An overview of the advance emerging techniques in textile industries

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ABSTRACT

Textile industry is one of the largest industry worldwide. Technological development within this industry is still continuous and various new advance technologies are emerging from last a few decades. In this paper an overview is taken with these technologies regarding their advantage and development.

Key words: Enzyme catalysed, plasma technology, biotech, electron ray, electrochemical dyeing, fuzzy LOZIC, H₂O₂, vat dyes.

INTRODUCTION

There are significant development throughout the world from the last a few decades and the textile industry is not any exception with this regard. Textile processing, dyeing techniques are taking new advantages day by day as to fulfill the requirements of advance textile market. Textile industry is mainly dependent of processing, dyeing, and finishing technologies. Some important emerging techniques are discussed here.

Enzyme catalysed finishing processes

Enzymes are proteins that act as biocatalysts activating and acceleration chemical reactions which would otherwise normally need more energy. Their excellent substrate selectivity allows more gentle process conditions compared to conventional processes. Enzymes are present in bacteria, yeasts and fungi.

At present enzymes are used and under study only for natural fibers, the use of enzymes for man-made fibers is not mentioned in literature. Some enzymes, such as the amylases in the desizing process, have been widely applied for a long time; other enzymes are still the object of investigations. Table 6.1 lists main enzymatic processes already in use or currently emerging in the textile sector.

Energy savings (lower processing temperatures) and lower water consumption (reduced number of rinsing steps) are some of the promising advantages of enzymatic processes, along with the omission, in some cases, of the use of hazardous/harmful substances. Also enzymes can be used in catalytic amounts and as a biocatalyst they can be recycled.

Plasma technology

A plasma can be described as a mixture of partially ionized gases. Atoms, radicals and electrons can be found in the plasma. The electrons in low temperature plasmas are able to cleave covalent chemical bonds, thereby producing physical and chemical modifications of the surface of the treated substrate.
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 have been shown to enhance dyeing rates of polymers, to improve colorfastness and wash resistance of fabrics, to increase adhesion of coatings, and to modify the wet-ability 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. Recently, plasma treatments have produced increased moisture absorption in fibers, altered degradation rates of biomedical materials (such as sutures), and deposition of low friction coatings.

Unlike wet processes, which penetrate deep into the fibers, plasma produces no more than a surface reaction, the properties it gives the material being limited to a surface layer of around 100 angstroms. These properties are very varied and can be applied to both natural fibers and polymers, as well as to non-woven fabrics, without having any effect on their internal structures. For example, plasma processing makes it possible to impart hydrophilic or hydrophobic properties to the surface of a textile, or reduce its inflammability. And while it is difficult to dye synthetic fabrics, the use of reactive polar functions results in improved pigment fixation. Also, with plasma containing fluorine, which is used mainly to treat textiles for medical use, it is possible to optimize biocompatibility and haemocompatibility - essential for medical implants containing textiles.

Four types of plasma are generally used: the corona plasma, Atmospheric pressure plasma technique plasma, dielectric barrier discharge:

Electron-ray treatment
Electron-rays start free-radical initiated polymerization reactions that can then be used for coating, lamination and for graft co-polymerization reactions on textiles pre-coated with monomers or pre-polymers.

The advantage over thermal curing is that solvent-free formulations can be used. This reduces the emissions of VOCs during drying operations. The technique is already established in other sectors and therefore its implementation in the textile sector is foreseeable in the next five years.

Use of supercritical CO$_2$ in dyeing processes
Supercritical fluids are capable of dissolving organic molecules of low to medium polarity.

Carbon dioxide has the advantage over other gases of being unflamable, non-explosive and non-toxic.

Carbon dioxide in dyeing of PES and PP fiber is already developed on an industrial scale. However, the application of this technique on wool, PA and cotton is still problematic due to the polar nature of the dyestuffs used to colour these fibers.
CO₂ dyeing of PES and PP can be carried out under optimal isothermal and isobaric conditions at 120 and 300 Dc. Dye uptake and fastness properties are very similar to water dyeing. Nevertheless some precautions need to be taken. Excess dye dissolved in the dyeing medium must be extracted with fresh supercritical CO₂ at the end of the dyeing cycle.

