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Directions of the Finishing of Fibres and Textile Development

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Abstract
The development of textile finishing techniques and technologies outside of reports in world-wide publications is also very visible at subsequent fairs. At international fairs, such as ITMA, ATMA and FESPA, machine, equipment and dye manufacturers present new techniques and technologies. The development of chemical fibre processing nowadays goes mainly towards the "ecological optimisation" of technological processes as well as the economics of processes. In this article, the main development directions of the chemical treatment of textiles in the field of the pre-treatment, bleaching, dyeing, printing and finishing of textile products are discussed.

Key words: *pre-treatment, bleaching, dyeing, printing, finishing technologies.*

Introduction

Progress in finishing techniques and technologies is predominantly determined by subsequent ITMA, ATMA etc. fairs. At these fairs manufacturers of machinery and equipment, dyes and chemical agents introduce new techniques and technologies. However, the direction of progress can be seen based on international and national publications as well as machineries and auxiliaries suppliers technic data sheets [1 - 72]. The development of the chemical treatment of textiles is mainly determined by ecology and economics [3, 5, 8].

The finishing of textiles comprises energy, water and chemical agent consuming processes. Additionally, increasing textile production results in an increases in energy, water and chemical consumption. Hence this necessitates ecological the optimisation of technological processes, consisting in the reduction of:
- water, energy and chemical agent consumption
- harmful substance emissions to the atmosphere
- wastes load to water, etc.

Pre-treatment

Low quality of raw cotton fibres (from the crops of Brazil, Russia, Turkey, India & Pakistan) as well as new machine construction characterised by a low liquor ratio, increased bath flow and reduction of water and energy consumption lead to shortening treatment time and reducing the number of technological operations, which necessitates the modification of pre-treatment processes.

Poor quality of cotton raw material makes it necessary to apply an additional demineralisation operation - often combined with boiling and peroxide bleaching.

Manufacturers of chemical agents for textiles [23 - 26] offer special agents for textile pre-treatment to help the process of demineralisation, scouring and bleaching and allow the combination of several technological operations in the one bath.

Textile pre-treatment processes enable proper effects of consecutive technological operations. It is estimated that 8% of errors in dyeing processes (consisting of non-uniform dyeing effects) result from incorrectly carried out pre-treatment processes [17, 18].

The scouring processes of cotton fabric can be omitted using the following :
- cold pad-batch bleach,
- desizing - mercerisation in the so-called "Mega - white" peroxide Pad - Steam bleaching,
- oxidative desizing - peroxide bleaching.

Bleaching

Bleaching processes are aimed at the decomposition of colour substances found in textile products, which are natural substances that are difficult to remove in alkali pre-treatment processes.

The removal of natural colour substances from textiles occurs through oxidation reaction. The most common oxidising agents for textile are sodium hypochlorite, sodium chlorite, hydrogen peroxide, and others.

The oldest bleaching oxidising agent is sodium hypochlorite ($NaClO$), mainly used for the bleaching of cotton goods. As a result of side reactions occurring in hypochlorite bleaching, organic chlorinated by-products are formed, which cause problems in the treatment of wastewater. An alternative to the sodium hypochlorite oxidising agent is hydrogen peroxide. Bleaching methods using hydrogen peroxide are becoming more and more common. Due to being a large environmental hazard, sodium hypochlorite has gradually limited application.

Hydrogen peroxide at boiling in an alkali condition removes most of the natural plant fibre impurities. Generally the perhydroxyl anion is believed to be the main species responsible for the bleaching effect of hydrogen peroxide [18]. However, the presence of large amounts of reactive oxygen forms can cause the degradation of the bleached fibre. To avoid these problems, peroxide stabilising agents are added to the bleaching bath. The use of stabilisers causes a gradual decomposition of hydrogen peroxide, allowing oxidation of the coloured natural impurities of plant fibres (cotton, flax). The main tasks of peroxide stabilisers are as follows:
- protection against fibre damage,
- improving of goods whitening index,
- reduction of chemical agents and energy consumption,
- reduction of wastewater.

