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# Determination of limiting fibers blend irregularity

D B Ryklin<sup>1</sup>, A M Navumenka<sup>2</sup>

<sup>1</sup>Vitebsk State Technological University, Faculty of Manufacturing Technologies,  
Department of Textile Technology

72 Moscow av., Vitebsk 210038, Republic of Belarus

<sup>2</sup>Vitebsk State Technological University, Faculty of Information Technologies and  
Robotics, Department of Information Systems and Production Automation,  
72 Moscow Ave., Vitebsk 210038, Republic of Belarus

e-mail: ryklin-db@mail.ru

**Abstract.** Aim of the research is obtaining formulae for determination of limiting blending irregularity of fiber assemblies on the base of simulation. Obtained formulae show the influence of the fibers properties and their percentage on blends irregularity and can be used for evaluating blending process efficiency. Comparison of actual blend irregularity and limiting values allows to assess potential opportunities of the process improving. It was experimentally proven that influence of fiber blends parameters on actual blend irregularity corresponded to obtained formulae.

## 1. Introduction

For a long time blended yarns are ordinary kind of products for a lot of spinning mills. Combination of different types of fibers allows producing textiles with required complex consumer properties. At present, a wide range of blended yarns produced both from combinations of conventional types of fibers (for example, cotton / polyester, wool / acrylic) and innovative blends (meta-aramid / cotton [1], glass fiber / polyamide 6 [2], Kevlar / polypropylene fibers, etc. [3]) is presented on the market textiles. Because of significant difference between properties of fibers it is very important to find the method of evaluation of the blending irregularity.

On the other hand, very often the components of blends very differ by its cost. High-performance fibers which provide particular properties of textiles as a rule are much more expensive in comparison with other fibers. Accordingly, to achieve these properties along the entire length of yarn or over the whole area of fabric the manufacturer must ensure the required percentage of the component with the highest cost even in the case where this percentage is very small. So, the more blending irregularity of yarn, the more quantity of expensive component must be added to the fibrous blend. It is necessary to take into account that relatively few researches are engaged in the development of the methods for blending quality evaluation.

The publications propose the use of several methods to assess the composition of fibrous materials and their heterogeneity. The microscopic method [3, 4] is focused on the determining the fibers number in cross-sections of slivers or yarns. The main disadvantage of this method is the high labor intensity of the samples preparation and counting the fibers in the cross-sections. Therefore, this method is mainly used to study the composition and structure of the yarn. The chemical method [5] allows to investigate of composition of fiber assemblies during exposure to chemical reagents, solvent



one of blending components. This method cannot be applied to determine the percentage content of the flax/cotton blends due to the similarity of their chemical composition. The colorimetric method [6] is determined the percentage of components in the material by measuring their color characteristics. The disadvantage of the colorimetric method is that the measuring is carried out in the outer layer of textile materials. But the outer layer of yarns includes up to 50% of the fibers, for slivers their number is not more than 10%. This fact reduces the reliability of the results.

Thus, despite the variety of methods for fibers blending evaluation their use has a number of limitations. In addition, there is a problem of the minimum (or limiting) blending irregularity determining. It is known that Martindale and other researchers have carried out theoretical investigations with respect to the limiting irregularity and defined certain relationships mathematically. The results of such investigations are shown in the following formula:

$$CV_{\text{lim}} = \frac{100K}{\sqrt{n}} (\%), \quad K = \sqrt{1 + 0,0004CV_d^2}, \quad (1)$$

where,  $n$  is the mean number of fibers in the cross-section,  $CV_d$  is the coefficient of variation of fiber diameter in %.

Similar indicators for the blending quality are not developed. The objective of the presented investigation was to determine the factors which influence on blending irregularity limit.

## 2. Method used

For experimental research in this work the dielcometer method was used. This method can be used for determination the percentage of components in the material by placement of matter in electrocapacitive transducers and measuring the their dielectric characteristics. The design of differential electrocapacitive transducers in the form of multisection screened attachable measuring capacitors was developed [7]. Transducers provide the generation of fields along and across fibers and the measurement of the difference between two capacitors.

