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Dyeing and finishing of fabrics with low or without water

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Abstract
The textile industry is believed to be one of the largest consumers of water. Conventional textile dyeing uses large amounts of fresh water and which then is disposed as waste water containing dyestuff chemicals. On average, an estimated 100 - 150 liters of water are needed to process 1 kg of textile material. Water is used as a solvent in many pre-treatment and finishing processes, such as washing, scouring, bleaching, dyeing, rinsing and finishing. The contaminated water must then be handled and treated prior to disposal or recycling. Water scarcity and increased environmental awareness are world-wide concerns causing a sharp rise in prices for intake and disposal of water. To reduce these water processes, new technologies have been introduced by the scientists. These technologies use at least 95% less water and 80-90% less energy than conventional fabric dyeing processes.

Keywords: Dyeing, finishing, low water processes

Introduction

Conventional textile dyeing is water intensive and generates highly polluted water that must be subject to costly treatment processes prior to discharge into rivers. A new commercial scale dyeing technology for dyeing synthetic fabric, DyeOx, has been implemented in Taiwan that utilises carbon dioxide ($C0_2$) instead of water in the dyeing process. The technology uses no water, no auxiliary chemicals and reduced energy when compared to conventional processes [1].

After agriculture, the textile industry is the heaviest industrial consumer of water. By 2030, it is estimated that the world demand for fresh water will increase by 40 percent with the increased population, and by 2050, an estimated billion-plus people will also lack the water they need for daily living. Up to 26 gallons (100 liters) of water are needed to dye just two pounds (one kilogram) of cotton fabric. The daily water consumption of an average sized textile mill having is about 1.6 million liters. Specific water consumption for dyeing varies from 30 – 50 liters per kg of cloth depending on the type of dye used. The overall water consumption of yarn dyeing is about 60 liters per kg of yarn. Dyeing section contributes to 15% – 20% of the total waste water flow. In recent years, there has been increased pressure placed on the textile industry by governments, NGOs and consumers to do a better job protecting the environment and to take a more proactive approach in reducing the industry's environmental footprint. The intense scrutiny is not likely to abate anytime soon. In fact, the industry will likely see tighter regulation as governments step up efforts through new legislation to improve oversight and reduce water pollution by the textile industry around the world. There is a critical need for the textile industry to take responsibility and adopt sustainable business practices to truly reduce environmental impact. For many years, the textile industry has tried to identify new ways to reduce the water consumption in the industry, such as lowering the liquor ratio or using textile dyes that require less water during the dyeing process [9].

Finishing processes with low water

- Enzymatic scouring
- Catalytic bleaching
- Ultrasound
- Plasma technology and Plasma-treatments
- Ink-jet technology
- Super critical CO_2

Dyeing processes with low water

- Air dyeing process
- Supercritical CO_2

Presently, there are so many textile industries follow without use of water or low water finishing processes. The following methods are given below:

Enzymatic processes

A high-quality bio-scouring enzyme offering up to 60% energy and water savings in textile pre-treatment processing. Eco-Scour is a bio-scouring enzyme with a neutral pH operating range. Eco-Scour operates in medium to low temperatures and prepares fabrics for dyeing medium to dark shades. Compared with conventional scouring in a textile pre-treatment process, the enzymatic Eco-scour process offers textile mills both economic and sustainability (It refers to save water and energy) benefits [10].

Table 1: Features and benefits of enzymatic processes in textiles

Features	Benefits
No caustic soda	Up to 31% shorter process
Neutral pH scouring process	Softer fabrics
Combined scouring and bio-finishing	Enhanced absorbency/dye uptake
	Reduced fabric weight loss
	Low temperature Less severe processing conditions Improved product quality For • desizing • anti-pilling effect

Catalytic Bleaching

Use of catalysts in order to [17]

- lower the bleaching temperature (65 °C; no steamer)
- shorten the bleaching time (5-10 min)
- decrease the damage of the fabric (DP value > 2000)
- reduce the chemical consumption (3 g H2O2/l, pH 10)

Ultrasonic washing

Highly efficient, environmentally friendly process:-Apart from making up, ultrasound is also used in the finishing of textiles. Currently SONOTRONIC has adapted the technology to washing and has developed innovative ultrasonic washing units.

