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DYES AND EFFECTIVENESS OF FIXING AGENTS FOR FIXATION OF REACTIVE DYES

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Abstract

This research explores the efficacy of fixing agents in the color fixation of reactive dyes, particularly emphasizing their use in the textile sector. An important part of textile processing is the efficiency of fixing agents in color-fixing. Distinct reactive dye samples, each representing a different color or formulation, will be systematically collected for the study. Then we will prepare separate dye baths with water, a selected sample of reactive dye, and the selected fixing agent. Reactive dyes and fixing agents undergo testing to see how well they work at different concentrations, temperatures, and pH levels to find the optimal conditions for the required color fastness characteristics. Prepare the fabric and dye bath, add reactive dye and fixer agents then immerse the fabric samples and maintain the temperature. After the desired dyeing time, remove the fabric, rinse to remove excess dye and fixer agents, post-treat with detergent, rinse again, and dry. This study will investigate improving the color fastness and adhesion of different colorants, including reactive dyes and pigments.

A dye is a colored substance that chemically bonds to the substrate it is being applied to (Kumar *et al.*, 2021). A dye is a substance that colors a substrate such as textile fibers (Gürses *et al.,* 2016c), foodstuffs and powders. Colors can be classified into two categories: soluble colors, known as dyes, and insoluble colors, known as pigments (Anliker *et al.*, 1980). Dyes are organic compounds that are soluble in water and/or an organic solvent (Gordon & Gregory, 2012) and form a solution, while pigments are insoluble and result in a suspension (Gürses *et al.*, 2016a). Dyes and pigments are the most important colorants used to add color or change the color of an object (Abel, 2012). They are broadly used in textile, pharmaceutical, foodstuff, cosmetics, synthetic, paint, ink, and paper industries (El Harfi & El Harfi, 2017). Dyes are colored substances that break up or go into solution during the submission process and pass on color all the way through discriminatory absorption of beam (Chequer *et al.*, 2013).

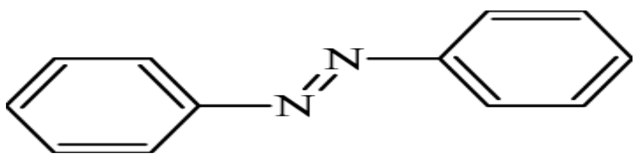


Figure 1: Basic structure of Azo Dye

Dyes are broadly used in various industries such as textiles, paints, cosmetics, food and medicine. They are used to pass on color to a variety of materials and can be derivative from plants, animals or minerals (Saxena & Raja, 2014). Dyeing is the process of applying color to a material to create a new and lasting color. The choice of dyes depends on factors such as safety, chemical composition, and compatibility with the target material (Gregory, 1990).

Over the years, humans have used colouring matter, known as dyes and pigments, for their aesthetic properties and to beautify various subjects and the world in which they lived. Indigo, the oldest well-known dye was revealed in India; Tyrian purple (or royal purple) was discovered in the earliest city of Tyre(Cao *et al.*, 2008); Alizarin was discovered amongst the Turks; and cochineal was revealed amongst European and Mexican dyers (Do *et al.*, 2024).

1.1 Importance

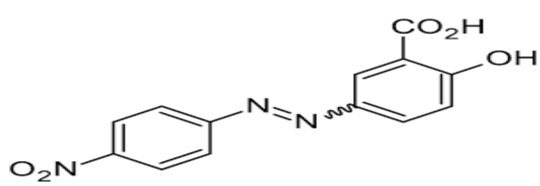


Figure 2: Alizarin yellow R, Azo dye

Materials such as textiles, paper, plastics, and food can be colored with dyes, which can be made from natural or artificial sources. Synthetic dyes are synthesized through chemical synthesis, whereas natural dyes originate from plants, animals, and minerals (Hagan & Poulin, 2021). Since the 19th century, synthetic dyes have been extensively utilized and provide a broader variety of colors and properties. There are various categories of dyes, including vat dyes, disperse dyes, acid dyes, basic dyes, and direct dyes (Islam *et al.*, 2022). Dyeing is defined as the creation of a new and permanent colour, especially by dyeing on any material ie textile, paper or leather. Modern dyeing machinery consists of numerous steps determined according to the fibre's nature and the dyes' properties and pigments for use in the fabric (Chakraborty, 2010). The purpose of dyeing is to provide a uniform color for all fibers making up the material to match with a predetermined color. Dyeing is mainly done as a continuous or batch process (Gürses *et al.*, 2016b).

1.2 Classification of Dyes

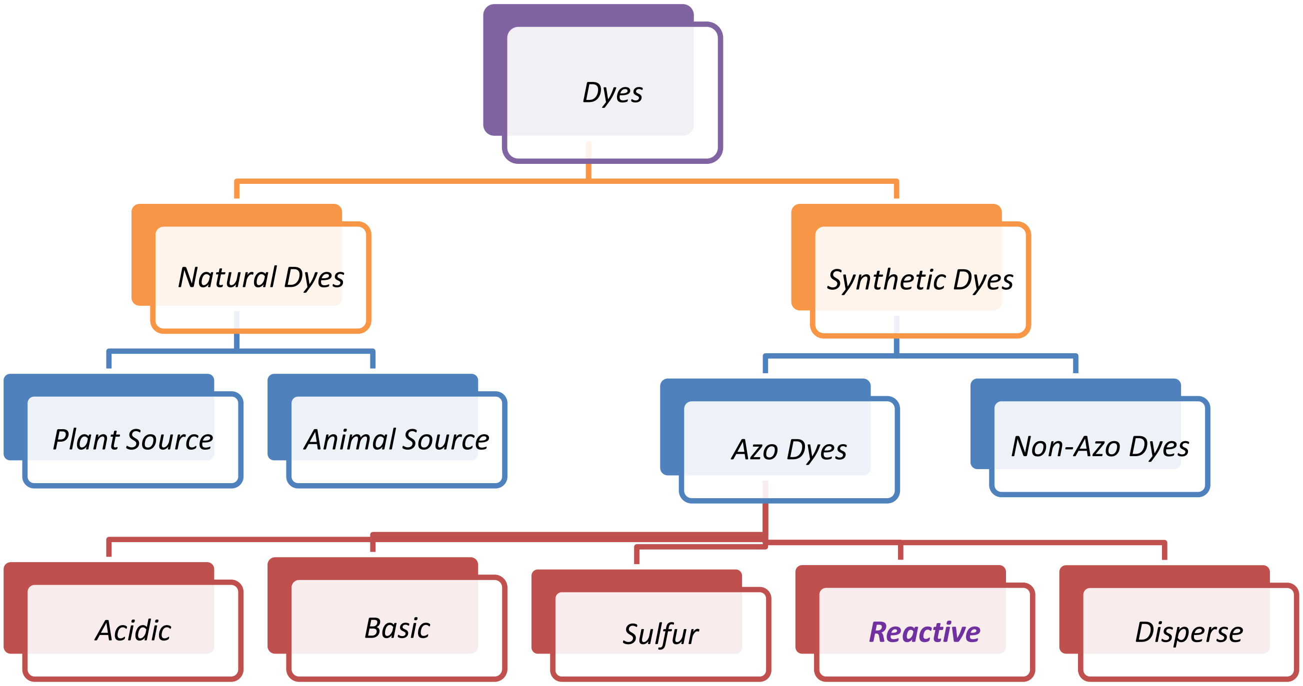


Figure 3: Classification of Dyes

1.3 Inorganic colorants

Among the inorganic materials used to add color to microscopy preparations are iodine and silver nitrate. Colorless inorganic reagents can also react to form colored products; for example, Ferro cyanide and ferric ions can react to form Prussian blue, an insoluble pigment (Lewis, 1998).