In conclusion, only special dye formulations can be used because dispersing agents and other auxiliaries typically present in conventional dye formulations strongly influence dye uptake in supercritical CO₂. Hydrophobic preparation agents should be extracted before dyeing because of their solubility in supercritical CO₂. They are first extracted from the fiber during the dyeing process, and then precipitate as oily droplets at the end of the process.

**CO₂ dyeing has a number of advantages**

- Almost zero water consumption
- Zero off-gas emission (CO₂ can be recycled)
- No drying step necessary after dyeing
- Leveling and dispersing agents are not needed at all or, in some cases, they are added in very small amounts;
- The dyestuff residues can be recycled.

Nevertheless, the investment cost for the equipment is high and this is a significant drawback, especially when considering that PES textiles are normally low-price products.

**Ultrasonic treatments**

Ultrasonic treatments improve the dispersion of dyestuffs and auxiliaries and enhance their ability to emulsify and soluble. This allows improved liquor homogenization, which then results in higher bath exhaustion and level dyeing properties. In addition, ultrasonics produce a de-aeration effect in the liquor and on the fabric, which is normally obtained by adding special auxiliaries (de-aerating agents).

**Ultrasonic technology can be attributed to various mechanisms**

The effect of ultrasonic depends on various mechanisms as follows:

- Radiation pressure
- Heat
- Streaming
- Cavitations
- Agitation
- Interface instability and friction
- Diffusion and mechanical rupture

**The mechanisms**

1. Increasing swelling in water.
2. Reducing glass transition temperature of the fiber (dilation of amorphous regions).
3. Increasing the fiber/dye bath partition coefficient.
4. Enhancing transport of the dye to the fiber surface by reducing the boundary layer
5. Thickness.
6. Breaking up of micelles and high molecular weight aggregates into uniform dispersions in the dye bath. As Dr G Mock, R McCall, D Klutz carried out experiments. Five different vat dyes of known structure were examined, most of which had previously been used in ultrasound dyeing trials. A 5-gpl solution of each dye was prepared, and then divided in half to give two samples for each dye. One sample of each dye was treated with 20 kHz ultrasound at 25° C for 60 minutes; The other sample was used as a control untreated sample. The dye samples were measured with a Honeywell Microtrac Particle Size Analyzer. The results are shown in table-3.0.

Ultrasound reduced the average size of the dye particles for each of the dyes tested. The effect ranged from virtually nothing in the case of Vat Black 25 to greater than 1.75 microns in the case of Vat Violet 1. The effect of ultrasound on particle size is most evident when examining the before and after graphic distributions drawn by the analyser. Ultrasound had the greatest effect on vat dyes with a bimodal particle distribution. After these dye samples were treated with ultrasound the large particles were completely eliminated. Without ultrasound vat dyes may contain particles larger than 14 microns, but when vat dyes are treated with ultrasound the largest dye particles are smaller than 2 microns.
The main environmental benefits achievable with ultrasonic treatments in textile finishing are:
- energy savings (lower process temperatures and shorter cycle times)
- reduction in auxiliaries consumption.

**Nanotechnology**
Nanotechnology seeks to provide and apply knowledge of the behaviour of objects in the nanometre (nm) size range to the assembly of complex structures for use in a variety of practical applications. The tiniest substances promise to

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### Table 1: Enzymatic processes in textile finishing[77, EURATEX, 2000], [179, UBA, 2001]

<table>
<thead>
<tr>
<th>Material</th>
<th>Enzymes</th>
<th>Substrate</th>
<th>Degree of development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>Amylases, amylglucosidases, Pectinases</td>
<td>Starch, Cotton fibre adjacent material, Lignin, dyestuffs, glucose</td>
<td>State of the art, Available, Emerging</td>
</tr>
<tr>
<td>Scouring</td>
<td>Enzymatic mixture</td>
<td>Cotton fibre adjacent material</td>
<td>Available</td>
</tr>
<tr>
<td>Bleaching</td>
<td>Laccases, glucoseosidases, Peroxidases</td>
<td>H$_2$O$_2$</td>
<td>Available</td>
</tr>
<tr>
<td>Bio-polishing</td>
<td>Cellulases</td>
<td>Cellulose</td>
<td>Available</td>
</tr>
<tr>
<td>Bio-stoning</td>
<td>Celluloses</td>
<td>Cellulose</td>
<td>Available</td>
</tr>
<tr>
<td>Wool</td>
<td>Lipases</td>
<td>Lanolin</td>
<td>Available</td>
</tr>
<tr>
<td>Scouring</td>
<td>Special enzymes</td>
<td>Sericin</td>
<td>Emerging</td>
</tr>
<tr>
<td>Degumming</td>
<td>Sericinases</td>
<td>Sericin</td>
<td>Emerging</td>
</tr>
<tr>
<td>Softening</td>
<td>Pectinestearases</td>
<td>Flax fibre adjacent material</td>
<td>Emerging</td>
</tr>
<tr>
<td>Jute</td>
<td>Cellulase, xylanases</td>
<td>Jute fibre adjacent material</td>
<td>Emerging</td>
</tr>
</tbody>
</table>

