3.3 RESEARCH ON THE PROCESS OF CONTAMINATING TEXTILE MATERIALS

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Contamination of textiles is the main purpose of their consumer properties loss. It damages their hygienic properties, adds them unpleasant smell, and causes the material ruining. Contaminations change the textile colour and serve as a source of pathogenic microorganisms. Adipose matter present in natural fibers as well as that one added with other contaminants contributes to pigment contamination particles fastening on textiles. Contaminations deteriorate appearance and hygienic properties of textiles and ruin them. For instance, dust, sand ant other sharp edge particles constantly move and wear the fabric out [1].

Contaminations are heterogenic mixtures of substances that differ in their chemical composition and physical properties. Contaminants can be relatively uniformly distributed on a cloth fabric surface (general contaminations). They can also get on textiles and remain there in form of separate particles, namely stains (local contaminations). Clothes are contaminated especially non uniformly. Thus, places of the strongest contamination are the parts of contact with human skin such as a collar, cuffs, pockets and fastenings. Fibrous dust is collected in inner seams and folds of articles. General contaminations are caused by pigment particles as a result of diffusion of particles with 0,1 mcm particle size from the air, falling bigger parts (1-2 mcm) out, picking them up from an air stream, electrostatic attraction of particles with 0,2-0,5 mcm particle size. Local contaminations in form of stains are caused by liquids penetrating into filament capillaries, between filaments and threads of fabrics thus changing the degree of the light dispersion, a textile colour, its colouring and tints [2]. Fig.1 presents the surface of polyester material contaminated with pigment particles.

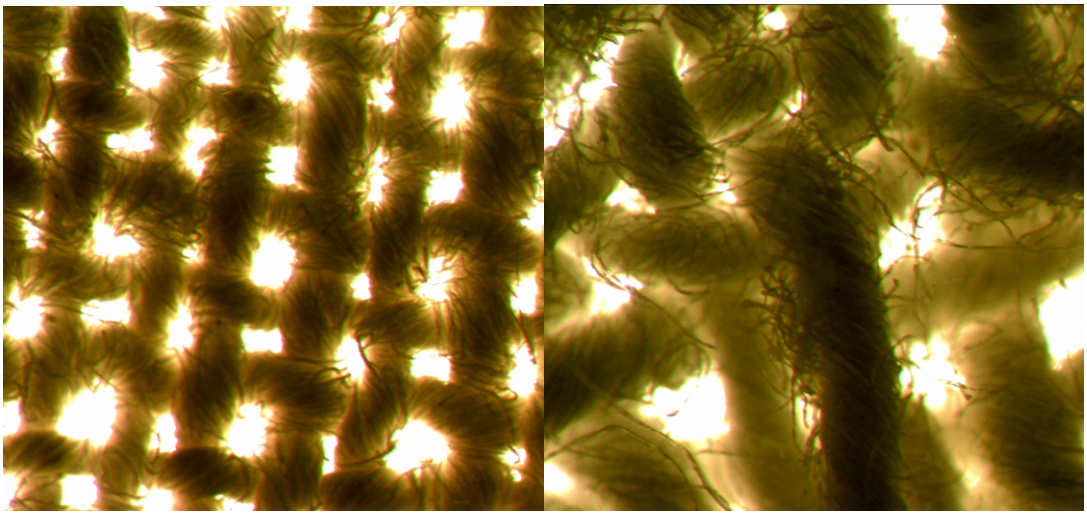

Fig.1. Contaminated surface of the polyester material

A contamination composition, its colour, quantity and the degree of its fixing on a fabric depend on its function (either outer clothing or underwear) and are mostly determined by the environmental conditions as well as by industrial and everyday activities of people. All contaminations can be divided into three main classes [3]:

1) soluble in water organic and inorganic substances (sugar, urea, albumins, salt, organic acids, etc.);

2) soluble in organic solvents but insoluble in water contaminations (e.g. fat, oil, resin, lacquer, asphalt, fatty acids, etc.);

3) insoluble in water and in organic solvents substances (earth pigments, clay, silicates, cement, soot, atmospheric aerosols).

Experience and research have proved that more than half of contamination components found on outer clothing are soluble neither in organic solvents nor in water. Approximately 10% are soluble in solvents and nearly one third of all contaminations consist of substances soluble in water [4].

All textile contaminations can be divided into industrial and domestic ones depending on their source. Qualitative and quantitive composition of domestic contamination is fairly varied [3]. Difficulty of their removing is determined by different energy of their connection with textile filaments and is characterized by different degree of their penetration into a fabric structure [2]. For instance, the strongest connection of contamination with a filament takes place due to covalent connection working at 0,07...0,2nm distance. Such

connections are formed by unsaturated fatty acids, ether oils, resins and dyes with cellulose, wool and polyamide fibers. Coordinating connections are formed at interaction of substances containing tannin and a metal atom - contaminations caused by juice or beverages. Hydrogen connections are formed by atoms of hydrogen and electrically negative atoms (those of oxygen, chlorine and nitrogen) working at 0,24... 0,33 nm distance. Van der Waals forces manifest themselves in condition of articles contamination by liquids and act at 0,3...0,4 nm distance.