- **Applications:** Ultrasonic washing is ideal for the energy efficient washing out of sizing agent and spinning oils prior to dyeing and for removing non-fixed dye particles from narrow fabrics or broad fabrics, ropes or cord, after thermo-fixing.
- **Efficient process:** Simply passing through an ultrasonic washing unit is enough to replace several baths of conventional, highly tempered systems. At the same time the washing distance is shorter and because ultrasound is used, water and energy consumption, as well as the use of chemicals are reduced when washing.
- **Incorporation in machines:** Depending on the type of fabric or degree of soiling, one or more directly connected ultrasonic washing units can be linked into finishing processes. Because of the compact design, subsequent installation in existing systems or incorporation in new machine concepts is a simple matter [18].

Advantages

- Reduction of water consumption
- Reduction of energy consumption, washing in "cold" water
- More flexibility
- Reduced use of chemicals
- Compact machine design
- High shortening of the washing process, Only 1-3 passes instead of 4-8, Short washing distance
- Increased efficiency as a result of several units being connected one behind the other

Embossing with ultrasound

Individual embossing of patterns and logos:-With ultrasonic embossing, individual texts or logos can be stamped with little force into, for example, imitation leather, corsetry or non-woven fleeces. Ultrasonic embossing units are used as built-in components both in standard and special machines in the textile and automotive industries [11, 18].

Little force and embossing time: The thermoplastic material is heated by the ultrasound oscillations, with the result that the amount of force used in ultrasonic embossing is significantly less than in mechanical processes. The sonotrode presses the heated material into the anvil, by which it is very quickly transformed on the surface. The result is top-quality, visually pleasing embossing [17].

Advantages

- Short embossing time
- Little application of force
- Environmentally friendly and energy saving
- Ultrasound can help to speed up processes 100 – 1000 times
    - chemical uptake (impregnating)
    - washing

Ink-Jet Technology

Digital finishing

Major benefits of "digital finishing" provided by inkjet [18].

Benefits

- Multi functionality
- Single sided application possible
- Two sides can have different functions
- Patterning
- Functionality applied efficiently to textile surface only
- Highly consistent coat weight
- Environmental and energy savings
- Not influenced by underlying substrate variations

- Not influenced by bath concentration and dosing variations

Inkjet Finishing
- Inkjet approach to digital finishing
- Modelling droplet interaction with textile and patterning processes
- Pragmatic experimentation with new functionalities
- Monitoring of textile and the jetting process.

Applications
- Slow release technology
- Digital dyeing
- Hydrophobic coatings
- UV
- Antimicrobial

Digital Dyeing
Approach
- Methods developed to use "difficult" aggressive dyes (VAT dyes)
- Not usually used in "printing" but give higher end user performance

Benefits
- Environmentally friendly, efficient use of natural resources
- Very high fixation, with low discharge of unfixed dye
- Low water and energy usage compared to traditional dye baths
- Consistency of product quality
- Consistent quantity of dye is laid down
- Does not rely on pick-up of dye from dye bath
- Different colour possible on each side of the textile [11]

The supercritical co2
The process involves the use of less energy than conventional processes, resulting in a potential of up to 50% lower operating costs.

The solution
In the fourth quarter of 2010, the branded fabrics were produced by using a novel process as Dry-Dye process. Elimination of the water process and chemicals is a real and significant breakthrough for the textile dyeing industry. This new process utilises supercritical fluid carbon dioxide (CO_2) for dyeing textile materials. It is a completely waterless dyeing process using only nominal amounts of recycled CO_2. Dry-Dye fabrics dyed with this unique waterless process will have the same quality of dyeing as current, conventionally-dyed fabrics. The process is an innovative & environmentally responsible step to produce quality fabrics and garment for premium brands in the sports and intimate wear markets. By pioneering and implementing this new waterless dyeing process, the companies can eliminate their annual use of millions of litres of fresh water in dyeing fabrics. Dry- Dye fabrics were expected to be available to consumers in early-2011 in the global market [2].

Super critical fluid dyeing: Technical Parameters
- Instead of current aqueous dyeing systems, Dry-Dye fabrics will be dyed using supercritical carbon dioxide. Normally supercritical fluids have been used in various extraction processes.
- Supercritical fluids are highly compressed gases which have unique properties of both liquid and gas and, because of this, have advantages for textile processing.
- Supercritical CO_2 may act as both a solvent as well as a solute, ideal for the textile dyeing process in which disperse dyes (without additives, dispersing agents, etc) are used. Supercritical fluids have higher diffusion coefficients and lower viscosities than liquids, as well as the absence of surface tension, allowing better penetration into materials.
- The three main stages of matter at ordinary temperatures and pressures are gas, liquid and solid.
- The molecules in a solid are so close together that the forces between them hold them in a given shape.
- When more energy is added, these forces are overcome and the substance becomes a liquid. Add more and it becomes a gas. When both the temperature and pressure get high enough, liquid and gas phases become indistinguishable and the phase is called a supercritical fluid.