The trends to bleach cotton fibres in low temperature peroxide technology are observed. Tanatex [22] has developed BE-GREEN technology for low temperature peroxide bleaching of textiles. The Tanatex products (Tenasperse BE and Tenade Green) and technology enable up to 60%

reduction of CO_2 emission. Tenasperse BE is a multifunctional dispersing and sequestering agent for demineralisation of cotton fibres while Tenade Green is a washing agent and low temperature hydrogen peroxide activator. CHT Group [23, 24] introduced Vario Bleach 3E bleaching technology. The technology is suitable for use in low to high temperatures. Vario Bleach 3E is a multifunctional additives for discontinuous peroxide bleaching of cotton. It accounts for peroxide activator as well as dispersing and sequestering agent for cleaning and demineralisation of fibres.

Ecological textile bleaching processes are conducted using hydrogen peroxide in a modern one-stage bleaching machine or sets for cold pad-batch bleaching processes.

The sets for cold pad-batch bleaching processes contain the following a padder equipped with a device to roll the fabric onto a beam, and an open-width washing machine.

Ramisch – Kleineweffers, for example, offered a single-stage continuous bleaching set with several configurations. The set consisted of the following:

- controlled device for applying bleaching bath RACO - YET,
- steamer- Combi - Stegmer Box,
- open-width washing machine.

Brugman [26] offered bleaching machines for semi-continuous or continuous bleaching processes. The continuous bleaching machine, known as the Brubo-Sat, consists of devices for applying a bleaching solution coupled with a roller steamer. Washing after bleaching is carried out in a modern ecological Brubo-Matic open-width washing machine giving excellent results on the woven fabric.

Benniger's [27] bleaching machines for woven fabric consists of:

- device for desizing - INJEKTA,
- devices for padding - IMPACTA,
- steamer - REACTA,
- washing machine - FORTRACTA-EXTRACTA or TRIKOFLEX.

Dyeing

The ecology and economy of dyeing processes are the two most important directions of development. Considering the ecology of dyeing processes, it should be noted that:

a) natural fibres such as cotton, wool, flax and jute account for about one-third of textile industry production. Such fibres are renewable and biodegradable. The remaining two-thirds are synthetic fibres requiring processing after use.
b) regardless of ecological trends, the dyeing of textiles necessary and will be used in the future.

Dyeing is carried out at all stages of goods processing. Hence it is necessary to reduce the ecological impact of this process. The ecological and economical impacts of textile dyeing are reduced to:

- the dye auxiliaries and chemical selection in order to eliminate harmful products for the environment and health,
- reduction of dye, auxiliary and chemical amounts used to the minimum necessary for the proper course of physico-chemical and chemical processes,
- reduction of chemical additives by increasing the simultaneous interaction of physical factors, such as temperature, magnetic field pressure, currents - high frequency fields and microwaves, infrared heaters as well as low temperature plasma,
- replacement of chemical technologies requiring the use of aggressive chemicals, such as sodium hydroxide and sulphuric acid by biotechnologies,
- reduction of energy and water consumption by using, for example, the optimisation of mechanical dehydratation or heat exchangers.
  The technology of dyeing in the future will require a new approach to the programming of the dyeing process, the structure of reactive dyes, and attempts to find a universal dye for all types of fibres (dispersion dyes would possibly fulfill this aim).
- searching for other media for dyeing, eg supercritical carbon dioxide (sCO_2) .

In order to meet the ecological and economic requirements of users, the manufacturers of dyes and auxiliaries improve their products and application.

Recent developments in dyestuffs mainly concern reactive dyes. In 2010 Hunstman introduced Avitera SE poly-functional reactive dyes [28]. The dyes enable high exhaustion and fixation on cotton in a low salt and low temperature dyeing process. The high exhaustion and fixation ensure shortening of the dyeing time and washing off after dying to 3 - 4 baths compared to 6 - 8 baths for conventional reactive dyes.

Bazactiv GO [29, 30] reactive dyestuffs were developed by CHT Group. These dyes are low temperature reactive dyes using both the exhaust dyeing processes in 40 °C as well as cold pad-batch process. Bezactiv GO and developed GO technology of reactive dyeing enable lowering of the dyeing temperature and shortening of the dyeing time.

The activities of companies with respect to environmental protection and energy savings consist in the elimination of metal-containing dyes, especially chromium. Therefore the elimination of acid dyes for chromation and the limitation of metal-complex dyes are observed.

Exhaust dyeing processes

Exhaust dyeing processes include the processing of loose fibre, yarn and warp fabric, woven and knitted fabrics (in the band and width) as well as garments. The most important problems of exhaust dyeing processes are as follows:

- reduction of water consumption
- reduction of the costs of energy, dyebath additives and dyes,
- shortening the processing time without detriment to the quality of the dyed textiles,
- the need of lowering the liquor ratio.