Textile contamination depends on its filament contamination as well as on the filament structure. Filament contamination is determined by its chemical structure, various furrows, scales, cracks and other rough things which keep contamination particles. Moreover, a textile article contamination depends on conditions of its exploiting and on its capacity to keep dirt [1,2]. All textiles are porous sorbents. The majority of domestic and industrial contaminations are initially absorbed in mezzo and macro pores, mezzo pores being inter-filament gaps and macro pores - inter-filament capillaries. These pores are transport channels for contamination particles penetration into a filament structure.

Thus, textiles and textile articles contamination is a complicated physical and chemical process connected with the material structure as well as with the nature of contaminants themselves that is with the environment that can be the source of contaminations and their interaction.

Such stages can be traced in the process of textile contamination: diffusion of contamination into a fabric surface; absorption of contaminants by the textile surface; their diffusion into the filaments; their fastening on the filaments [3].

Textile contamination is determined by surface interaction between the particles of dirt and a fabric that is possible due to spare free energy on the fabric surface, surface tension that appears due to unbalanced forces of molecular cohesion on the upper layer. A possible chemical connection between interacting particles of dirt and a fabric which appear in the process of their wearing out and ruining (chemical absorption) should be mentioned. Furthermore, the process of contamination is followed by lowering surface energy of a textile.

Dry contamination and dirt binding of a textile material depend on its surface resilience and cleanness. A layer of finishing agent, oil or fatty layers on its surface heighten its contaminating capacity, dirt particles binding. The worse that layer dissolves in a detergent, the more difficult it is to remove the dirt from the textile material [1].

Interaction of liquid contaminations containing water or oil with textile surface appears in the form of moistening. The lower the surface energy of liquid contamination is, the more obvious the difference between the surface energy of the textile and the liquid contamination is and thus, the more effective the process of moistening is.

Hydrophilic properties of textiles play important role in their contamination by soluble in water contaminants (juice, wine, coffee). Diagram 2 presents hygroscopicity of natural and chemical fibers in standard conditions.

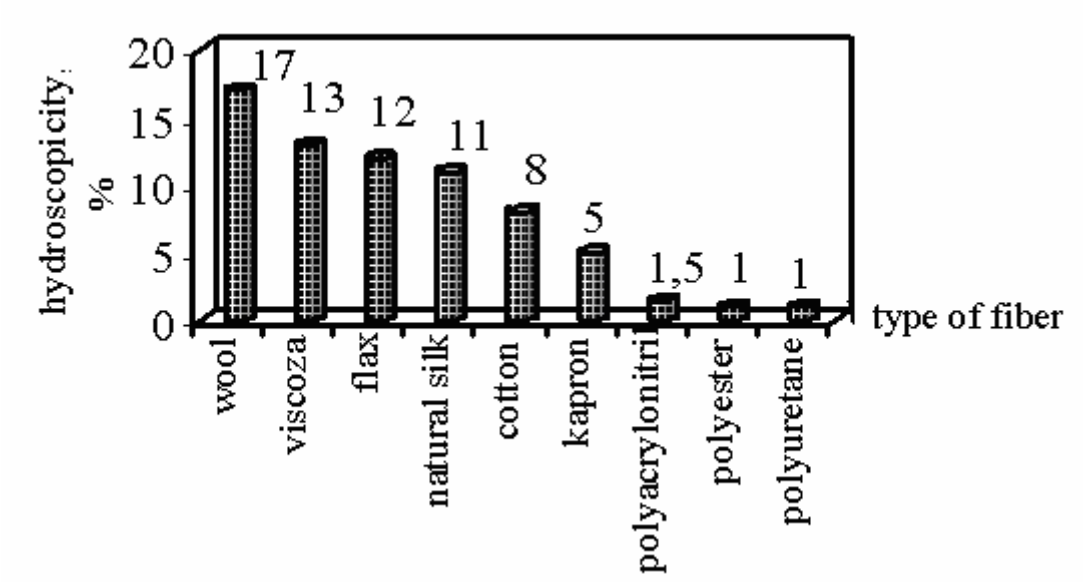

Fig.2. Hygroscopicity of the fibers

Growing hydrophilic properties of textiles help liquid contamination penetrate into a fabric quicker while soluble in water natural contaminants fasten on the fabric firmly due to intermolecular forces [5, 6].

Textile contamination by oil and fatty contaminants is explained by its oilphilic characteristics. These characteristics help moisten the fabric with oil- and fat-containing contaminants, penetrate them into the textile and fasten on it.

According to contemporary standards the complicated process of textile cleaning is influenced by such factors as contaminants nature and concentration; chemical composition and morphology of a surface, which is subject to cleaning; nature and concentration of a micelle-forming surfactant (or its mixtures); certain chemical components (electrolytes, complex- forming agents, anti-sorbents); technological parameters of the cleaning process; stability of contamination dispersion in the process of cleaning and its capacity of hetero coagulation on the substrate surface. These factors are interconnected and depending on circumstances can be determinant or insufficient.

