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Dependence Between Climatic Conditions and Electrical Properties of Polyester Fibres and Yarn Breakage

Abstract
The ability of electrostatic charging, which means generation of electrostatic stationary charges on the fibre surface, is a characteristic feature of almost al kind of fibres. This paper presents an attempt to determine the relations between electrical fibre parameters, such as resistivity and electrostatic field intensity, fibre cohesion in yarn, temperature and humidity of the air, and the yarn breakage. These relations should be a basis for predicting the spinnability of fibres. All tests of this research were carried out with the use of polyester fibres.

Key words: *polyester fibres, temperature, humidity, electrostatic field properties, yarn, cohesion, yarn breakage.*

Introduction

The spinning process requires determined climatic conditions, especially temperature and relative humidity of air surrounding the fibres. The parameters of climatic conditions depend of the kind of the processed fibres and of their electrostatic properties. Especially sensitive are synthetic fibres, whose processing in inappropriate climatic conditions is at all impossible, considering the generation and accumulation of electrostatic charges on the fibre surface. Problems connected with climatic conditions in modern spinning mills should be continuously verified as new kinds of fibres and new high-efficient technologies are implemented constantly in the spinning process.

Electrostatic properties of fibres

The ability of electrostatic charging, which means the accumulation of stationary electrostatic charges on the fibre surface is a characteristic feature of almost all kinds of fibres [1, 3, 5, 11, 12, 13]. The degree of charging depends on the kind of fibre. The smallest ability to charging have plant-origin natural fibres (hemp and flax) and artificial cellulose fibres, significantly greater ability have animal-origin natural fibres (wool and natural silk), whereas synthetic fibres and artificial acetate fibres are characterised by an incomparable higher charging ability. The tendency to accumulate electrostatic charges is a negative fibre feature, accompanied by phenomena which can be divided into the three following groups:

- disturbances in proceeding of the processes of fibre manufacturing,
- decreasing of the usability value of textile products, and
- possibility of creating threatening states for humans and negative influence on the human organism.

The disturbances in proceeding of fibre processing caused by electrostatic charges takes place with different intensity in each of the stages of processing fibres into the final product [4, 8, 14]. The most unbearable secondary effects of fibre charging take place in spinning processes (carding, combing, and drawing). The disturbances, which appear during these processes, are characterised by two kinds of phenomena. Firstly, as the result of formation electrostatic charges of different signs (plus and minus) on the fibres and on the working machine elements, the fibres cling to these elements. This results in decreasing of the working element's fitness, the necessity to stop the technological process allowing to clean the machines, and the decreasing of the machine's efficiency. Secondly, as the result of repulsion of the electrostatic charges with the same sign accumulated on the fibres, difficulties arise in formation of webs, battings, bands, slivers, rovings, and yarns.

Electrostatic charges are created on the fibre surface as the result of non-movable (resting) contact, and next as the result of fibre motion in relation to other fibres and to other bodies. The amount of electrostatic charges depends on the following factors:

- the area of fibre contact,
- the chemical structure of the fibre material,
- the supermolecular structure of the fibre material, and
- the parameters of the air surrounding the fibres.

The charging effect increases with the increase in the area of the fibre's contact surface. Considering the chemical structure, the polymer polarity [12, 13] has decisive importance for the process of generation electrostatic charges, as well as on their decay.

The main parameter of the fibres' supermolecular structure is their crystallinity degree [12, 13]. With increase in crystallinity degree the ability to charges generation on the fibre surface arises, whereas the electrical conductivity of the fibres worsens, and as the result of these phenomena the ability of charge decay through charge conducting decreases.

Considering the fibre environment, the most intensive influence on durable electrostatic charging have the relative humidity of air, its ionisation degree, temperature, atmospheric pressure, and air contamination. Changes in the parameters mentioned above mainly influence the processes of charge decay by dispersion. With increase in relative humidity, ionisation degree, contamination content, and decrease in atmospheric pressure, the ability to electrostatic charging of fibres decreases.

Assessment of electrical properties of fibres

The electrical resistance and the intensity of the electrostatic field, which is generated around the fibres, are the electrical fibre properties, which are most important considering fibre processing into yarn.