In order to meet these requirements, the automation of dyeing processes is necessary, but the scope and priority of controlled parameters and activities must be proportional to the development of dyeing machines. The automation of dyeing processes includes the following:

- the reproducibility of fabric dyeing,
- increasing the productivity,
- reduction of energy consumption,
- shortening the dyeing time to the minimum necessary,
- reducing the costs of direct and indirect labour,
- manual convenience of use.

The scope of automation of exhaust dyeing processes is practically unlimited. It can be limited to several technological operations as well as extended to the whole technological process, with computerised colour matching, a colour kitchen, dyeing machinery control as well as loading and unloading.

The concept of small automation has been introduced (automation of several operations) as well as full automation (covering the whole dyeing process).

The repeatability of dyeing using exhaust methods depends on many factors comparing to a continuous process.

Exhaust dyeing processes may be carried out using the following:
1. automatic colour kitchen, which includes:
   - a dye warehouse with a weighing station ,
   - a dyebath additive warehouse in the form of pastes and powders,
   - containers for liquid chemicals,
   - a central computer.
2. automatic dosing of bath additives for pre-treatment, dyeing and final treatment.
3. dyeing using liquor ratio 1:3 ÷ 1:5.
4. automatic flow control.

Already in the 90s of the twentieth century there was an increase in demand for exhaust dyeing, manifested by an increase in new machineries installed.

Therefore there is an observed tendency towards automation manifested by an increase in mechanical and electronic instrumentation, for example, supplying hot water to devices, improving the cooling of machines and waste water disposal, post-production heat recovery, as well as shortening dyeing times.

Continuous and pad-batch dyeing processes

The technique and technology of dyeing using the continuous and pad-batch methods have not changed much in recent years. The changes mainly concern an improvement in the technique, especially automation, and in the physicochemical parameters of the dyes used.

Regardless of whether dyeing is carried out with Pad-Steam, or Pad-Dry-Pad-Steam, or Pad-Direct-Steam or Thermofix, Pad-Batch, the highest demands are placed on padding machinery, which must meet a number of requirements.

Among other things, the following are important:

- determination of the hardness of the bowls - 70 - 80 º Shore,
- the ability to adjust and control the pressure of the bowls over the entire width (the same pressure over the entire width),
- floating bowls,
- a small, movable vessel,
- even application of the baths across the entire width,
- temperature regulation.

In the drying process after padding, it is important to carry it out so that there is not too much migration of the dye, which leads to:
- an uneven colouring effect,
- differences between the edges and the middle,
- a difference between the left and right side of the fabric.

The dryer consists of several segments, such as the pre-drying (infrared radiators), drying and cooling segments.

DyStar and Monforts companies [19] proposed ECONTROL T-CA dyeing technology for continuous dyeing of cellulose/PES blends using reactive dyes Levafix or Remazol and disperse dyes Dianix. ECONTROL T-CA is a simple, single pad process. The fabric is padded with bath containing auxiliary and dyes (reactive and disperse), next drying to 25 - 30% humidity, heating using Manfords Thermex hotflue dryer and washing up. An innovation of this technology is one step fixation of dyes (reactive and disperse) in the dryer, in an atmosphere of hot, humid air.

The Danitech company [31], specialising in the construction of machines for the dyeing of knitted and woven fabrics, has made a real revolution in rope dyeing machines. Daniflow dyeing (Danitech) has the most modern technical and technological solutions, which allow to achieve greater efficiency and better quality of dyed fabric. The dyeing machine guarantees minimal consumption of media, which is important for the environment. The patented system used in Daniflow dyeing machines ensures, due to a special diffuser, excellent distribution of the bath in each jet system. Also the colour measurement sensor works in direct contact with the dyebath. Daniflow machines, due to the innovative system of bath and fabric circulation, can dye fabric at a 1:4 and 1:5 liquor ratio. Also Danitech offers dyeing machines with a small load capacity (5, 10 kg), which can be used as laboratory devices. Standard dying machines have a capacity of 50 - 100 kg.

