IMPACT OF THE PRODUCTION VARIABLES IN FILTER TOW QUALITY

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Introduction

The process control of the production unit of filter tow for cigarette is made by the individual supervising of usual production variables through the determination and control of C_{pk} for each variable. C_{pk} or process capability is the index which evaluates the centralization of a process, relating the difference between the process average and the closest specified limit value to half of process total variation, i.e., it is the comparison between process variability with specified amplitude. Mathematically C_{pk} is represented by the minimal obtained value from:

$$Cpk = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$$

Where:

M: average of the observed values;

Σ: standard deviation of the observed values;

USL and *LSL*: upper and lower specified limits;

C_{pk}: calculation is performed coherently with *σ*, differentiating when the calculation is performed in short term, or for small samples, from long term calculation, or greater samples, in such a way that the results are comparable. (Breyfogle, 1999[1]).

At present the process under study is controlled by individual and independent supervision of the production variables, and the effectiveness of the process could be evaluated through Table 1. Considering the presented Cpk, the objective of the present work has been defined as developing a work methodology, using statistical tools, which allows correlate the indicated production variables, controlling the answers' variability, reducing it, improving the product quality.

Table 1 Original process situation through C_{pk} calculation

Production Variable	C_{pk}	Production Variable	C_{pk}
X_1: *spinning oil content*	0.37	X_5: *global title*	1.33
X_2: *residual acetone content*	1.23	X_6: *tensile strength*	0.63
X_3: *crimping factor*	0.98	X_7: yield	0.92
X_4: *final moisture* (F_e)	0.84		

Process description

The process of the industrial unit in which this work has been performed is identical to the described in the encyclopedias (Kirk-Othmer, 1984[2]; Ullmann's, 1994[3]).

Using acetone as the solvent for the dissolution of the 2,5 cellulose acetate, the dope is obtained, followed by filtration, in order to eliminate gels and other impurities, before performing the spinning or extrusion, feeding the pre heated dope to the spinnerets by using positive displacement pumps. The spinneret has multiple holes, with accurate dimension, in order to get the desired filament's profile.

The obtained filaments' bundle passes through the spinning column or cell, 6 to 8 meter long, provided of a steam jacket, which heats the air, flowing concurrently with the filaments' movement. The acetone originally present at the dope evaporates, initially, at the spinneret exit, by flash, due the significant pressure difference, and after, during the spinning cell length, gradually, in a process involving the acetone diffusion through the filament wall, constituted by 2,5 cellulose acetate, followed by its evaporation at the filament's surface.

All obtained acetone vapor, mainly from spinning, but also from subsequent sections must be collected and recycled, constituting a significant operating cost.

At the exit of spinning cell approximately 80% of the initially fed acetone has been evaporated. The hundreds of filaments get together in order to form the yarn, passing through a bath of spinning oil aqueous solution, getting together to the other yarns, obtained in the further spinning cells, in order to form a strand or filter tow band, which passes to the crimping step, followed by drying and then laid into higher boxes, which are completely filled in regular patterns, being then compressed by heavy presses into filter tow bales, packed and dispatched (Rustemeyer, 2004[4]). It is important to indicate that the studied industrial unit has two spinning sections, also considering the drying sections, identified by Spinning 1 and 2, with some process differences between them.

Statistical analysis

The statistical analysis of the initial overall historical data, composed of 391 data sets (Reis, 2003[5]), started by building the correlation matrix, followed by the Pearson correlation to define which are the dependent variables. At this moment, the independent variables are codified to determine, with the aid of the software Minitab the choice of best subsets, what allow establishing the preliminary multiple regression models for the answers *yield* (Y_1) and *tensile strength* (Y_2). Complementary phenomenological process studies been performed, bringing some aid to the statistically obtained models: a kinetic modeling of the cellulose polymer degradation during the acetylating reaction explains how some parameters could influence the polymerization degree, with a possible impact over tensile strength (Nasser, 2003[6]). A study about drying, specifically about the impact of the additional water (Cronemberger & Nasser, 2003[7]) showed a interesting phenomenological correlation between two variables (residual acetone content and moisture), simplifying the statistical analysis, also suggesting a differentiate way of getting the historical data. (Reis, 2004[8]), as follows:

Global Final – considering 1223 data sets, taken from both spinning sections; *Spinning 1* – considering 493 data sets; *Spinning 2* – considering 730 data sets; *Spinning 1, Title 32K* – related to the product 2,2Y32000, the most common at the time of data collection, considering 324 data sets; *Spinning 2, Title 32K* – ditto the previous, but for Spinning 2, considering 210 data sets.

