Chapter 13

Giving Functional Properties to Fabrics Containing Polyester Fibres from Poly (Ethylene Terephthalate) with the Printing Method

Ewa Skrzetuska, Wiesława Urbaniak-Domagała,
Barbara Lipp-Symonowicz and Izabella Krucińska

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/48636

1. Introduction

Polyester fibres from polyethylene terephthalate have a leading position among synthetic fibres, it represent about 72%. According to Oerlikon Textile, the production and demand for polyester fibres were equal to 32 million tonnes in 2008. An increase in demand at the level of 3,2% was observed. The SRI (Socially Responsible Investment) Consulting analysts predict that till the year 2013 a further 4,2% increase in demand will occur. In 2008, there was an increase of about 1.6% in production of polyester filaments. The global production was equal to 17,3 million tonnes. The leader in the market of polyester fibres' producers is Asia including the first five companies of highest production capabilities: Reliance Industries (India), Sinopec (China), Formosa Plastics Group (Taiwan), Tuntex Group (Thailand and Taiwan) and Invista [1,2].

These fibres (PET) are used in different types of textiles and technical products due to very good dielectric, mechanic and strength properties, good resistance to aging and action of light, good thermal resistance, high chemical resistance to the action of diluted acids, alkalis, aliphatic and aromatic hydrocarbons, complete biological resistance, resistance to squishing and stability of dimensions [3,4].

According to the increasing demand for its included products, polyester fibers are applied widely by extended rate in technical and special products in various fields of life. In fabrics, the polyester fibers are often mixed with natural fibers such as cotton.

The polyester fibres are dyed almost entirely with suspension dyes using special dyeing methods. The positive results are also obtained during printing with those dyes.

The printing technology was successfully implemented in the textile industry for many years ago. For a very long time it fulfills the role of adornment thanks to placing decorative patterns. It can be noticed that printing on textiles is of increasingly broader use due to implementing/developing more and more modern printing technologies. It is an important fact that printing in the recent time, apart from the decorative role, fulfills also additional specific functions, such as giving antistatic properties [5,6], electroconductivity [5-8], bacteriostatic properties [9] and sensoric activity on the different exterior stimuli [10].

Printing is reckoned as a key and attractive technology in the range of electroconductive paths' design, leading to the creation of intelligent products. A constant progress in miniaturisation of microelectronics together with new technologies enables the integration of functionalities in clothing, enabling completely new applications. The vision of wearing intelligent clothes describes the future electronic systems as an integral part of casual clothes [11].

In the presented work carbon nanotubes were used for giving specified functionality to textile with the printing techniques. The characteristic properties of carbon nanotubes, such as: heat conductivity, electric conductivity, high elasticity module, high strength or resistance to chemicals induce its wide applications.

The carbon nanotubes, similarly as carbon fibres, are resistant to the action of chemicals. However, the physical properties differ greatly the nanotubes from fibres. The electric properties of nanotubes are typical for two-dimensional conductors, the electric conductivity changes, depending on the construction of nanotubes (one- and multi-wall) and on their structure (chirality); it is sensitive to the influence of external factors, such as electric and magnetic fields, mechanical factors, state of environment (temperature, content of vapours of specific chemical substances). The optical properties are characterised by the optical activity, susceptibility to selective absorption and photoluminescence in near infrared dependent on the electron structure of the nanotubes. The magnetic properties are characterised by high diamagnetic susceptibility, increasing with the increase of temperature, and after modification with iron the nanotubes show ferromagnetic susceptibility [10,12]. The mechanical properties are characterised by high mechanical strength, elasticity, susceptibility to deformations at bending and twisting, flexibility – e.g. during drawing the length of a nanotube can increase up to 40% without changing of its structure [12].

The rare properties of nanotubes nominate its application in many fields of nanotechnology, for example in creating nanocomposites with sharing nanotubes in the role of strengthening and functionalising material for the composite, in creating nanocontainers for storage of gasses, e.g. hydrogen [12], in effective removal of dioxins from the residues of burning medical and chemical wastes [12] (an important role of nanotubes in protection of the environment). However, the biggest hopes are seen in using the unique electrical properties of nanotubes, e.g. in microelectronics [13], and the advantages more than silicon technology.

In this work the electric sensorial properties of carbon nanotubes were used for functionalising the textile backing. The multi-wall nanotubes, combined with a binding

substance in order to assure the durability of their connection with the surface, were used to creating printout on a textile surface. The printout is actually a composite of a binding agent, as a warp, and of nanotubes as a strengthening component that functionalises the surface of a fabric. In this solution the percolation threshold of electric conductivity was achieved at low share of carbon nanotubes in the printout.

The deposition of printouts was made based on two types of fabrics: polyester (100%) and cotton-polyester (70/30%). In the current work the electric, sensory and microbiologic properties of the printed textile backings, and their durability during multiple washings were examined.

2. Materials and methods

As a base for conductive printouts in the work, the water dispersion of carbon nanotubes with commercial name AquaCyl (AQ0101) from the Nanocyl company was used. The carbon nanotubes have a firm position in the group of nanomaterials used in sensorics. It is an open problematic to apply the nanotubes in such way, so that they are toxicologically safe in use, permanently connected with the substrate and so that they guarantee the highest sensitivity to the examined stimuli, with their minimum possible content in the sensoric element.

The electric properties of nanotubes were used by Kordas and his associates [14] to create conductive printouts on foils and on paper with the inkjet printing technique, where the ink was the water dispersion of nanotubes without binding agents. The authors have undertaken the work on creating water dispersions by sharing auxiliary agents with pastes used in film printing, in order to modify the fabrics containing polyester fibres from polyethylene terephthalate.

