CLEANTEX

Clean and Innovative Textiles Strategy for Circular Economy

MODULE 6
Sustainable Chemical Processes and Textile Care

Unit 6.3
Sustainable Functional Finishing and Textile Care

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This unit covers the following topics: biomolecules for functional finishing, nano finishing guided by green chemistry, plasma coating for textile surface functionalization, foam finishing and spray coating, laundry technology for circular economy requirements, clever care and eco-labelling relating to environmental impacts

6.3.1 Biomolecules as functional finishing agents

Functional biomolecules and bio-based products are used as flame retardant, antimicrobial, insect repellent, UV protective and crosslinking agents. Among green flame retardants, whey proteins, caseins, hydrophobins, DNA and phytic acid have been established for use in textiles[1-4]. These molecules are rich in phosphorus, sulphur and nitrogen, which provide flame retardancy. The flame retardancy mechanism of these molecules involves the promotion of the formation of a stable protective char, resulting in a decrease in combustion rate and heat release and an increase in chair residue.

Natural antimicrobial agents include chitosan, which is of animal origin, phenols and polyphenols (phenolic acids, flavonoids, tannins, coumarins), terpenoids, curcuminoids and acemannan polysaccharide of plant origin[1,5-9]. The antimicrobial mechanism of these natural agents is based on the controlled release of the active compounds from the textile substrate. The antimicrobial activity of chitosan is based on the electrostatic interactions between the protonated amine groups and the negatively charged microbial cell membrane. Chitosan can also penetrate the microbial cell and bind to DNA. This leads to inhibition of microbial growth and consequently cell death. The main antimicrobial mechanisms of plant extracts include formation of complexes with the cell wall, disruption of the cell membrane, inactivation of enzymes, and interaction with DNA.

Natural insect repellents are secondary metabolites found in essential and natural oils. They include terpenoids, phenols, alkaloids and triglycerides[1,9-12]. Since most essential oils are highly volatile, the mechanism of insect repellency is based on the formation of a vapour layer on the textile surface with an odour unbearable to the insect. They can interact with the insects' olfactory receptors and make them flee. Microencapsulation of essential oils significantly improves the repellent effect for a longer duration, as this allows a controlled release of the volatile compounds from the microcapsules on the textile fibres.

Several active compounds in plant extracts also exhibit UV protective properties[1,9,13-15]. These compounds are aromatic molecules that can absorb UV radiation. Because they contain chromophores, they are coloured and are referred to as natural dyes. Another group of UV absorbers are biomolecules, such as lignin and sericin. The mechanism of UV protection is based on absorption of harmful UV radiation and conversion of UV energy into harmless thermal energy. This leads to a significant reduction in the UV transmittance of the fabric and consequently to a significant increase in the UV protection factor.

Plants are also a source of polycarboxylic acids, which can be used as green crosslinking agents in easy care and durable press finishing of cellulose[16,17]. Polycarboxylic acids, which include citric acid, malic acid, tartaric acid, and succinic acid, are mainly derived from fruits, corn, sunflower seeds, and lignocellulosic biomass. In addition to crosslinking cellulose, polycarboxylic acids can also be used to attach various functional agents to the textile surface.

6.3.2 Nano finishing guided by green chemistry

Biosynthesis of nanoparticles includes biological pathways and plasma-assisted synthesis[18-22]. Both approaches use green reducing and stabilising agents. Biological methods use plant extracts, biopolymers and microbes as reducing agents that can provide the electrons necessary to reduce precursor metal cations to nanoparticles. In this way, various NPs such as Ag, ZnO, TiO_2 can be synthesised without or in the presence of textile fibres.

Silver NPs are also successfully synthesized using a plasma without the presence of chemical reducing agents. This process involves adsorption of metal ions onto textile fibres from precursor salt solution and reduction of these ions by plasma species. To this end, both atmospheric pressure and low-pressure plasmas can be used. The aim of plasma is to provide the energetic electrons, required for the reduction of silver cations to NPs.