The intensity of the electrostatic field in the neighbourhood of the tested fibre is the quantity which characterises the fibre ability to accumulate electric charges, whereas the fibre electrical resistivity (or resistance) characterises the ability to conducting these charges. Many methods allowing determining the above mentioned quantities have been developed. The methods used in our research, as well as in previous investigations [2, 6, 7, 9, 10, 11, 14] are presented below.

Method for measuring the electrostatic field intensity.

A convenient method of measuring the intensity of electrostatic fields uses the RMEL-Fi radioisotopic electrostatic field intensity meter [9, 10]. The meter is devoted to measure the intensity of fields generated by charges accumulated on the surface of metallic or dielectric bodies. The RMEL-Fi meter allows for electrostatic field measurements of an intensity up to 30,000 V/cm which is related to a charge surface density of 1,410 pC/cm^2. The meter indicates the sign of the charge accumulated on the surface.

Method for measurement the electrical resistance

According to standard PN-76/P-04871, the measurements of electrical resistance can be performed with the use of the P-435 insulation meter which enables electrical resistance measurements in the range from $4\times10^6\Omega$ to $10^{12}\Omega$. This meter has been developed in the Department of Spinning Technology and Yarn Structure.

The samples tested (sliver, roving or yarn), formed in parallel segments (2 in Figure 1) are placed between electrodes displaced at a distance of 1 cm. The electrodes are placed (Figure 2) in a screening can (4) during the measurement, and connected to the meter (1) by high-voltage cable (2).

Influence of electrical properties of the fibres on their spinnability

The spinnability is a set of features determining the ability of textile raw materials to processing into yarn of appropriate linear density and quality, at yarn breakage occurring on the spinning machine not greater than accepted in practice.

The fibre spinnability depends in a great degree on the kind of fibres and its surface properties, firstly the frictional. A too high value of friction led to spinnability worsening and occurring of the electrostatic charging phenomena which further disturbs the processing of fibres.

From the phenomena presented above, we can conclude that to the most important fibre properties, which decide about their spinnability, we can include the following:

- the geometrical dimensions of fibres and the shape of fibre cross-section,
- the surface properties of fibres, such as fibre cohesion, as well as the amount and composition of the preparation deposited on the fibre surface,
- the electrostatic field intensity and the electrical resistance of the fibres,
- the fibre humidity and the hygroscope properties, and
- the fibre deformability.

The majority of the properties mentioned above is correlated mutually, which makes difficult to select the more or less important. For example the fibre humidity and the amount and composition of the deposited preparation influence the cohesion and deformability of the fibres, as well as the electrical properties, whereas in turn, the fibre humidity depends of the crystallisation degree of the fibre material.

One of the methods for evaluation the technological usability of fibres is determination of their spinnability on the basis of evaluation of the whole process carried out in the spinning mill, firstly on the basis of yarn breakage on the spinning machine. This factor, i.e. the number of yarn breakage per 1,000 spindles and one hour is the best synthesised parameter which characterises the fibre spinnability. This factor indicates also the correctness of performing the process, the selection of climatic conditions, as well as machines and their settings.

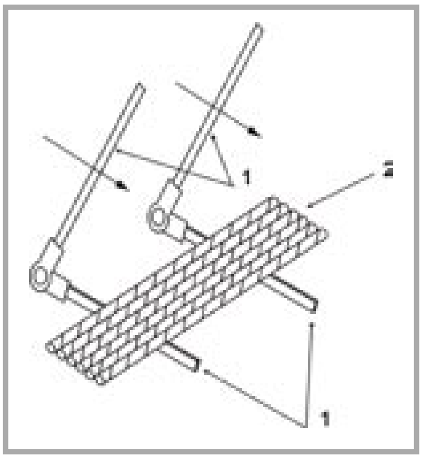

Figure 1. *Scheme of the measuring electrodes; 1 – measuring electrodes, 2 – roving.*

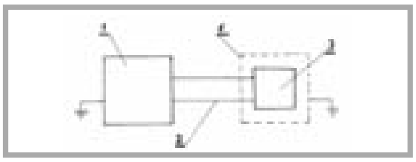

Figure 2. *Simplified scheme of electrical resistance measurement; 1) P-435 insulation meter, 2) connecting cables, 3) measuring electrodes, 4) screening can.*

The aim of research

The aim of this research is an attempt to determine the relation between electrical parameters of the fibres, such as electrical resistance and intensity of the electrostatic field, as well as between the fibre cohesion, temperature and humidity of air and the fibre breakage. Such a relation could be the basis for prediction of the fibre spinnability. All tests were carried out for polyester staple fibres of 38 mm length and linear density of 1.2 dtex. Polyester yarns of linear density 12 tex and 30 tex and metrical twist factor α_m=105 were manufactured by means of the classical medium-spinning system, with the use of the PJ-42 spinning machine. The spinning scheme is presented in Table 1.

