Environment Sustainability through Waterless Dyeing

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ABSTRACT

The textile industry is one of the biggest polluters of clean water in the world. A large amount of fresh water is being utilised by textile industries for dyeing, rinsing and various treatments of textiles. After dyeing process is complete, the water used for dyeing is disposed off as waste water which contains very harmful dyestuff chemicals. These toxins end up in world's lakes, rivers and oceans causing a horrific damage. Today, water scarcity is getting more worse because of the increasing water needs due to rise in population and urbanisation. Considering these factors, there is a need to implement the techniques of dyeing which eliminate or minimise the use of water in dyeing and subsequently the hazardous waste water, which is the byproduct of dyeing fabric. These techniques reduce the consumption of water and pollution by the textile industries. Taking this into account, the present study on dyeing will focus on history, present techniques used for dyeing in the textile industry and alternatives available for dyeing in an eco-friendly manner so that we can save our precious resource-water and help in environment sustainability.

Keywords - Dyeing, textile industry, pollution, water consumption

Background :

Colour is recognised as the most important element in textile sales and merchandising. It is the colour of the dyed fabric that first attracts and then draws consumers to particular items for sale. But human desire to look appealing and glamorous has ended up causing harm to the environment.

Natural dyes and pigments obtained from plant, insects and minerals were used exclusively to colour fabrics until the discovery of synthetic colorants. In 1856, William Henry Perkins discovered the first synthetic dye (mauve). Today almost all industrial dyeing uses synthetic dyes since they produce a greater colour range, improved colour-fastness, better shade consistency, and more reliable sources.

The conventional dyeing process requires large amounts of water and the same amount of water is then disposed off as waste water which contains highly toxic dye-stuff chemicals. This makes the textile industry one of the biggest polluters, second only to agriculture in the world. On an average 100 - 150 litres of water is required to process 1 kilogram of textile material and approximately 28 billion kilos of textiles are being dyed annually. The World Bank estimates that the colouring and treatment of textiles account for 17 - 20 percent of global industrial pollution. Around 72 toxic chemicals reach out our water supply from textile dyeing. Many of these chemicals cannot be filtered or removed. These toxins pollute the world's lakes, rivers and oceans threatening species of fish and aquatic plants. The global textile industry discharges 40,000-50,000 tonnes of dye and more than 200,000 tonnes of salt into our rivers. The presence of these compounds also make practical water use unhealthy and dangerous as some of these compounds are carcinogenic.

Today, 1/3rd of world population do not have access to clean water. As water scarcity and increased environmental awareness are worldwide concerns, there is a need for the industry to look for options that help in reducing the consumption of water during the dyeing and the pollution caused by waste water after dyeing.

Dyeing with less or no water :

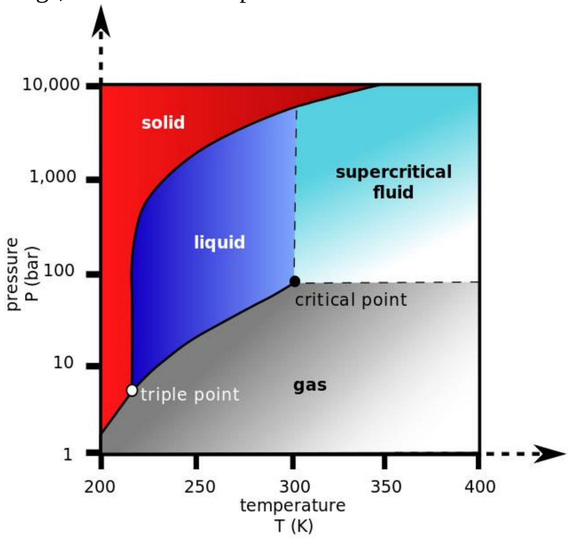
To save trillions of gallons of water annually, there are few techniques that can be implemented by textile industries globally. These include:

