects. The main objective of these treatments is to impart desired end use properties to the textile materials. These processes generate enormous amounts of effluents which contain different types of chemicals that can harm the environment and humans. It is reported that almost 20% of all water pollution is caused by textile treatments like scouring, bleaching and coloration processes etc. [2, 3]. In conventional textile dyeing process, about 1000 kg of fabric could pollute more than one lakh litres of water [4]. So there is a need to highlight the role of green chemistry in suggesting means and ways to effectively reduce the consumption of water, using renewable resources, carry out safe and energy efficient methods in the wet-treatment processes, reduce or eliminate the effluents discharged by the textile industry and if discharged effectively treat the waste before discharging in the water bodies.

Sustainability, at present is the prime concern around the world. The growing concern of the consumers about environment pollution and human safety has encouraged the textile industry to adopt various sustainable or green or eco-friendly manufacturing approaches. The UN launched its 17 Sustainable Development Goals in the year 2015. The Paris Agreement was signed by all 196 members in the same year i.e. 2015 to reduce greenhouse emissions. Of the 17 SDGs, Goal 9, “Industry, Innovation, and Infrastructure”, and Goal 12, “Responsible Consumption and Production”, directly challenge the textile industry to implement “environmentally sound management of chemicals and all wastes throughout their life cycle and significantly reduce their release to air, water and soil in order to minimize adverse impacts on human health and the environment".

Over the past decade the textile technologists have been conducting research on sustainable textile manufacturing. Different methodologies have been proposed on the lines of the 12 principles of Green Chemistry by numerous specialists time and again to address the issue by using eco-friendly measures like dyeing with natural dyes, designing energy efficient and safe processes and by the use of biotechnology.

Green Chemistry or Sustainable Chemistry is a branch of chemistry which is mainly concerned with the optimizing processes or creating new processes with an aim to completely remove or reduce the amount of toxic substances released in the environment. It is a field of chemistry that involves the use or development of chemical products that decrease or eliminate the production of harmful chemicals. This can cover everything from chemical reagents, reactions, products, their design, manufacture, usage, and their disposal.It also provides opportunities for people working in different areas to focus on green technology research and development.

Paul Anastas and John C. Warner, in the year 1998 presented a set of principles which govern green chemistry [5]. These twelve principles have provided a number of options for reducing the environmental and health consequences of chemical manufacturing. The 12 principles are as follows:

- Prevention of Waste: It aims at reducing waste generation rather than cleaning the waste after generation of waste.
- Atom economy: It focuses on designing processes in such a way as to utilize the maximum amount of raw material to make a product. The main aim is to reduce waste.
- Avoiding the generation of hazardous chemicals: Various processes should make the minimum use and generation of toxic and harmful substances which could harm human life and the surrounding environment.
- The design of safe chemicals: The chemicals chosen for any process should be safe.
- Design of safe auxiliaries and solvents: The use of auxiliaries in various chemical processes must be avoided.
- Energy efficiency: The energy consumption should be minimized and new processes must be designed that are highly efficient and make the maximum utilization of the energy being used.
- Incorporation of renewable feedstock: The processes must make the maximum use of renewable resources and renewable energy and raw materials in order to produce the products.
- Reduction in the generation of derivatives: The generation of derivatives must be minimum as they require additional resources to de-toxify them and as a result generate more waste.
- Incorporation of Catalysts: Non-toxic catalysts must be used as they tend to increase the rate of process and lowers the total energy consumption.
- Designing the chemicals for degradation: When creating new products, care must be taken that the product or chemical is non toxic to environment and easily degradable to prevent pollution.
- Incorporating real-time analysis: Processes must be monitored in real time and the data must be readily available.
- Incorporation of safe chemistry for the prevention of accidents: The chemicals that are being used must be safe to use and handle. This will ensure minimum risk of accidents and also provide a safer environment to work.

2. TEXTILE WET PROCESSING

Textile material goes through various wet processes before dyeing and finishing (Fig 1). For example - one such process is the use of sizing agents, which are applied during weaving to impart strength to the textile material. However, these sizing ingredients decrease the wettability and results in non-uniform dyeing and finishing operations. These ingredients should therefore be removed to improve the wettability and make it receptive towards other treatments. The conventional desizing methods involve removing the sizes by the use of surfactants, by using mild acid solution or by using a hot alkaline wash. The subsequent processes include dyeing and finishing, which are based on the types of fibers and end-use requirements [6]. All these finishing and dyeing processes use large amount of water. The textile industry is one of the high water-consuming industries. At present the biggest concern for the scientific community is the high consumption of water for textile processing as already there is scarcity of water around the world [7].