Fig 1: Supercritical instrument used for dyeing (Normal view)

Other attributes of carbon dioxide are:
- It is an inexhaustible resource.
- Its use does not release volatile organic compounds (VOCs).
- It is biodegradable as a nutrient for plants.
- There are no disposal issues. It can be recovered and reused from the dyeing process.
- It is nonflammable and non-corrosive.
- It is non-toxic and low cost.

Dyeing with supercritical CO_2
- Using supercritical fluid CO_2, polyester and other synthetics can be dyed with modified disperse dyes.
- The supercritical fluid CO_2 causes the polymer fibre to swell allowing the disperse dye to easily diffuse within the polymer, penetrating the pore and capillary structure of the fibres.
- The viscosity of the dye solution is lower, making the circulation of the dye solutions easier and less energy intensive. This deep penetration provides effective colouration of polymers which are characteristically hydrophobic. Dyeing and removing excess dye are processes that are done in the same vessel.
- Residue dye is minimal and may be extracted and recycled. Supercritical CO_2 dyeing gives excellent results as far as dye levelness and shade development, and the physical properties of dyed yarns are equivalent to conventional methods.

- Conventional textile dyeing is very water and energy-intensive in pretreatment, dyeing, and post-treatment (drying). The supercritical CO_2 process involves the use of less energy than conventional processes, resulting in a potential of up to 50% lower operating costs. The only overlap is in the pre-treatment process, which is essentially the same for both.

NIKE, Inc., based near Beaverton, Oregon (USA) has entered into a strategic partnership with Dye Coo Textile Systems B.V. that manufactures machines for waterless textile dyeing. By using recycled carbon dioxide, Dye Coo's technology eliminates the use of water in the textile dyeing process. NIKE, Inc. considers this as a significant step towards its long-term commitment to ensure sustainable business and cleaner environment [4, 7].

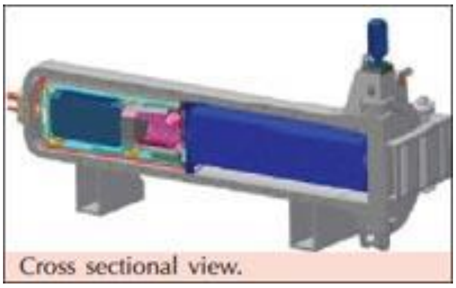

Fig 2: Supercritical instrument used for dyeing (Cross-sectional view)

There are three components in the supercritical CO_2 dyeing process

1. **The gas,**
2. **Dyestuff and**
3. **Fiber polymer**

- During the dyeing of polymer fibers, CO_2 loaded with dyestuff penetrates deep into the pore and capillary structure of fibers.
- This deep penetration provides effective coloration of these materials which are intrinsically hydrophobic.
- The process of dyeing and the act of removing the excess dye can be carried out in the same plant.
- A further advantage of this dyeing technique is that the dye can be easily separated from CO_2 and each can therefore be recycled [7].

Equipments: The apparatus used for dyeing with supercritical CO_2 consists of

- Temperature controller,
- Stainless steel dyeing vessel,
- Heater that surrounds the vessel,
- Manometer (an instrument for measuring the pressure of a fluid),
- Carbon dioxide pump and
- Cooler for cooling the head of the carbon dioxide pump.

Table 2: Difference between conventional and dyeing with supercritical CO_2

Conventional dyeing	Dyeing with supercritical CO_2
High volumes of waste water with the residual dye chemicals, etc.	No waste water at all. Dye remains as powder. No need for dispersing, leveling agents.
High-energy requirements	Only 20% energy requirement
Dyeing/washing, drying times is 4 - 0 hrs per batch	Only 2 - 3 hours.

Advantages of supercritical dyeing

- Elimination of water consumption
- Elimination of wastewater discharges
- Wastewater treatment process eliminated
- Elimination of drying and dryer effluent
- Reduction in energy consumption
- Reduction in air emissions
- Dyeing time significantly reduced
- Pure dyes used. Surfactants and auxiliary chemicals in dyes eliminated
- Dye utilisation is very high with very little residue dye. Unused dye can be recaptured and reused
- Approximately 95% of CO_2 can be recycled
- Fewer re-dyes are required and colour correction is easier compared to aqueous dyeing

Air Dye

Air dye technology manages the application of color to textiles without the use of water. It was developed and patented by Colorep, a California-based sustainable technology company. Depending on the fabric, and type of dyeing, Air Dye uses up to 95% less water, and up to 86% less energy, contributing 84% less to global warming, according to an independent assessment requested by the company. Air Dyed fabrics do not leach colors or fade as easily as vat dyed fabrics, because the dye is actually inside the fibers. The process of making textiles can require several dozen gallons of water for each pound of clothing. The Air Dye process employs air instead of water to help the dyes penetrate fibers, a process that uses no water and requires less energy than traditional methods of dyeing; the technology works only on synthetic materials_and is currently available only in the United States [14, 16].