The vacuum suction technique in the form of a slotted beam occurs, among others, in the Henriksen device (Denmark), vacuum pre-treatment technology Wet-Tex (Germany) and vacuum technique EVAC, used in the continuous dyeing process. The vacuum suction method is an effective way to remove excess water, dyeing bath or finishing bath from textiles. The advantages of this technique are saving energy and the possibility of reducing the consumption of finishing agents (e.g in the process of anti-wrinkle finishing of cotton fabrics containing a certain proportion of PET fibres).

Dyeing in water after magnetic treatment

The use of physical phenomena for water treatment in water systems has been known in the world for 60 years. Water flowing through an electromagnetic or magnetic conditioner changes its physical structure, but does not change its chemical composition.

The following water properties change:
- the surface tension of water increases, thus changing the sorption-absorbing properties of water,
- the viscosity of water decreases,
- the specific gravity of water changes slightly,
- the electrical conductivity of water changes.

The physical properties of water after magnetic treatment and the possibility of adjusting the processing parameters depending on the technological processes in which it is applied, have contributed to the use of the magnetic field effect on water in many fields, including textile. Czaplicki and Sedelnik [33 - 36] developed a technology of dyeing wool fibres and fabrics in water after magnetic treatment.

The evaluation of individual water variants and selection of the optimal variant of water treatment were carried out during dyeing tests:
- fabrics containing 100% wool,
- Australian sheep's wool, washed, white, and with a diameter of 24 μm.

The dyeing processes were carried out using navy blue and green 1:2 metal-complex dyes. The technology developed allows to increase dye exhaustion as well as improvement of colour fastness to washing at 40 ºC and colour fastness to wet rubbing.

Optimal conditions for water treatment is a magnetic field with an induction of 0.18 tesla and treatment time of 4 - 5 seconds. The technology developed was implemented in the textile industry. The measurable effects achieved were a 15% reduction in the demand for dyes.

Ultrasound-assisted dyeing processes

Since the 1990s many scientific works have been conducted on the use of ultrasounds (cavitation phenomena) in wet textile processes [37 - 55]. The research on ultrasound-assisted textile treatment concerned:

- the washing of fibres and textiles [38 - 39], leather [52], and medical tools [43];
- cotton bleaching [42];
- the dyeing of cellulose fabrics [37, 55], woollen fabrics [44, 45, 47, 50 - 53], acetate fabrics of cellulose fibres [49], and textile products from PAN fibres [51].

The ultrasonic technique can also be used in chemical research on the qualitative analysis and evaluation of cotton/polyester blended products [46].

Research on the dyeing of cellulose (cotton) fabrics was also carried out in Poland by Ruszkowski [37]. Fabric samples were dyed with direct dyes and with ultrasound support of the dyeing process. The variable parameters were the temperature and staining time. The dyeing of cellulose fabrics with direct dyes allowed to obtain brighten colour than in the classical method. The high fastness to wet rubbing observed corresponded to the fastness of much more expensive vat dyes. The possibility of shortening the dyeing time from 70 to about 30 minutes within the same end result was observed.

Czaplicki and Ruszkowski [39] solved the problem of washing alpaca wool with the use of ultrasound assisted washing. Alpaca wool washed using typical methods in an industrial washer shows a tendency to muddle up. The muddled wool fibres are unsuitable for further mechanical processing. Washing with the use of an ultrasound device (Sonic-14) gives not muddled alpaca wool fibres afterwards. The ultrasonic-assisted washing process also resulted in shortening the washing time as well as a reduction in water, energy and detergent consumption. Ultrasonic washing technology was implemented in 2011 on an industrial scale.

The research results obtained for ultrasound-assisted textile treatment indicate great possibilities of obtaining measurable economic effects. The main benefits arise from the following:

- water and energy savings,
- shortening the treatment time,
- reducing chemical agents in washing, bleaching and dyeing processes,
- limiting pollution of the environment (clean wastewater).

Directions of textile printing development

The development of textile printing techniques and technology are influenced by the following:

- dissemination of the printing of sports goods, rugs, youth clothing, etc.
- introduction of patterning automation on a large scale.
- introduction of electronic control of printing processes, in particular the reporting and automation of printing form production.
- further development of transfer printing.
- development of digital printing.

Similar to other chemical treatments of textile in textile printing, ecology has become a major problem. This refers to the threats to the environment posed by printing processes, whereby the contamination of wastewater from the colour kitchen as well as wastewater after the washing of printed goods are of fundamental importance.