A significant portion of biotic components are already facing problems due to scarcity of fresh water. The problem is further aggravated by the discharge of the textile wastewater containing noxious chemicals which has adverse impact on both biotic and abiotic components of the environment [8]. It is therefore mandatory to ensure that the application of dyes, chemicals, and other reagents meet the environmental criteria. It should be the responsibility of the respective industry to effectively treat the wastewater before discharging, so that it does not pose any adverse impact on any living being [9]. Different chemicals such as acids, alkalis, oxidizing, reducing agents, dyes, pigments, thickeners etc. are used in all processes from pre-treatment to finishing. These chemicals are harmful for both health and the surrounding environment in terms of high amount of chemical oxygen demand (COD), biological oxygen demand (BOD), pH and toxicity. The salts which are used as electrolytes during dyeing and printing affects the productivity of the soil. Most of the dyes used in the textile industry are not biodegradable and the dyes containing chlorine may be carcinogenic. These carcinogens, heavy metals, and other chemicals in the long run, can cause physiological and biochemical malfunctioning of the organs of the body [10].

3. ECO-FRIENDLY PRE-TREATMENT OF TEXTILES

The traditional desizing process,involving the use of dilute acids like HCl and H_2SO_4 to hydrolyze the starch can be a problem as it shows a negative impact on cellulose fibers in the fabrics. The solutions to this problem are enzymes, which can remove starch without causing any fiber damage. These enzymes can be extracted from bacteria, animals and vegetables. For desizing, on a commercial scale, enzymes such as amylase and maltase are widely used. The use of these enzymes causes the breakdown of starch to small sugars like glucose and maltose and does not cause any harm to cellulose. Enzymatic desizing needs firm control of pH, temperature, water hardness, electrolyte addition, and selection of appropriate surfactant.

Fabric scouring is an important pretreatment process, especially for natural fibres. The process of scouring removes hydrophobic materials like waxes and other impurities like pectin from the fibers. In textile wet processing, the waxes and pectins hinder wetting and subsequent processes like dyeing and printing etc. Traditionally, the hot aqueous solution of NaOH is used to remove the hydrophobic impurities from the fiber surface. Although scouring with alkali is a general process, neutralization is also required due to the use of highly concentrated NaOH. Though the use of alkali during scouring is efficient and economical, the alkali scouring requires large amounts of water and consumes electrical energy. As a result significant improvement has to be done to meet the present energy and environmental requisitions. The use of enzymes for scouring is one such sustainable process. Enzymes such as pectinases, cutinases and lipases are used for scouring. The biosourcing process is carried out at neutral pH and reduces water consumption by 30% to 50% as compared with traditional cleaning processes. Pectinases, are a group of enzymes which can be utilized to break this outer pectin layer of cotton fiber. These enzymes cause the hydrolysis of 1, 4-alpha-D-galactosiduronic linkages in pectin constituents. These pectinases are of four types depending upon their role in pectin degradation. These enzymes are protopectinases, pectin esterases, polygalacturonases, and pectin lyases [11]. A bio-scouring enzyme named “Scourenz ABE Liquid” is widely used for cotton and cotton blends. The enzymatic scouring process requires a low temperature, smaller treatment time and less water. The enzymatic process is therefore economical and eco-friendly.

Textile substrates, when subjected to biobleaching using oxidoreductase, xylanase and laccase show good results in terms of absorbency, whiteness, dyeability, and the strength of fibres.

4. PHYSICAL PRE-TREATMENT METHODS

The physical treatments like ultraviolet radiation (UV), plasma, ozone and microwave are eco-friendly methods for the surface modification of textile fibers without using water (Fig. 1). UV technology can be used for bleaching and surface modification processes prior to dyeing and printing. UV also increases the wettability of hydrophobic fibers in the printing process and prevents pilling [12]. Plasma technology can be used for desizing and to remove natural or synthetic grease and wax from textile fibers and as a result increases the dyeing rates of textile polymers, and improves the diffusion of dye molecules into fibers to increase color intensity and wash fastness [13]. Ozone can be used to oxidize organic or inorganic impurities in textile substrates [14]. The bleaching with ozone can be done at low temperature conditions, using less water. It can therefore replace hydrogen peroxide. Microwaves can be used for desizing, scouring, bleaching processes, dyeing, and drying processes as a heating source [15].

5. NATURAL DYES

In the current scenario, researchers are now focussing on alternatives to replace synthetic dyes, mainly due to functional and environmental benefits of natural dyes over synthetic dyes. The natural dyes can be sourced from renewable materials, are less toxic, are biodegradable and some natural dyes have special properties like antimicrobial, insect repelling, antioxidant, and UV protection.