From the point of view of physics and chemistry, the mechanism of contamination removal is considered as adsorptive displacement followed by the change of selective moistening conditions and the process of emulsification, solubilization as referred to fat-like dirt [7, 8].

The fundamental principle of a cleaning process is the textile capacity to get moistened, the main characteristic of which is edge corner moisten [9]. The smaller the figure is the better the textile moistening capacity is. A contaminated fabric has fat- or oil-like layer on its surface. That's why in the process of the dirt removal it's necessary to influence the system that consists of a hard surface and two liquids, namely oil and a detergent (Fig. 3). At the beginning of the process of oil contamination removal the detergent ball-like particles spreading takes place on the fabric surface. The result of the contaminated fabric moistening is the contrary process of oil turning into balls and their removal from the fabric. The oil covering the fabric surface moves off in some places under the detergent influence thus forming segments, which turn into semi-circles. After that a ball-like drop is formed, which is removed into a wash tub as a result of a slight mechanical action.

Due to detergents found in washing solutions oil drops are emulsificated, splintering into smaller drops. Surfactant molecules are absorbed on the surface between oil and water thus forming a protective capsule around each drop. The speed of emulsification mainly depends on interphase tension while the emulsion stability is primarily determined by the firmness of capsules around oil drops as well as by the degree of dispersity [7, 10].

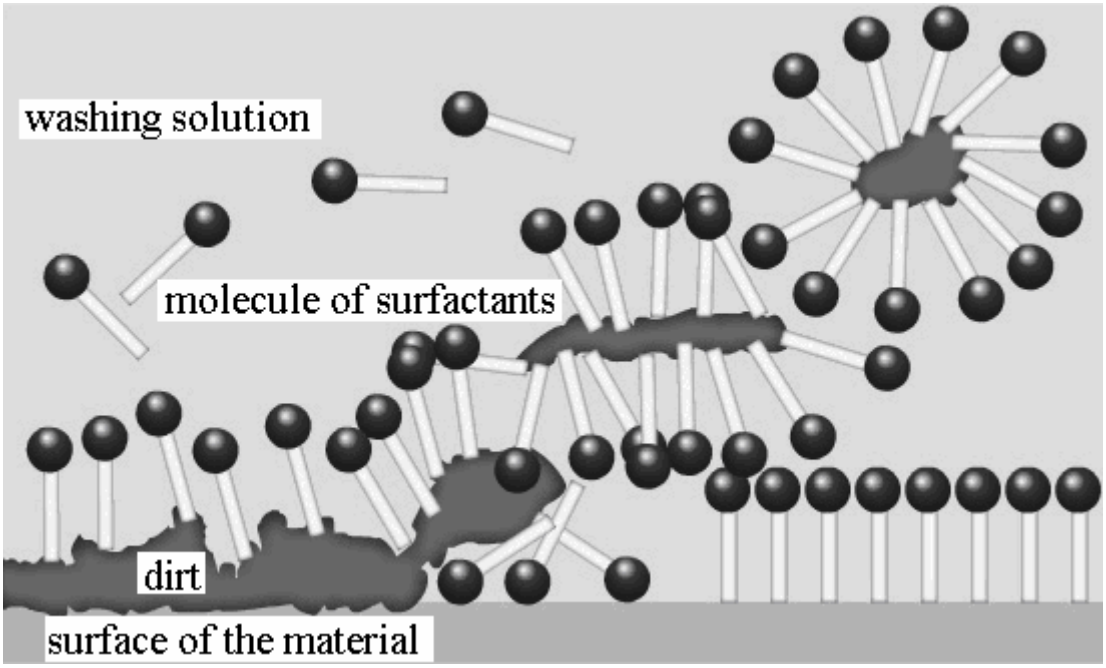

Fig. 3. Mechanism of dirt removing from the surface of textiles

It's much more difficult to remove hard dirt as pigment contaminants are often found in the form of conglomerates combined by fatty substances. Cleaning detergents moisten hard dirt thus forming protective capsules around separate particles. Detergents penetrate into separate cracks and reduce the forces attracting separate particles. A pigment complex is ruined and then separate free particles are again surrounded by the oriented absorptive layer. Dispersed pigment dirt is removed from the fabric mechanically by means of electrostatic repulsion.

As a result of a detergent absorption on the fabric surface with drops and particles of dirt adsorption - solvate layers are formed. Their forming helps to separate dirt particles from textiles and prevents them from recurring accumulation. But dirt can be separated from textiles in form of particles and aggregates where particles interact directly with unprotected parts of surface or through thin layers of liquids. Stabilization of dirt particles detached from textiles in a detergent plays important role for their effective removal as it prevents them from recurring accumulation (resorption) on the fabric. In case of insufficient dispersion stabilization dirt particles adhesion or their fixing in a secondary potential hole may take place in course of their interaction via the liquid layers [1, 3]. Thus, for removing dirt from a textile fabric it's necessary to

ruin the connection between contaminants and filaments and remove the dirt from the fabric surface.