The yarns were manufactured at different climatic conditions: air temperature of

Table 1*. Spinning scheme.*

L.p.	machines	Ttz, ktex	number of connections	drawing ratio	Ttw, ktex
1	picking machine				271.4
2	revolving flat card	271.4	1	92	2.95
3	gill draw frame	2.950	8	6.74	3.5
4	gill draw frame	3.5	8	7.0	4.0
5	flyer roving frame	4.0	1 1	10.8 6.0	0.370 0.667
6	ring spinning frame	0.370 0.667	1 1	31.0 22.2	0.012 0.030

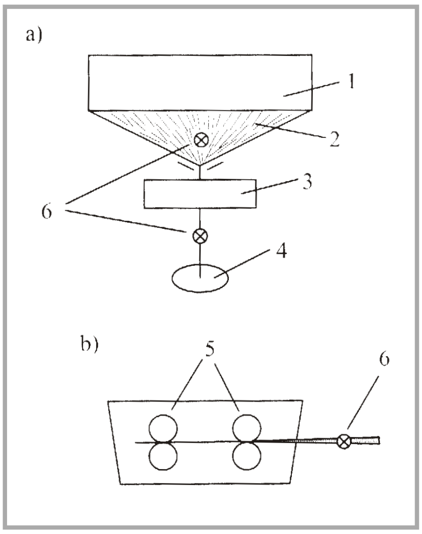

Figure 3. *Measuring points for the electrostatic field intensity: a) carding machine, b) drawing frame, 1 - stripper, 2 – web, 3 – delivery rolls of the carding machine, 4 – can, 5 – drafting arrangement, 6 – measuring points.*

20, 23, 24, 26, and 29^0C and relative air humidity of 40, 50, 60, and 70%.

The electric fibre properties, such as the electrical resistance and the intensity of the electrostatic field were carried out for various fibre streams over the successive stages of the spinning process. The electrostatic field intensity was measured on the carding machine (web and sliver) and the drawing frame (sliver). The measuring points are shown in Figure 3. The electrical resistance was assessed for rovings of two linear densities: 370 tex and 667 tex.

The cohesion of rovings with the mentioned both linear densities and roving of linear density 4.0 ktex from the drawing frame were carried out under dynamic conditions with the use of F460 Stick-Slip Friction Tester from Zweigle. The force generated during drawing the fibre stream was measured continuously by this apparatus.

Sliver strength measurements were carried out with the use of the F460 Stick-Slip Friction Tester at the following drawing parameters: drawing ratio of 1.5, transport velocity of the sliver of 5 m/min, pressure 2 bar (200 kPa), and over a measuring period of 30 s.

The rovings were tested at the following parameters: drawing ratio of 1.5, transport velocity of the roving 10 m/min, pressure 5 bar (5oo kPa), and over a measuring period of 60 s.

Five measurements were carried out for each variant tested. The results presented as the average breaking strength F obtained by the F460 Stick-Slip Friction Tester and the calculated specific strength are defined as the sliver or roving cohesion.

Analysis of research results

The results of the fibre parameters analysed are presented in Figures 4-15. On the basis of the dependencies shown in these figures the following statements can be formulated:

- Yarn breakage increases with the decrease in air humidity and increase in its temperature.
- The intensity of the electrostatic field measured over the web and sliver formation on the carding machine and drawing frame decreases with rising air temperature and humidity. Positive (+) charges were accumulated on the web and sliver from the carding machine, and negative (-) charges on the sliver from the drawing frame.
- The electrical resistance of the roving decreases with increase in the temperature and humidity of air. The resistance also decreases with the increase in the linear mass of rovings.
- The cohesion of slivers and rovings slightly decreases with the increase in air temperature and humidity.

The regression analysis were used with the aim to formulate mathematical dependencies between spinning process parameters, such as air humidity, air temperature, electrostatic field intensity, fibre cohesion, and electric resistance ant the yarn breakage. For each parameter listed in Table 2 the regression function Y=ax+b were determined by means of the least squares method.