- **Solvent dyeing** process in which solvents (non-polluting) are used instead of water resulting in saving of energy and cost because high temperatures for dyeing are not needed. Solvent can be recycled eliminating the problem of effluent control but solvents are expensive resulting in higher production cost.
- **Foam dyeing** in which dyestuff is applied by suspending in liquid that is foamed with a special mixture. This method also requires less energy to dry the fabric as there is less water to evaporate.
- **Low liquor ratio jet dyeing machines** in which less amount of water is used than the traditional method (the material to liquor ratio in traditional dyeing is 1: 30-40, but low liquor ratio machines work on material to liquor ratio of 1:4).
- **Air-dye technique** -a patented textile dyeing process that makes use of air instead of water to dye but this works only on synthetics. According to independent assessments, this technique uses 95 percent less water, 86 percent less energy than traditional dyeing process. This contributes 84 percent less to global warming.
- **Use of supercritical fluid carbon dioxide(SC-Co2)** as an alternative solvent of water - The principle of dyeing with supercritical Co2 was invented in Germany 25 years ago but the technique became functional recently with the development of equipment for dyeing without water. The process requires only nominal amounts of Co2 that has the property of both liquid and

gas at a certain pressure and temperature and can be recycled after dyeing, is non toxic and economical. It is a completely waterless technique without any waste water, very less energy requirement and lesser time is required (15-60 minutes) as compared to conventional dyeing(3-4 hours)

3. Dyeing with supercritical fluid:

Supercritical fluid is a substance which can be either liquid or gas, used in state above the critical temperature and critical pressure where gases and liquids can coexist. It shows unique properties that are different from those of either gases or liquids under standard conditions. Supercritical fluids have been used to extract natural substances for production of drugs, cosmetics and spices.



This phase of a substance can replace water in the dyeing technique and dyeing occurs with high degree of levelness. Super-critical carbon dioxide is one of the supercritical fluids used in dyeing fibres. When carbon dioxide is heated to above 31 degree celsius and pressurized to above 74 bar, it becomes super-critical.

Super-critical carbon dioxide has liquid like densities, which is useful for dissolving hydrophobic dyes, and gas like viscosities and diffusion properties, which can lead to shorter dyeing times as compared to dyeing with water.

Fabric and dye are put in the container before dyeing. Then the apparatus is sealed and heated to a pre- selected dyeing temperature while Co2 is pumped simultaneously to the settled pressure. After some time, the pressure is reduced step by step while temperature is still maintained at dyeing temperature until the pressure is reduced to atmospheric pressure. The whole process can be carried out in one plant. The process involves only changing the temperature and pressure conditions. There are many benefits of using SC-Co2 in coloration of textile fibres. These are:

Shorter dyeing time
Complete elimination of water
Reduced energy costs because of elimination of drying step
No auxiliary required
No after treatment required
Improved diffusion and high degree of dye exhaustion
Non toxic, non flammable and inexpensive
Super critical conditions are easily achieved

Comparison of conventional dyeing and dyeing in supercritical CO2

Conventional dyeing	**SC-CO2 dyeing**
Large amount of water is required for dyeing	Complete elimination of water in the process
Huge volumes of waste water carrying residual dye and chemicals	No waste water at all
Very less recycling of chemicals	Carbon Dioxide used in the process can be recycled up to 90%
High energy requirement	Less energy requirement because of elimination of drying step
Takes more time to dye and dry	Less time required to dye and dry
Less dye uptake	More dye uptake in CO2 medium

Both hydrophobic and hydrophilic fibres can be dyed in supercritical carbon dioxide. This method gives better levelling results and greater economic efficiency.

Saus and Schollmeyer (1992) used supercritical carbon dioxide to replace water in dyeing. The polyester fibre was successfully dyed with disperse dyes in supercritical carbon dioxide.

Hebert et al. (1994) carried out modification of cotton and wool fibre and then these were dyed in supercritical carbon dioxide using disperse dyes. The results revealed that fastness of dyeing was not ideal.