To assess the articles cleaning process adequately model samples were used. They were contaminated by a complex contaminant on the basis of oil and indissoluble substances as they are the most resistant to cleaning.

For that purpose 5 x 15 cm models were used. They were treated with the substance consisting of 100 ml kerosene, 2 g spindle oil, 0,2 g black pigment. They were treated for 5 minutes in mixing condition. Then the models were wrung out and dried during 24 hours. Uniformly contaminated models were used to determine the degree of the dirt removing [11].

Contamination (Z) (Table 1) of textiles was determined according to different Indices [3].

Table 1 - Contamination of materials according to different methods

Fabric	R_0	R_3	Z_1	Z_2	Z_3	Z_4
Wool	0,55	0,122	2,975	77,82	0,65	0,522
Polyester	0,705	0,116	3,307	83,55	0,78	1,013

The research on textiles contamination proves that different optical methods for determining the degree of textile contamination result in inter-coordinated figures. According to these methods wool is contaminated poorer than polyester.

The process of removing contaminations is complicated by the fact that textiles can be contaminated by different quantity of contaminants that differ in their chemical nature and solubility in organic solvents.

For detailed research on the process of textile contamination conformities filaments of wool, lavsan, nitron, kapron, viscoza and triacetate were contaminated with fatty and soluble in water substances in organic solvents such as Perchlorethylene (PChE). The chosen filaments are mostly found in form of two- or three-component combinations with wool that are used for making outer clothing. Solutions of 50 g/l and 100g/l sunflower oil in PChE and 10% salt and sugar water solutions were used as models of contaminations. The contaminations were added by means of slop-padding at MB = 20 during 15 minutes and the model samples were wrung out between cylinders. All the

examples were dried at room temperature. The degree of contamination was determined by graviametric method. In addition, to determine the quantity of NaCl the photometric method of analysis was used. The polarimetric method was used to determine the quantity of sugar [12].

All the materials depending on their hydrophilic or hydrophobic capacity are stronger contaminated with soluble in water substances than with fatty ones as they sorb more water than PChE, which is the environment for contamination dissolution (Table 1). That also explains the fact that the contamination of filaments by sugar is almost the same as that one by salt. The exclusion is viscoza that is characterized by high level of hygroscopicity and the amount of moist sorbed by the model example influences its mass in the process of determining the degree of its contamination with the help of gravimetric method. Thus, when contaminations are added this way they mostly fasten on fibers due to mechanical filling pores and capillaries with the liquid containing them. On the other hand, the contaminations themselves influence the process of wringing fibers out: wringing salt and sugar water solutions out of the examples is more difficult and irregular than that of clean water. In this case, the concentration of salt and sugar in the wrung samples is smaller (3-8%) than in the initial contaminant solution (10%) as the molecules of water from the solution can penetrate inside filaments and the contamination stays on their surface or slowly diffuses into the near-surface layers [13].

Table 2 - Contamination Z, mg/g textile filaments

Type of contaminant	Type of filament					
	wool	polyester	polyacrylonitrile	polyamide	viscose	acetate
fatty substance	48,7	30,2	61,5	36,7	28,7	27,2
salt	96,1	70,5	107,8	68,2	142,0	68,2
sugar	92,1	70,1	118,0	64,3	72,8	55,6

By analogy, we can trace the interdependence between textile contamination by fatty substances and the degree of PChE sorption (S, %)

determined after the dipping model samples into a solvent for 15 minutes and their subsequent wringing in a centrifuge at the regime unified for all filaments .

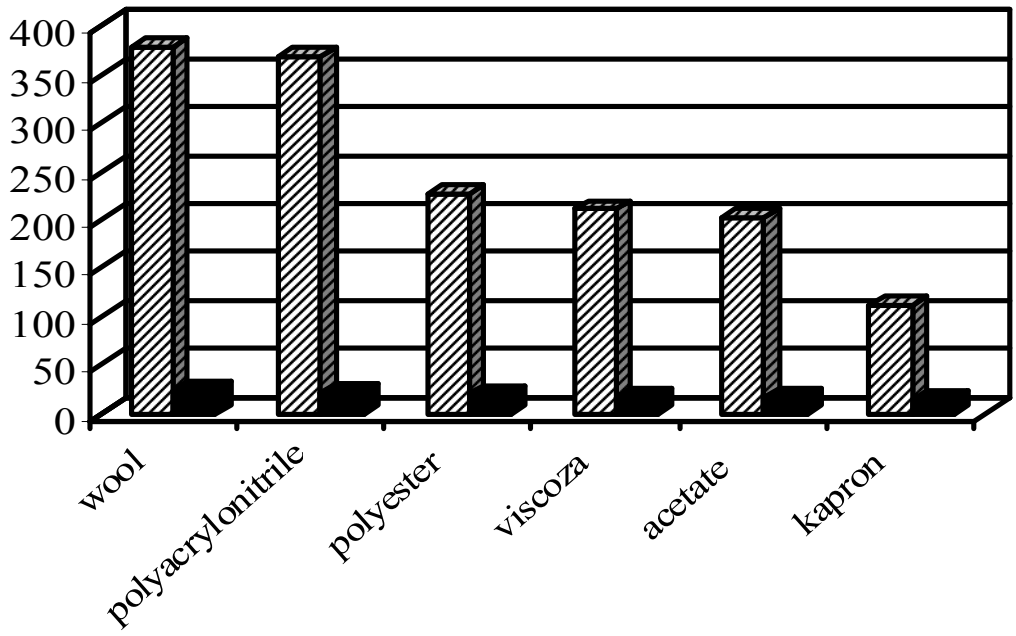

Fig. 4. Contamination (▨ - Z, mg/g) and sorption of pollution (■ - S, %) in the filament