1.4 Nitro-so dyes

These are the end product of the reaction between nitrous acid and phenols, which forms a nitro-so group on an ortho- or para-carbon atom of the phenolic (Benkhaya *et al.*, 2022).

1.5 Nitro dyes

These yellow dyes contain one or more nitro groups. NˆO bonds of the nitro group are equivalent because of resonance, and they are conjugated with the resonating CˆC bonds of the aromatic ring (Dyes, 1991).

1.6 Azo dyes

The azo institution is present in greater commercially to be had dyes than some other chromophore. There are many programs in each industry and the laboratory for the dyes themselves and for the intermediate compounds that react with one another to shape azo dyes or pigments (Bafana *et al.*, 2011). The presence of hydrochloric acid during diazotization can be confirmed using Congo red paper, which turns blue when dipped in the solution (Chattopadhyay, 2011a). Excess nitrous acid can be detected using a starch-iodide paper, which turns blue. The use of certain azo dyes, such as Congo red, has been restricted due to their carcinogenic effects, leading to their withdrawal from manufacturing ranges (de Almeida *et al.*, 2014). Direct dyes can be easily stripped from dyed fabric by boiling with a soap solution or by reduction and solubilisation using sodium hydrosulphite in the presence of caustic soda, or by bleaching with a suitable bleaching agent (Aspland, 1991). Sulphur dyes are water-insoluble dyes that contain sulphur as an integral part of the chromophore and in attached polypeptide chains. They are applied in the alkaline-soluble reduced form and converted back to their original form by oxidation (Chattopadhyay, 2011b).

1.7 Aryl methane dyes

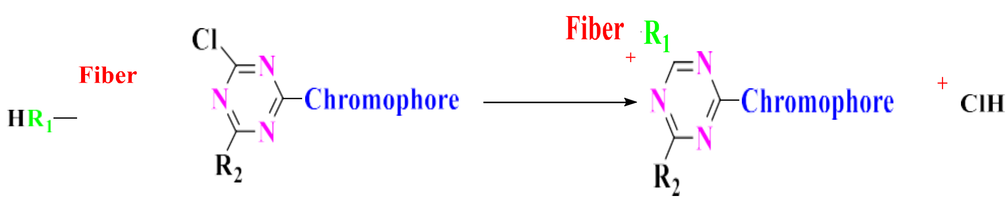
The widespread components for this huge organization of dyes are: where R and R zero are benzene or naphthalene earrings (Zimina & Pavlenko, 1990).

1.8 Xanthenes dyes

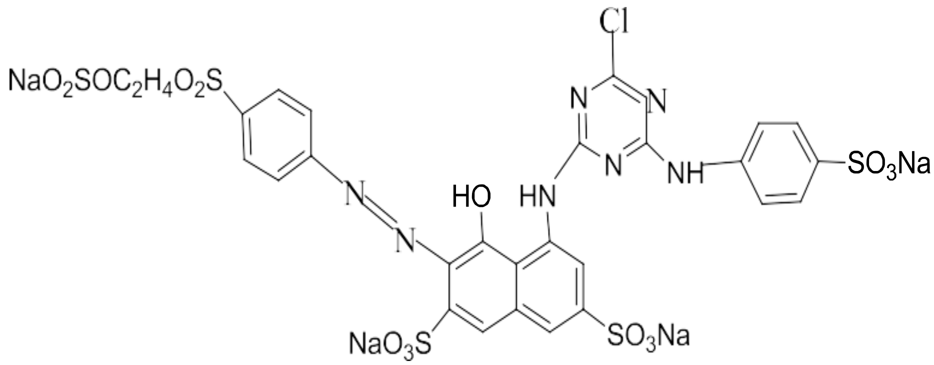
The chromospheres in these dyes include the planar skeleton of the oxygen-containing heterocyclic compound xanthene. In the general components, R can be a hydrogen atom or an aliphatic or aromatic institution, and X is nitrogen in the amino xanthenes or oxygen inside the hydroxyxanthenes (Kamino & Uchiyama, 2023).

1.9 Reactive Dyes

Reactive dyeing directly links the colorant to the fibre by formation of a covalent bond (Vickerstaff, 1957). For many years, it was known that this technique might produce great wet fastness for cotton dyes; nevertheless, preliminary trials used extreme conditions that led to partial fiber breakdown (Taylor, 2000). Reactive dyes are a type of dye used primarily for dyeing textiles (Lewis, 2014). They are called "reactive" because they chemically react with the fibers of the textile, forming a covalent bond (Aspland, 1992). This reaction makes the dye molecules highly durable and resistant to washing and light, resulting in long-lasting and vibrant colors (Lewis, 2014).The chemistry of reactive dyes involves a chromophore (coloring group) attached to a reactive group. The reactive group typically contains a nucleophilic center, such as a hydroxyl (OH), amino (NH_2), or vinyl sulfone ($SO_2CH{=}CH_2$) group. These reactive groups enable the dye molecules to react with functional groups present on the textile fibers, such as hydroxyl or are suitable (Renfrew & Taylor, 1990).



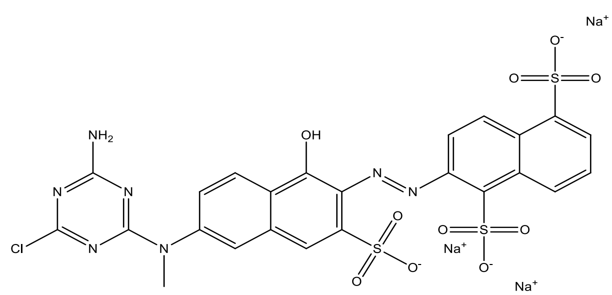
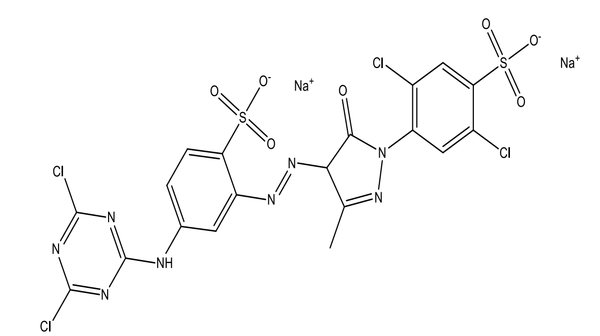
There is a common basis for the production and subsequent bonding of these three new dyes (yellow, red, and blue) with fibers: the reactivity of chlorine on a triazine ring. The oxygen and nitrogen of the OH and NH2 groups easily displace it. Reactive dye is created when cyanuryl chloride and an amino group-containing dye react, linking the two through nitrogen (Değermenci *et al.*, 2019).