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### Table 2:

<table>
<thead>
<tr>
<th>Application</th>
<th>Material</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrophilic finish</td>
<td>PP, PET, PE</td>
<td>Oxygen plasma, Air plasma</td>
</tr>
<tr>
<td>Hydrophobic finish</td>
<td>Cotton, P-C blend</td>
<td>Siloxane plasma</td>
</tr>
<tr>
<td>Antistatic finish</td>
<td>Rayon, PET</td>
<td>Plasma consisting of dimethyl silane</td>
</tr>
<tr>
<td>Reduced felting</td>
<td>Wool</td>
<td>Oxygen plasma</td>
</tr>
<tr>
<td>Crease resistance</td>
<td>Wool, cotton</td>
<td>Nitrogen plasma</td>
</tr>
<tr>
<td>Improved capillarity</td>
<td>Wool, cotton</td>
<td>Oxygen plasma</td>
</tr>
<tr>
<td>Improved dyeing</td>
<td>PET</td>
<td>SiCl$_4$ plasma</td>
</tr>
<tr>
<td>Improved depth of shed</td>
<td>Polyamide</td>
<td>Air plasma</td>
</tr>
<tr>
<td>Bleaching</td>
<td>Wool</td>
<td>Oxygen plasma</td>
</tr>
<tr>
<td>UV protection</td>
<td>Cotton/PET</td>
<td>HMDSO plasma</td>
</tr>
<tr>
<td>Flame retardancy</td>
<td>PAN, Cotton, Rayon</td>
<td>Plasma containing phosphorus</td>
</tr>
</tbody>
</table>
transform industry and create a huge market. In chemicals, cosmetics, pharmaceuticals, technology and textiles, businesses are researching and manufacturing products based on nanotechnology, which uses bits of matter measured in billionths of a metre.

The technology, utilising materials a thousand times smaller than the width of a human hair, is showing up in everything from auto parts to sunscreens and clothing. However, nanotechnology has been used to improve products that most of us use everyday. These include laundry detergent, 6-pack rings, and surgical tools. One of the most widespread applications of nanotechnology is in clothing. Nanotechnology is also called a “bottom up” technology owing to using such small-scale building units, in contrast to bulky material engineering that is considered a “top down” approach. Many textile industries and research organisations have already developed fabrics with distinguishing properties. Scratch-and-sniff clothing is one example. Pleasantly scented, tiny polymer beads are added to clothing, such as within a strawberry applied on a shirt. Then there are menthol pajamas, scented to open the nasal passages of people suffering from colds, ensuring a good night’s sleep.

Table 3.

<table>
<thead>
<tr>
<th>Dye</th>
<th>Manufacturer</th>
<th>Without ultrasound (microns)</th>
<th>With ultrasound (microns)</th>
<th>Average size Decrease (microns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat violet 1</td>
<td>Catawba Charlab</td>
<td>2.447</td>
<td>0.606</td>
<td>1.841</td>
</tr>
<tr>
<td>Vat black 25</td>
<td>Catawba Charlab</td>
<td>0.462</td>
<td>0.405</td>
<td>0.057</td>
</tr>
<tr>
<td>Vat black 25</td>
<td>Sunbelt</td>
<td>0.516</td>
<td>0.514</td>
<td>0.002</td>
</tr>
<tr>
<td>Vat green 3 (dyeing)</td>
<td>Catawba Charlab</td>
<td>0.941</td>
<td>0.268</td>
<td>0.673</td>
</tr>
<tr>
<td>Vat green 3 (printing)</td>
<td>Catawba Charlab</td>
<td>1.434</td>
<td>0.292</td>
<td>1.142</td>
</tr>
<tr>
<td>Vat green 1</td>
<td>Catawba Charlab</td>
<td>0.454</td>
<td>0.392</td>
<td>0.062</td>
</tr>
<tr>
<td>Vat violet 13</td>
<td>Sunbelt</td>
<td>0.444</td>
<td>0.431</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Table 4: Nano-particles and potential textile applications