The correlation factor was determined for each regression equation. Next its significance was verified with the aim to find if correlation dependence exists between the selected spinning process parameters and yarn breakage. The significance of the regression factor a was tested within the next stage. The calculated results of the correlation factor and the regression equations are presented in Table 2. From the tests carried out and the data listed in Table 2 results that distinct connections exist between the spinning process parameters and yarn breakage. Climatic conditions, such as air temperature and humidity, as well as fibre cohesion influence essential the changes of electrical parameters of the fibres, what in turn influence yarn breakage according to the regression equations determined.

Counter action against electrostatic charging of fibres

Various treatments are applied aiming at elimination or reduction of harmful secondary effects of electrostatic fibre charging. They can be divided into the following four groups [12]:

- modification of the molecular and submolecular fibre structure,
- physical changes of the state of the product,
- physical changes of the fibre enviroment,
- deposition of preparation on the product.

Modifying the supermolecular structure of fibres consists on introducing compounds, which increases the electrical conductivity of polymers, in the polymer material which serves as raw material for fibre formation.

Treatments of the second group concern fibres, as well as half-finished products. In each case the aim of conduct is decreasing the real contact surface of fibres, and in this weakens the process of charges generation. In practice this consists on the change of the cross-section character (by the so called grading) from a circular, regular into a cross-section with a developed boundary line.

The third group includes such typical treatments as earthing of working machine elements, supplying charges with opposite sign to the charges generated on the fibre surface, increasing the relative air humidity, and air ionisation [2, 5].

The last treatment group includes deposition of special, anti-electrostatic preparations in the form of oil films and sizes on the fibre surface.

The best effects are achieved by deposition of special anti-electrostatic preparations [1, 5, 6, 15]. These substances are mixtures of products, which increase the electrical conductivity, and typical finishes. The electrical conductivity of fibres depends in a great degree on ions existing on their surface. From this results that the preparation deposited on fibres must increase the amount of ions, which means that it should be iono-geni-

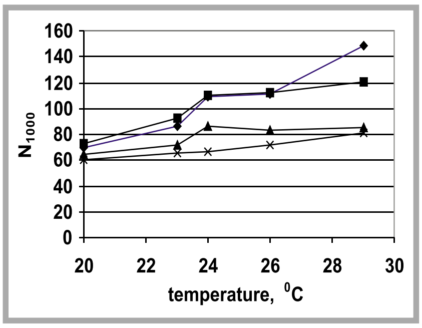

***Figure 4.** Dependence between air temperature and yarn breakage with linear density of 12tex at different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%, N_{1000} - number of yearn breakage per 1000 spindles and hour.*

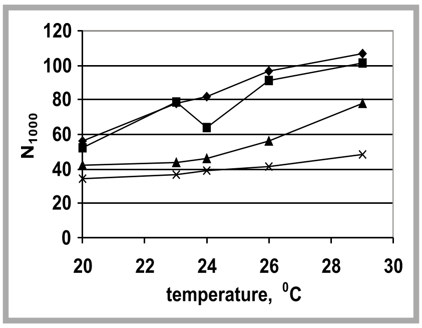

***Figure 5.** Dependence between air temperature and yarn breakage with linear density of 30tex at different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%, N_{1000} - number of yearn breakage per 1000 spindles and hour.*

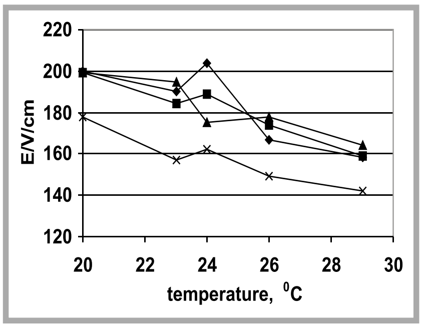

***Figure 6.** Dependence between air temperature and electrical field density of the card web at different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%.*

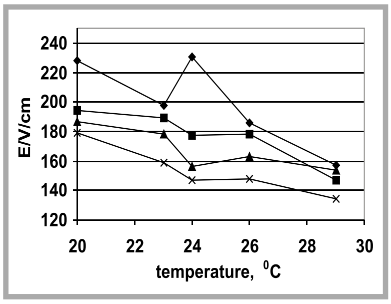

***Figure 7.** Dependence between air temperature and electrical field density of the card slivers at different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%.*

