IMPROVING A MATURITY TESTING DEVICE BY THE MEANS OF AN IMAGE ANALYSIS REFERENCE SYSTEM

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Abstract

Characterizing cotton maturity by an integral mean value does not meet the requirements of the processing industry because the processes are determined by the characteristics of single fibers rather than the fiber collectives' properties.

It is shown how to improve the quality of the testing results of a standard testing device by the means of an adapted design and by an image analysis based reference system.

Introduction

On the global markets, a multitude of natural raw material – i.e. wool and cotton - for the production of yarns is available - at a variety of different and constantly changing grades and prices. To the processing industry it is a commercial imperative to react quickly to the varying raw material properties. Knowledge of individual origins accumulated over long years of experience is of little use given this situation so that the call for improvements in quality assessment is entirely justified.

Adding Value to Cotton

Cotton maturity is of decisive significance for the further processing of this raw material.

An overview of maturity related values from the Bremer Baumwoll-Rundtest is shown in figure 1. The figure shows that considering the variance of the devices the quality criterion "maturity" is only an approximation.

The spinning and dyeing processes are determined by the characteristics of individual fibers and not mainly by the fiber bundle properties. Because of the continuous quality improvements demanded of the raw material and the ensuing desire to utilize the raw material even more efficiently single fiber tests will increase in importance, particularly in the field of reference methods.

The dyeing capability of yarns and fabrics and the occurrence of broken ends during the spinning process are particularly negatively influenced by the presence of immature fibers in the raw material. The usual characterization by mean values of maturity is not sufficient due to the fact that the amount of immature fibers can reach considerable degrees even with a relatively high value of maturity.

Although the exact knowledge of the distribution of maturity is more desirable than the mean value, the purchase of new equipment and the involved necessity for additional qualification of the laboratory personnel is expensive and counterproductive in the sense of an optimal utilization of the raw material. For that reason this paper is following up the possibility of modifying existing equipment and by the use of a reference system in such a manner that more meaningful data is acquired. The airflow-based Fineness/Maturity Tester (FMT) with its different versions is the most common device for the determination of maturity and the fineness of fibers. The great significance of the Micronaire value as a characteristic value emphasizes the meaning of airflow-based testing devices for the characterization of cottons.

Functioning Principle of the FMT

The measurement principle on which the FMT is based corresponds to that of the micronaire apparatus, the micronaire value generated by these devices represents both maturity and fineness of the material under review. With the FMT a distinction between these characteristics is achieved by generating a second, modified micronaire value and then applying empirical formulas. Details of the FMT apparatus are shown in figure 2.

Fluid Dynamic Fundamentals of the Airflow Passing a Fibre Collective

According to Hagen/Poiseuille [Bob61] the amount of flow passing narrow pipes with a circular cross-section and laminar flow is represented by the following relation:

$$Q = \frac{\left(\frac{D}{2}\right)^4}{\delta \cdot \eta} \cdot \frac{\Delta P}{L},$$

meaning the amount of flow Q is proportional to the fourth power of the pipe's radius and the drop of pressure over the length L; h denoting the absolute viscosity and d the density of the flowing fluid.

Koszeny [Koz31] extended this relationship to airflow through porous media:

$$Q = \frac{1}{k_0} \cdot \frac{m^2 \cdot A \cdot \Delta P}{\eta \cdot L}.$$

k_0 is a constant, A the area being flown through and m that part of free space of the overall volume of the fiber plug (porosity).

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:745-748 (2000)
National Cotton Council, Memphis TN

If *Koszeny's* formula is to be used in the determination of maturity and fineness of fibers, then it is necessary to introduce dimensions, which relate to those characteristic values in this formula.

The specific surface O_{spec} of fibers is the ratio of fiber surface *O* to Volume *V*, $O_{spec} = \frac{O}{V}$, for fibers with a circular cross-section with radius *r* it is $O_{spec} = \frac{2}{r}$; for fibers with any cross-section apply the cross-sectional circumference *U* and the cross sectional area *F* is $O_{spec} = \frac{U}{F}$.