<table>
<thead>
<tr>
<th>S.No</th>
<th>Nano-Particles</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silver Nano-Particles</td>
<td>Anti-bacterial finishing</td>
</tr>
<tr>
<td>2</td>
<td>Fe Nano-Particles</td>
<td>Conductive magnetic properties, remote heating.</td>
</tr>
<tr>
<td>3</td>
<td>ZnO and TiO₂</td>
<td>UV protection, fiber protection, oxidative catalysis</td>
</tr>
<tr>
<td>4</td>
<td>TiO₂ and MgO</td>
<td>Chemical and biological protective performance, provide self-sterilizing function.</td>
</tr>
<tr>
<td>5</td>
<td>SiO₂ or Al₂O₃ Nano-particles with PP or PE coating</td>
<td>Super water repellent finishing.</td>
</tr>
<tr>
<td>6</td>
<td>Indium-tin oxide Nano-Particles</td>
<td>EM / IR protective clothing.</td>
</tr>
<tr>
<td>7</td>
<td>Ceramic Nano-Particles</td>
<td>Increasing resistance to abrasion.</td>
</tr>
<tr>
<td>8</td>
<td>Carbon black Nano-Particles</td>
<td>Increasing resistance to abrasion, chemical resistance and impart electrical conductivity, colouration of some textiles.</td>
</tr>
<tr>
<td>9</td>
<td>Clay nano-particles</td>
<td>High electrical, heat and chemical resistance.</td>
</tr>
<tr>
<td>10</td>
<td>Cellulose Nano-whiskers</td>
<td>Wrinkle resistance, stain resistance, and water repellency.</td>
</tr>
</tbody>
</table>
Some other type of clothing niche being explored on many fronts, with perhaps more staying power than scratch-and-sniff shirts, involves the nanoscale improvement of fabrics and fibres. Nanotechnology is adding its labels to popular clothing brands with various products: Resists Spills, Resists Static, Coolest Comfort, and Repels and Releases Stains. Researchers all around the world are looking at all sorts of metal additives and polymer additives, inorganic, organic materials to take them at nanoscale to impart lots of interesting properties to textiles.

Preparation of nano-sized materials
There are several physico-chemical methods for preparation of nano-sized material mentioned as below (4):
- Vapour phase reaction.
- Chemical vapour deposition.
- Inert gas condensation.
- Laser ablation.
- Plasma spraying.
- Spray conversion.
- Sputtering.

Some commercially available nano-particles
Nano-particles may consist of various elements and compounds. The size of the molecules is the sole criterion for inclusion in the category of nano-particles. Nano-particles have a length of 1 to 100 nm. Conventional materials have grain sizes ranging from microns to several millimeters and contain several billions atoms each, nanometre sized grains contain only about 900 atoms, exhibit new and improved properties compared to the corresponding bulk material (Table 1). Some nano-particles currently available are as follows (5-7):
1. Metals: Pd/Pt, Ag, Fe, etc.
   - Inorganic: TiO2, ZnO, Fe2O3, MgO, SiO2 etc.
3. Polymer: - cellulose nano-whiskers
   - carbon nano-whiskers.

Electrochemical dyeing
Vat and sulphur dyeing involves both a reducing and an oxidising step, which are carried out with chemical oxidants and reducing agents. The environmental concerns associated with the use of these chemicals are described in Section 2.7.8.1 An attractive alternative technique is to reduce and oxidise the dye by means of electrochemical methods.

With direct electrolysis the dye itself is reduced at the surface of the cathode. In indirect electrolysis the reducing power of the cathode is transferred to the solution by a soluble reversible redox system (e.g. based on anthraquinone chemistry or iron complexes). With this reversible redox system the reducing agent is continuously regenerated at the cathode, which thus allows full recycling of the dye bath and the reducing agent.

Direct cathode reduction in an electrochemical cell is applicable to sulphur dyes. Vat dyes are reduced by indirect electrolysis.