Features of Air dye Technology

- Does not pollute water in the color application process. By using air instead of water to convey dye, no hazardous waste is emitted and no water is wasted.
- Greatly reduces energy requirements, thereby lowering costs and satisfying the strictest standards of global responsibility.
- Does not use boilers, screen printing machines, drying ovens, or cleaning step and simplifies the process, creating revolutionary possibilities of new industry and employment in unfarmable, arid regions of the world.
- Gives consumers a way to choose style and sustainability at a realistic price at the point of purchase.
- The process of making textiles can require several dozen gallons of water for each pound of clothing, especially during the dyeing process. 2.4 trillion gallons of water are used in synthetic dyeing, Air Dye's addressable market, each year. Air Dye technology eliminates hazardous wastewater as a byproduct of dyeing fabric. Water scarcity affects one in three people on every continent and is getting worse as water needs rise with population

growth, urbanization and increased usage by households and industries [16].

- Depending on the fabric, and type of dyeing, Air Dye uses up to 95% less water, and up to 86% less energy, contributing 84% less to global warming, according to an independent assessment. Additionally, some companies state that with Air Dye technology they can print to order which eliminates production excess and waste.
- Colorep claims that its Air Dye Process is priced competitively compared to traditional technology. Additionally, Colorep claims that companies using the technology find the Air Dye process reduces waste as 10% of traditional, vat-dyed fabric is damaged during the process, whereas with Air Dye, only 1% is damaged. Colorep also says that Air Dye enables companies to wait longer to decide what color or print to put onto their fabric, which would reduce the need for apparel makers to guess what colors consumers will want to wear months ahead [14].
- The Air Dye process manufactures fabric that can be washed at any temperature, with whites or colors, with or without bleach. Because the Air Dye process injects the dyes in the fabric and not on the fabric, bleach and cleaning agents do not affect them.
- With Air dye, a company estimates for every 25,000 T-shirts sold, the plant will save:
- Energy: 1,132,500 mega joules
- Water:- 157,500 gallons
- Green House Emissions: 57,500 (Kg CO_2 equiv. emissions). By using Air Dyeing amount of fresh gallons of water can be saved instead of traditional dyeing methods.

Conventional dyeing vs. air dye?

- Vat dying or cationic dying, can produce good looking results from conventional dyeing. On the down side, they use polluting heavy metals, a huge amount of precious water and do not provide permanent coloration. Sublimation printing has been used to decorate textiles but is limited in application. Air Dye advances both. Here are four microscopic photos of the neck section of a dyed synthetic T-shirt [12].
- **Standard Sublimation & Heat Transfer Printing:** The dye does not completely penetrate the fibers, therefore, white fiber may show after cutting or needle penetration.
- **Conventional Dyes:** After treatment in a water dye-bath, the fibers show complete dye penetration. However, colorfastness is low to moderate.
- **Air Dye Controlled Penetration:** Using our proprietary Sibius™ Dyes, penetration is deeper. Colors are richer and colorfastness is better. Penetration control is used with Dye Contrast, Print 2 Dye, and Print to Print products, including Air Dye woven.
- **Air Dye Complete Penetration:** Air Dye is so advanced that it not only colors the yarn, but also thousands of filaments in each piece of yarn, yielding rich, brilliant colors [13].