2.1. Materials used

The AquaCyl AQ0101 dispersion contains from 0,5 to 1,5% MWCNT of the Nanocyl®7000 series, which are characterised by purity of about 90%, average diameter of nanotubes is 9,5nm and average length up to about 1,5μm. They are also characterised by surface tension of about 57 mN/m, viscosity 36 cP and pH 7. These parameters were determined under the temperature of 25 ^{o}C. The dispersion contains additionally the dispersing agent of 0,1-3%.

For the modification of the commercial dispersions the following auxiliary substances were used: DBSA ($C_{12}H_{25}C_6H_4SO_3H$) solution 70 wt% in isopropanol (analytically Pure from Sigma Aldrich) and SLS ($CH_3(CH_2)_{11}OSO_3Na$, analytically Pure from Sigma Aldrich), Ebecryl 2002 (aliphatic urethane acrylate from Cytec, water compatible, UV curable system) and Esacure DP250 (water dispersion of photo initiators from Lamberti SPA).

The fabrics with different raw material content and different weaves were used in this work.

In current study, the polyester and cotton-polyester fabrics were used.

The cotton-polyester fabric with twill weave was purchased from a Dutch company Ten Cate Protect bv. The research of the fabric was made according to the 100 Oëko-Tex standard. Based on the results obtained it can be stated that the mentioned fabric meets the human-ecological standard required for products contact directly with skin.

The polyester fabric with plain weave is a product of a Polish company Miranda.

2.2. Characteristics of the paste and the used printing technique

Obtaining of an antibacterial and antistatic ink from AquaCyl is based on implementing into the 10% AquaCyl (in volume) of an addition of dodecylbenzenesulphonic acid (DBSA) or of sodium lauryl sulfate acid (SLS). These two substances were selected based on the antibacterial properties of sulphur. Such prepared ink is subject to filtration in order to remove the created agglomerates. The filtration is performed in a decreased pressure by using filter of pore sizes about 0.45 micrometer.

The obtained dispersions are used for printing fabrics containing polyester fibres with the use of a conventional technique (screen printing). The ink compositions obtained in this way were placed on fabrics in combination with the selected networking composition containing photo initiator (10% Esacure DP250 by volume) and the aliphatic urethane acrylate (0,7% Ebecryl 2002 by volume). The modified dispersion of carbon nanotubes after combination with the networking composition was mixed for 30 minutes with a magnetic mixer. Next it was placed on fabrics in A4 format with the use of a stencil. The whole surfaces of 0,05m^2 were printed and optionally the stripes with 1cm width and 20cm length (Fig. 1). Such prepared printouts, were subjected to the networking process under a radiator of UV lamp, length of 195mm (2100W), from Philips company.

UV-C 335 W of radiation dose equal to 3.5J/cm^2 was used [15].

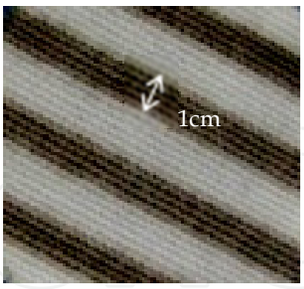

Figure 1. Polyester fabric printed with a stripe pattern with 1cm width and 20cm length.

2.3. Investigation methods used

The investigation of physical properties of fabrics containing polyester fibres was characterised by examining the thickness using Arthur Meiber KG LTG thickness meter. The research was done based on the PN-EN ISO 5084:1999 standard. The value of pressure during the measurement was equal to 2 Pa, and the measuring surface was 1000 mm^2. Ten measurements were performed per 1 m^2 of the sample, and next the average thickness of the fabrics was determined with the accuracy of 0,01mm.

The measurements of linear mass according to the PN-EN 29073-1:1994 standard were also performed. From a unit of a product the sample was taken with full width, and length not smaller than 50000mm^2, in accordance with PN-EN ISO 186:2004. The sample was subject to the process of acclimatisation in 23^{0}C and 25%Rhw during 24 hours, and next its width, length and mass were measured. The mass of the fabric was determined with the accuracy of 0,1% of the weighted mass. Based on the obtained results the surface mass (m_ρ)was calculated, according to the equation (1):

$$m_p = \frac{m}{S \cdot L} \tag{1}$$

where:

m - average mass of the acclimatised samples, g
S - width of the acclimatised samples, m
L - length of the acclimatised samples, m

Based on the obtained results of research of thickness and surface mass of the sample, the apparent density was calculated. The apparent density is a quotient of the mass of a textile material and its volume, together with the volume of spaces between the elements of its structure, expressed in kg/m^3. The measurements were done in a room under normal climate, on acclimatised samples. The apparent density (ρ) of a sample was calculated with the accuracy up to 2 significant digits, according to the equation (2):

$$\rho = \frac{m}{S \cdot L \cdot G} \tag{2}$$

where:
m - mass of the sample, kg
L - average length of the sample, m
S - average width of the sample, m
G - average thickness of the sample, m

The electric conductivity of the printed fabrics was characterised by measuring the surface resistance according with the standard EN 1149-1:2008 – Protective clothing - Electrostatic properties - Part 1: Surface resistivity (Test methods and requirements)

The research were performed with a direct electromagnetic method using Keithley 610C electrometer. The source of electric voltage was the DC power supply 4218 (from RFT company) with the range of voltages 0-3000 V. The system of electrodes together with the investigated sample was placed on a Faraday screen. The processes of conditioning and investigating the samples were retained at a constant level: temperature 23^{0}C, RH=25%.

The electrostatic properties according to EN 1149-1:2008 standard are fulfilled by homogeneous materials, which show the surface resistivity below 2,5×10^{9}Ω. In case of non-homogeneous, coated or laminated materials at least one of the surfaces should meet the requirements concerning the homogeneous materials.

The assessment of antibacterial activity of the printed fabrics was investigated on the plates with agar culture. The behaviour of bacteria was assessed in the zone of contact between the agar and the working sample, and the retardation zones around the sample were determined according to the EN ISO 20645:2006 standard. The assessment of the antibacterial activity was based on observation of the occurrence of the phenomenon of bacterial growth or its lack in the zone of contact between the agar and the working sample, and presumptive determination of the retardation zone around the working sample.