The utilization of printing ink leavings of and their residues in effluents is a huge and partially solved problem.

From an ecological and economic point of view, the problem of the effective treatment of printing effluents and waste recycling is very important. Manufacturers of dyes, pigments and chemical agent are looking for new solutions for the treatment of printing waste and effluent. Reactive dyes and pigments are most often used as colour substances for the printing of textile goods.

The limitations of using traditional natural thickeners are observed, which are substitutes fir synthetic thickeners.

The development of new printing technologies

Spray-nozzle printing, developed by the Japanese companies Canon and Canebo and the Dutch company Stork, is known under the name “Ink-jet”. Ink-jet printing is becoming an alternative to screen printing due to a lack of printing forms, design and colour possibilities as well as easy changing of the printed pattern. Ink-jet printing technology is based on two treatments:

- initial preparation of raw material,
- printing using the ink-jet system.

The subsequent course of proceedings, such as dye fixation, washing and drying, are identical to those in classical printing post-treatment. The total quantity of effluents from ink-jet printing amounts to 10% of that from screen printing technique.

A machine for the spot dyeing of carpet yarns produced by SUPERBA (France). The machine is very popular, especially for the spot dyeing of PA and PAN yarns.

The transfer printing technique was introduced in industrial application in the early 1970s. After the first euphoria and the opinion that it would replace the screen printing technique, it turned out that transfer printing is practically applicable to polyester and polyamide products. At the turn of the 80s and 90s of the twentieth century, new wet transfer technology (named DANSKTARFERTRYK AIS KAST) designed for cotton fabric was introduced by AIS KAST (Denmark) and Keuster (Germany). The cotton transfer printing machine was first introduced in 1993 at the OTEMAS fair. The transfer printing of cotton textiles with reactive dyes does not play an important role in the textile printing industry.

Pigment printing

Although pigment printing is not a new step in the development of printing techniques, due to the recent greater interest in this field of print on the part of users and manufacturers of chemicals, it has recently been given more attention.

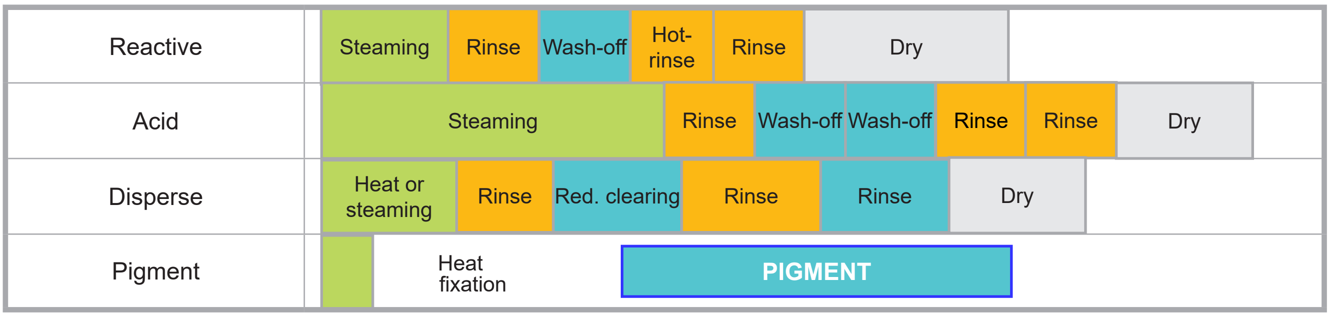

Figure 1. *Post - treatment flow for different inks (ALPHA INK P).*

Pigment does not have any affinity to textile fibres. Pigments are mechanically attached to a fabric surface using binders.

The method of fixing pigments onto fibres is universal, allowing them to be applied to all textiles: natural, synthetic and mixed fibres. The advantages of pigment printing is the lack of after printing washing, which is absolutely essential from an ecological point of view.

Hybrid ink-jet printing

Mimaki [56 - 58], a manufacturer of large format inkjet printers (Tx300P-1800 and Tx300P-1800B), has revolutionised the digital printing machine to allow the use of one printer for direct printing on a wide range of fabrics without the need to replace ink systems. The device is used to load pigment inks as well as sublimation dye inks. This new technology, which until now has been unattainable, is a breakthrough in improving productivity and increasing the flexibility of Mimaki's textile printers.