Different parts of plants like roots, leaves, branches, stems, bark, flowers, fruits, and seeds can be used to obtain natural dyes. However, in case of natural plant dyes the scientific knowledge should be enhanced to optimize some variables in the dyeing process.

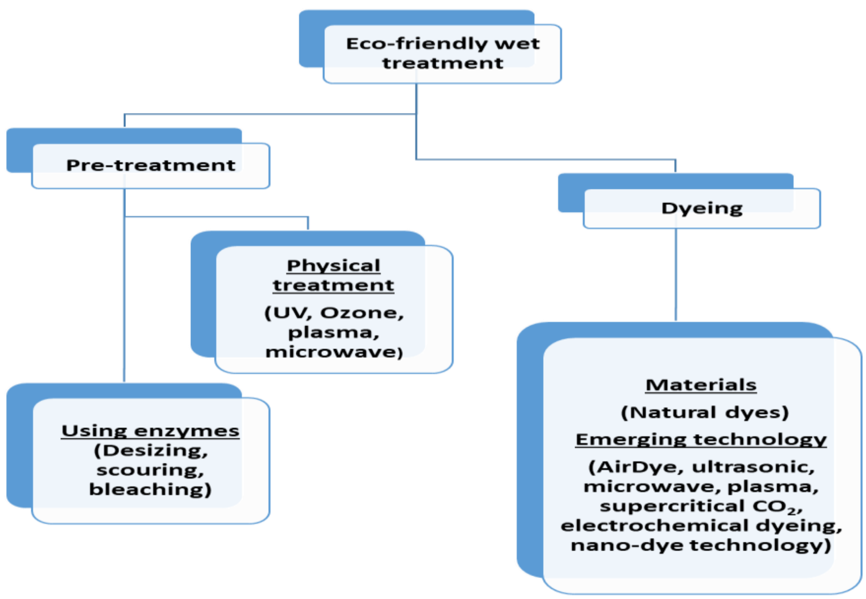

Fig. 1: Eco-friendly wet treatment processes

The use of microorganisms to obtain dyes and pigments for textile application is expanding. The latest advances in the production of bacterial pigments by cloning the genes responsible for the biosynthesis is making this approach economically feasible. The use of *Escherichia coli* bacteria for the production of indigo on an industrial scale is an example worth mentioning [16].The pigments obtained from microbial sources has many advantages like low cost for production, producing desired quantity, ability to obtain different colours and tones and ease of production [17].

Colorifix Limited was the first company to promote a biological process for coloring textiles on an industrial scale. The process of dye development begins with identifying the colour that can be obtained from a natural source like animal, plant, insect, or microbe. After identifying the organism, by the process of DNA sequencing, the genes responsible for the production of the dye is identified, and then translation of this DNA code is done to create a microorganism. This microorganism can produce the pigment in the same way as the natural one [18]. The use of natural dyes alone cannot make a process sustainable. The process has to be considered in a global way to make it sustainable i.e. keeping stock of all the products that will be added during each stage, consumption of water, natural raw materials available to meet the demands of the textile industry and development of new technologies for dyeing processes. Studies are being carried out to develop technologies, such as plasma, supercritical CO_2, AirDye, ultrasonic, microwave, electrochemical dyeing, and nano-dye technology on a larger scale (Figure 1). The use of emerging technologies for the dyeing process on a large scale still has some questions like limitations in relation to some textile fibers, implementation of new equipment, economic feasibilty, and the knowledge of textile chemists and designers in relation to materials and processes. Therefore, further investigation is necessary so that these emerging technologies can be used on a global scale.

6. CONCLUSION

Green or sustainability chemistry has given the scientific community a vision to address the problems faced by the industries worldwide in terms of discharge of toxic effluents in air, water and soil, energy intensive processes, depletion of non-renewable resources and water scarcity etc. The awareness of consumers about environmental regulations and legislations in several countries have stimulated the research and development of ecofriendly materials and processes. The development of new materials, methods and equipments are providing sustainable solutions in the field of textiles. It is the responsibility of the textile chemists, technologists and the designers to contribute towards a sustainable textile system by laying emphasis on materials and processes which are safe to both human life and environment. More research has to be done on the use of natural dyes, equipments used in the dyeing process and the energy consumed in the process to make the process of dyeing environmentally and economically sustainable. Last but not the least is the development of technologies for wastewater treatment. The conventional effluent treatment systems are known for high energy consumption, lack of infrastructure maintenance, and an unsatisfactory pollutant removal rate. This paper, therefore discusses the application of green chemistry principles in the textile wet-treatment and making it more energy efficient, safe, eco-friendly and sustainable.

Conflict of interest

None declared

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None declared

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