The basis of the blending quality evaluation was the determination the coefficient of variation referred to the coefficient of dielectric permittivity anisotropy, which reflects the blending irregularity of the investigated fiber assemblies. The coefficient of dielectric permittivity anisotropy is given by:

$$K_\varepsilon = \frac{C_{=}^H - C_{\perp}^H}{C_{=}^L - C_{\perp}^L}, \quad (2)$$

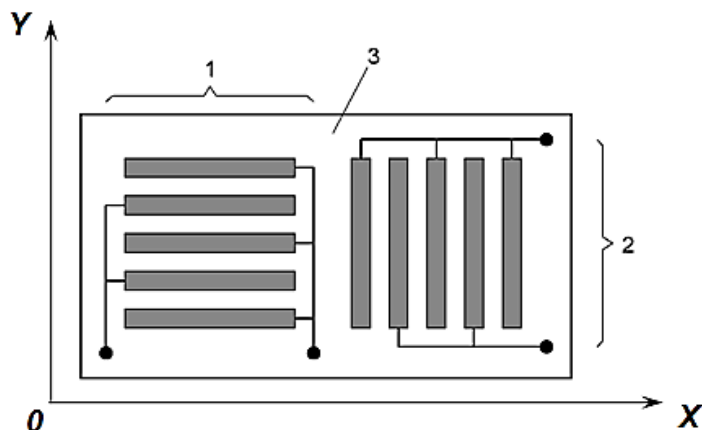
where,  $C_{=}^L$  is capacity measured along fiber with the low frequency of the electromagnetic field ( $f = 1$  kHz);  $C_{\perp}^L$  is capacity measured across fiber with the low frequency of the electromagnetic field ( $f = 1$  kHz);  $C_{=}^H$  is capacity measured along fiber with the high frequency of the electromagnetic field ( $f = 100$  kHz);  $C_{\perp}^H$  is capacity measured across fiber with the high frequency of the electromagnetic field ( $f = 100$  kHz).

The capacitive sensor oscillates an electromagnetic field oriented along or across the fiber. Capacitor includes two identical tape electrodes 1, 2 located on the flat surface of the substrate and rotated by  $90^\circ$  relative to each other (Figure 1) [8]. With the reflecting electrodes which are installed under and above measuring electrodes 1 and 2 sensor generates a plane-parallel field across and along fiber.

Theoretically and experimentally it is proven that coefficient of variation referred to coefficient of dielectric permittivity anisotropy ( $CV_{K_\varepsilon}$ ) is proportional to blending irregularity  $C_{BI}$ . To evaluate the irregularity of the fibers composition indicator “Blend Irregularity” was used which calculated by the following formulae [9, P. 401]:

$$C_{BI} = \sqrt{\frac{1}{k} \sum_{i=1}^k C_{\beta i}^2}, \quad (3)$$

where,  $C_{\beta i}$  is coefficient of variation of the fibers  $i$  percentage:  $k$  is the number of components in the blend.



**Figure 1.** The design of the capacitive sensor.

For determining the minimum blending irregularity the simulation model of ideal fiber assemblies (yarns, rovings, slivers) was developed. In accordance to this model ideal blended fiber assembly was considered as the sum of several Poisson random flows of each intermixture fibers (Martindale model). In other words, the number of each type of fibers in yarn (roving, sliver) cross section follows Poisson distribution. In other words, probability of  $k$  leading fibers end location at yarn cross section can be calculated using this formula:

$$P(X = k) = \frac{e^{-\lambda} \lambda^k}{k!}, \quad (4)$$

where,  $\lambda$  is average number of fibers leading ends in the interval  $\Delta$  between cross sections of yarn:

$$\lambda = \frac{N \cdot \Delta}{l}. \quad (5)$$

Here  $N$  is the average number of fibers in cross section of yarn,  $l$  is the average fibers length.