6.3.3 Plasma coating for textile surface functionalization

Plasma polymerisation and magnetron sputtering are green technologies for functional textile finishing[20,23-27]. Both processes use low-temperature and low-pressure plasmas. Plasma polymerisation is used to deposit very thin water-repellent films on the textile surface. Non-fluorinated liquid precursors are used for this purpose, of which hexamethyldisiloxane is the most commonly used. In this process, the liquid precursor is evaporated and exposed to plasma. The excited electrons generated in the glow discharge cause fragmentation of the precursor molecules, which break down into free electrons, ions and radicals. These species are then adsorbed onto the textile substrate where they condense and polymerize to form a dense coating.

Magnetron sputtering is used to deposit metal or metal oxide films on the textile surface. In principle, high-energy gas cations are generated and accelerated to the sputtering target. They bombard the target and eject the target atoms, clusters and ions, which then move to the textile substrate and incorporate into the growing film. This method can produce high-purity silver, copper, TiO_2 and ZnO nanocoatings that impart antimicrobial, photocatalytic self-cleaning, UV protective and antistatic properties, electrical conductivity, electromagnetic shielding and thermal conductivity.

6.3.4 Foam finishing and spray coating

In this section foam finishing and spray coating are presented as eco-friendly alternatives to the conventional pad-dry cure process[28,29]. In foam finishing, the chemical agent is prepared in a foam and applied to the textile substrate. Compared to the pad-dry-cure process, foam finishing reduces the wet pickup by 50 to 70%, saving more than 50% water and energy. Foam finishing can be applied to one or both sides of the fabric, using different foam applicators. Since the volume of the foam solution is 7–10 times greater than that of the padding, this results in faster treatment of the fabric, with fewer chemicals and heat.

Spray coating is also advantageous compared to padding. It is a non-contact method that uses a minimum amount of water and chemicals and does not require a drying step. This guarantees a reduction in water, chemical and energy consumption of up to 50%. Multiple nozzles allow large area coating on one or both sides of the fabric. Novel ultrasonic nozzles create uniform microscopic droplets that do not clog, resulting in a more uniform coating with less waste.

6.3.5 Laundry technology for circular economy requirements

In order to meet the requirements of the circular economy, the washing machine (WM) industry must be transformed toward the product service system (PSS). The concept of PSS is a special case of servitization. The focus is on "selling the use" rather than selling a product. In our case, the customer pays for a wash cycle instead of buying a washing machine. In this case, the customer benefits from restructuring the risk, responsibility, and cost traditionally associated with ownership. On the other hand, the manufacturer can improve its competitiveness, retain ownership of the WM and further improve its utilization, reliability, design and protection[30,31].

There are three main reasons why the WM industry is suitable for PSS, and they are: (i) WMs have all the characteristics that make them suitable for PSS, as they are relatively expensive and technically advanced, require maintenance and repair, are relatively easy to transport, and are infrequently used by customers; (ii) the use phase of WMs is predominant, accounting for more than 60% of the total cost of ownership; (iii) WMs have great potential for environmental improvements, as there are important advances in technology that enable savings in water and energy use[32-35].

To implement the product-service system in WM industry, we need to follow four important steps, starting with (i) PRODUCT REDESIGN (design for reliability, durability, and maintainability; design for standardization and compatibility; design for end-of-life); (ii) DEVELOPMENT OF NEW BUSINESS MODELS (sharing, pay-per-use or pay-per-performance, and leasing of refurbished WMs); (iii) SUPPLY CHAIN REDESIGN, where user return of products to the manufacturer is encouraged; and (iv) THE

INTEGRATION OF THE INTERNET OF THINGS, which provides multiple ways for the manufacturer or service to interact with WMs[30,36-40].
Despite the many factors favouring the adoption of PSS in the WM industry, there are important barriers that must be overcome for the successful transition of the WM industry to such a system[41,42].