Following the same procedure described for the preliminary statistical analysis, exception made to the selection of the dependent variables, the statistical analysis performed with the complete data, also following the recommendations of the process studies, confirmed that is possible to control the process by supervising both dependent variables, *yield* (Y_1) and tensile strength (Y_2), as presented at Table 2.

Table 2 Summary of the multiple regression models adjusted to the complete historical data

Data Sets	Exclusion outliers	Dependent Variables	Multiple Regression Adjusted Model
Global Final	without	Yield	$Y_1 = 595 - 15.2 \cdot X_1 + 8.83 X_3 - 6.86 \cdot X_4 + 9.90 \cdot X_5$
		Tens. Str.	$Y_2 = 9.51 - 0.39 \cdot X_1 - 0.53 \cdot X_2 - 2.56 \cdot X_3 + 0.33 \cdot X_4 + 1.82 \cdot X_5$
	with	Yield	$Y_1 = 596 - 25.2 \cdot X_1 + 5.4 \cdot X_3 - 5.9 \cdot X_4 + 18.8 \cdot X_5$
		Tens. Str.	$Y_2 = 9.56 - 0..41 \cdot X_1 - 0.48 \cdot X_2 - 2.86 \cdot X_3 + 0.37 \cdot X_4 + 1.91 \cdot X_5$
Spinning 1	without	Yield	$Y_1 = 596 - 18.4 \cdot X_1 + 14.9 \cdot X_2 - 11.5 \cdot X_4 + 19.1 \cdot X_5$
		Tens. Str.	$Y_2 = 9.66 - 0..36 \cdot X_1 - 0.44 \cdot X_2 - 3.07 \cdot X_3 + 0.37 \cdot X_4 + 2.62 \cdot X_5$
	with	Yield	$Y_1 = 599 - 26.8 \cdot X_1 + 15.2 \cdot X_2 - 10.2 \cdot X_4 + 26{,}7 \cdot X_5$
		Tens. Str.	$Y_2 = 9.66 - 0.36 \cdot X_1 - 0.44 \cdot X_2 - 3.07 \cdot X_3 + 0.37 \cdot X_4$
Spinning 2	without	Yield	$Y_1 = 598 - 11.8 \cdot X_1 + 6.96 \cdot X_2 + 8{,}73 \cdot X_3$
		Tens. Str.	$Y_2 = 9.72 - 0.26 \cdot X_1 - 2.14 \cdot X_3 + 0.34 \cdot X_4$
	with	Yield	$Y_1 = 599 - 21.2 \cdot X_1 + 9.88 \cdot X_5$
		Tens. Str.	$Y_2 = 9.76 - 0.18 \cdot X_1 - 2.17 \cdot X_3 + 0.37 \cdot X_4 + 1.11 \cdot X_5$
Spinning 1 2,2Y32K	without	Yield	$Y_1 = 609 - 21.0 \cdot X_1 + 15.2 \cdot X_2 - 7.5 \cdot X_4 + 16.8 \cdot X_5$
		Tens. Str.	$Y_2 = 11.10 - 0.66 \cdot X_1 - 2.33 \cdot X_3 + 1.11 \cdot X_5$
	with	Yield	$Y_1 = 613 - 27.4 \cdot X_1 + 18.5 \cdot X_3 - 7.9 \cdot X_4 + 15.9 \cdot X_5$
		Tens. Str.	$Y_2 = 11.10 - 0.76 \cdot X_1 - 2.24 \cdot X_3 + 0.16 \cdot X_4 + 1.06 \cdot X_5$
Spinning 2 2,2Y32K	without	Yield	$Y_1 = 593 - 7.9 \cdot X_4 + 7.2 \cdot X_3 - 7.9 \cdot X_5$
		Tens. Str.	$Y_2 = 11.10 + 0.36 \cdot X_2 - 1.95 \cdot X_3 + 0.27 \cdot X_4 + 0.29 \cdot X_5$
	with	Yield	$Y_1 = 596 + 11.2 \cdot X_2 7.97.2 \cdot X_4 + 9.1 \cdot X_5$
		Tens. Str.	$Y_2 = 11.10 + 0.28 \cdot X_2 - 1.99 \cdot X_3 + 0.25 \cdot X_4 + 0.29 \cdot X_5$