De Giorgio (2000) compared dyeing of polyester fibre in water and supercritical carbon dioxide. It was found that K/S value of polyester fibre dyed in supercritical carbon dioxide at 80 degree Celsius and 240 bar was equivalent to the effect of water dyeing at 120 degree Celsius.

Lewis et al (2000) used Sodium Benzoate and Polyethylene Glycol to modify cotton fibre. Good dyeing effect was obtained but modification reduced the tearing strength of cotton fabric. Moreover, the cost was very high due to which it could not be commercialised.

Bach and Schollmeyer (1998) found that Tg point of temperature of polypropylene fibre decreased when the pressure of carbon dioxide was higher than 250 bar. Thus, supercritical carbon dioxide plastified polypropylene fibres effectively and helped disperse dye to penetrate into fibres to dye it.

Bach, et al. in their research work found that dye uptake of polypropylene fibres in Co2 is more than in water. Gangopadhay,et al, (2012)in their research work found that lesser temperature was required for dyeing polyester substrate with disperse dye in supercritical carbon dioxide dyeing as compared to conventional dyeing. It was also found that fixation percentage of dyeing in supercritical carbon dioxide was 100% as compared to fixation in conventional dyeing (97%). They also found that dyeing of cotton substrate with supercritical carbon dioxide was comparatively satisfactory to conventional method of dyeing.

It is difficult to dye natural fibres with high colour fastness properties and high colour depth using this medium mainly because of its inability to break hydrogen bonds present in many natural fibres including cotton, wool and silk. Another problem in dyeing natural fibres using super critical $CO2$ is that reactive, direct and acid dyes which are suitable for dyeing natural fibres are insoluble in SC-Co2. A research project on SC-Co2 dyeing concluded that chemical modification of natural fabrics or a new fixation mechanism is required to overcome limitations of dyeing natural fibres with super critical carbon dioxide. So, solubility of dye in SC-Co2 is one of the important parameters for dye selection and also for process, temperature and pressure optimisation.

Nandhakumar et al (2012) also found that dyeing with SC-Co2 technique requires significantly lesser energy as compared to conventional method of dyeing.

Table 1- The comparative energy requirements of conventional dyeing and dyeing with SC-Co2

	Conventional	SC-Co2
Dyeing	45,250 J	30625 J

A total of 49 % energy is saved using supercritical carbon dioxide.

Hence, dyeing with supercritical carbon dioxide helps in saving substantial amounts of water and energy and have a potential of lowering operating costs up to 50%. This is particularly important because the water supplies are becoming increasingly scarce. The only challenge lies in cost of new equipment to be installed by textile industries. Successful implementation of supercritical carbon dioxide processing will help textile industries to improve the economics of dyeing and eliminate waste water discharges, reducing energy consumption and above all eliminate use of our precious resource water.

Initiative by textile industries:

Increase in the pollution and decrease in sources of water has forced the textile industry to adopt strategies that make optimum use of water. Indian Government is also taking strict action. Many dyeing units in Tirupur and other parts of the country were closed by State Pollution Control Board due to excessive water pollution. Many eco-conscious companies (Yeh Group, Thailand; Nike, Adidas, Levi's) have started launching their lines of fabric and garments dyed using carbon dioxide thus eliminating their annual use of millions of litres of fresh water in dyeing process.

Summary:

The conventional dyeing process using water as a solvent has many disadvantages. Elimination of water and chemicals from dyeing process helps in reducing time, energy and even cost to a great extent. The Indian textile industry should consider conservation of water primarily because of the increased competition for clean water due to declining water tables, reduced sources of clean water and increased demands from both industrial and residential growth, resulting in higher cost for this natural resource. The industry should seriously adopt and implement the waterless dyeing techniques for the sustainability of our precious environment. State governments should strictly enforce eco-friendly dyeing and help in setting up of new machinery for waterless dyeing. Environmental supervision of the textile industries should also be strengthened so as to save water for our future generations.

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