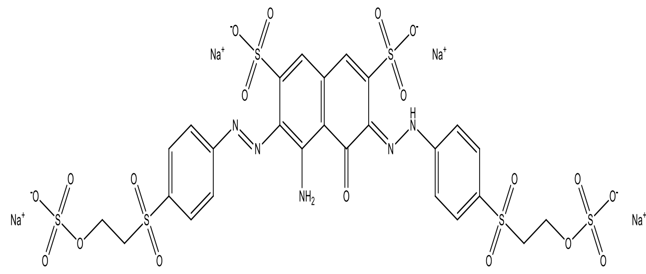
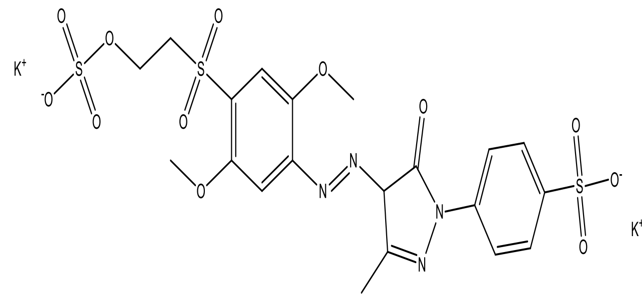
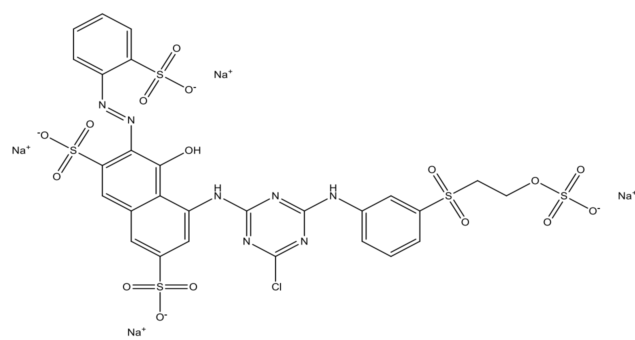
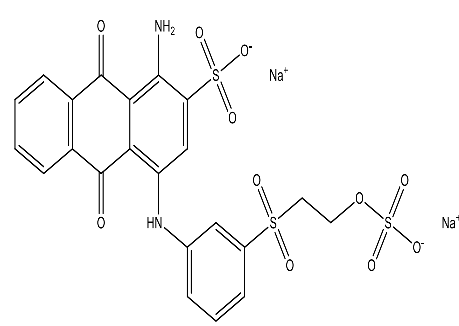


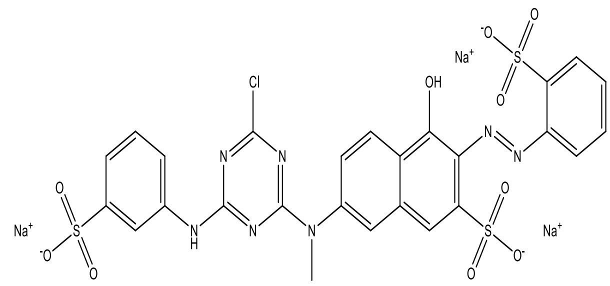
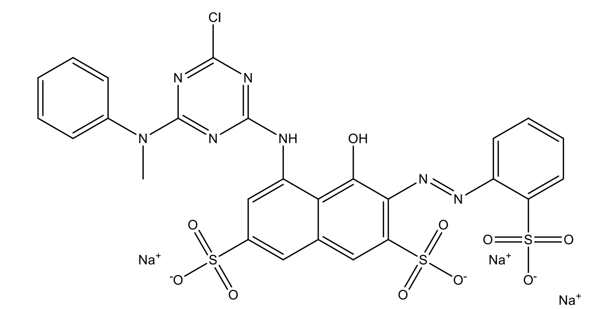
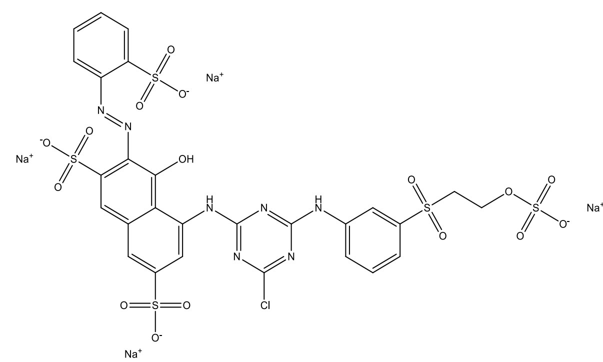
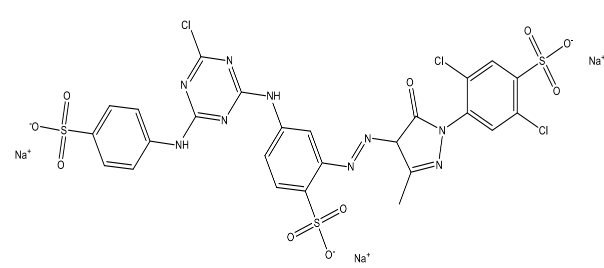
Dye (C.I. Reactive Red 198)

Reactive dyes are popularly used for the dyeing of cellulosic fibers either through nucleophilic substitution or addition reaction (Stamm, 1964). The popularity of reactive dyes on a commercial scale is mainly due to their acceptable price, the brilliancy of shade, wide range of color gamut, reasonably good colorfastness properties, wide range of application methods, etc. However, reactive dyes suffer environmental issues while applied to cellulosic fibers (Maulik *et al.*, 2022).

Table 1: Reactive Dyes

Dye	Molecular formula	Chemical structure
Reactive Orange 13	trisodium 2-[[6-[(4-amino-6-chloro-1,3,5-triazin-2-yl)methylamino]-1-hydroxy-3-sulphonato-2-naphthyl]azo]naphthalene-1,5-disulphonate	 trisodium 2-[[6-[(4-amino-6-chloro-1,3,5-triazin-2-yl)methylamino]-1-hydroxy-3-sulphonato-2-naphthyl]azo]naphthalene-1,5-disulphonate
Reactive yellow 1 (C.I. 18971) Triacion Yellow C-6G. Aclive Brilliant Yellow 5Zkh	disodium 2,5-dichloro-4-[4-[[5-[(4,6-dichloro-1,3,5-triazin-2-yl)amino]-2-sulphonatophenyl]azo]-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl]benzenesulphonate	 disodium 2,5-dichloro-4-[4-[[5-[(4,6-dichloro-1,3,5-triazin-2-yl)amino]-2-sulphonatophenyl]azo]-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl]benzenesulphonate