According to the abovementioned data we can conclude that wool (among the researched textiles) is subject to the strongest contamination by fatty substances while kapron is the least contaminated by them. As for the soluble in water contaminants - viscoza and kapron are accordingly. Low contamination capacity of kapron can be explained by the smooth surface of its filaments. In case the filaments contain a week old or older fatty substances, their removal quality is much lower as fatty substances are rather quickly oxidize even at room temperature, the result of which is forming linoxin layer that is hard to dissolve in water [3]. That phenomenon once more proves the fact that such factors as a fabric structure, the order of separate filament placement, the mode of interweaving, ant the characteristics of its surface have an important impact on its contamination. It's impossible to compare the amount of contamination determined by optical methods for various materials (e.g. the degree of polyester contamination in comparison with other materials) as the results are different.

The research has proven that all the forces and factors depending on the structure and qualities of dirt and a textile as well as on the environmental

conditions and an article exploitation produce complex effect. In each case under certain conditions one of the factors prevails, thus determining the degree of a contaminant fastening on a fabric. That's why it's necessary to study the process of textile articles contamination for their quality cleaning.

Such progressive technologies as information technologies, nano-, bio-, plasmic, lazer technologies allow to conduct research on objects at all levels of their structure from macro- to nano- level [14-16].

Cleanliness analysis with using vision methods

In production practice, the definition of textile contaminations is connected with certain difficulties, especially the nature and structure of artificial polluting substances, methods of their application and fixation, and the method of determination of their amount.

The main objective of this research is to obtain images of clean and polluted materials and to present techniques for vision assessment of the rate and extent of soiling of textile materials [17, 18, 19, 20]. For test purposes, fabric made of cotton (100% cotton) and polyester (100% polyester) were used. The soiling was associated with the presence of oil and pigments on the textile fibres. Samples of fabrics were treated with the model composition of pollutants, and then dried at the temperature of 20°C. The study used a vision system with a resolution of 2560x1920 pixels with a monochrome CMOS sensor. The vision system was equipped with two types of lenses. The first is a telecentric measuring lens that allows observation of a large portion of the material and assessment of the degree of soiling. The second type is a microscopic lens, which was used to enlarge the assessed portion of the material and verify the quality of the algorithm developed for the purpose of evaluating the degree of contamination. In the study of surface topography, a digital measuring microscope was also used, enabling the construction of a three-dimensional image of the surface enlarged from 300 to 1000 times.

Figure 1a shows an image of clean polyester and clean cotton 1b taken with the telecentric lens, with illumination passing through the material. Figure 1 shows also an image of clean polyester and clean cotton taken with the microscope lens, with light reflected from the material.

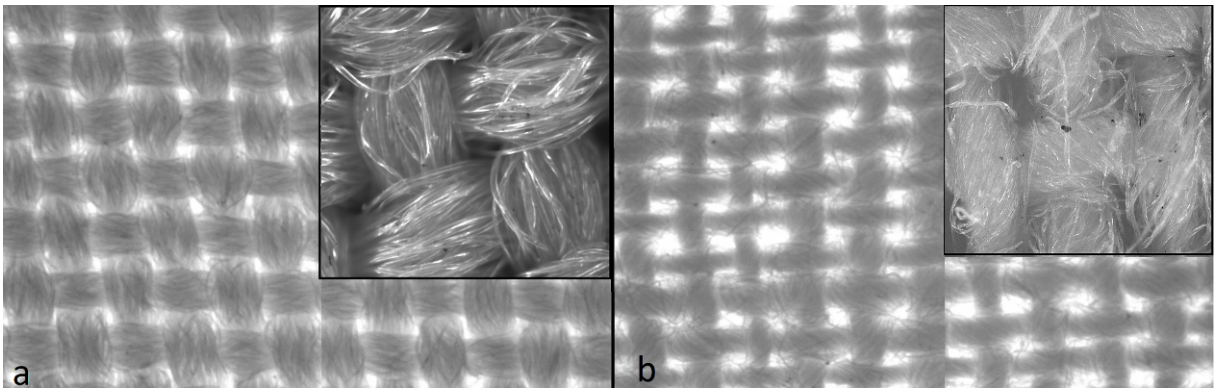

Fig. 5. Clean polyester (a) and clean cotton (b) with enlarged portion of the material

Technological process of production of textiles from cotton and polyester fibre conducted in industrial conditions generates a need to assess cleanliness of the material. During the process, dirt is deposited on the fibres in the form of particles of water, oil, pigment or other chemicals used in the process. Both during production and after its completion, the material should be examined from time to time in order to control the degree of soiling. The figures below show images of polyester and cotton with visible dirt deposited during the manufacturing process.