Manufacturers can quickly and easily change the types of fabrics by choosing the right ink system for each one. Inks do not require the use of water in the process of additional treatment, which also makes them environmentally friendly. Mimaki offers 5 different types of ink for the printing of textile, including sublimation dye, disperse dye ink, pigment ink, reactive dye ink and acid dye ink.

The Tx300P-1800 printer allows to print directly onto almost any type of natural or manmade fabric. The Tx300P-1800 printing machine allows to print on various types of natural and man-made fabrics and is an ideal solution for the clothing industry in the production of clothes and soft materials for interior decoration.

In 2016 - 2017 [57] at trade fairs Mimaki showed the industry printing machine TIGER-1800B. The TIGER-1800B printing machine was developed for direct printing on textiles. The Mimaki company with TIGER-1800B has moved from basic and middle-class printing machines to an industrial machine, which can accelerate the current transition in the industry from analogue to digital technology.

On 16th - 18th May 2018 [58] in Berlin, the FESPA digital trade fair took place. At the event, the company Mimaki presented a series of Rimslow printing machines - a complete system for digital printing on textiles and clothing. This series includes a new industrial digital printing machine - TIGER 1800B MkII for textiles. This printer enables inkjet printing directly on textiles.

Recently new possibilities have appeared in the digital industrial printing of textile materials using pigment inks containing a binder [58]. The digital production process has enabled the printing time of textile materials to be shortened at every stage as compared to the analogue screen printing technique. The Polish textile industry has become faster in operation thanks to digital printing and has adapted to the global trend of reducing the printing costs of individual material designs while increasing the number of types of printed designs at the same time. Currently a new technology - printing textile materials with pigment inks containing a binder can change large-scale textile digital printing. The technology of printing with pigment inks containing a binder was developed by DurstPhototechnik AG for printing with the Alpha190/330 series of digital industrial printers [59]. Until now, reactive inks (acid and disperse inks to a lesser degree) have been used in the industrial printing of materials as the most effective and durable, covering the widest range of textiles. Thanks to the innovative features of pigment inks containing a binding agent, this situation may soon change. First of all, technology using pigment inks containing a binder allow to save time and reduce production costs compared to technology using acid, dispersion and reactive inks. The binder contains pigment inks and does not require chemical preparation of the textile material, and unlike other types of ink (***Figure 1***), it does not require chemical fixing, washing, steaming or other additional activities after the printing process. The only necessary element is fixing the printout at a suitable temperature using a frame drier, and the production process ends at this stage [59].

Another advantage of pigmented inks containing a binder is their durability and resistance to various degradation factors. Pigment inks are not inferior to other types of inks, and often exceed them.

An additional feature of the binder containing pigment inks, which is very important from the user's point of view, is their colour range (the ability to obtain saturated colors, shades and deep black). It remains practically at the same level as in reactive inks [58]. This fact raises the attractiveness of this type of ink by another level. The binder containing pigment inks outperforms the remaining types of inks also in terms of light fastness. The level of light fastness is the basic parameter for many printed materials. Taking into consideration the above features of innovative pigment inks, it may be expected that their application in textiles printing processes will become popular.

Textile finishing

The finishing of textiles not only gives functional features like anti-shrinkage, anti-wrinkle, water-repellent or flame-retardant properties, but it also changes the handle, the smoothness of the surface goods, as well as the surface look.

Moreover manufacturers of textiles have to meet the requirement of fashion designers in the scope of colour, handle and other added properties.

Natural (most often cotton) as well as man-made fibres, such as viscose and synthetic fibres (polyester, polyamide), are the most common used for the production of textiles. There is observed a tendency to make synthetic fabric similar to natural fabric by giving it a soft, silky handle using appropriate finishing processes. A number of finishes are introduced, but trends in world fashion determine the kind of finishing process used.

In the field of traditional textile finishing, we can observe the introduction of a number of new chemical agents intended for finishing, such as softening, anti-wrinkle, anti-shrinkage, water-repellent, flame-retardant, antibacterial and UV-blocking finishing.

Machines for the chemical and mechanical post-treatment of textile such as padders, dryers, tumblers, brushes and other finishing machines have been modernized. A tendency is observed to use nanotechnology in textile finishing. Some nanomaterials, such as montmorillonite and carbon nanotubes (CNT) added to a standard flame-retardant finishing agent have significantly improved fabric resistance to flame [60]. Silver nanoparticles (AgNPs) are widely used for antibacterial finishing of textiles [61-63]. Textiles dyed with some cationic dyes as well as those finished using some softening agents have antibacterial and antifungal activities [64].

