Volume 3 - Issue 10– October,2023
SABUJEEMA
An International Multidisciplinary e-Magazine

Recent Advances in Textile Dyeing

[Article ID: SIMM0303]

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Introduction

Dyeing in textiles is a process in which color is transferred to a finished textile or textile material (like fibers and yarns) to add permanent and long-lasting color. Textile dyeing consumes a large amount of energy and involves the use of chemicals assisting, accelerating or retarding the reaction rates and must be carried out at elevated temperature to transfer mass from processing liquid medium across the surface of textile substrate in reasonable time. The textile industry is considered as one of the major environment polluting sectors with an estimated 20 percent of all water pollution caused by textile treatments, such as coloration processes. In conventional textile dyeing, 1 tonne of fabric could result in the pollution of upto 200 tonnes of water. The wastewater produced in textile processes is highly colored and contains complex concentrations of chemicals, such as salt, dye, detergents, peroxides, and heavy metals. In addition to water pollution, other environmental issues emerge from the burning of fossil fuels, which result in atmospheric emissions and contribute to climate change and greenhouse gases. Therefore, the present-day scenario in the textile processing calls for the conservation of water and energy or usage of low amount of water and energy. This may be achieved by the various methods discussed in the article.

DIFFERENT METHODS OF TEXTILE DYEING

1. Ultrasonic technology

The first technological application of ultrasound was an attempt to detect submarines by Paul Langev in 1917. In 1950s and 1960s, there are many reports describing about the beneficial effects of ultrasound in textile wet processes. When ultrasonic waves are absorbed in liquid system, the phenomenon of cavitation takes place, which is the alternate wave formation and collapse of tiny bubbles or cavities. During the rarefaction of the portion of the wave cycle, dissolved gas molecules act as nuclei for the formation of cavities, which may expand relatively slowly up to a diameter as much as 0.1 cm and then quickly collapse during the compression portion of the cycle. Improvements observed in ultrasound-assisted dyeing processes are generally attributed to 3 main phenomenons i.e., dispersion, degassing and diffusion.

2. Microwaves dyeing

In 1945, the specific heating effect of a high-power microwave beam was discovered by Percy Spencer. Microwaves are electromagnetic waves whose frequency ranges from 1000MHz to10,00,000 MHz. Microwaves are so called since they are defined in terms of their wavelength in the sense that micro refers to tiny. Microwave dyeing takes into account only the dielectric and the thermal properties. The dielectric property refers to the intrinsic electrical properties that affect the dyeing by dipolar rotation of the dye and influences the microwave field upon the dipoles. The heating mechanism is through ionic conduction, which is a type of resistance heating. Depending on the acceleration of the ions through the dye solution, it results in collision of dye molecules with the molecules of the fiber. The mordant helps and affects the penetration of the dye and also the depth to which the penetration takes

place in the fabric. This makes microwave superior to conventional dyeing techniques.

3. Ion implantation technology

Ion implantation was first done by Rutherford in 1906, when he bombarded aluminum foil with helium ions. Ion implantation is an innovative production technique with which the surface properties of inert materials can be changed easily. It shows distinct advantages because it is environmentally friendly. Ion implantation can be used to induce both surface modifications and bulk property enhancements of textile materials, resulting in improvements to textile products ranging from conventional fabrics to advanced composites.

4. Electrochemical dyeing

Electrochemical dyeing is still in the laboratory stage but could become the dyeing process of the future of the vat, indigo and sulphur.

There are two methods: -

- **Direct electrochemical dyeing**

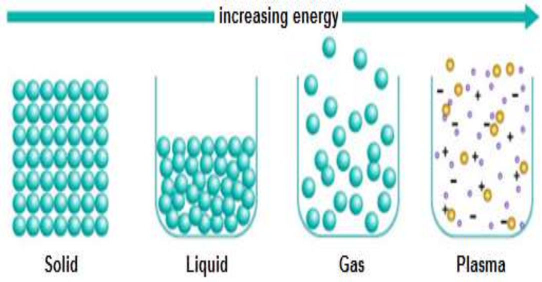
Organic dyestuff is directly reduced by contact between dye and electrode. However, in practice, the dyestuff is initially partially reduced by using conventional reducing agent and then complete dye reduction is achieved by electrochemical process which facilitates the improved stability of the reduced dye. Once the reaction has set in, it is not needed anymore and further process is self-sustaining. The system is found successful in case of sulphur dyes.

- **Indirect electrochemical dyeing**

Patented by Thomas Bechtold in 1993. Here, the dye is not directly reduced at the electrode. Rather, a reducing agent is added that reduces the dye in the conventional manner which in turn gets oxidized after dye reduction. The oxidized reducing agent is subsequently reduced at the cathode surface, which is then further available for dye reduction. This cycle is continuously repeated during the dyeing operation. In electrochemistry, the agent, which under goes reduction and oxidation cycles, is known as reversible redox system and is called a mediator. Therefore, this system is known as indirect electrochemical dyeing.

5. Plasma technology

Plasma is the fourth state of matter, after solids, liquids and gases, and this fourth state was first proposed by Sir William Crooke in 1879 as a result of his experiments in the passage of electricity through gases. The word plasma comes originally from a Greek term meaning something formed, fabricated



and molded and was first used by Irving Langmuir in 1929.

- **Principle of Plasma Application**

The plasma atmosphere consists of free electrons, radicals, ions, UV-radiations and lot of different excited particles in dependence of the used gas. Different reactive species in plasma chamber interact with the substrate surface cleaning, modification or coating occurs dependent of the used parameter.