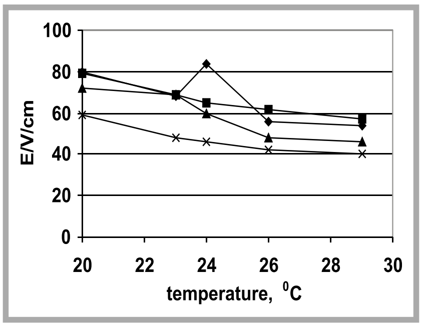

***Figure 8.** Dependence between air temperature and electrical field density of the slivers from drawing frame at different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%.*

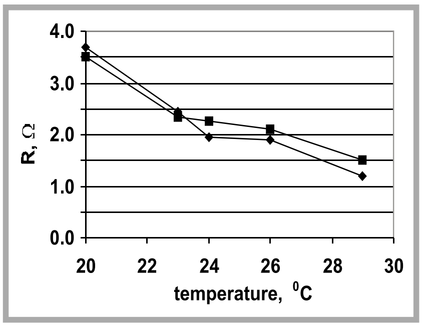

***Figure 9.** Dependence between air temp. and electrical resistance of rovings at air humidity of 40%, for rovings of 370tex (♦) and 667tex (■).*

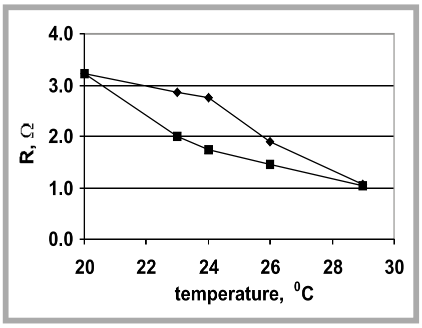

***Figure 10.** Dependence between air temperature and electrical resistance of rovings at air humidity of 50%, for rovings of 370tex (♦) and 667tex (■).*

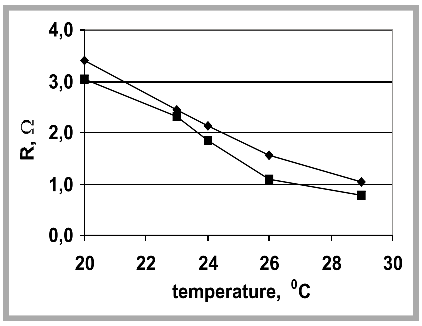

***Figure 11.** Dependence between air temperature and electrical resistance of rovings at air humidity of 60%, for for rovings of 370tex (♦) and 667tex (■).*

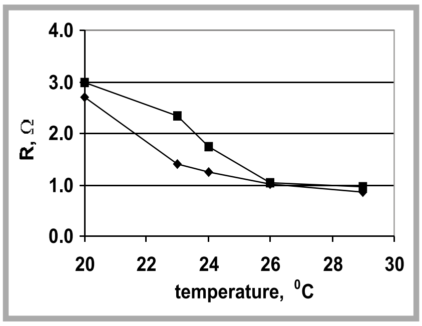

***Figure 12.** Dependence between air temperature and electrical resistance of rovings at air humidity of 70%, for rovings of 370tex (♦) and 667tex (■).*

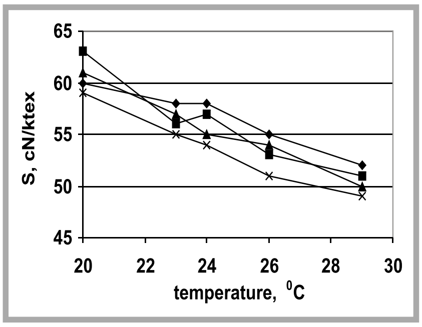

***Figure 13.** Dependence between air temperature and cohesion of slivers for different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%.*

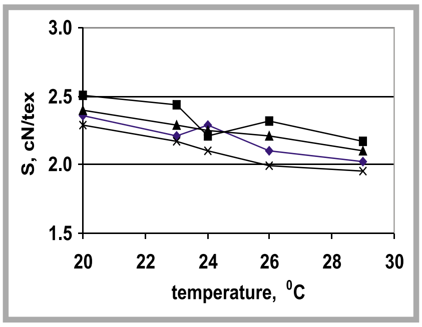

***Figure 14.** Dependence between air temperature and cohesion of rovings with linear density of 370tex for different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%.*