Table 3: Applications of air Dye technology in textiles

Applications	Products
Promotional items	• Banners • Retail display / signage • Short run branded products • Tote bags / reusable bags / aprons
Apparel	• Fabric for all types of garments • Finished accessories – scarf / ties / aprons, etc. • Specialty fabrics for custom items • Flags / umbrellas / awnings / tents • Uniforms – civic / corporate / medical • Swimwear / sarongs • Outerwear • Sportswear / yogawear / activewear / dancewear • Infant / toddler apparel • Junior apparel • Missy apparel • Wen’s wear • Lingerie / intimate apparel / sleep wear • Accessories / handbags / cosmetic bags / etc. • Shopping bags
Interiors	• Carpet / ceiling tiles • Drapes / curtains / blinds • Top of bed product–coverlets / bedspreads, etc. • linens • Wall covering • Tabletop / napkins • Shower curtains (72") • Pillows / mattress coverings • Upholstery – sofas, chairs, etc.
Industrial Print Applications	• Hard surface laminate • Melamine • Thin paper • Vinyl transfer • Thermo films

Medical	• Cubicle curtains • Hospital gown

Plasma Technology

Plasma Treatments: It is an environmentally friendly method for fabric finishing and modification. The process uses plasmas, gases in a highly excited state consisting of ions and free radicals, to interact with polymer surfaces and radically change the nature of those surfaces [6].

- The use of high energy plasma to create a continuous non-aqueous fabric treatment system, encompassing desizing, scouring, dyeing and especially finishing. It is low pressure technology.
- Plasma treatments have been 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.
- These treatments can enhance dyeing rates of polymers, improve colorfastness and wash resistance of fabrics and change the surface energy of fibers and fabrics.
- Research has shown that improvements in toughness, tenacity and shrink resistance can be achieved by subjecting various thermoplastic fibers to a plasma atmosphere.
- In other research, plasma treatments showed promise for producing hydroscopicity in fibers, altering degradation rates of biomedical materials (such as sutures) and depositing antiwear coatings.
- Plasma treatment can be done either at low (vacuum) or atmospheric pressures. While vacuum processes have been well-characterized, they have not been accepted by the textile industry due to their incompatibility with continuous processing.
- A few industrial atmospheric plasma devices are currently available, but due to the relatively short time that these devices have been on the market, the parameters for treatment have yet to be optimized. The interaction between atmospheric plasmas and textile substrates is still a subject of investigation [8].
- The several different textile materials treated including woven fabrics, nonwovens and filament yarns in atmospheric plasma. Our nylon samples showed no significant surface modifications, but the same treatment protocol significantly altered the surface chemistry and morphology of polypropylene (Fig 3).

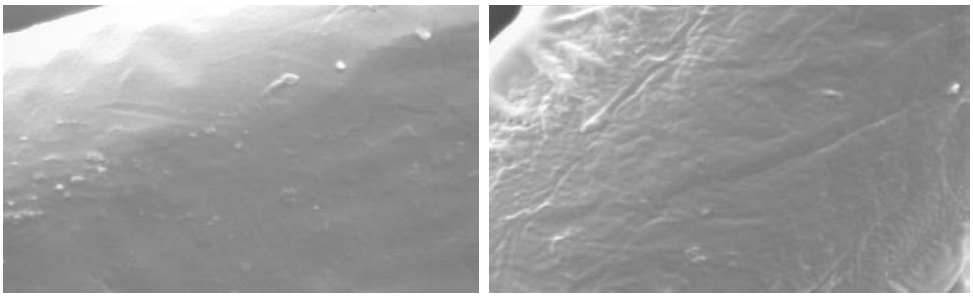

Fig 3: Polypropylene before (left) and after atmospheric plasma treatment

- The water repellency of denim fabric increased using both vacuum and atmospheric pressure plasmas. Additionally, we have been able to partially remove PVA size from fabrics and eliminate the need for hot water washing to remove the remaining size. Other treatments investigated include atmospheric plasma sterilization, decontamination, cleaning, and flame retardant treatments [5].
- A new atmospheric plasma device designed specifically for treating of rolled goods in a variety of gaseous environments. This device allows diagnostic characterization of the plasma during processing, controlled treatment variation throughout a fabric roll and continuous fabric processing [6].

Reduction of water consumption

- More efficient use of water
- pretreatment 5-10 l/kg
- Dying printing 30-50 l/kg
- Waste water treatment
- based on combined anaerobic – aerobic treatment
- degradation and/or coagulation of large range of dyes
- removal of color and COD >90%
- Water recycling needs additional treatment
- Water quality standards for different processes can be quite different
- Specific water plans for individual companies

Conclusion

The textile industry, one of the most water dependent industries is also the backbone of many developing economies. With the incorporation of new technologies such as waterless dyeing technology, digital printing, etc can help save water and help mills remain competitive while reducing their dependence on water and contributing to improve environment. These techniques or processes benefit is particularly important given that water supplies are becoming increasingly scarce, especially in the textile producing regions of China, India and other parts of Asia. However, there are still challenges regarding equipment cost, equipment maintenance and the dyeing of natural fibers.

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