The width of the retardation zone (H), i.e. the zone without bacteria near the edge of the working sample was calculated from the equation (3):

$$H = \frac{D - d}{2} \tag{3}$$

where:
H – width of the retardation zone in mm,
D –diameter of the working sample together with the width of the retardation zones in mm,
d – diameter of the working sample in mm.

Then the working samples were placed under the microscope with 20x magnification and bottom lighting, and the growth of bacteria in the zone of contact on the bottom side of the sample was assessed. The assessment of the antibacterial effect of the investigated sample was in accordance with the data presented in Table 1.

Retardation zone, mm Average value	Growth of bacteria on the medium below the working sample	Description	Assessment
>1	None	The retardation zone over 1 mm, lack of growth	Good result
1-0	None	The retardation zone up to 1 mm, lack of growth	Good result
0	None	Lack of the retardation zone, lack of growth	Good result
0	Weak	Lack of the retardation zone, only some colonies were limited, growth almost totally stopped	Limited effectiveness
0	Medium	Lack of the retardation zone, growth lowered to half in comparison to the reference	Insufficient effect
0	Strong	Lack of the retardation zone, lack of lowering of growth in comparison to the reference or just a slight lowering of growth	Insufficient effect

Table 1. Assumptions for the assessment of the antibacterial effect of the investigated antibacterial sample [EN ISO 20645:2006].

The measurements of sensory properties to fluid vapours, temperature and deformations were performed with the use of a station constructed by the Department of Material and Commodity Science and Textile Metrology, equipped additionally in Optris Laser SIGHT pyrometer.

The sensitivity of the printed fabrics to changes of temperature was investigated by using a specially constructed station, which is presented in Fig. 2. The station consists of a Keithley multimeter (1) connected with measuring electrodes (2). In a distance of 50cm from the sample there was an Optris pyrometer placed (3). Due to connecting the pyrometer and multimeter with the computer (4) it was possible to simultaneously register the recorded results of temperature and resistance. Increasing the temperature was possible due to using the heat source (5). The sensory properties of the fabrics were investigated in the range of thermal changes of 20^0C-70^0C. For each sample there were performed minimum four cycles of heating and cooling. The investigated samples were of the dimensions 1,5cm x 4cm.

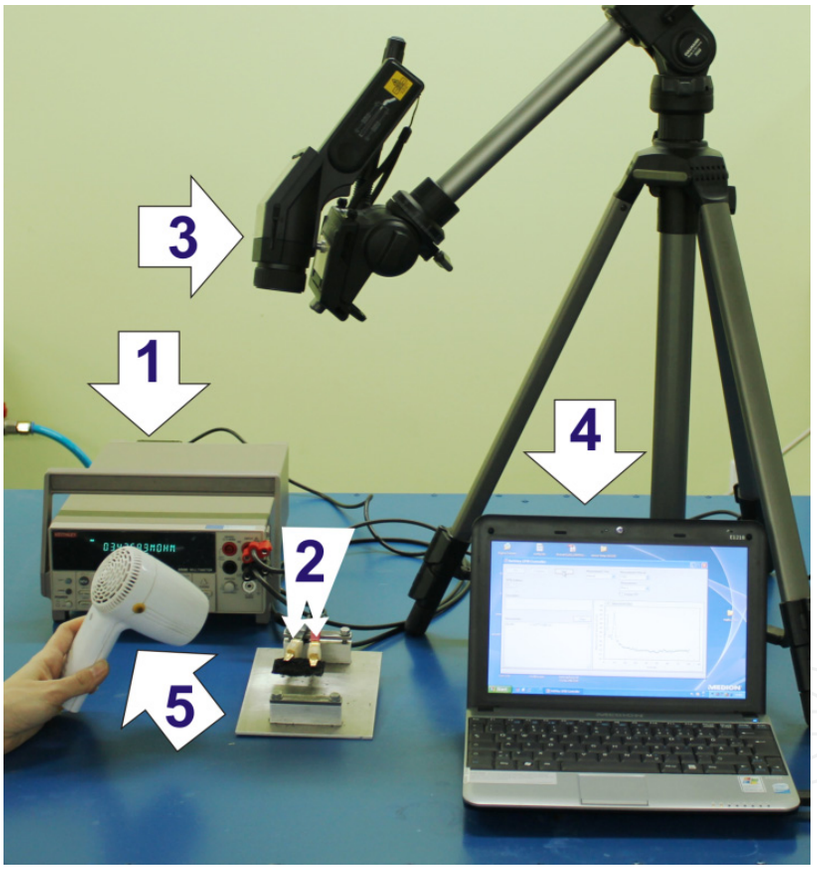

Figure 2. Measuring system for investigating the textile sensors to thermal stimulus:
1. Keithley multimeter, 2. measuring electrodes, 3. Optris pyrometer, 4. computer, 5. heat source.

The research of sensority to the presence of organic fluids was done in the same measuring system as the research of sensority to thermal stimuli. In case of the research of sensitivity to fluids the sample was cut in the shape of a letter U (Fig. 3). The bottom part of the sample was immersed in fluid up to 2/3 of the height from the base, so that the fluid would not get to the electrodes.

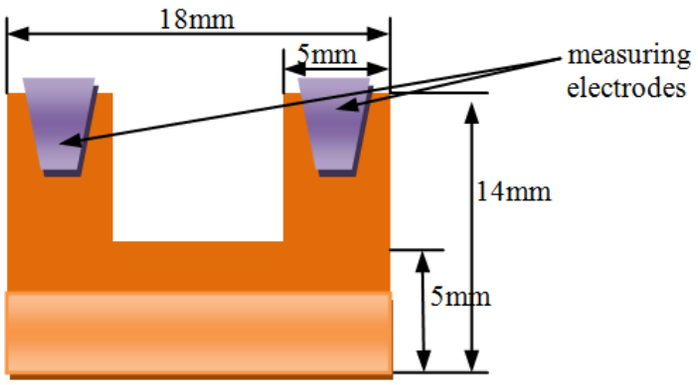

Figure 3. Scheme of preparing the sample to investigating the sensitivity to organic fluids.