Significant development of surface modification mechanical technologies of textile products was observed by microabrasion using a special, mineral fine-particle contained abrasive material or combined with enzymatic treatment.

Since 1991's ITMA, when the Italian company Biancalani presented the first machine (named AIRO 1000) for controlled textile surface treatment using hot air with additional use of enzymes, techniques and technologies of textile surface treatment have grown considerably.

The varieties of tumbler is universal flat textile processing machine, where treatment is carried out in a washing bath, in an enzyme bath or in hot air at temperatures exceeding 110 °C. The controlled treatment conditions (temperature and humidity of the product) allow softening (by breaking), drying and surface finishing.

Various treatments are applied in parallel: mechanical (tumbling), physical (abrasion), chemical (softening) or biochemical (enzyme treatment). This allows to obtain appropriate modification of the surface of fibres and products, giving them the effect of softness, fluffiness and better ductility.

The use of this type of treatment allows to obtain a whole range of currently fashionable surface effects, such as SNOW-SAN-WASHED, STONE WASHED, the Lunar Stone effect and telluric effect.

Telluric finishes using Sirrix LUNA [67] products i.e. bio-microlite with encapsulated cellulasic enzyme, modify the hand and look of a textile surface. This technology allows to control the bio-mechanical erosion of a textile surface with enzymes and microlite. The telluric finish produces a visual effect due to modification of light remission and decreasing of the gloss effect. According to some researchers, telluric finishing can make cotton similar to velvet, viscose to silk, and wool to cashmere.

Telluric finishing includes pre-treatment, alkaline treatment, the use of bio-microlytes, enzymes and special surface agents. The processing may be subjected to products of various structure, such as suede and artificial leather products.

Special effects of the surface finish (AIRO-hand) can be obtained in the AIRO [68] Biancalani washing and drying machines (AIRO-DUE, AIRO-QUATRO). The AIRO finishing is based on the combination of fabric transport by air and crashing fabric against special gird using high speed. The AIRO machines with washing function enable application of softener, washing, treatment with enzymes as well as desizing, scouring and bleaching.

Sol-gel coating of textile

Among the several technologies of textile chemical treatment currently developed, the technology of multifunctional nano-coat finishes using the sol-gel method should be mentioned [65]. This enables to give multifunctional special properties (self-cleaning, photocatalytic, bioactivity, UV-blocking etc.) to nano-coated textiles. Nano-coats by the sol-gel method enable the creation of very thin xerogel film, which is strongly adhesive and chemically bonded with the textile surface. This technology was developed at the Textile Research Institute and Wrocław University of Science and Technology [65]. The results obtained create real opportunities for technology applications in the textile industry.

The sol-gel method is used to produce ceramic sub-micro particles of 100-500 nm size, often functionalised with nanoparticles having different activities, mainly bioactive, and bonded adhesively to the surface of ceramic sub-micro particles developed.

An important area of the sol-gel method is the direct production on a textile surface of thin (100-300 nm thickness), crosslinked, inorganic, porous, gel coatings of semi-metals or metals oxides, mainly SiO_2 or TiO_2 [65]. These coatings are strongly bonded to the surface of the fibres as well as being flexible, transparent, colourless and resistant to chipping. Moreover the nano-coats do not change the original characteristics of the textile fabric, such as strength, aesthetics and use comfort. A very important feature of the coatings produced is their high ability to be filled with various types of active nanoparticles which may change the following properties of textile products:

- physico-mechanical properties, such as resistance to abrasion and pilling formation,
- surface properties, such as wettability, hydrophilicity, hydrophobicity, oleophobicity, and photocatalytic activity,
- barrier properties, such as protection against UV radiation or the ability to shield electromagnetic fields,
- bioactive properties in relation to bacteria and fungi,
- other properties, such as flame-retardant and optical properties.

The process of producing nano-coats on the surface of fibres with the sol-gel method can be divided into three basic stages [62]:
- the synthesis of nanosol from selected precursors, most often silanes,
- the application of nanosols to textiles, usually by padding,
- thermal processing - drying and post-heating / cross-linking.