Using the developed model the simulation of two types of blended slivers with a linear density of 6 ktex (cotton/ cottonized flax and cotton/polyester/ cottonized flax) was carried out in software Maple.

For the blended sliver of two components (cotton/ cottonized flax) 54 variants were simulated (9 combination of components percentage  $\times$  6 combination of linear densities of fibers). The percentage of each of the components was changed from 10 to 90% in 10% increments, and the linear densities of the fibers were set in accordance with the Table 1.

**Table 1.** Linear densities of fibers in simulated slivers (cotton/cottonized flax).

No	Linear density of cottonized flax fiber, mtex	Linear density of cotton fiber, mtex
1	190	190
2	400	190
3	600	190
4	800	190
5	400	150
6	400	120

For the blended sliver of three components (cotton/ polyester/ cottonized flax) 62 variants were simulated (31 combination of components percentage  $\times$  2 combination of linear densities of fibers). The linear densities of the fibers were set in accordance with the Table 2.

**Table 2.** Linear densities of fibers in simulated slivers (cotton/polyester/cottonized flax).

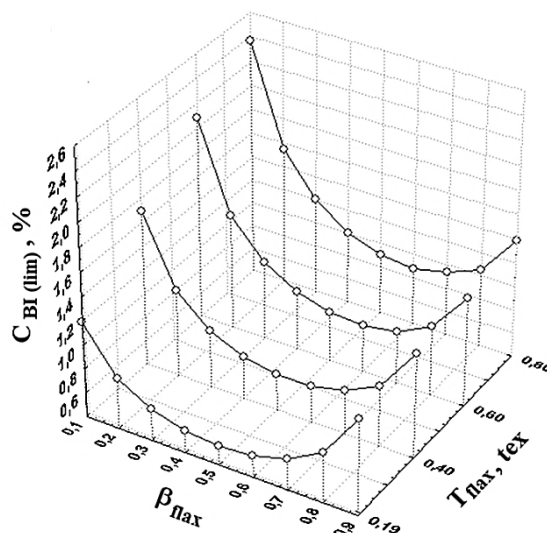
№	Linear density of flax fiber,	Linear density of cotton fiber,	Linear density of polyester
	mtex	mtex	fiber, mtex
1	400	170	170
2	800	190	150

To minimize errors of calculation we simulated 10000 cross sections of the sliver. The choice of these characteristics was based on the following premises. First, the flax is one of the most important raw materials for the textile industry in Belarus. This is the only kind of natural fibers produced in the country. Investigation of their co-processing with other types of fibers is one of the most relevant areas for research in Belarus.

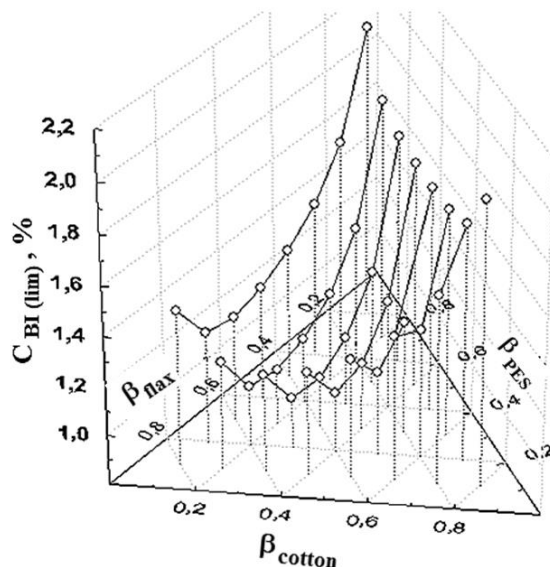
Secondly, blended fibers differ significantly in linear density. Consequently, the use of simulation results will allow to take into account this difference in the developed model, that would be impossible, for example, while cotton/polyester sliver simulation.