The behaviour of sensority in the presence of solvents' vapours was investigated in a laboratory measurement system. The station allows to measure humidity and temperature of the system, and to create and implement into the measuring system of the fluids' vapours with a specified concentration. The sensory sensitivity of the printed fabrics was investigated with the help of a measurement station presented in Fig. 4, composed of an aquarium used as a gaseous chamber (1), pump for mixing the gasses' vapours (2), measuring chamber (3) containing measuring electrodes (4) connected to Keithley multimeter (5), coupled with a computer. The gaseous chamber is used for evaporating a proper amount of solvent. The amount of solvent which should be evaporated in the gaseous chamber in order to achieve a concentration of e.g. 100ppm is calculated according to the equation (4):

$$Y = \frac{X \times M}{24.45}; \qquad M = Y \times V \tag{4}$$

where:
Y - density mg/m^3,
X - parts per million,
M - molecular mass,
V - volume m^3.

The number 24.45 in the equations above is the volume (litres) of a mole (gram molecular weight) of a gas or vapour when the pressure is at 1 atmosphere (760 torr or 760 mm Hg) and at 25°C.

Inside the gaseous chamber there is a thermometer and humidity sensor, thanks to which the research is being conducted in equal conditions (at a level of 23^{0}C and 25%Rh). After evaporation of the solvent in the gaseous chamber, the vapours are transmitted with the use of a pump to the measurement chamber, in which the investigated sample, with the dimensions of 2cm x 4cm, is placed on the measuring electrodes. The sensory properties of the fabrics were investigated for the vapours of different solvents and the changes of resistance were registered. The measurements were done before and after implementation of the vapours of the investigated fluids.

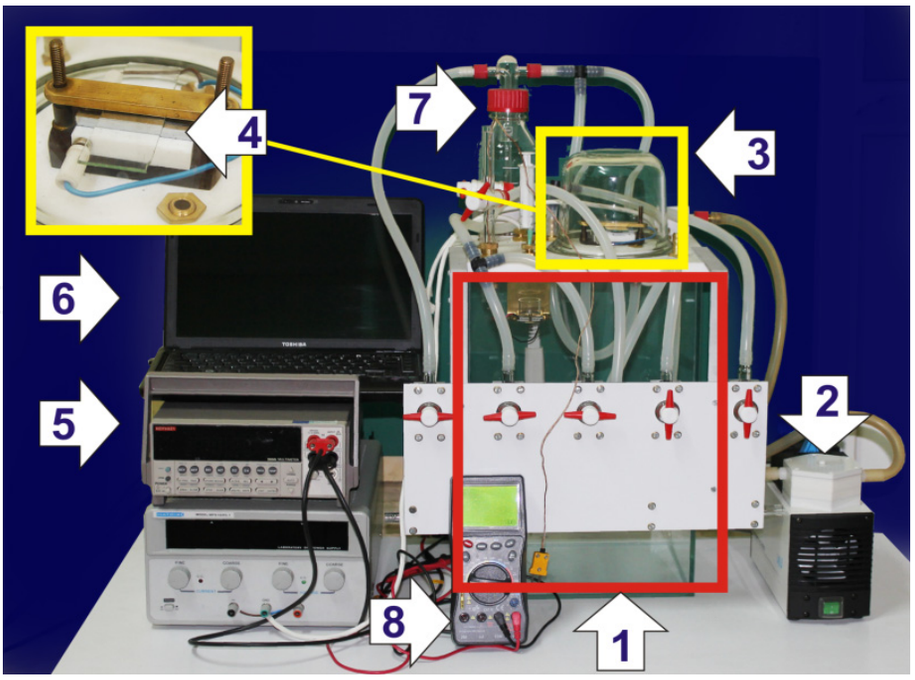

Figure 4. Measuring system for investigating the vapour textile sensors:
1. gaseous chamber with the volume of 0,024 m^3, 2. pump, 3. measurement chamber, 4. measuring electrodes, 5. Keithley multimeter, 6. computer, 7. system ensuring proper humidity of the environment, 8. thermometer.

3. Results and discussion

Physical properties of the functionalised fabrics containing polyester fibres were studied and represented in Table 2.

Material compositions	PET content [%]	Weave	Surface mass [g/m^2]	Thickness [mm]	Apparent density [kg/m^3]
PET	100	plain	214,9	0,53	421,3
PET/Cotton	30/70	twill	205,5	0,52	387,7

Table 2. Physical characterization of the fabrics used.

Fabrics with similar surface mass and thickness were selected for the research.

Table 3 presents the results of measuring the electric conductivity of the printed polyester and polyester-cotton fabrics.

By analysing the electric conductivity obtained from the examined fabrics, presented in Table 2, it can be noticed that for commercial form of AquaCyl water dispersion not containing the networking composition the conductivity is much worse after the process of multiple washings. The addition of the networking composition allows to obtain printouts resistance to the utilisation processes. It should also be noticed that printouts obtained on a polyester fabric with plain weave are characterised by a slightly worse conductive

properties than printouts on a polyester-cotton fabric with twill weave, which can be connected with the increased adhesiveness of the printing paste to the cotton fibre.

Table 4 and Figure 5 are showing the assessment of the antibacterial activity of the obtained printouts on fabrics containing polyester fibres before and after the washing process.