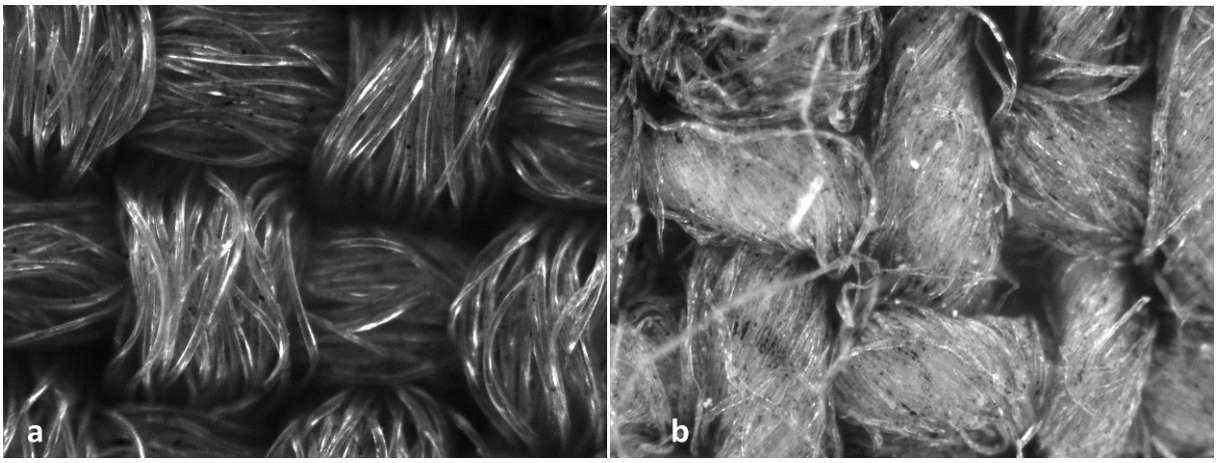

Fig. 6. Soiled portion of fabric made of polyester and cotton fibres

In project was used an automatic system for continuous monitoring of contamination of the material passing through the technological line between the successive technological operations equipped with vision system. The camera in the vision system can perform up to 50 inspections per second and enables

incorporation of a measurement signal describing the degree of contamination of the material directly into the line control system.

In the phase of testing the system and the algorithms developed for textile examination, the camera was simultaneously watching clean and filthy material. This enabled comparative evaluation of the tested material in relation to material previously determined to be clean. In the top part of Figure 7, there is soiled cotton, and in the bottom part – clean cotton.

For testing the cleanliness of the material, several parameters indirectly describing the cleanliness parameter were chosen. Figure 7a shows an image taken with transmitted light and shows the difference between clean and dirty material for soiled coton (top) and clean material. The light, i.e. its colour and intensity, is chosen on the basis of analysis of the properties and colour of the tested material. Clean cotton was used as a calibration standard for each of the discussed methods for imaging. In the image of that sample, characteristic features such as the intensity and shape of cotton fibres, the spacing between fibres, etc. were determined. Then, based on those patterns, the limit values were defined in a vision assessment programme, and testing of soiled samples.

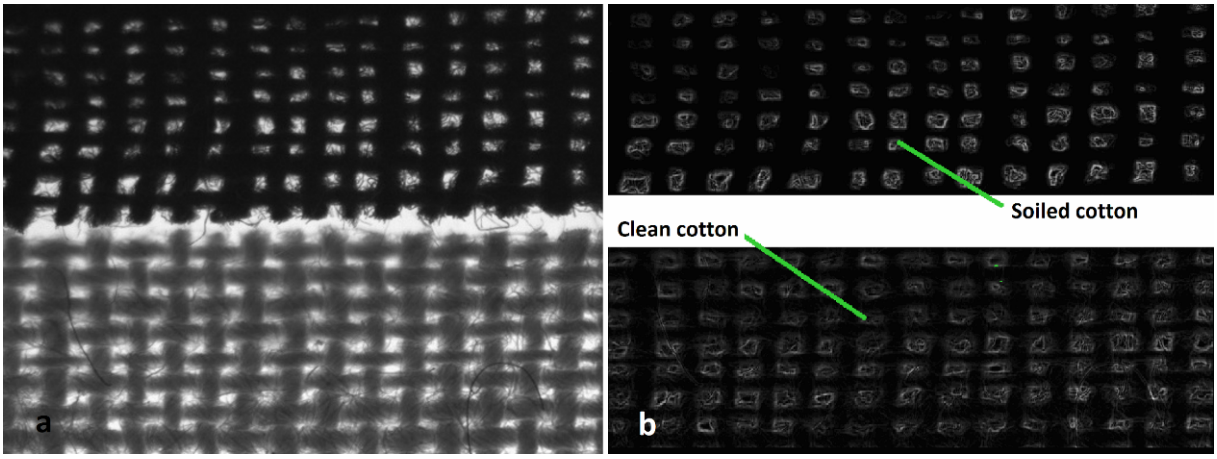

Fig. 7. Clean and soiled cotton (a) and image of cotton after contextual transformation

The first parameter used was the assessment of fibre micro-edges, which had been identified using contextual image transformations. In those transformations, the intensity of each pixel of the resulting image is determined based on the analysis of many pixels in the source image. Such an analysis

requires the development of a function and definition of its value, in which the arguments are the intensity values of pixels forming the structural element in the source image. The result of such comparative analysis is shown in Figure 7b.