6.3.6 Clever textile care

The 'eco' programmes of the current washing machine offer a lower washing temperature and a longer programme duration, which corresponds to the principle of Sinner's circle[43]. This concept indeed helps to save energy[44] and has been shown to work very well in terms of soil removal, together with the use of modern detergents[45]. For example, the same cleaning performance can be achieved with a standard programme at 60°C or an extended programme at 40°C.
However, numerous studies have confirmed a significant effect of temperature on the reduction of microorganisms, proving that only temperatures above 60°C cause a significant logarithmic reduction of microorganisms on a textile surface during washing. Accordingly, washing at low temperatures results in hygienically unsuitable textiles. Of particular concern is the cross-contamination of pathogenic microorganisms from different environments (e.g., when we wash clothes for home and work together), which increases the possibility of development of new diseases and their spread.
In addition, there is also a risk of secondary contamination of already washed laundry, as washing machines are a source of recontamination of textiles by biofilms formed on the internal parts of the washing machine. The biofilm can break off and be transferred to the laundry[45].
The problem of laundry hygiene can be partially solved by using washing powders containing active oxidising bleaching agents (AOB) in the form of perborates or percarbonates. However, liquid detergents, which are preferred by consumers, do not contain AOB, as they are not stable in liquid form. Therefore, it is important to use disinfectants when washing at low temperatures. Among the ecologically acceptable and highly effective disinfectants, hydrogen peroxide and peroxyacetic acid are important, as both are already used in professional laundries[46].

6.3.7 Eco-labelling relating to environmental impact

Textile care consumes more water, chemicals, and energy than textile production (e.g., pretreatment processes, dyeing, printing, finishing). Maximum energy, water and chemical savings are the goal, while toxic and hazardous chemicals are supplemented with more ecologically beneficial products that have less harmful effects on the environment and human health. The eco-labels reflect a positive statement about the environmental aspects of a product and a reward for the product's environmental leadership[47,48].
Most EU ecolabels consider toxicity as one of their main criteria. According to the European Textile Fibres Regulation, one of the main environmental goals of many European countries such as Switzerland is to maintain a "non-toxic environment." Therefore, the EU agencies responsible for developing eco-labels pay special attention to toxicity. In addition, the toxicity of chemicals and dyes used in the textile industry has significant health implications, including long-term adverse effects on the environment from the discharge of untreated toxic effluents. In addition, chemicals are considered an important criteria because there is a significant relationship between toxicity and chemicals[49].
The success of eco-labels is variable and there is a need to further educate consumers and encourage them to act in a sustainable manner. In addition, eco-labels are not easy to understand and may not be as good a marketing tool as assumed. It is difficult to track the entire life cycle of the manufacturing process, as most countries tend to export the materials needed for the processes. Developing country-specific eco-labels that take into account the gate-to-gate approach could be one of the solutions. In fact, countries that have already adopted such an approach have already significantly improved their textile export market thanks to the high transparency they have created through region-specific eco-labels[49,50].

Conclusions

- Biomolecules and bio-sourced products are suitable candidates for functionalization of textile fibres to achieve flame retardancy, antimicrobial activity, insect repellency, UV protective properties and crease resistance. An important challenge that remains is to increase the coating durability.
- Biological mediated and plasma assisted synthesis of metal and metal oxide nanoparticles represents environmentally-friendly and fast method for nanoparticles production.
- Plasma polymerisation, magnetron sputtering, foam finishing and spray coating are eco-friendly alternatives to conventional padding as they save water, chemicals and energy.
- The washing machine industry needs to move from a product-only to a product-service-system business model, aiming at lower production but of higher quality and higher energy efficiency products and consequently lower disposal.
- For hygienic and sustainable textile care, an increasing proportion of green and/or biotechnological materials needs to be introduced within the chemistry variable of the Sinner's circle.
- Eco-labelling provides environmental and social information to consumers to purchase more sustainable products. As eco-labelling continues to evolve, the creation of country-specific eco-labels with a gate-to-gate approach was deemed necessary.

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