Reactive Black 5 (Black B)	Tetrasodium (3Z)-5-amino-4-oxo-6-[4-(2-sulfonatooxyethylsulfonyl)phenyl]diazenyl-3-[[4-(2-sulfonatooxyethylsulfonyl)phenyl]hydrazinylidene]naphthalene-2,7-disulfonate	 Tetrasodium (3Z)-5-amino-4-oxo-6-[4-(2-sulfonatooxyethylsulfonyl)phenyl]diazenyl-3-[[4-(2-sulfonatooxyethylsulfonyl)phenyl]hydrazinylidene]naphthalene-2,7-disulfonate This name appears to be ambiguous
Sumifix Yellow G Pemazol Yellow G (Reactive Yellow 17)	4-(4-((2,5-Dimethoxy-4-((2-(sulfooxy)ethyl)sulfonyl)phenyl)azo)-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl)benzenesulfonic acid dipotassium salt	 4-(4-((2,5-Dimethoxy-4-((2-(sulfooxy)ethyl)sulfonyl)phenyl)azo)-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-1-yl)benzenesulfonic acid dipotassium salt
Adifix Red F3BL Reactive Red 194 REACTIVE RED 194	Tetrasodium 5-((4-chloro-6-((3-((2-(sulphonatooxy)ethyl)sulphonyl)phenyl)amino)-1,3,5-triazin-2-yl)amino)-4-hydroxy-3-((2-sulphonatophenyl)azo)naphthalene-2,7-disulphonate	 Tetrasodium 5-((4-chloro-6-((3-((2-(sulphonatooxy)ethyl)sulphonyl)phenyl)amino)-1,3,5-triazin-2-yl)amino)-4-hydroxy-3-((2-sulphonatophenyl)azo)naphthalene-2,7-disulphonate
C.I. 61200 Reactive Blue 19 C.I.Reactive Blue 19	disodium 1-amino-9,10-dioxo-4-[(3-{[2-(sulfonatooxy) ethyl] sulfonyl} phenyl) amino]-9,10-dihydroanthracene-2-sulfonate	 disodium 1-amino-9,10-dioxo-4-[(3-{[2-(sulfonatooxy)ethyl]sulfonyl}phenyl)amino]-9,10-dihydroanthracene-2-sulfonate

Reactive Orange 5 Reactive Orange K-GN C.I.Reactive Orange 5	trisodium 7-[[4-chloro-6-[(3-sulfonatophenyl)amino]-1,3,5-triazin-2-yl]-methyl-amino]-4-hydroxy-3-(2-sulfonatophenyl)azo-naphthalene-2-sulfonate	 trisodium 7-[[4-chloro-6-[(3-sulfonatophenyl)amino]-1,3,5-triazin-2-yl]-methyl-amino]-4-hydroxy-3-(2-sulfonatophenyl)azo-naphthalene-2-sulfonate
Reactive Red 24 Synocron Red P-BN Reactive Red K-2BP	Trisodium 5-[[4-chloro-6-(methyl-phenyl-amino)-1,3,5-triazin-2-yl]amino]-4-hydroxy-3-(2-sulfonatophenyl)azo-naphthalene-2,7-disulfonate	 trisodium 5-[[4-chloro-6-(methyl-phenyl-amino)-1,3,5-triazin-2-yl]amino]-4-hydroxy-3-(2-sulfonatophenyl)azo-naphthalene-2,7-disulfonate
Adifix Red F3BL Reactive Red 194 Reactive Red M-2BE C.I.Reactive Red 194	Tetrasodium 5-((4-chloro-6-((3-((2-(sulphonatooxy)ethyl)sulphonyl)phenyl)amino)-1,3,5-triazin-2-yl)amino)-4-hydroxy-3-((2-sulphonatophenyl)azo)naphthalene-2,7-disulphonate	 Tetrasodium 5-((4-chloro-6-((3-((2-(sulphonatooxy)ethyl)sulphonyl)phenyl)amino)-1,3,5-triazin-2-yl)amino)-4-hydroxy-3-((2-sulphonatophenyl)azo)naphthalene-2,7-disulphonate
CI 18972 Reactive Yellow 2 C.I.Reactiveyellow2	Trisodium 4-((4-chloro-6-((4-sulphonatophenyl)amino)-1,3,5-triazin-2-yl)amino)-2-((1-(2,5-dichloro-4-sulphonatophenyl)-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-4-yl)azo)benzenesulphonate	 Trisodium 4-((4-chloro-6-((4-sulphonatophenyl)amino)-1,3,5-triazin-2-yl)amino)-2-((1-(2,5-dichloro-4-sulphonatophenyl)-4,5-dihydro-3-methyl-5-oxo-1H-pyrazol-4-yl)azo)benzenesulphonate

According to the present invention, the reactive dye composition has characteristics of good dye reproducibility, excellent light fastness, excellent washing fastness, excellent perspiration fastness, high color fixing rate and the like, can be used for printing-dyeing and ink jet printing of cotton, silk, polyamide and other fibers (Sufian *et al.*, 2016), can provide corresponding sunlight-resistant, washing-resistant and perspiration-resistant black reactive dye products according to the needs of customers, has wide uses, further has advantages of high color fixing rate, high dyeing rate, good cotton cloth hand feeling, abrasion resistance, ater-washing resistance, sunlight resistance, perspiration resistance and other excellent fastness (Mazumder & Haque, 2011).The reactive dye has the advantages of high fastness and wet fastness (Shan *et al.*, 2019), bright color, excellent performances and strong applicability, the hue and the performances of the reactive dye can adapt to market requirements of the formula and uses of the reactive dye in fibers and clothes , and the dye has excellent fastness, especially color fastness to light, color fastness to chlorine and color fastness to perspiration, and also has very good lifting capacity level. The dye has good contact color fastness uniform tone after being washed, and the hue and the performances of the dye can adapt to market requirements on the fibers and the clothes (Siddiqua *et al.*, 2022).

2. Properties of Reactive Dyes

2.1 Reactive Dye for Leather

The reactive dye prepared to improves the color fastness of leather. The concentration of residual dye in the dye waste solution is improved by using the reactive dye and its preparation method (Chen *et al.*, 2015).

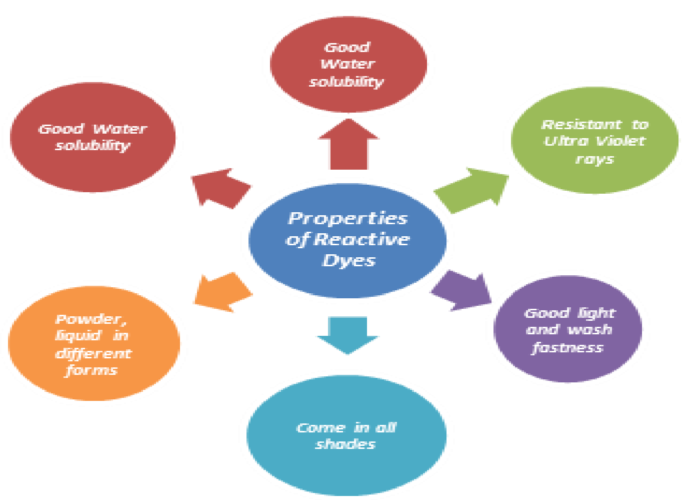


Figure 4: Properties of reactive Dyes

Introducing amino residues at the modified sites on cotton can result in excellent dyeing with reactive dyes at pH levels below 5, without the need for electrolyte, and with a high degree of dye fixation. Ammonia, ethanolamine, and methylamine are effective reactive amines for improving dye yield and fixation on modified cotton (Lewis & Lei, 1991).