The synthesis of nanosols consists in the acid or alkaline hydrolysis (in water or in a mixture of water with organic solvents, such as ethyl alcohol) of precursors in the form of metal oxides or semimetals, alkoxides, and most often organosilicone - modified silanes and alkoxysilanes. These nanosols can be modified chemically or physically, which creates wide possibilities of their functionalisation [68].

As a result of the production of thin coatings on the surfaces of finished textile products, the finished "nanocoated" products can obtain many different added properties (***Table 1***) [65 - 68]. The selection of these additional functions depends on the type and use of the finished textile products and the expectations of end users, while the special feature of nanocoating finishes is multifunctionality. This multifunctionality results both from the protective action of xerogel coats as well as the addition of functional nanoparticles.

As a result of research carried out at the Textile Research Institute and Wrocław University of Science and Technology – a gel for textile materials for various uses was developed, enabling optimisation of their already existing functional properties or giving them the new features expected [65]:

- sol-gel coating to increase the durability of textile materials.
- sol-gel coating of PET/CO woven fabric with bioactive and increasing durability properties.
- sol-gel coating of PET/CO 80/20 fabrics with increased durability and photocatalytic self-cleaning and UV barrier properties.

Sol-gel coating of PET/CO 67/33 fabric with increased durability and bioactive, photocatalytic self-cleaning and UV barrier properties.

The technologies of thin-layer coatings using sol-gel methods allow to give textiles new, special multifunctional properties and will be implemented in the textile industry [65].

Table 1. *Examples of the functionalisation of textile materials as a result of sol-gel coating [65 - 68].*

Functionality	Exemplary precursors / additive used in the synthesis of sols	
	precursors	additive
increased durability, resistance to abrasion and pilling formation	epoxyalkyltrialkoxysilanes, e.g. 3-glycidylpropyloxytrimethoxysilane, tetraethoxysilane, aluminium isopropoxide	nanoparticle Al_2O_3
bioactivity	epoxyalkyltrialkoxysilanes, tetraethoxysilane	nanoparticle Ag, Cu, AgCu, AgCl, ZnO, organic biocides
photocatalytic activity	titanium isopropoxide, epoxyalkyltrialkoxysilanes	nanoparticular TiO_2, ZnO
UV-barrier	epoxyalkyltrialkoxysilanes, tetraethoxysilane	nanoparticular TiO_2, ZnO, organic UV absorbers
hydrophobicity	alkyltrialkoxysilanes, hydrophobic polysiloxanes, vinyltrimethoxysilane, phenyltriethoxysilane	organic fluorocarbon compounds

Summary

The ecology and economic aspects of technological processes in the textile industry determine the application and development of techniques, technologies and chemical agents used (including dyes).

Ecology is an important goal of all technical progress. Moreover the ecological optimisation of technological processes also has an economic aspect. Avoiding the use of materials or processes that pose a threat to the environment is cheapest, while all activities aimed at eliminating damage and environmental degradation, thus cleaning the environment, are more difficult and more costly.

Ecological optimisation is conducive to the manufacturing of products using technologies and materials that do not pose a threat to the natural environment of man.

The economical management of technological processes results from the reduction of production costs, and thus the reduction of the consumption of water, energy, raw materials, chemicals, human work and machine operation time. The development of waste-free modern technologies is also observed.

Economics and the free market impose the necessity of manufacturing products of high quality at the lowest cost.

Analysing the development of techniques and technologies of the chemical treatment of textiles, it can be concluded that:

- In pre-treatment processes, limitation of strong alkali and strong bleaching agent use (chlorine derivatives) and replacing them with environmentally friendly chemical agents, such as H_2O_2, is observed. There is a tendency to combine several stages of pre-treatment processes into one, as well as bleaching processes in low temperature;
- There is a tendency in dyeing processes to limit the use of methods and chemicals harmful to the human and environment. In many countries, regulations prohibit the use of a whole range of dyes and auxiliaries. Construction solutions for dyeing machines and devices are not undergoing huge changes; mainly the electronics are changing. Manufacturers offer energy-saving machines partially or fully automated, with advanced process control.
- In printing processes, the development of new printing techniques is observed, especially digital printing, which is a revolution in textile printing technology.
- New techniques and technologies, such as plasma treatment, digital printing, dyeing in supercritical CO_2, dyeing in water after magnetic treatment and ultrasound-assisted dyeing still require time for wider industrial applications.
- New technologies for the finishing of textiles using the sol-gel method are important achievements that have a real chance of application in the textile industry.

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