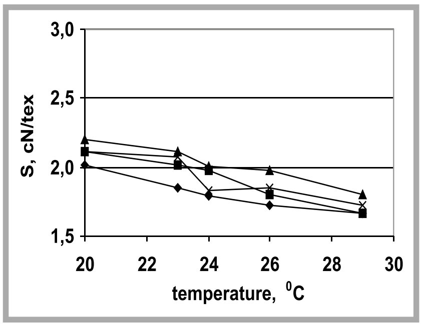

***Figure 15.** Dependence between air temperature and cohesion of rovings with linear density of 667tex for different humidity; ♦ - 40%, ■ - 50%, ▲ - 60%, × - 70%.*

Table 2. *Values of the correlation factor between yarn breakage Z and the selected parameters of the spinning process. Regression equations; * cvc - critical value of the correlation factor r_{kr}, p=0.05, ** scf - significance of correlation factor.*

parameter	correlation factor r	cvc*	scf**	test statistic	critical value of test statistic	significance of regression factor	regression equation
Air temperature t, yarn 12tex	0.901		+	10.21		+	Z=3.95t + 28.83
Air humidity φ, yarn 12tex	-0.921		+	5.48		+	Z=-1.58 φ + 146.74
Air temperature t, yarn 30tex	0.821		+	2.28		+	Z=2.33t - 53.61
Air humidity φ, yarn 30tex	-0.856		+	8.95		+	Z=-0.83 φ + 126.48
Electrical resist. of roving R_N	0.858		+	8.18		+	Z=10.98 R_N + 27.29
Sliver cohesion f_1, cn/tex]	0.690	0.311	+	9.23	2.02	+	Z=11.76 F_t + 59.14
Roving cohesion f_n, cn/tex	0.668		+	7.12		+	Z=80.67 F_N –107.20
Electrostatic field intensity in the card web e_{zr}	0.839		+	3.12		+	Z=0.97E_{RZ} + 0.47
Electrostatic field intensity in the card sliver e_{zt}	0.848		+	5.02		+	Z=0.85 E_{tz} - 94.91
Electrostatic field intensity in the drawing frame sliver e_{rt}	0.838		+	4.33		+	Z=1.44 E_{tR} -28.08

cally. A positive, anti-electrostatic part can play only such substances, which can intensive dissociate, and split-off ions. Poly-alcoholes, soaps, sulphated fats, and cation-active compounds are products most often applied which increase the electrical conductivity.

At present, applying of anti-electrostatic preparations is the most common way of decreasing the ability to electrostatic fibre charging. Disadvantages of this kind of treatment are the generation of adverse changes in some of the product features, such as the fabric handle and the fabric arrangement ability, as well as the relative unstability of the obtained anti-electrostatic effect, as the result of successive removing the preparation over using the products.

An effective and simple way of decreasing fibre charging is increase in the relative air humidity and determining an optimum air temperature. The effects depend on the fibre hygroscopy. If the hygroscopy rises, the unloading increases. Obtaining a high humidity in the surrounding of fibres requires maintaining a high humidity in the whole spinning room. This latter demand is impossible to secure under industrial conditions, as it increases the machine corrosion. Changes in the temperature of the surrounding air, which cause changes in the fibre temperature, influences the process of charge generation, as well as the charge decay by means of conductivity. With the increase in temperature the generation of electrostatic charges is intensified thanks to the pyro-electrical effect, whereas at the same time the fibres' electrical conductivity increases. The final effect is increasing in yarn breakage during the manufacturing process.

By analysing the research results can be stated that an air temperature of 23^0C and a relative humidity of about 60% are optimum climatic condition for the processing of polyester fibres.

Conclusions

- The electrical fibre parameters, such as electrical resistance and intensity of the electrostatic field generated around the fibres have significant influence on yarn breakage during spinning.
- The climatic conditions in the spinning room, i.e. the air temperature and humidity essential influence changes of electrical parameters of fibres and of yarn breakage. A decrease in air humidity and increase in its temperature causes a rise of yarn breakage. A temperature of 23^0C and a relative humidity of about 60% are optimum climatic conditions for the processing of polyester fibres.
- The cohesion of fibre streams in the form of slivers and rovings decreases with the increase in air temperature and humidity.
- Measurements of the electrostatic field intensity should be carried out on machines which manufacture fibre streams of large linear densities, such as carding machines and drawing frames.

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