With such an image of the material prepared, index W_K was proposed to account for the shape, surface area, and the number of designated micro-edges. The image presented above shows significant differences in the distribution, filling, and shape of the designated micro-edges. In the image of clean cotton, regular clusters of rectangular micro-edges with similar overall dimensions can be seen. To assess the degree of contamination, one may also use an image of the materials subjected to binarization. The example discussed below uses single threshold binarization (Fig. 8a). The use of a single threshold allows transformation to present the difference between clean and soiled material in a very clear way. The figure 8a shows an image after binarization and graphically presents the difference between soiled and clean material.

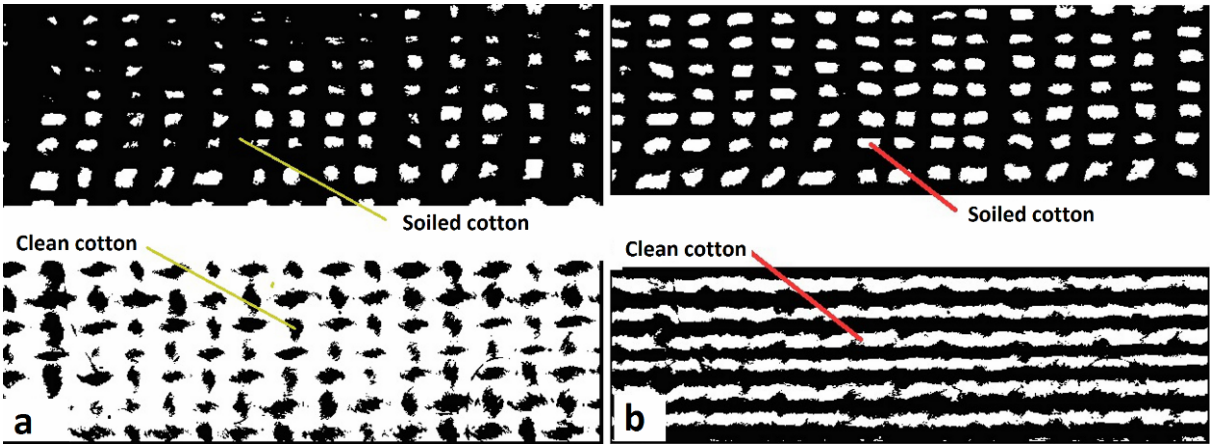

Fig. 8. Binarization of the cotton image (a) and analysis of the shape of gaps between fibres (b)

In assessing the shape and size of stains and the average intensity of the image after binarization, another assessment index was proposed, W_B, to describe the cleanliness of the material. Also, the contextual transformation was used in the evaluation algorithm as an auxiliary index to enable analysis of the bright parts of the image of the material, i.e. the gaps between the cotton fibr es. The transformation allows detection of the shape and edges of openings between

the fibres and the strengthening of selected edges. That index was described as W_G and presented in Figure 8b.

Final evaluation of the cleanliness of the material is performed by examining all the indices identified during image analysis. Indices W_K, W_B, W_G enable the development of an assessment process taking into account the average intensity of the material, the shape of micro-edges detected on the fibres, and the shape and size of holes visible between the fibres. The vision algorithm enables precise examination of the following: the degree of contamination of the material, both cotton and polyester, the control of textile structure, such as the size of openings in the material and their shape, and the control of defects associated with the rupture or entanglement of fibres of the textile as shown in the weaving pattern. Analysis of the size of openings in textile materials in accordance with the algorithm can detect a very clear distinction between clean and dirty samples. That index is also used as an aid to assess the cleanliness of the material.

Analysis of fabric cleanliness with a nanoscanner

The study used a microscope designed for research in nano-scale. The device is a combination of AFM and STM technology, enabling study of both conductive non-conductive materials. In studying polyester and cotton, the AFM function of the microscope was used to reproduce the topography of individual fibres in the material. The aim of the study in nano-scale was to verify the possibility of detecting contamination on the single fibre and the possibility of imaging such cleanliness defects onto the image of fibre surface topography. Additionally, the possibility of imaging fibres and defects on three-dimensional images in nanometre scale was tested.

As part of the study, the surface of clean and dirty cotton was scanned with a nano-scanner. Scanning was performed over an area of 86x86 μm at 8000 and 16000 nm/s. Following the test, it was observed that further increase of the scanning speed results in significant deterioration in the quality of the resulting image.