2.2 Poly-functional Reactive Dye

A poly-functional reactive dye containing two dichloro-s-triazine residues linked through aliphatic amino groups via a third triazine system to the chromophoric residue has been prepared (Morris *et al.*, 2008). The alkylamino-linked dichloro-s-triazine dyes show very different dyeing properties when compared with those shown by the parent dichloro-s-triazine dye, which has the reactive group linked directly into the aromatic chromophore; in particular, the new dyes have high fixation efficiencies when dyed on cotton at 50 °C and the dye–fibre bond stability to boiling acidic conditions is very good (Morris *et al.*, 2008). Reactive dyes, which form covalent bonds with the fiber, offer excellent wet fastness and are considered the "high tech" end of the textile dyeing business. Sumitomo has patented the use of mixed bifunctional dyes to cover a wide shade gamut, indicating ongoing technological advancements in reactive dyes. Monochlorotriazine has been the commonly patented reactive system used in conjunction with the sulphatoethylsulphonyl group, but other reactive species have also been patented by Sumiton

2.3 Sumifix Supra dyes

Sumifix Supra dyes are technically excellent and show robustness to application conditions, aligning with the "right first-time" concept pursued by dyers(Harada & Yoshida, 1992).

2.4 Indosol dyes

Indosol dyes, although not strictly classified as reactive dyes, are marketed by Sandoz and offer exceptionally high wet fastness, competing in the conventional reactive dye mark (de Oliveira *et al., 2016).*

2.5 Phosphonic acid dyes

Phosphonic acid dyes, while offering benefits, had technical drawbacks such as high temperature requirements for fixation and dye migration, leading to their withdrawal in 1987 (Renfrew & Taylor, 1990).

2.6 Classification of Reactive Dyes

The reactive dye can be classified into 3 types:

- Based on reactive group
- Based on dyeing temperature
- Based on reactivity (Lewis, 2014)

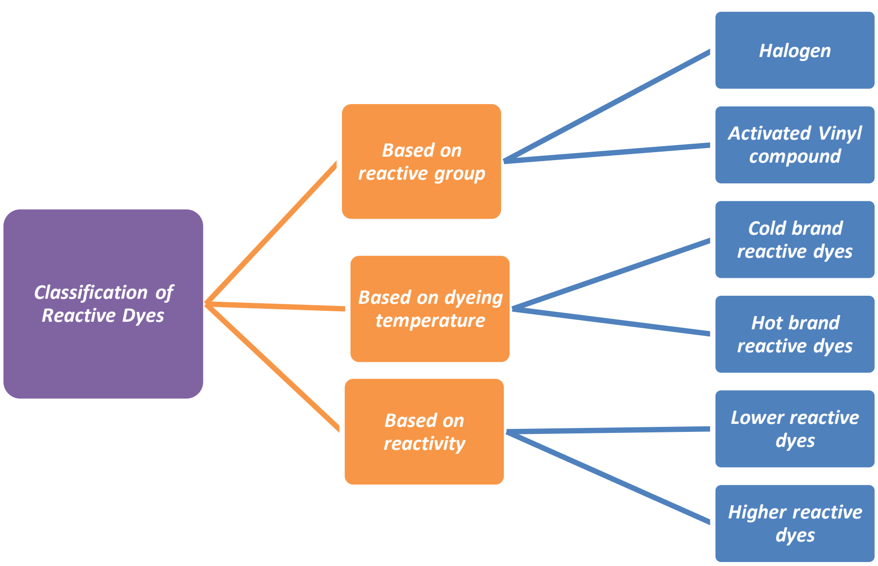


Figure 4: Classification of Reactive Dyes

2.7 Types of Reactive Dyes

Table 2: Reactive dyes come in a variety of forms, and their uses vary according to their characteristics.

Types of Reactive Dyes	Properties
; Monochlorotriazine Dye	➢ Reaction condition: A highly energetic reaction ➢ Temperature: 80 degrees Celsius ➢ PH: 10.5
Bi-Functional Dye	➢ These dyes have two reactive groups and good fastness. ➢ The temperature is 60 degrees Celsius. ➢ Fixation: Heterocyclic halo (Karapinar, 2007)
Dichlorotriazine Dye	➢ Non-toxicity and ease of use define these dyes. ➢ Fastness: Excellent ➢ Temperature: 80 degrees Celsius
Aminofluorotriazine Dye	➢ Easy to apply and simple to remove excess dye. ➢ Comes with a limited choice of colors. ➢ Temperature: 50 degrees Celsius (Kusmierek *et al.*, 2011)
Reactive Cold Dyes	➢ 40 degrees Celsius is the temperature. ➢ Solubility: Blends well with water ➢ Fixation: Strong tinctorial values and high fixation
Reactive Hot Dyes	➢ Temperature: 60 Degrees Celsius ➢ The dye is fixed at 100–150 degrees Celsius by steaming. ➢ Sustainability: The hydrolyzed dyes' poor stability
Vinylsulphone Dye	➢ Temperature: 60 Degrees Celsius ➢ Long-lasting in water due to the "masking" group ➢ Fixation: Double bond activation (Kan & Fong, 2017)

2.8 Characteristics of Reactive Dyes

2.8.1 Chemical Reactivity

Reactive dyes include useful groups that chemically react with the hydroxyl groups found in cellulose fibers (which includes cotton). These reaction paperworkcovalent bonds, leading to high-quality color fastness and sturdiness (Arslan-Alaton, 2003).

2.8.2 Wide Color Range

Reactive dyes offer a wide range of colors and sun shades, making them famous for generating colorful and long-lasting colorings in textiles (Chinta & VijayKumar, 2013).

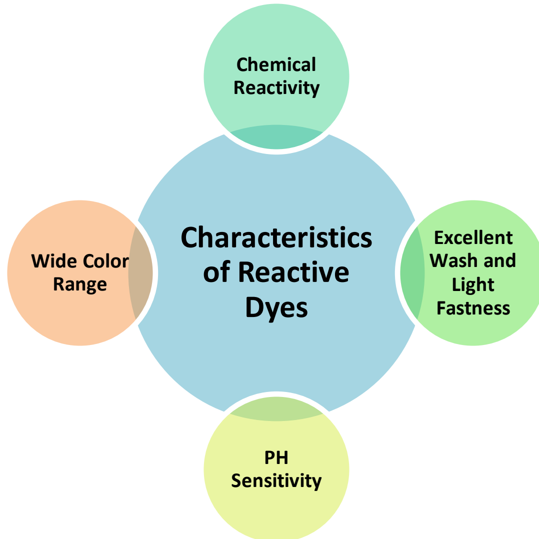


Figure 5: Characteristics of Reactive Dyes

2.8.3 Excellent Wash and Light Fastness

Due to the sturdy chemical bonds fashioned for the duration of the dyeing system, reactive dyes offer brilliant resistance to washing and fading from publicity to light (Shabir *et al.*, 2017).