Ink composition	Fabric type	**Surface electrical resistivity [Ω] (RH=25%, t=23^{0}C)**	
		Before the washing	After the washing (25 cycles)
AquaCyl	PET	538	22289
AquaCyl	PET/COTT	280	17103
Aquacyl+ networking composition	PET	1029	1601
Aquacyl+ networking composition	PET/COTT	800	856
Aquacyl+ networking composition +DBSA	PET	2285	2769
Aquacyl+ networking composition +DBSA	PET/COTT	1818	1890
Aquacyl+ networking composition +SLS	PET	498	617
Aquacyl+ networking composition +SLS	PET/COTT	181	321

Table 3. Results of electrical conductivity of the obtained printouts before and after the washing process.

Ink composition	Fabric type	Bacteria retardation zone [mm]			
		E.coli (gram-)		B.subtilis (gram+)	
		Before the washing	After the washing (25 cycles)	Before the washing	After the washing (25 cycles)
AquaCyl	PET	0,0	0,0	0,0	0,0
AquaCyl	PET/COTT	0,0	0,0	0,0	0,0
Aquacyl+networking composition	PET	0,0	0,0	0,0	0,0
Aquacyl+ networking composition	PET/COTT	0,0	0,0	0,0	0,0
Aquacyl+ networking composition +DBSA	PET	0,5	0,0	6,0	4,0
Aquacyl+ networking composition +DBSA	PET/COTT	0,5	0,0	6,5	4,5
Aquacyl+ networking composition +SLS	PET	0,0	0,0	3,5	2,0
Aquacyl+ networking composition +SLS	PET/COTT	0,0	0,0	4,0	2,0

Table 4. Results of microbiological activity for the obtained printouts.

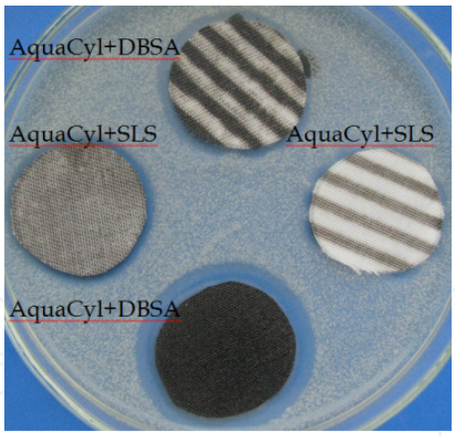

Figure 5. Bacillus bacteria growth retardation zone on polyester fabric.

By analysing the results obtained, it should be noticed that the commercial form of AquaCyl without additives used in this study does not show the antibacterial properties. The addition of dodecyl benzene sulfonic acid (DBSA) or sodium lauryl sulfate (SLS) causes the dispersion composition of ink with bi-functional properties, it is obtaining of carbon nanotubes' dispersion having at the same time electrostatic and antibacterial properties. It is a very important fact that after the process of multiple washings, the bacteriostatic properties are still retained. The obtained compositions show better bacteriostatic properties against gram-positive bacteria. In case of gram-negative bacteria there are no retardation zones around the sample, but below the sample there is not growth of bacteria. Such situation suggests that bacteriostatic properties are also retained for gram-negative bacteria.

In tables 5-8 there are presented the results of sensory measuring to fluids and their vapours. The sensority of the printed fabrics was investigated due to exposure of the selected polar and non-polar organic fluids, and the vapours of selected organic fluids:

- ethanol,
- acetone,
- toluene.

Below there are also presented the diagrams characterising the sensory behaviour of the ink compositions on textile backings containing PET fibres to the selected fluids.

As a quantitative coefficient of the sensory properties, the sensority coefficient (Ss) was taken, expressing the relative changes of electric resistance of the printed fabric's surface, caused by a chemical stimulus of a given type.

$$Ss = \left(\frac{\Delta R}{R_0}\right) \times 100\% \tag{5}$$

where:
Ss - Sensority coefficient
ΔR – absolute change of electric resistanceof the fabric , $\Delta R = R - R_o$
R – resistance of the fabric under the influence of external stimulus
R_o - resistance of the fabric before the action of stimulus

Type of chemical substance	Sensority coefficient [%]	Coefficient of variation [%]
Liquid vapours		
Ethanol	Ss = 42	3.96
Acetone	Ss = 37	4.72
Toluene	Ss = 27	6.57
Organic liquids		
Ethanol	Ss = 76	4.09
Acetone	Ss = 84	3.56
Toluene	Ss = 54	3.99

Table 5. Sensority coefficients for polyester-cotton fabric printed with AquaCyl dispersion modified with DBSA.

Type of chemical substance	Sensority coefficient [%]	Coefficient of variation [%]
Liquid vapours		
Ethanol	Ss = 47	3.69
Acetone	Ss = 39	4.50
Toluene	Ss = 28	6.59
Organic liquids		
Ethanol	Ss = 77	3.89
Acetone	Ss = 88	3.43
Toluene	Ss = 54	5.58

Table 6. Sensority coefficients for polyester fabric printed with AquaCyl dispersion modified with DBSA.

Type of chemical substance	Sensority coefficient [%]	Coefficient of variation [%]
Liquid vapours		
Ethanol	Ss = 31	4.47
Acetone	Ss = 25	8.44
Toluene	Ss = 17	13.44
Organic liquids		
Ethanol	Ss = 66	4.95
Acetone	Ss = 67	4.63
Toluene	Ss = 42	6.85

Table 7. Sensority coefficients for polyester-cotton fabric printed with AquaCyl dispersion modified with SLS.

Type of chemical substance	Sensority coefficient [%]	Coefficient of variation [%]
Liquid vapours		
Ethanol	Ss = 31	6.49
Acetone	Ss = 27	7.27
Toluene	Ss = 19	10.47
Organic liquids		
Ethanol	Ss = 67	4.48
Acetone	Ss = 72	4.31
Toluene	Ss = 44	7.30

Table 8. Sensority coefficients for polyester fabric printed with AquaCyl dispersion modified with SLS.