Dependent variables

One of the remarkable physical characteristics of all fibers is their tensile strength, which for filter tow is very important, as the first step of processing at the client is to stretch the product in order to conform the filter cigarette, and ruptures at this step cause undesirable discontinuity to the process; for this reason, from a sample taken from the bale, occurs the determination of the *tensile strength*.

On the other hand a simulation of performance at the client's facility of the produced filter tow can be performed in the *Filter Machine*, which performs in laboratory scale all the operations that actually occur at the client. Instead of cigarette filter, the mentioned machine produces specimens, which are in fact cylinder with standard dimensions, similar to cigarette filter, but longer, used to precise hardness, actual dimensions and weight. The main determination consists in imposing a standard pressure drop to the specimen, checking the product weight in order to achieve it; a smaller weight means that more cigarette filters by unit of mass could be produced. This determination is designated by y*ield*.

Final established regression models versus present process control

The statistical analysis performed with the complete set of differentiate historical data has confirmed the possibility of adjust multiple regression models with differentiate quality.

In statistical and operational terms it is better operate with the Spinning 1, because the present title is close to the average practiced at the time of the data collection, as well as, it is provided of individual and more flexible spinning machines and best driers.

As it has been already mentioned, the complementary process studies have been very useful for better knowing the process and mainly for the filter tow drying study to improve and simplify the statistical analysis, even allowing to observe and confirm that, due the separation of data set universes, the multiple regression models adjusted for the Spinning 1 historical data, present a much better adequacy.

The process variability that cannot be explained by the regression models can be by the present way of individual controlling the production variables, independent adjusted, during the production of a bale, with the aim of improving its quality. Although the process is continuous, the process adjustment is typical of a batch process, in which the production unit is the filter tow bale.

Validation of the established regression models

Considering the conflicting character of the multiple regression models for the dependent variables, yield and tensile strength, adjusted for the Spinning 1 data set, an optimization would be possible by determining the adjust for the independent variables which would allow to get the minimal yield conjugated with the maximal tensile strength.

With the aim of performing a validation of such models, it has been proposed to adjust the independent variables occurring in both models, also contributing for the conflicting character of the models, like *spinning oil content* and *global title*, to be kept in its average. For moisture it has been proposed the maximal, by controlling the additional water flow rate, in order to achieve the minimal acetone content, in accordance with the process study about filter tow drying. For the crimping index it has been considered the minimal value in order to increase the tensile strength.

The validation trial took place in the machines number 19 and 20 of the Spinning 1, which have in common the dryer, contributing to achieve the proposed conditions. At these conditions, 10 bales have been produced, taking samples in order to perform the routine analysis.

The detailing of the regression models validation is presented at the Table 6.1.

A precise evaluation of the effectiveness of the adjusted models' validation is possible by establishing the Descriptive Statistical, as available at Minitab, comparing the results for *yield* _ Y_1 and *tensile strength*_ Y_2 obtained from the analysis performed by using original historical data with those obtained during the validation trial, as shown at Figure 1.

With these results it is possible to observe that, due a significant reduction of standard deviation and process centralization, the values of C_{pk} were greater than 1 (Machine 19 ➔ $C_{pk}(Y_1)$ = 6,16; $C_{pk}(Y_2)$ = 1,06; Machine 20➔ $C_{pk}(Y_1)$ = 2,11; $C_{pk}(Y_2)$ = 1,06), confirming the effectiveness of the proposed way of control, mainly if compared to the original values as indicated at Table 1.