- **Dyeability of cotton substrate:** It has been reported that plasma treatment on cotton in presence of air or argon gas increases its water absorbency. The effect of plasma treatment in two different gas atmospheres (air and oxygen) for different treatment times was studied by applying 2% of Chloramine Fast Red K. The effect of plasma treatment in air and oxygen appears to increase both the rate of dyeing and the direct dye uptake in the absence of electrolyte in the dye bath.
- **Dyeability of synthetic fibres:** In the synthetic fibres, plasma causes etching of the fibre and the introduction of polar groups. In this case, in situ polymerization of acrylic acid has been applied to polyester, polyamide and polypropylene fabrics in order to evaluate the improvement in dyeability of basic dyes. This procedure could later be extended by using different

monomers to improve the affinity of these fibres for other types of dyes.

- **Microdenier polyester:** Plasma-induced surface modification of microdenier polyester produces cationic dyeable polyester fibre., silicone tetrachloride ($SiCl_4$) (ST) and radiofrequency (RF) generated plasma are used to create a polysiloxane type surface in polyester and provide sites for basic dyes. The researchers believe that the possibility of using basic dyes on polyester could lead to a continuous flow system, low energy consumption, and more environmentally friendly consumption, low temperature dyeing technology on polyester substrates.
- **Dyeability of polyamide:** Polyamide (Nylon 6) fabrics have been treated with tetrafluoromethane low temperature plasma and then dyed with commercially available acid and dispersed dyes. The morphology of the treated surfaces was examined by scanning electron microscopy and chemical surface charges characterized by X-ray photoelectron spectroscopy. Dyeing results showed that the plasma treatment slows down the rate of exhaustion but does not reduce the amount of absorption of acid dyes. The dyeing properties of disperse dyes on plasma treated nylon fabric charged markedly when compared with untreated fabric. The dyeing process had only a minor effect on the water-resistant surface, indicating that a stable surface has been achieved by the plasma treatment.

6. Laser technology

Laser technology was first invented in 1964 at Bell Labs, New Jersey by Kumar Patel, an electrical engineer. A laser is a device that emits light (electromagnetic radiation) through a process of optical amplification based on the stimulated emission of photons. Laser processing as a new processing method with its processing of accurate, fast, easy, automatization, in leather, textile and garment industry increasingly widely used. The materials like polymers, woods, metals, semiconductors, dielectrics and quartz modified by laser irradiation often exhibit physical and chemical changes in the material's surface. Laser technology can offer digital design capabilities combined with the ability for short run production. This is a dry technology, which if used as an alternative to traditional textile wet processing, has the potential to offer increased environmental sustainability through significant reduction in energy and wastewater effluent.

7. Supercritical carbon dioxide (CO_2) technology

In 1822, Baron Charles Cagniard de la Tour discovered the critical point of a substance in his famous cannon barrel experiments. Prominent substances exhibiting super critical phases are CO_2, H_2O and Propane, of which CO_2 is the second most abundant and second least costly solvent. Low temperature and pressure are needed to convert carbon dioxide gas into super critical fluid. In the supercritical state CO_2 exhibits very low viscosity and surface tension properties. Supercritical CO_2 is one of the most popular fluids currently used in manufacturing processes because it is abundantly available, easily handle able, environment friendly, nontoxic, nonhazardous, low cost, no waste generation and chemically inert.

- **Dyeing process**

The sample to be dyed is wrapped around a perforated stainless-steel tube and mounted inside the autoclave around the stirrer. Dyestuff powder is placed at the bottom of the vessel and the apparatus is sealed, purged with gaseous CO_2 and preheated. The CO_2 and excess dyes are separated and recycled. After this dyeing procedure, the dry sample is removed and rinsed with acetone if necessary to remove the adhering residual dye.

8. Aerodynamic dyeing

In 1726, Isaac Newton became one of the first aerodynamicists in the modern sense when he developed a theory of air resistance, which was later verified for low flow speeds. Aerodynamic dyeing or "Jet dyeing" basically refers to the mechanism of dyeing which is based on the application of dyes on substrates by air flow or advanced spraying mechanism. The air-flow is generated by a fan as a special force that atomizes the dye molecules while the fabric runs in the machine. This mechanism of dyeing is one of the recent sustainable dyeing solutions which aims at reducing water, energy and chemicals (WEC) during textile processing which is greatest in textile finishing compared to yarn spinning and fabric production – weaving and knitting.

9. Ozone technology

Ozone was first generated and characterized by a German scientist named Schonbein in 1840. Ozone is a nonlinear triatomic molecule possessing two interoxygen bonds of equal length (1.278 A) and an average bond angle of 116°49'. Ozone is a natural occurring gas that can be both beneficial and detrimental to organisms on Earth. It is important that sufficient amount of this pale blue gas is present in the stratosphere, where O_3 molecules would shield most of the UV radiation from reaching Earth. Ozone gas has a pungent odor readily detectable at concentrations as low as 0.02 to 0.05 ppm (by volume), which is below concentrations of health concern. Ozone technology improves the dyeability of fibres, have lower water and chemical consumption than conventional wet processes.

Conclusion

The dyeing process, regardless of the textile substrate is complex and requires a high degree of knowledge and skill on the part of the manufacturers. Dyeing requires clean textile substrates in order to maximize product quality. The environmental issues of conventional dyeing methods are widely known and therefore, should be resolved. The amount of water needed for the steps of conventional dyeing processes must be reconsidered, with a focus on emerging technologies with dry processes or circular processes. It is estimated that 18 to 42 percent of the total water used during textile dyeing is used in the pretreatment steps. There are several physical processes that can be used to replace the use of chemicals and water in the pretreatment processes which are discussed in the article.

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