2.8.4 High Efficiency

Reactive dyes have excessive fixation prices that mean they can correctly switch color to the fabric substrate, resulting in deep and even color (Smith *et al.*, 2006).

2.8.5 Environmentally Friendly

Modern reactive dyes are designed to limit environmental effect, with many formulations being low in toxicity and complying with environmental rules (Philips, 1996).

2.8.6 pH Sensitivity

The effectiveness of reactive dyes is encouraged with the aid of pH levels during the dyeing manner. Optimal pH situations are frequently vital to ensure right dye fixation and color development (Makedonski *et al.*, 2004).

2.8.7 Cold-Water Dyeing:

Unlike some other forms of dyes, reactive dyes can be used for bloodless-water dyeing methods, offering flexibility and power financial savings in textile production (Khatri *et al.*, 2011).

2.8.8 Color Mixing

Reactive dyes can be blended to create custom shades and sunglasses, permitting textile producers to attain precise and personalized coloration palettes for their products (Joo *et al.*, 2007).

2.8.9 Dyeing Properties

Reactive dyes show off wonderful penetration and migration homes, making sure uniform color distribution in the course of the textile substrate. This asset is particularly critical for attaining constant color in huge-scale manufacturing runs (Omura *et al.*, 1995).

2.8.10 Dyeing Conditions:

The dyeing conditions, along with temperature, time, and agitation, play a considerable function in the performance of reactive dyes. Optimal conditions range relying at the precise dye and fabric substrate getting used (Siddiqua *et al.*, 2021).

3. Factors Affect the Behavior and Performance of Reactive Dyes

3.1 Fiber Type:

Reactive dyes are ordinarily used for dyeing cellulosic fibers including cotton, linen, and rayon. The kind and shape of the fiber have an impact on dye uptake, fixation (Dolby, 1977), and color fastness.

3.2 pH Level:

The pH stage of the dye bath drastically affects the reactivity and fixation of reactive dyes. Optimal pH conditions vary relying on the precise dye and fiber kind however typically 10 and pH 11 range among pH (Órfão *et al.*, 2006).

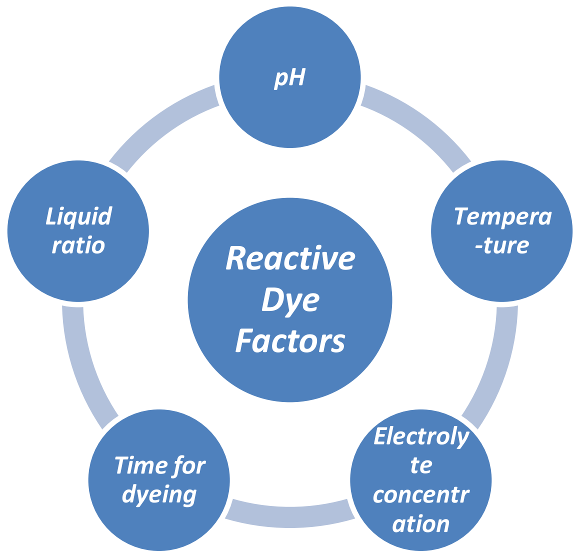


Figure 6: Factors Affect the Behavior and Performance of Reactive Dyes

3.3 Temperature:

Reactive dyes require improved temperatures for efficient dyeing and fixation. Higher temperatures beautify dye diffusion and reaction kinetics, main to progressed coloration uptake and fastness properties (Al-Degs *et al.*, 2008).

3.4 Salt Concentration:

The addition of salt (generally sodium chloride) to the dye bathtub helps sell dye adsorption and migration onto the fiber surface. Salt attention influences dye exhaustion, leveling, and color yield in reactive dyeing methods (Suesat, 2008).

3.5 Dye Concentration:

The concentration of reactive dyes inside the dye bath impacts dye uptake and coloration depth. Higher dye concentrations can result in deeper and extra intense shade however may additionally result in uneven dye distribution and increased expenses (Khatri *et al.*, 2018).

3.6 Dyeing Time

The period of the dyeing procedure influences the extent of dye diffusion and fixation onto the fiber substrate. Longer dyeing times allow for expanded dye penetration and bonding, leading to progressed color fastness (Lewis, 2014).

3.7 Auxiliary Chemicals

Various auxiliary chemical compounds, which include alkalis, dispersants, and leveling dealers, are frequently used in reactive dyeing methods to manipulate pH, enhance dye dispersion, and decorate color uniformity and reproducibility (Koyuncu, 2003).

3.8 Water Quality

Water nice parameters, together with hardness, alkalinity, and impurity levels, can affect dyeing performance and color yield. Water remedy and conditioning may be important to optimize dyeing consequences and reduce processing troubles (Wu & Wang, 2001).

3.9 Reactions Involved in the Dyeing Process with Reactive Dyes

3.9.1 Nucleophilic Substitution: The reactive dye molecule carries a reactive organization, which include a hydroxyl (OH), amino (NH_2), or vinyl sulfone ($SO_2CH=CH_2$) organization. These groups act as nucleophiles and react with purposeful groups at the fabric fiber, inclusive of hydroxyl or amino companies (Blackburn & Burkinshaw, 2003).

3.9.2 Covalent Bond Formation:

The nucleophilic reactive organization at the dye molecule undergoes a nucleophilic substitution reaction with the electrophilic purposeful organization at the fabric fiber. This response leads to the formation of a covalent bond (Siddiqua *et al., 2017)* between the dye molecule and the fiber.

3.9.3 Dye-Fiber Interaction:

The covalent bond shaped among the dye molecule and the fiber ensures the dye stays firmly attached to the textile. This interaction makes the dye molecules tremendously long lasting and immune to washing and mild (Stamm, 1964).

3.9.4 Examples

3.9.5 Reactive dye with amine group (cellulose fibers):

The amine institution on the reactive dye molecule reacts with the hydroxyl group at the cellulose fiber, ensuing in the formation of ether (-O-) linkage. This reaction is usually known as the "monochlorotriazine" or "MCT" response (Hande *et al.*, 2022).

3.9.6 Reactive dye with carboxyl organization (wool fibers):

The carboxyl institution on the reactive dye molecule reacts with the amino organization on the wool fiber, forming an amide (-CONH-) linkage. This response is called the "azoic" or "azo coupling" response (Hande et al., 2022).

3.9.7 Reactive dye with sulfonic acid organization (artificial fibers):

Synthetic fibers, along with polyester or nylon, don't have reactive functional businesses like cellulose or protein fibers. However, reactive dyes can still be used to dye those fibers by using the usage of a -step procedure (Dash *et al.,* 2018).

The first step includes pretreating the artificial fiber with a cationic agent, which gives the fiber with positively charged websites. In the second step, the reactive dye, which incorporates sulfonic acid companies, reacts with the undoubtedly charged websites on the fiber through ionic interactions (Jiang *et al.*, 2021).

4. Reactive dye with hydroxyl institution (silk fibers):

Silk fibers comprise hydroxyl organizations, just like cellulose fibers. Therefore, reactive dyes with hydroxyl-reactive groups can react with silk fibers through the formation of ether (-O-) linkages (Spadaro *et al.*, 1994).