Alternative textile auxiliaries
Complexing agents
The use of polyaspartic acid as a substitute for conventional dispersing and complexing agents is under study.

Cross-linking agents
Polycarboxylic acids can be used as an alternative to N-methylol-based cross-linking agents, which are responsible for formaldehyde emissions.

Biopolymers
Besides cellulose, chitin, the main structural component of crustacean shells (crabs, lobster, etc.) and insects, is the second main biopolymer. Its deacetylated derivative, chitosan, which is easier to handle due to its higher solubility, is increasing in importance.

Some examples of potential applications of chitosan and its derivatives in the textile sector
Antimicrobial treatment for textiles: a permanent effect can be obtained by blending 10% of chitosan fibers with cotton fibers to produce a mixed fibre yam or by spraying chitosan solutions on non-woven fabrics. Compared to other commonly used antimicrobials, chitosan is not toxic to aquatic life nor to humans (it is therefore of special interest for those fabrics that stay-in close contact with the skin)
After treatment to improve fastness properties when dyeing with direct dyes: cationic modified derivatives of chitosan are reported to be suitable for this application.

Furthermore, chitosan increases the dyestuff uptake and can act as a softening agent or binding agent for non-woven fabrics. It can also be used as an additive in printing pastes and in sizing agents. Its application can also be interesting in waste water treatment.

Fuzzy logic

Significant improvements in process reliability are achievable with the use of fuzzy logic (i.e. expert systems based on self-learning software systems, which auto-enlarge their knowledge by algorithms). The application of fuzzy logic in the textile industry is the object of a number of research projects. Two examples are reported concerning the control of the sizing process and the control of the condensation reaction of cross-linking agents.

The main advantages to be expected are the improved process control, which subsequently can result in increased productivity and enhanced quality of the final product.

Indirect environmental benefits are associated with the potential savings in energy and chemicals as a result of the improved process control.

The main limitation in the implementation of these expert systems in the textile industry is often the lack of a reliable database.

On-line Monitoring

Process control by on-line monitoring enhances operation efficiency in the direction of “right first time production”.

Examples of on-going research in this area are Dyeing

The concentration of the COD (related with the dyestuff concentration) is measured on-line during washing and rinsing operations in discontinuous dyeing processes. When the dyestuff concentration in the rinsing bath is negligible, the rinsing process is automatically stopped. This technique allows considerable water and energy savings.

dyeing and bleaching

by using a special amperometric sensor, the concentration of reducing or oxidising agents on fabrics can be controlled on-line. For example, the completeness of $\text{H}_2\text{O}_2$ removal after bleaching or the concentration of reducing agents in vat dyeing can be monitored and excess use of chemicals avoided.

dyeing with vat dyes

by monitoring the redox potential, it is possible to detect exactly the point at which the reducing agent is completely rinsed off. When this point is reached the rinsing process can be stopped and the oxidant added to the bath.

Future development of advanced oxidation processes in the textile industry:

Advanced oxidation processes are already applied in the textile industry (see Section 4.10.7) and further research is under way. The BIOFL-UV project is one example. The aim of this research is to develop and test a waste water treatment based on the UV-activated photolysis of hydrogen peroxide (for the decolouration of the spent bath) combined with a bioflotation process (for the destruction of the residual organic load). The combination of these waste water treatment processes is expected to achieve a complete decolourisation of the process waters for every type of wet process (finishing, bleaching, dyeing, etc.). The project will also develop and implement a process-control software based on artificial neural network and systems dynamics. The ultimate goal is the recycling, after filtration of 75% of the process water and dye destruction [313, BIOFL-UV, 2002].

Textile companies are facing problems in some instances of crisis proportions, in dealing with the effluent that they generate. The solution to the problem will vary from company to company depending on many variables such as the volume and nature of the effluent, location, site geography and finance available. Unfortunately for some companies, the inevitable conclusion will be that there is no viable solution. There will be in-house debates but there should also be frank discussions.
with all those concerned and those who can help, particularly from water service companies, suppliers of plant and equipment for effluent treatment and also chemical suppliers.

CONCLUSION

Above discussed techniques are no doubt significantly in continuously developing context of textile industries. These techniques are helpful to improve the quality of textile in all respects, as well as to making the industry eco friendly. Furthermore these technological development also contribute for the economic aspects of textile industry and there is requirement of further continuous research and developments with these advance technologies to make them more feasible.

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