Journal of Advanced Zoology
ISSN: 0253-7214
Volume 43 Issue 1 Year 2022 Page 1397-1401

An Overview of The Significance of The Dyeing and Colour Fading Processes for The Selection and Design of Dyes in The Textile Industry as Well as Its Use in Clinical Diagnostics

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Abstract

The development of synthetic dyes has resulted in significant changes in the textile industry, which in turn have had a significant influence on the environment and on the concept of sustainability. It is possible to minimise the amount of human work, land for the cultivation of raw materials, and bring about progressive change in the socioeconomic status of cultivators through the use of synthetic colour. The design of dye is necessary for industrial application of dye. Dye ought to be non-hazardouss to the environment and should have a minimally toxicological impact on the ecosystem when it is released into the environment after its usage. Even though the majority of synthetic dyes are mutagens, their cytotoxic properties are utilised in clinical diagnostics as well as in therapeutic procedures.

Keywords: Dye-design, environment, mutagen, cytotoxicity, surfactant

1. Introduction

A dye is an organic chemical that, in most cases, has a preference for polymeric media in order to reach its setting fixing point. There is a long tradition of using natural dyes, which are produced from vegetable sources or stones, as a colourant simply or in conjunction with mordants for the purpose of dyeing fabrics and various ceramic materials. This practice dates back approximately three thousand years. In the process of pre-treatment of the fibre, mordants as pre fixer are used, either weak acids, bases, or salts. These mordants mix with the dye to fix it on react with the fibre and the dye, so creating a chemical bridge between the two substances. Natural dyes are difficult to use for the colouring of textiles on a wide scale because of their low or moderate resistance to the effects of sunshine and washing, the fact that certain dyes have a low affinity for the fibre materials, and the fact that some dyes require mordants that are harmful to the environment in order to keep their colour. Although the creation of natural dyes may be environmentally beneficial and sustainable, the production of raw materials for natural dyes requires a significant amount of water and land in order to maintain production on an industrial scale. Because of its superior fastness, synthetic dye has the potential to serve as an alternative to natural dye for usage in industrial applications. The dyeing feature of some dyes is advantageous since it allows them to be utilised as histochemical reagents [1] in selective DNA staining [2] due to the photochemical activities that they possess. In the field of clinical diagnostics, particularly in the context of cancer prognosis, this staining method is utilised rather often [3]. Additionally, it is utilised as a doping reagent in thin films, the purpose of which is to act as a sensitising agent [4].

In contemporary fibre dyeing processes, dye-surfactant interactions play a significant role. These interactions also play a role in environmental sustainability practices, such as the removal of dye, particularly from textile industry waste water, which is an essential dye separation technique [5]. In the process of dye separation, the choice of a surfactant can be made on the basis of the reciprocal interaction that exists between the dye in question and the surfactant [6–8].

Hydrolysis of the dye, which is a pH-dependent equilibrium process that turns the coloured dye molecule into its leuco-form (a carbinol), is the cause of the fading of low heat-resistant triphenyl methane dyes in alkaline media. This phenomenon is caused by the dye's reaction with the alkaline medium. In the presence of surfactant, a kinetics investigation of the fading process reveals that there is either a catalytic or inhibitory impact. This is the case both before and after the micellar concentration of surfactant. When the interaction between the dye and the surfactant favours the accumulation of hydroxyl ion at the water micellar pseudo interface, a catalytic effect of the surfactant is observed on the fading reaction. Additionally, a retardation effect is observed due to the formation of surfactant-dye adducts, which prevent the OH ion from hydrolysing the carobo carbo-cationic centre of the dye [8]. Whether the rate has a catalytic or inhibitory impact is determined by the strength of the binding between the surfactant and the dye adduct. It is possible to properly describe the catalytic effect by employing number of different kinetic models. The surfactant in the solvent medium provides an ionic environment to the dye for ion-ion interaction at low surfactant concentrations, and it provides a hydrophobic environment to interact with the hydrocarbon moiety of the dye with the micellar core at high surfactant concentrations at and above the critical micelle concentration (CMC) [8]. This suggests that the mode of interaction between dye and surfactant molecules can be examined. The majority of kinetic models also make it easier to evaluate the enthalpy and entropy of activation of such a process, as well as the temperature-dependent rate constant values at pre and post micellar surfactant concentrations, the nature of the interaction between dye and surfactant, and the binding constant of dye and surfactant molecules.