4.1 Textile Substrates (Fiber)

Any material created by knitting, weaving, or joining fibres together is referred to as fabric (Hearle, 2001). It is a flat, flexible material that is frequently used to make linens, clothes, upholstery, and other things. Natural fibres like cotton, silk, wool, or linen, as well as synthetic fibres like polyester, nylon, or rayon, can be used to create fabrics (Khan *et al.*, 2017). In many applications, including wearable antennas and smart textiles, textile substrates are essential. They are employed for the incorporation of features such as monitoring and conductivity (Raji *et al.*, 2017).

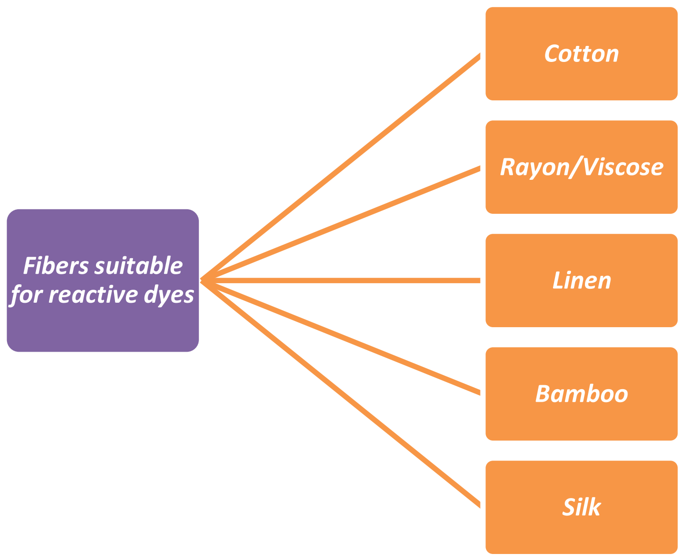


Figure 7: Fibers suitable for reactive dyes

4.2 Natural and man-made fibrous polymers

It was once traditional to sub-divide fibers into herbal, regenerated and artificial fibers, with regenerated fibers being those wherein the spine of the fibrous polymer had no longer been synthesized, but had pre-existed in a natural product (Yang *et al.*, 2021), e.g., cellulose in cotton-linters or wood pulp, which may be transformed into viscose-rayon, or secondary cellulose acetate. Now, it's far to subdivide fibers into handiest the 2 companies: herbal or guy-made. But this division is no help in figuring out how and with what forms of dyes the individual fibers is probably dyed (Ryszard M *et al.*, 2012).

4.3 Structure of Fiber

In dyeing, dye bath situations are adjusted as per the era for software of a selected dye. In a few cases, a fiber may be dyed with a particular dye however in trade for some damage in it, e.g. Dyeing of wool and silk with sulphur, reactive emblem and vat dyes. The incredibly alkaline pH maintained at some stage in dyeing at excessive temperature in part disintegrates those fibers causing fall in tensile electricity (Gupta, 2008).

4.4 Absorbency and Whiteness of Fibers

Natural textile for dyeing should have required absorbency, whiteness (reflectance issue) and pH. Various chemical pre-treatment techniques as well as dyeing are finished at particular pH; if there is healthy in running pH of both (Sawazaki, 1964), it does now not come to be crucial to move for neutral pH concept of fabric to start dyeing, e.g.

Dyeing of mercerized cotton with vat dyes does not require necessarily a cloth of impartial pH; in this kind of case, neutralization of mercerized cotton can be neglected and can immediately be sent for dyeing, thus lowering time and price each (Kabir *et al.*, 2014).

4.5 pH of Fibers

The pH of man-made fibers must be impartial as those are forever dyed in acidic pH. Well-pre-handled herbal textiles own correct absorbency which in flip enhances charge of dyeing through better floor deposition of dye observed by way of its diffusion (Chase & Kushmerick, 1988).

4.6 The Dyeing Process

There are 3 separate steps inside the dyeing method: dye sorption by using the fiber (substrate); dye diffusion into the fiber, and dye fixation at the fiber (Vickerstaff, 1957). In batch dyeing (i.e., in dyeing a set weight of goods in a fixed weight of dye bath), the first step, dye sorption, is achieved by using circulating the dye bath via the goods, or shifting the products via the bathtub, or both (Khatri *et al.*, 2015).

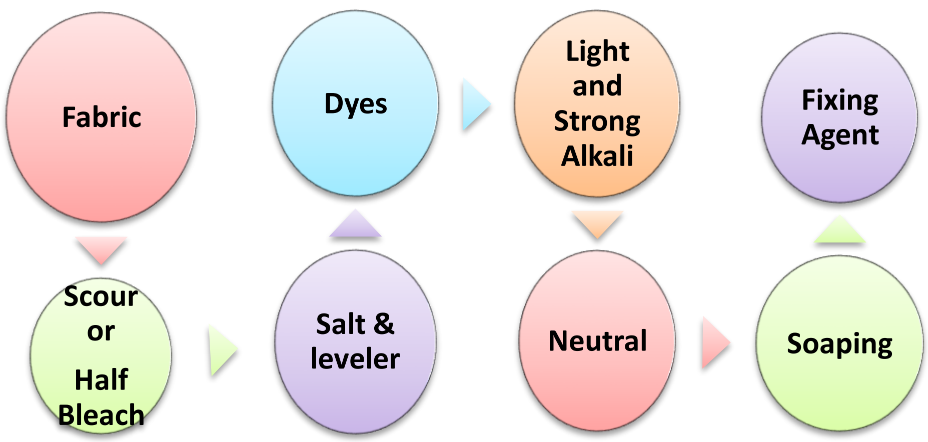


Figure 8: The Dyeing Process

In non-stop dyeing, step one is the mechanical placement of dyes at or near to the fiber surfaces. It is the second one step, dye diffusion, which calls for the dye to be in a monomolecular shape (Allègre *et al.*, 2006). Once the monomolecular dye has diffused into the fiber, fixation in the fiber can be because of 3 reasons: bodily bonding between dye and fiber; chemical bonding among dye and fiber, and conversion of the soluble coloring count number into an insoluble pigmentary form (Koprivanac *et al.*, 1999).

4.7 Fixing Agents

In the dyeing procedure, fixing agents, additionally called mordents or chemicals used to enhance the color fastness of the dyed fabric (Whewell, 1970). They assist to bolster the bond among the dye molecules and the fibers, making the color extra resistant to washing, light, and different environmental elements (Cronshaw, 1939). Fixing agents can range depending at the kind of dye and fiber getting used. Here are a few common types of fixing agents used in dyeing:

4.8 Metal-based totally Fixing Agents:

Metal salts, such as aluminum sulfate (alum), iron salts (ferrous sulfate), or chromium salts (chromium sulfate), are usually used as solving agents. These metallic salts form complexes with the dye molecules, growing insoluble precipitates inside the fiber matrix. This method complements the dye-fiber interaction and improves shade fastness (Petrunkevitch, 1943).

4.9 Tannins:

Tannins are herbal polyphenolic compounds discovered in plants, inclusive of o.k. Galls or extracts from barks or end result. Tannins can act as a solving agent for certain dyes, mainly natural dyes. They shape stable complexes with the dye molecules, improving coloration fastness (Julkunen-Tiitto & Haggman, 2009).