The results of the testing for validation of the multiple regression models adjusted to Spinning 1 historical data show that the proposed control allowed the process stabilization

Table 3 Validation of models adjusted to the Spinning 1 historical data set

Variable	Historical data set Spinning 1			Present spec.	Suggested values for analysis	Agreed values for trial	Target Present Control	Measured Values During trial	Predict Values	Remarks
	minimal	maximal	average							
Spinning oil content %	0.21	0.59	0.40	0.4±0.1	0.40	0.40	0.4	0.40	–	kept constant
Residual acetone %	0.10	0.57	0.34	<0.5	0.10	0.30	<0.3	0.33	–	not adjusted
Crimping Index %	20.6	36.5	28.55	28.8±5	20.6	25.5 a 27.0	<26.5	26.7	–	minimal possible
Moisture %	2.3	6.55	4.43	5.0±1.8	6.55	5.5 a 6.0	>6.0	6.0	–	maximal possible
Global Title den	25770	35490	30630	3000±3%	30630	30630	30630	29930	–	kept constant
Tensile strength	6.4	14.3	10.2	9 a 11	13.2	10.9	13	10.9	9.9*	*model
Yield (g)	515	633	574	575±13	574	579	570 a 575	579	589*	*model

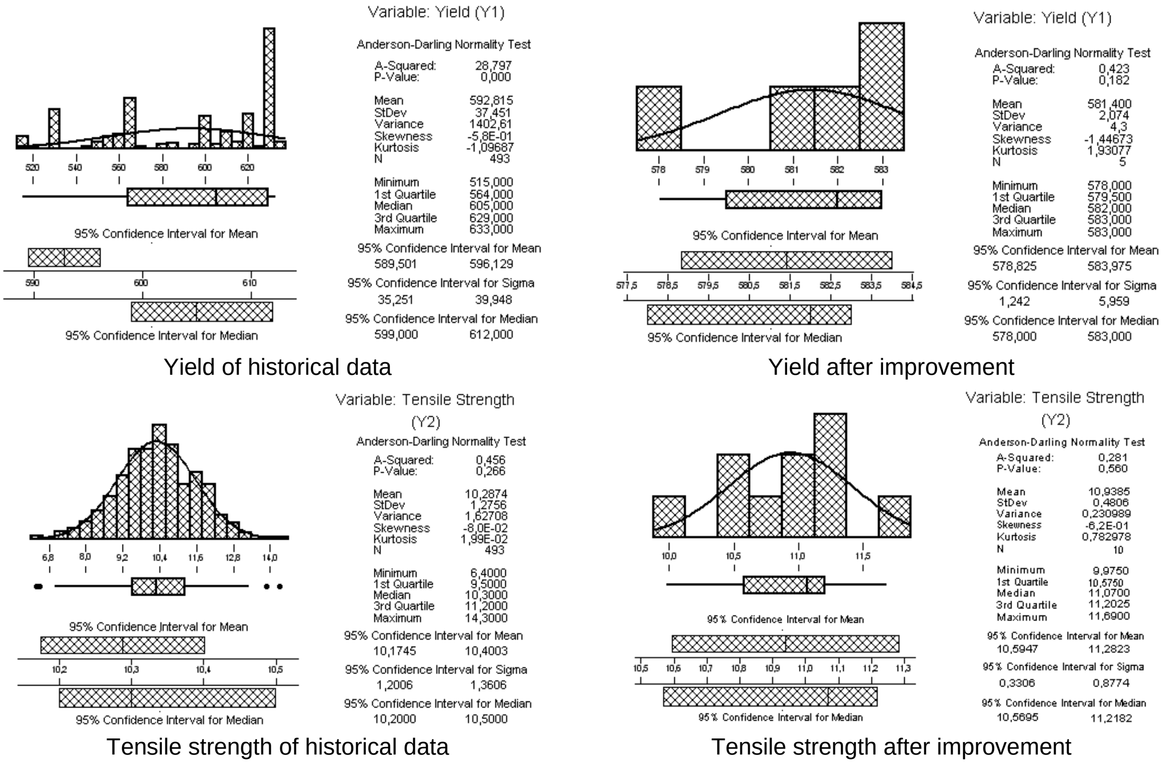

Figure 1 Descriptive statistics comparing dependent variables for historical data and after improvement

Conclusion

According to the proposed as objective of this study, the statistical analysis performed over the historical data showed cause and effect relationship of the production variables, allowing to establish models of multiple regression for *yield* and *tensile strength*, as well as the possibility of supervising the process through the C_{pk} control of these dependent variables, what is easier and more accurate, being confirmed by their variability.

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