### 3. Results

The Figures 2 and 3 show the results of the blended slivers simulation. It can be noted that with the small percentage of each component its distribution in the sliver becomes more uneven, which leads to blending irregularity increasing. This result confirms the well-known fact that in real conditions obtaining the uniform distribution of a component with the low content is achieved with much greater efforts.



**Figure 2.** Influence of proportion and linear density of flax fibers on limiting blend irregularity of flax/cotton blended sliver (linear density of cotton fibers was 0,19 tex).



**Figure 3.** Influence of different fibers proportions on limiting blend irregularity of flax/cotton/polyester blended sliver with different linear densities of fibers ( $T_{\text{flax}} = 0,8 \text{ tex}$ ,  $T_{\text{cotton}} = 0,19 \text{ tex}$ ,  $T_{\text{PES}} = 0,15 \text{ tex}$ ).

If the linear densities of the blended fibers are identical the minimum value of limiting blending irregularity is achieved with their equal contents in the sliver (ratio is 50/50 for two-component blends). However, for blended fibers of different linear densities the limiting blending irregularity is minimum one with another ratio.

The influence of the flax fiber content and its linear density on the limiting blending irregularity for the blend sliver (flax / cotton) determined as a result of the simulation.

As a result processing of simulation data the following formulae were obtained:

- for fiber assemblies contained 2 types of fibers

$$C_{BI(\text{lim})} = \frac{100}{\sqrt{2T_A}} \sqrt{\frac{1}{\beta_1} + \frac{1}{\beta_2} - 2\sqrt{T_{F1}\beta_2K_1^2 + T_{F2}\beta_1K_2^2}}; \quad (6)$$

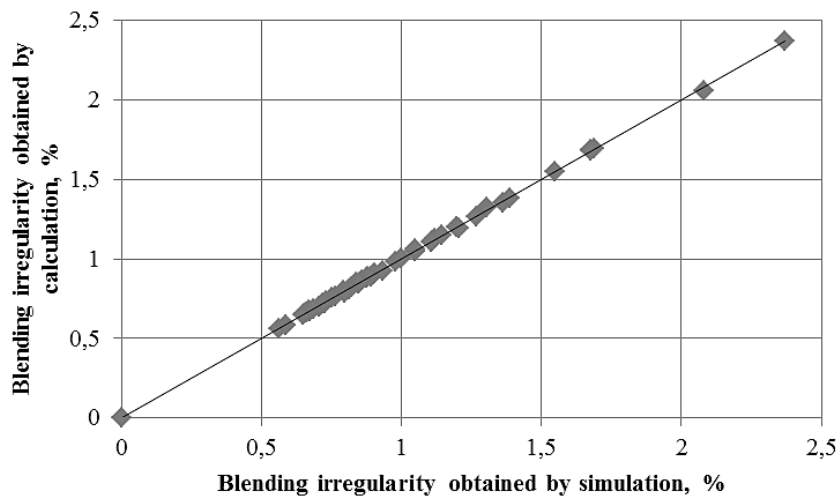
- for fiber assemblies contained 3 types of fibers

$$C_{BI(\text{lim})} = \frac{100}{\sqrt{6T_A}} \sqrt{\frac{1}{\beta_1} + \frac{1}{\beta_2} + \frac{1}{\beta_3} - 3\sqrt{T_{F1}S_1K_1^2 + T_{F2}S_2K_2^2 + T_{F3}S_3K_3^2}}; \quad (7)$$

$$S_i = (1 - \beta_i)(\beta_1^2 + \beta_2^2 + \beta_3^2 - 0,5) + \frac{4\beta_1\beta_2\beta_3}{\beta_i}, \quad (8)$$

where,  $T_A$  is the mean linear density of fiber assembly in tex;  $T_{Fi}$  is the mean linear density of fibers  $i$  in tex;  $\beta_i$  is the proportion of fibers  $i$  in the blend;  $K_i$  is the coefficient depended on the fibers diameter variation.