While analysing the results of research presented in tables 5-8 for the fluids' vapours, one can notice that they obtained printouts react the strongest to the vapours of polar fluids. The best sensory properties were observed for vapours of ethanol, at the level of S_s factor over 40% for printouts with DBSA and at the level of about 30% for printouts with SLS. In case of vapours of non-polar fluids the sensory reaction of the printed fabrics with the share of polyester fibres is much weaker – at the level of the S_s factor of about 30% for printouts with DBSA and about 20% for printouts with SLS.

The strongest sensory reaction of the printed backing in case of fluids was observed for polar fluids, e.g. acetone, at the level of the S_s factor of over 80% for printouts with DBSA and at the level of about 70% for printouts with SLS. In case of non-polar fluids the sensory reaction of the printed fabrics is much weaker – at the level of the S_s factor of about 50% for printouts with DBSA and about 40% for printouts with SLS.

It is a significant fact that the results are repeatable, which can be certified by a low coefficient of their changes in the presented tables.

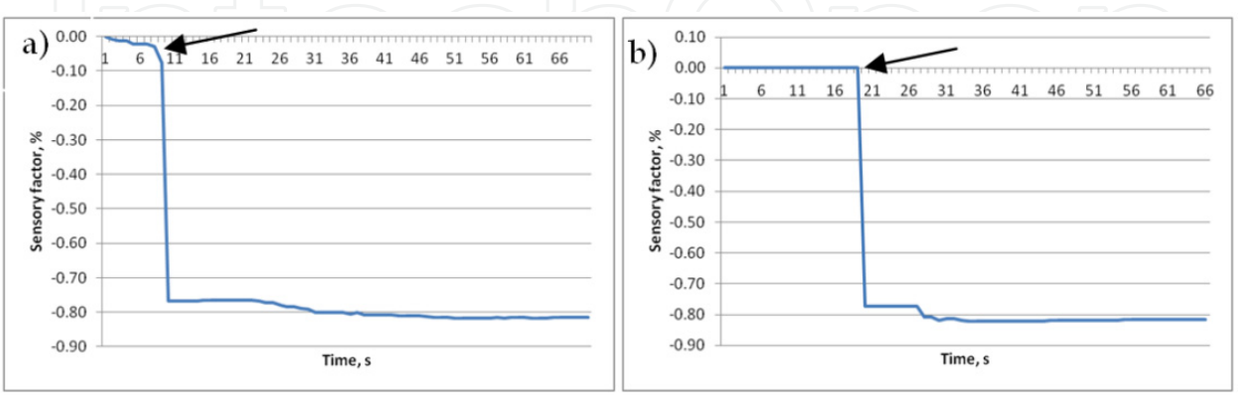

Figure 6. The sensory reaction curves for the polyester-cotton fabric printed with AquaCyl dispersion with the addition of DBSA for selected solvents: a) ethanol, b) acetone

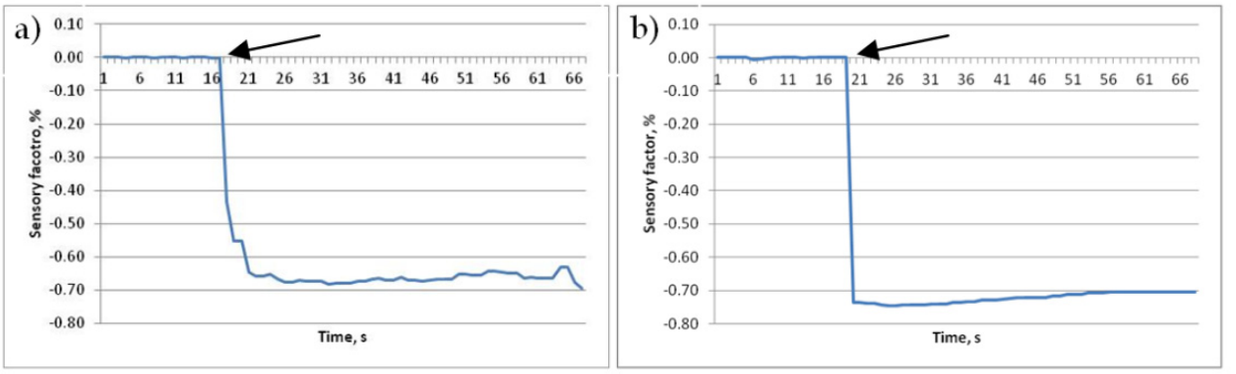

Figure 7. The sensory reaction curves of the polyester fabric printed with AquaCyl dispersion with the addition of SLS for selected solvents: a) ethanol, b) acetone

On the diagrams the arrow presents the moment of immersing of the samples in the selected solvents. The diagrams present the sensory reaction due to the given external stimulus.

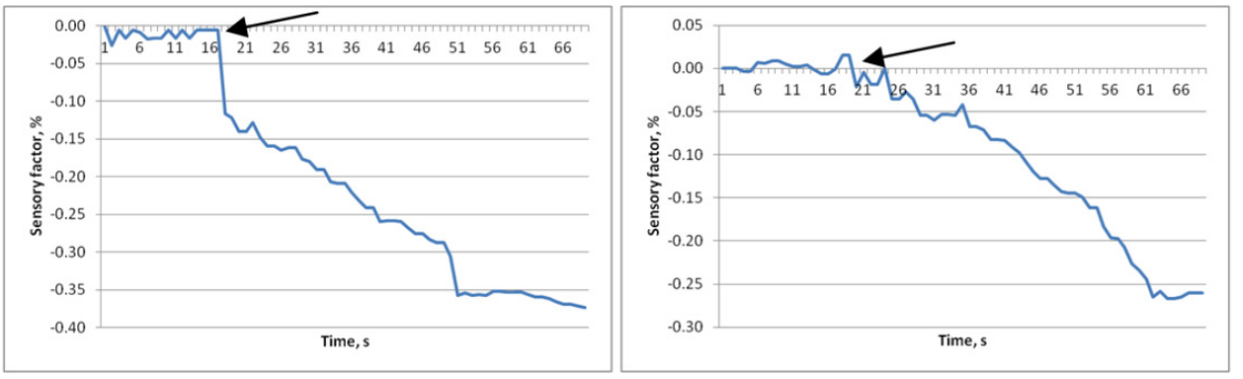

Figure 8. The sensory reaction curves of the fabric printed with the AquaCyl dispersion with the addition of DBSA for the vapours of the selected solvents: a) on polyester-cotton fabric – acetone, b) on polyester fabric – toluene

While analysing Figures 6-8 one can observe that the printed textile backings with the share of polyester fibres, subject to the influence of a fluid, show an immediate reaction, while in the case of fluids' vapours the reaction occurs after a few seconds.