2.a Dye Design is used in the textile industry:

It is common for the effectiveness of a dyeing process or printing process to be dependent on the affinity that exists between the dye and the substrate. Dye formulations are specifically formulated for a particular substrate. However, in order for dyes to be able to fix on the target substrate, they need to have the ability to have two characteristics: a) a higher affinity for the substrate than the medium, and b) a high degree of fastness when exposed to water (wet fast) and/or sunlight (light fast). In 1997, Aspland developed a general set of criteria for the concerns that are related with the production of dyes for fiber-based polymeric substrates (9) [9]. The availability of colourants for a particular substrate type is the product of a planned molecular design process that takes into consideration the substrate that is being specifically targeted as well as the application that will ultimately be used.

On the basis of molecular structure , most organic compounds 1) absorb the visible spectrum (400–700 nm) of light, 2) have at least one chromophore (colour-bearing group), 3) have a conjugated system, i.e. a structure with alternating double and single bonds, and 4) exhibit resonance of electrons, act as dye that includes azo dyes (mostly use in textile industry due to their wide range of shade of colour, high fastness in light and washing.), triphenyl methane dyes (usually used chiefly in paper printing industry to paper copying, hectograph and as printing inks, and also in textile applications for which light fastness is not an important requirement on account to its poor persistence to light and to chemical bleaches. So dyes in this category are used to staining DNA) and Phthalein dyes.

2.b.i The process of choosing a dye for the textile industry

i. 1) Dye-fibre interaction

In the case of polyamide and protein substrates like nylon, wool, and silk, acid and basic dyes are the first option.

Most of the time, ionic bonds are formed between the polymer matrix and acidic and basic dyes. When the dyes have a negative charge, they are bonded with a positively charged substrate, which is often polyamides, wool, silk, and leather, which have a positive charge (also known as a cationic charge). Acid dyes are a type of anionic dye that may be used for treating polyamide and protein substrates. Acid black 1 is an example of an acid dye. Cationic dyes, on the other hand, are responsible for the formation of ionic bonds inside the polymer matrix, which includes an anionic substrate and cationic dyes acid black 1. In this particular instance, a substrate such as poly(acrylonitrile) is utilised on a fixing surface for the purpose of colouring using dyes that possess a basic charge that is positive (cationic) charge. A well-known example of basic dye is Basic Red 18.

2) For hydrophobic substrates like polyester and acetate, scatter dyes in the aforementioned substrates.

The dyes that were designed specifically for polyesters are referred to as dispersing dyes. This particular instance of colouration is accomplished by the process of "dissolving" the dye in the polymer matrix, which results in the formation of a solid–solid solution. It is necessary for them to have a carrier in order to expand the fibres and allow the finely ground particles to get through. Although they are coloured hot on hot condition, they do not include any salt like direct dyes do. In the process of heat transfer printing, disperse dyes like disperse blue 165 is are frequently utilised. Here is an example: diserse blue 165. Unlike hydrophilic polymers, disperse dyes do not have any attraction for them.

The third category includes both direct and reactive dyes that are used for cellulosic substrates including cotton, rayon, linen, and paper.
Due to the fact that cellulosic substrates are hydrophilic by their very nature, dyes that are water soluble are necessary in order to colour them. In addition, it is necessary to choose dyes that are able to keep their affinity even after the substrate has been exposed to water. In spite of the fact that it is prone to removal during the heating process and has a low wet fastness, indigo continues to be the most significant colourant for polyester cotton fibre fabric. It is possible for direct dyes to connect with the cotton fibre matrix even when there is no mordant or binding agent present. These dyes 1) have a tendency to be oriented linearly, and 2) are able to go close to the chain of cellulose, which allows them to maximise the effects of intermolecular interactions like as H-bonding. The application of water-insoluble colours to cotton has recently seen the development of a number of different processes. An example of such dyes like vat and sulphur dyes are is the incorporation of a water-insoluble dye into the polymer matrix, which would result in increased wet fastness. Azoic colourants are made up of two essential components, which have been designed for cellulosic substrates. Following the application of these components in isolation, they undergo a reaction inside the polymer matrix, which results in the formation of a colourant that is insoluble in water. Reactive dyes are the last category of colourants that are appropriate for use with cellulosic fibres . Their name comes from the fact that they are formed by a chemical reaction with cellulose, which results in the formation of a covalent bond. The introduction of reactive dyes paved the way for the achievement of remarkable all-around fastness, which encompasses superior resistance to washing, light, sweat, chlorine, and rubbing[10–12].