However, the specific fiber surface does not make any statements about fiber fineness and maturity.

One dimension for the fineness of fibers is the relationship between fiber length to fiber mass, $Tt = \frac{G}{L}$, for any fiber cross section *F* the mass *G* results for the length *L*

$G = F \cdot L \cdot \gamma$, γ: specific density.

Out of these results finally the specific surface of fiber with arbitrary cross section is

$$O^2_{spez} = \frac{U^2}{4 \cdot \pi \cdot F} \cdot 4 \cdot \pi \cdot n \cdot \gamma .$$

The factor $\frac{U^2}{4 \cdot \pi \cdot F}$, called form factor by *Lord* [Lord81], corresponds exactly to the definition of Q, the dimension for maturity. Although the form factor of cotton does not exactly correspond to the degree of maturity – the lumen has to be subtracted from the sectional area – although the systematic error is minor because most fibers have collapsed and thus the lumina become fairly small. This means that the *Koszeny's formula* provides a theoretical base for the determination of fiber fineness as well as maturity by airflow testing.

In [Bob61] it is shown that by integration further dimensions of influence into the formula of *Koszeny* it can be specialized to an exact numerical relationship between the difference of pressure and the fineness of fiber.

However this method has it limitations, because simplified assumption of the different properties of the raw material like surface constitution, size of the remaining lumen, density, etc. has to be used describing all fibers of a collective only approximately. This restriction reflects the fact that sufficiently complex events cannot be formalized in a complete manner.

The Modified Test Device

For the practical purpose of airflow testing with the FMT it is not possible to derive a numerical relationship for the calculation of fineness and of maturity from the *Koszeny*-Formula. This is the reason why empirical formulas have been developed by the manufacturers of the testing device and have been implemented as a calculator program. To do this there has to be a measurement of the drop of pressure behind the specimen chamber at an airflow rate of 4 l/min and large specimen chamber volume and then the drop of pressure after lowering the volume of the specimen chamber and decreasing the airflow rate down to 1l/min. The formulas for the degree of maturity MAT and the fiber fineness FIN go:

$$MAT = 0.247 \cdot P_L^{0.125} \cdot \left(\frac{P_L}{P_H} \right)^2$$

$$FIN = \frac{60000}{P_L} \cdot \left(\frac{P_H}{P_L} \right)^{1.75} .$$

The relationship between Θ and MAT according to *Lord*:

$\Theta = 0.577 MAT$ [Lord81]..

This evaluation is purely static, the dynamics of transition from one state to the next are not examined.

That is exactly the point where the adapted design sets in. With an additional flow sensor and corresponding hard- and software it is possible to record and analyze the course of the flow rate and the drop of pressure over the time passed. The used hardware enables a chronological dissolution of 0.75msec. Figure 3 shows the course of signals. The upper curve represents the signal of the flow sensor, the lower curve shows the signal of the built-in pressure sensor of the FMT. The course of the curves is clearly distinguished for cottons of different provenieces, whereas the specimen of the same provenience shows similar courses.

Evaluation

One criterion for the quantification of the curve diagram is time spent until final pressure or final flow rate respectively is reached. Looking at the signal of the flow sensor it becomes conspicuous that this characteristic data correlates with the degree of maturity. With mature fibers the final state of the airflow is reached earlier than with immature fibers. However, the value of the correlation coefficient of the transient delay and maturity is only 0.79. Fiber fineness does not contribute much to this value, the correlation coefficient is only 0.25. The transient delay is determinated by the degree of maturity, but not totally. From this, one can derive a hypothesis that cottons with the same mean value of maturity but different transient delays distinguish themselves in the amount of mature fibers in the specimen, i.e. the third moment or skew of the distribution of maturity.