The Figure 4 shows that for a sliver consisting of two components the results of calculations and simulations are practically identical (coefficient of correlation  $R=0,999856$ ). A similar result was obtained for a sliver produced of three components ( $R=0,998308$ ).



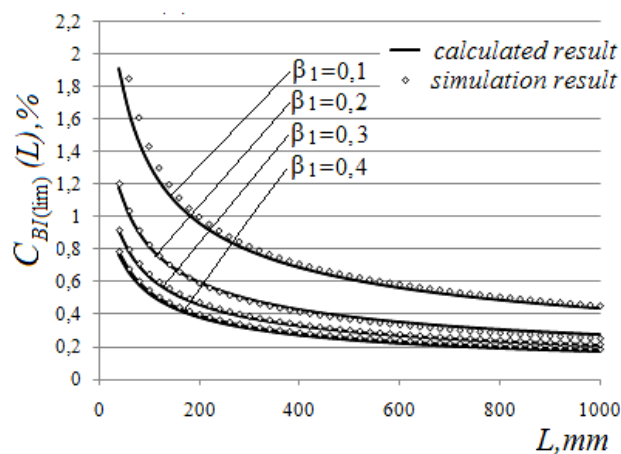
**Figure 4.** Comparison of results of limiting blending irregularity simulation and calculation of limiting blending irregularity for cotton/flax slivers.

The formulae (6) – (8) allow calculating the limiting blending irregularity  $C_{BI(lim)}(0)$  of minimum size samples or for slivers cross-sections. Simulation showed that for determining the with optimum distribution of different fibers in the sliver pieces of a certain cut length  $L$  it is possible to use a formulae similar to the formulae developed by Olerup and Breny for calculating the variance-length curve (Figure 5):

$$C_{BI(lim)}(L) = C_{BI(lim)}(0) \sqrt{1 - \frac{L}{3l}} \quad \text{for } L \leq l, \quad (9)$$

$$C_{BI(lim)}(L) = C_{BI(lim)}(0) \sqrt{\frac{l}{L} - \frac{l^2}{3L^2}} \quad \text{for } L > l, \quad (10)$$

where,  $l$  is mean staple length of the fibers in the blended sliver.



**Figure 5.** Influence of cut length  $L$  on blending irregularity  $C_{BI(lim)}(L)$  of ideal flax/cotton sliver with different flax fibers proportion ( $T_{flax} = 0,8 \text{ tex}$ ,  $T_{cotton} = 0,19 \text{ tex}$ ).

The formulae (9) and (10) are necessary in order to determine the blending irregularity for sliver pieces of a certain length in order to compare this value with experimental data, since when using the device it is required to test sliver samples of 5 g (833 mm).

Evidently, the actually measured irregularity is always higher than the limiting irregularity of a fiber assembly. The same result was obtained for blending irregularity.

Comparison of simulation results and experimental data showed that for flax / cotton slivers from card Rieter C40 with percentage of flax fiber from 35 to 65% the actual blending irregularity significantly exceeds the limiting value by 31 – 35 times. This ratio can be called the Blending Irregularity Index (IBI).

After one passage of draw frame Rieter RSB D-40 the Blending Irregularity Index decreases to 20 – 24 which indicates the great homogenization of the slivers. It can be argued that the blending effect is about 1.5.

Thus, the obtained formulae can be used to analyse and evaluate the effectiveness of technological processes for the manufacturing of blended yarn consisting of two or three components.

#### 4. Conclusion

As a result of simulation of two types blended slivers formulae obtained for calculation of minimum blending irregularity of fiber assemblies. These formulae show influence the fibers properties and their percentage on blends irregularity and can be used for evaluating blending process efficiency. Comparison of actual blend irregularity and limiting values allows to asses potential opportunities of the process improving. It was experimentally proven that influence of fiber blends parameters on actual blend irregularity corresponded to obtained formulae.

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