Based on the presented diagrams the moment of implementing the vapours of selected solvents into the measurement chamber of the measuring system, in which the investigated sample is placed, is marked with an arrow. The diagrams show the sensory reaction to the given stimulus.

The results presented in Tables 5-8 and in Figures 6-8 show the sensority coefficient calculated on the basis of the absolute change of electric resistance. The investigated samples were subject to the action of fluids and their vapours. The effect of fluids' vapours on the sensority was investigated at the concentration of 100ppm. The research were repeated 10 times for each of the selected solvents and for each of the investigated samples. Each ink composition contained the networking composition, consisting of a photoinitiator and aliphatic urethane acrylate. The printouts were subjected to the networking process in order to fix them on the textile backing.

By analysing the results obtained it should be noticed that samples containing DBSA show better sensory properties than samples containing SLS. Based on the obtained results of research of the sensory properties there were no significant differences noticed between the printouts obtained on polyester and polyester-cotton fabrics.

A very important aspect of the performed process is the fact that the sensors can be used repeatedly, because the damages of the sensor under the influence of the used fluids were not noticed. The experiment was repeated 25 times for each of the used fluids.

Table 9 presents the results of the sensority coefficient to the thermal stimulus of the printed fabrics. The samples were subject to constant investigation of resistance and temperature. The measurements were repeated several times for the same sample.

Variant	Sensority coefficient Ss , %
Aquacyl+networking composition	47
Aquacyl+ networking composition +DBSA	53
Aquacyl+ networking composition+SLS	25

Table 9. Results of research of the sensority coefficient to the thermal stimulus of the printed polyester-cotton fabric.

The results of research of sensory properties to thermal stimulus, presented in Table 9, in the form of S_s factor, indicate that the textile backings printed with the ink composition with the addition of DBSA are at the level of 53% (high), while printouts with the addition of SLS are at a much lower level (around 25%). It means that the sodium lauryl sulfate limits the sensory properties of the investigated textiles.

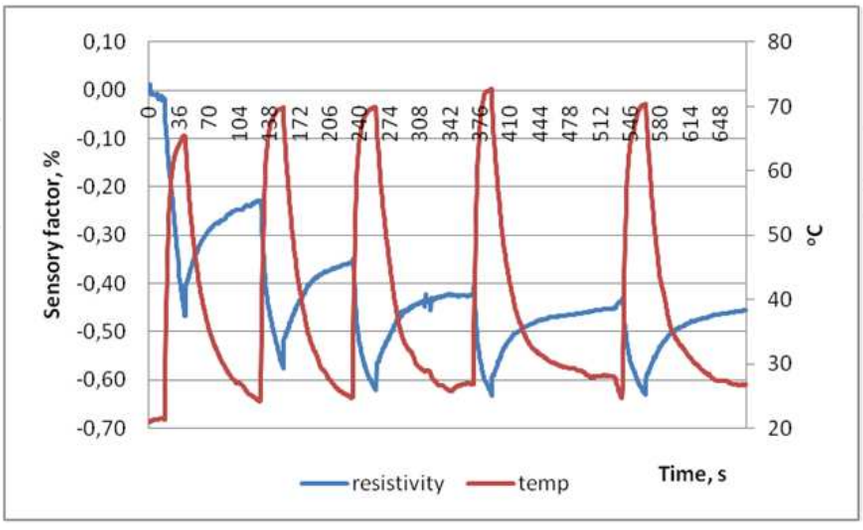

Figure 9. Dependence of the sensority coefficient on the temperature for the AquaCyl ink composition on cotton-polyester fabric

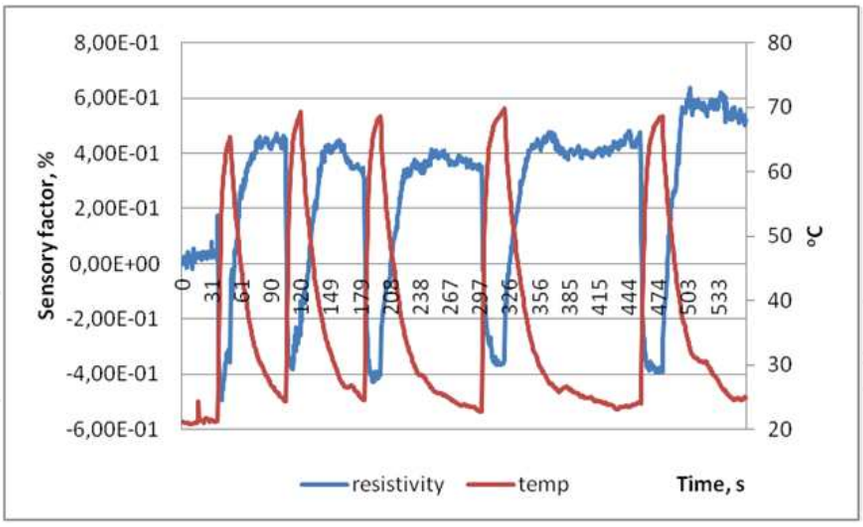

Figure 10. Dependence of the sensority coefficient on the temperature for the AquaCyl+DBSA ink composition on cotton-polyester fabric.