To illustrate this, Figure 4 shows the distributions of the degree of thickening of two cottons with nearly the same Theta (0.67 vs. 0.68) as were evaluated by an image analyzer. Theta is similar, the distributions are not. The skew of the first distribution is -0.47 and of the second one -0.71, obviously the cotton with a slightly higher value of Q contains more immature fibers. This is reflected in the smaller transient delay of 1.56 seconds with the first cotton and 1.8 seconds with the second one as shown in Figure 5.

Conclusions

The commercial implications of the results stated above are quite obvious: Using existing measurement technology raw cotton can be analyzed for distribution of maturity once the modified FMT analysis is calibrated on the basis of an available single fiber reference system [Schnei97]. Though still a lot of investigation has to be done in order to verify our results and to find out more about the shapes of fluid dynamic, it is possible on the basis of the current findings without excessive investments and with truly commercially viable efforts to considerably improve the characterization of the raw cotton.

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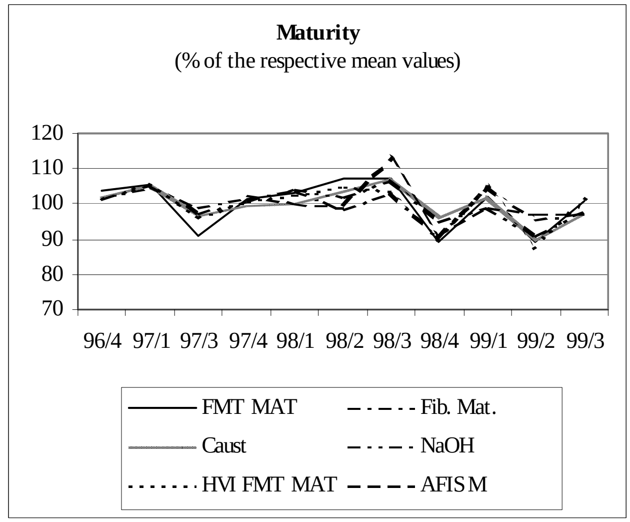