The figure 9a shows a probe scanning the tested material. The probe is moved over a length of 85 μm in axis X, collecting all the points of the profile within the range of the nanometre with the adopted scanning progress. After

construction of the first profile has been completed, it is moved in axis Y by the pre-set step and re-scans along axis X (Fig. 9b). Such profiles are then used to construct a three-dimensional image of surface topography in nanometre scale, as can be seen in Figure 9c.

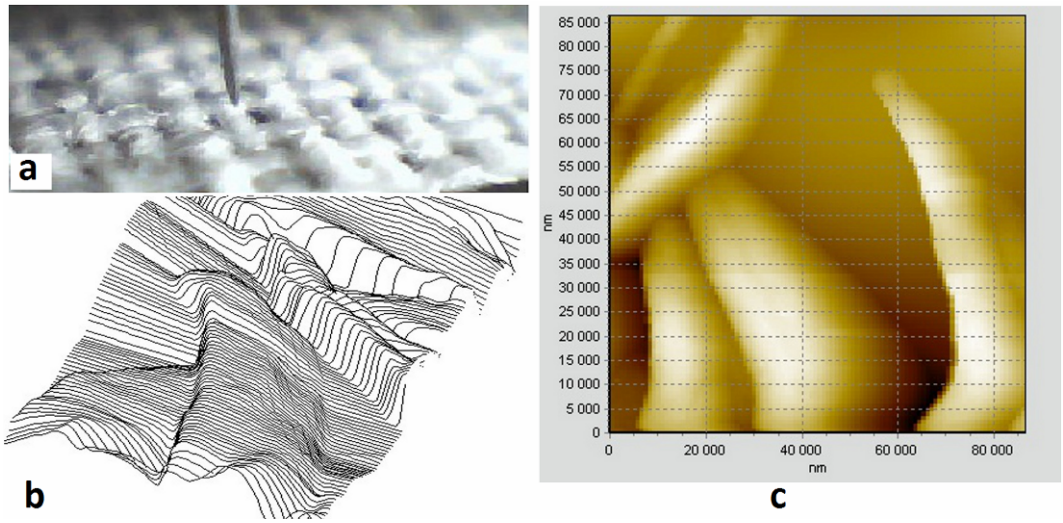

Fig. 9. Scanning probe above the material (a), profiles of scan (b) and 3D topography of the surface of clean cotton fibres (c)

The surfaces of fibres of clean cotton material are smooth and no inclusions can be seen between the fibres (Fig. 9c). That image can be treated as a reference image necessary for the comparative analysis with an image of material soiled with oil and pigments. The figure also shows descriptions of the dimensions of the scanning areas.

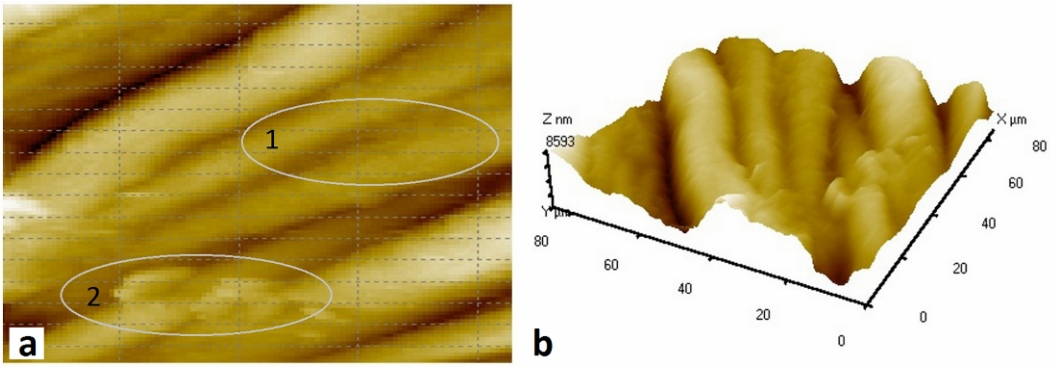

Fig. 10. A three-dimensional image with added colours depending on the height of the material

In the next stage of the study, the surface of material soiled with oil and pigments was scanned, with the dimensional parameters of the scanning field

and the scanning speed remaining identical as previously (Fig. 10a). Such action is intended to obtain an image of the dirty material for a comparative analysis enabling the detection of differences between the dirty and the clean material. A three-dimensional representation of the surface of dirty cotton fibres is shown in Figure 10b. The image of the surface of soiled cotton fibres reveals the presence of oil and pigment particles stuck to the surface of the fibre. This can be seen as a rough surface on the individual cotton fibres shown in Figure 10b is detail 1. There is also a larger disruption of the surface in the form of excess material, visible in Figure 10a as detail 2.

Conclusions

This work presents issue of material purity tests and methods for measuring the cleanliness of textile materials. Using vision system enables rapid and accurate assessment of cleanliness based on predetermined indices that allow assessment of multiple parameters associated with material cleanliness. That method is designed for industrial applications.

Using nanoscaner enables studies of material structure in the nanometre range. However, both the duration of testing and the conditions required to carry out such testing place that method in the group of laboratory methods.

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