The presented graphs show the cyclical measurements of sensority for heated and cooled samples.

By computing the results obtained, it could be observed that the addition of SLS in a significant way deteriorates the sensory properties of the fabrics to thermal stimulus. It should also be emphasised that in the particular measuring cycles there are no changes observed in the character of the course of the curves, which indicates that the sample is not damaged during heating at a specified level of temperature.

The obtained results of this work show a potential possibility of utilising the proposed method of printing for manufacturing textile sensors used as elements of protective, technical or firearms clothing's and in the mining industry.

4. Conclusions

The performed research confirms the validity of using ink compositions with nanotubes, for modification of fabrics containing polyester fibres, as sensors to chemical and thermal stimuli. By using the screen printing technique for modification of polyester products' surface one can manufacture resistance sensors in a cheap and fast way.

The characteristics of resistance changes caused by thermal stimulus in the range of temperatures: 20°C-70°C are repeatable and reproducible. It was observed that the sensority coefficient was increased from 47% to 53% after adding the DBSA to the dispersion of carbon nanotubes.

In case of the characteristic of resistance changes caused by the chemical stimulus it was observed that the change of DBSA to SLS caused lowering the sensitivity of printed textile backings. For printouts containing SLS, made from polyester fabrics, the sensority coefficient for acetone was 72%, and for printouts containing DBSA was 88%. An addition of

DBSA causes deterioration of electric conductivity, but positively influences the improvement of sensory properties and achieving of bacteriostatic properties.

Using the UV networking composition composed of the aliphatic acrylic urethane and photoinitiator enabled to obtain printouts resistant to the utilisation processes. The electric resistance of a commercial dispersion of carbon nanotubes after 25 washing cycles was equal to $1{,}71*10^{4}\Omega$, and with the addition of UV networking mixture - UV was $8{,}56*10^{2}\Omega$.

The textile sensors presented in this article can find potential application in medical care, in areas where there is a risk of chemical substances' explosion, in military and sport applications. In order to apply the proposed solution at an industrial scale it is necessary to perform the integration of the manufactured sensor with the system of processing and sending the data to the computer.

Author details

Ewa Skrzetuska, Wiesława Urbaniak – Domagała,
Barbara Lipp-Symonowicz and Izabella Krucińska
Lodz University of Technology, Departament of Material and Commodity Sciences and Textile Metrology, Poland

5. References

[1] Oerlikon group (2007) The fiber year 2006/07, A world survey on textile and nonwovens industry, Issue 7.
[2] Sesto, B.; Yoneyama, M.; Xiaoxiong, O. (2010) Polyester Fibers, Chemical Economics Handbook, April 2010, Available from http://chemical.ihs.com/CEH/Public/Reports/541.9000/
[3] Kardas, I.; Lipp-Symonowicz, B.; Sztajnowski, S. (2011) The influence of enzymatic treatment on the surface modification of PET fibers, Journal of Applied Polymer Science, 119 (6): 3117-3126
[4] Podsiadła-Bulsa, Z.; Michalczewski, A.; Kałużka, J.; Wcisło, P. A. (2009) Poliestrowa włóknina do oczyszczania oleju silnikowego, Problemy eksploatacji, 1: 167-175
[5] Trans, S.J.; Verschueren, A.R.M.; Dekker, C. (1998) Room-temperature transistor based on a single nanotube, Nature, 393: 49-52
[6] Krucińska, I.; Skrzetuska, E.; Urbaniak-Domagała, W. (2012) Prototypes of Carbon Nanotube-Based Textile Sensors Manufactured by the Screen Printing Method. Fibres & Textiles in Eastern Europe, 91: 79-83
[7] Bachtold, A.; Hadley, P.; Nakanishi, T.; Dekker, C. (2001) Logic Circuits with Carbon Nanotube Transistors, Science, 294: 1317-1320
[8] Kong, J.; Franklin, N.R.; Zhou, C.W.; Chapline, M.G.; Peng, S.; Cho, K.J.; Dai, H.J. (2000) Nanotube Molecular Wires as Chemical Sensors , Science, 287: 622-625
[9] Wei, J.; Sun, J.; Zhu, J.; Wang, K.; Wang, Z.; Luo, J.; Wu, D.; Cao, A. (2006) Carbon Nanotube Macrobundles for Light Sensing, Small, 2: 988-993

[10] Przygocki W.; Włochowicz A. (2004) Fulereny i nanorurki. Właściwości i zastosowanie, WNT, Warsaw, Poland
[11] Krucińska, I.; Skrzetuska, E.; Urbaniak-Domagała, W. (2011) The use of carbon nanotubes in textile printing, Journal of Applied Polymer Science, 121: 483-490
[12] Huczko, A. (2004)Nanorurki Węglowe. Czarne diamenty XXI wieku, ISBN: 8388442864 WNT Warsaw, Poland
[13] Graham, A.G.; Duesberg; G.S.; Seidel, R.V.; Liebau, M.; Unger, E.; Pamler, W.; Kreupl, F.; Hoenlein, W. (2005) Carbon Nantubes for Microelectronics? Small, 1: 382-390
[14] Kordas, K.; Mustonen, T.; Toth, G.; Jantunen, H.; Lajunen, M.; Soldano, C.; Talapatra, S.; Kar, S.; Vajtai, R.; M.Ajayan, P. (2011) Inkjet Printing of Electrically Conductive Patterns of Carbon Nanotubes, Small,8-9: 1021-1025
[15] Stempień, Z.; Tokarska, M.; Gniotek, K. (2010) Laboratory Stand for the Optimisation of the UV Curing of Fluids Disposed on Textiles, Fibres & Textiles in Eastern Europe, 18: 65-69