Figure 1. Results of the Bremer Baumwoll-Rundtest 1997 – 1998

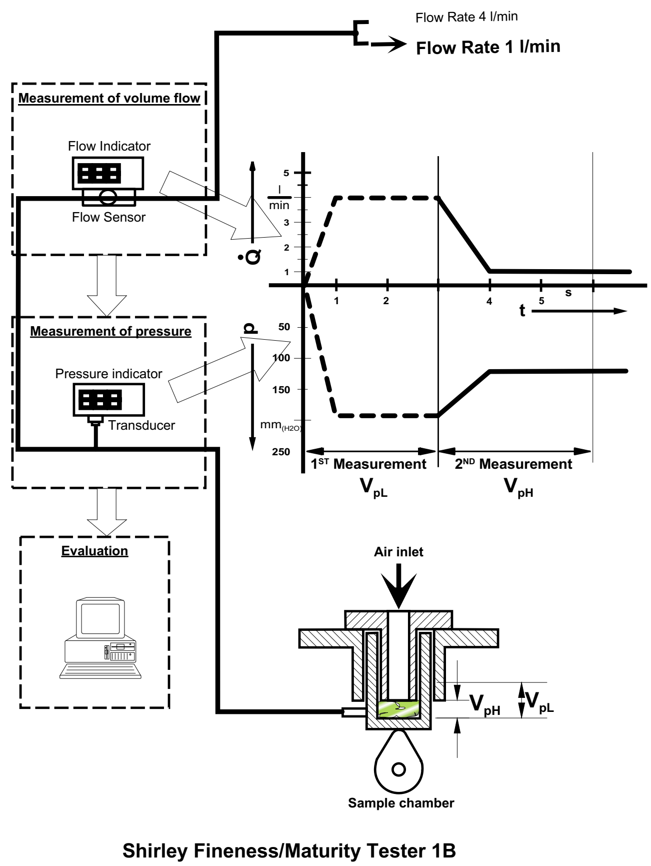


Figure 2. Functional Diagram of the FMT

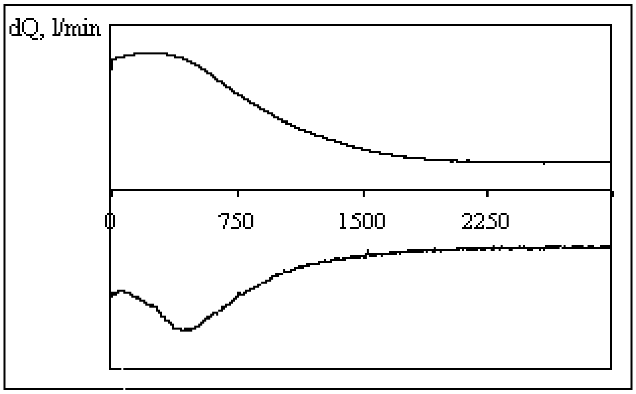
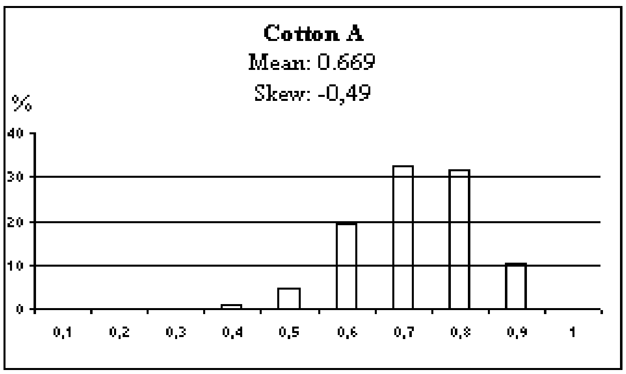


Figure 3. Course of flow and pressure over the time



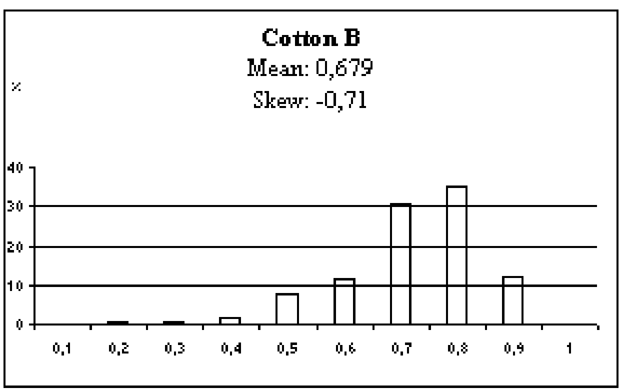


Figure 4. Sample Distributions of the Degree of Thickening

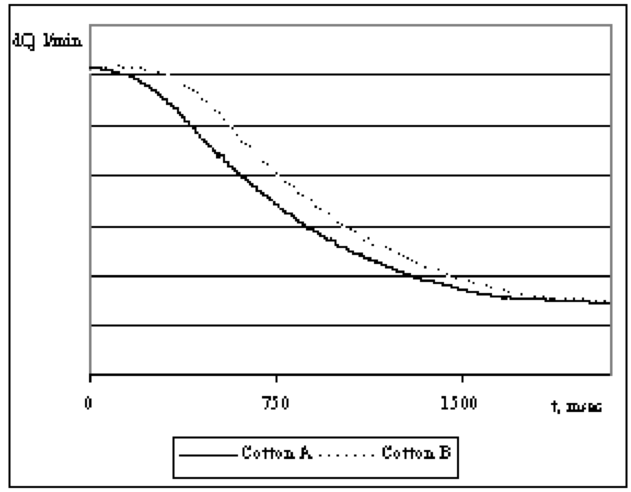


Figure 5. Course of Flow of Cotton A and B