4.10 Synthetic Fixing Agents:

Synthetic fixing sellers are chemicals especially designed to improve color fastness. These chemicals offer a robust affinity for each the dye and the fiber, forming covalent bonds or complicated structures that improve color fastness (Liu & Zhao, 2017).

4.10 Fixing Agents Properties

4.10.1 Enhancing Color Fastness:

Reactive dyes form covalent bonds with the fibers at some stage in the dyeing technique. However, some dye molecules may not react absolutely or may additionally stay loosely bound to the textile (Zhou & Tang, 2017). Fixing agents help to improve the fixation of reactive dyes by way of chemically reacting with any unreached or loosely connected dye molecules, thereby improving coloration fastness homes along with wash fastness and light fastness (Farha *et al.,* 2010).

4.10.2 Removing Unattached Dye:

After dyeing with reactive dyes, there can be excess or unattached dye molecules gift on the material surface. This procedure, referred to as after-washing or after-remedy, helps to improve the color fastness via lowering the threat of dye bleeding or fading for the duration of subsequent use or washing (Khattab *et al.*, 2020).

4.10.3 Improving Fiber-Dye Interaction:

Fixing agents can also enhance the interplay among the reactive dye molecules and the fiber. They can act as bridging dealers, facilitating more potent chemical bonding among the dye and the fiber. This improves the overall color fastness and durability of the dyed textile (Pei *et al.,* 2020).

4.10.4 pH Adjustment:

Fixing agents may also be used to modify or hold the pH of the dyeing bathtub in the course of the process. Reactive dyes commonly require alkaline surroundings for most fulfilling dye uptake and response with the fiber (Sung *et al.,* 2000).

5. Temperature and ph can affect the overall performance of fixers

5.1 Reaction Rate:

Higher temperatures usually growth the response charges among the fixer and unreacted or loosely connected dye molecules. This can cause faster and greater efficient fixation of the reactive dyes, resulting in stepped forward shade fastness (Uddin & Islam, 2015).

5.2 Dye Affinity:

Some fixers can also have temperature-structured affinities for reactive dyes. For example, certain metallic-based fixers can also shape stronger complexes with the dye molecules at accelerated temperatures, improving color fastness properties (Denizli & Pişkin, 2001).

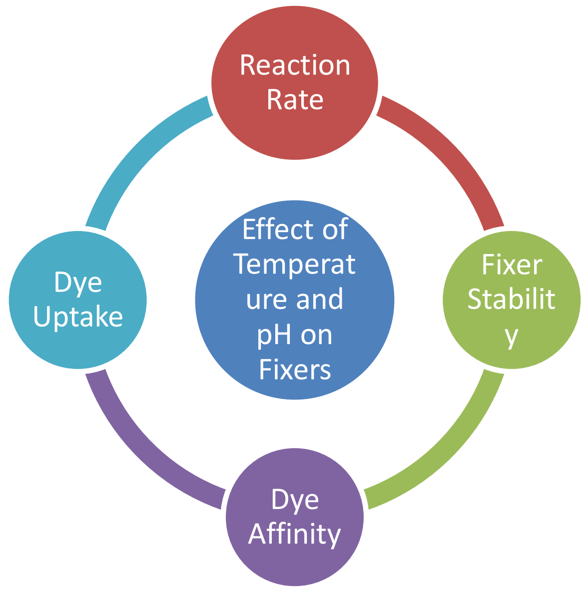


Figure 9: Effect of Temperature and pH on Fixer

5.3 Dye Uptake:

Higher temperatures can also promote dye uptake by using the fabric fibers. This cans useful resource inside the average dyeing system and make sure higher fixation of the reactive dyes (Bhalla *et al.*, 1990).

5.4 PH: Reaction Kinetics:

The pH of the dyeing tub influences the response kinetics among the fixer and the reactive dyes. Reactive dyes normally require an alkaline pH for premier dye uptake and response with the fiber. The fixer ought to be used inside the endorsed pH variety to make certain efficient fixation (Şahinkaya, 2013).

5.5 Fixer Stability:

The pH can also impact the steadiness of the fixer answer. Some fixers can be sensitive to pH modifications and can go through degradation or precipitation at severe pH stages. It is essential to maintain the suitable pH for the fixer to make certain its effectiveness (Chen *et al.*, 2022).

5.6 Dye-Fiber Interaction:

pH can have an effect on the charge distribution at the fiber surface and the dye molecules. This, in turn, influences the electrostatic interactions and chemical reactions between the dye and the fiber. Maintaining the right pH variety can help optimize the dye-fiber interplay and improve shade fastness (Mouxiou *et al.*, 2008).

6. Discussion

Reactive dyes and fixing agents undergo testing to see how well they work at different concentrations, temperatures, and pH levels to find the optimal conditions for the required color fastness characteristics. The proper selection of Reactive dyes and fixing agents are essential to achieve optimal dye fixation, vibrant colours, and excellent colour fastness in reactive dyeing. The purpose of this study is to investigate how the dyeing process is affected by varying fixing agents at different pH, concentration and temperature. Fixing agents in traditional dyeing processes encounter challenges in achieving durable color adhesion, leading to issues like fading, Bleeding, Shade variation and poor wash fastness. We will investigate how fixing agents affect colour fastness and dye retention during the reactive dyeing process in this study.

- Enhancing colour fastness (Strong bond Formation)
- Preventing dye Bleeding
- Reducing water wastage during dyeing process
- Minimising environment pollution
- Increase fabric life span

7. Conclusion

Cellulosic fibres are frequently dyed with reactive dyes using either an addition reaction or a nucleophilic substitution. Reactive dyes have gained commercial popularity primarily because of their reasonable cost, brilliant shade, broad colour gamut, respectable colorfastness, variety of application options, etc. Reactive dyes, however, have negative environmental effects when applied to cellulosic fibres. The primary environmental concern pertains to the extensive utilization of salts, specifically common and Glauber's salt, for the purpose of suppressing the negatively charged zeta potential that develops at the fiber surface during dyeing. This process ultimately results in an enormous effluent load. In addition, the reactive dye combines with the water to create hydrolyzed dye, which functions similarly to direct dye. This hydrolyzed dye has poor wash fastness qualities, and the hydrolysis of reactive dyes can lead to certain issues. Commercial reactive dyes typically reach a saturation point of 65% to 70%. Because of this, the process of removing the unfixed hydrolyzed dye requires a lot of time and energy. After the dyeing process, the hydrolyzed dyes should be eliminated by performing a soaping treatment. Generally speaking, the washing-off stages and effluent treatment account for 40% to 50% of the total cost of the reactive dyeing process. By improving colourfastness and dye retention, adjusting the fixing agent at a suitable pH and temperature can have a big impact on the dyeing process. By making this adjustment, the fixing agent's chemical reaction with the dye molecules is guaranteed to occur under ideal conditions, improving colourfastness and overall dyeing performance.

- Improved Colourfastness
- Enhanced Dye Retention
- Sustainable Dyeing Practices
- Environmental Impact

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