2.b.ii Considerations of a toxicological nature
Synthetic dyes are only suitable for use in industrial settings, unless the conditions under which they are used are such that they represent a minimal threat to the health of environmental components. Therefore, in the field of molecular design, environmental safety and sustainability are of the utmost importance. In this regard, the raw materials used in industrial production and the waste products that are produced by industrial processes should not have any negative effects on the environment. It has been demonstrated by the classic Salmonella mutagenicity experiment (Maron and Ames, 1983) that a significant proportion of aromatic amines (Anon, 1996) are discovered to be cancer-suspect agents or established mutagens [13]. According to Prival et al. (1984), it is evident that the utilisation of dyes and their subsequent release into the environment as a final product results in the production of biomagnification, which must present the possibility of causing genotoxicity in mammalian systems. In the case of many azo dyes, the creation of aromatic amines, such as benzidine, through the enzyme-mediated process of coupling diazo compounds is genotoxic and associated with the development of bladder cancer in humans when they consume these colours through the food chain. [13–14].

2.c variables Variables that impact the quality of the dyeing process
The following characteristics are included in a dyeing that is of high quality. The term "absorption" refers to the process by which dye molecules become entangled with the fibre matrix. Ionic forces, hydrogen bonding, Vander Wals' forces, and covalently binding covalent chemical connections are the four types of forces that are responsible for the attachment of the dye molecules to the surface of the fibre. Both of these forces are concentrated on the fibre surface.
second condition is known as exhaustion, and it involves activating the dye molecule in order to fix it on the surface of the fibre from the solvent. Additionally, it involves expanding the fibre in order to make it more responsive.
Controlling the dyeing conditions allows for the levelness or evenness of the dyeing to be achieved on the surface of the fibre through the process of levelling [10].

3. Colourants used in clinical diagnosis

The majority of dyes, both synthetic and natural, have the potential to be mutagens, and their bioaccumulation can be a genotoxic health hazard. However, the cytotoxic ability of dyes has been harnessed to use them as therapeutic agents against cancer. Furthermore, the fluorescent nature of certain dyes has made them a potential marker for staining living and dead cells in optical molecular imaging (OMI). [15] Some novel dyes may conjugate with tumour tumor targeting agents, which can facilitate diagnosis as well as cancer treatment agents. In the field of surgical oncology, a novel dye is also utilised for intra-operative imaging. [16] Intraoperative imaging operates according to a certain physical property, in which dyes are subjected to light of a particular wave length. This results in the production of a particular fluorescence, which has been utilised in the process of tumour tumor removal. The imaging quality is dependent on the fluorescence's ability to penetrate the tissue, the background autofluorescence effect being low, and the scattering impact of the fluorescence being emitted being as little as possible. In recent times, the hunt for protoprophyrin has been given a great deal of attention due to the fact that haematoporphyrin tends to build on cancer tissue. Protoprophyrin, when used as a dye, may readily conjugate with tumour tumor tissue and assist in the excision of tumours tumors with minimum harm. [17]

4. Conclusion:

For the most part, the textile industry uses wet processes to dye and print using fibre. Wet processes need the loss of a significant quantity of energy and water, in addition to the production of greenhouse gases. In order to replace the wet process with more advanced technology-guided physical processes such as supercritical carbon dioxide dyeing, air dyeing, plasma-assisted dyeing, and laser-assisted dyeing, as well as chemical processes such as enzymatic dyeing, reverse micelle dyeing, ozone-assisted dyeing, nano-bubble dyeing, and electro-chemical dyeing, Endeavour has been developed. In the textile sector as well as in the creation of therapeutically relevant dyes, there is a significant amount of room for development of novel and developing dyeing processes that are sustainable and non hazardous to the environment.

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