A DBD Plasma Machine in Textile Wet Processing

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Abstract
The design of new processes for preparation, dyeing and printing of high quality textile products is presented for a brand new technological solution involving a plasmatic Double Barrier Discharge (DBD) in textile substrates. Developments regarding the construction of the portuguese-german DBD machine and its implementation in production context are discussed. Results in semi-industrial and industrial prototypes are presented giving wide overview for advantages and benefits achieved in fields such as the shortening of preparation steps, the possibility of close combination of preparation and dyeing operations, the improvement of dyeing and printing properties in synthetic and natural fibres, the elimination of tensioactives in mercerization or the increase in efficiency of finishing agents and extension of durability of effects.
High performance finishing and the use of high technology for the improvement and durability of functional properties obtained in natural textiles are proved to be a great contribution to developments in quality, economy and ecology of textile processes.

1. INTRODUCTION

European textile industry, namely the sector of wet processing of textiles, is highly focused in the promising changes coming up of the announced innovation fields, like nanofinishing, functionalisation or smart textiles. These are non conventional areas in which plasmatic technologies play a decisive role. By using them, adhesion ability, reactivity, penetration, grafting of chemical groups or polymers are improved with a huge impact in the properties of products with a high added value regarding market expectations. This is now a very dynamic and increasing reality, but certainly not concerning the great majority of enterprises dealing with classical processes and products. The correct approach to the problems put by traditional forms of work must be seriously regarded as a decisive and inevitable challenge to promote innovation giving them the necessary tools to face competitiveness, providing ecological solutions, lowering costs, raising quality, this is, giving them the unique way out to survival: sustainability.
Plasmatic DBD technology is assumed as a means to achieve rather significant improvements concerning almost all phases of textile finishing, either modifying conventional ways of processing, or getting important results in efficiency and durability of functionalising properties. Results claiming complete desizing and a better bleaching of cotton fabrics at lower temperatures and less oxidative conditions, more efficient mercerization without wetting agent, dyeing of cotton raw fabrics with uniform and more intense colors, uniform and complete exhaustion of reactive and acid dyes in polyamide, pigment printing with higher rubbing fastness, less formaldehyde release and higher easy-care properties, much more durability in sterilization and water-repellency finishing of reusable medical garments, higher fire proofing capacity in cellulosic materials are a

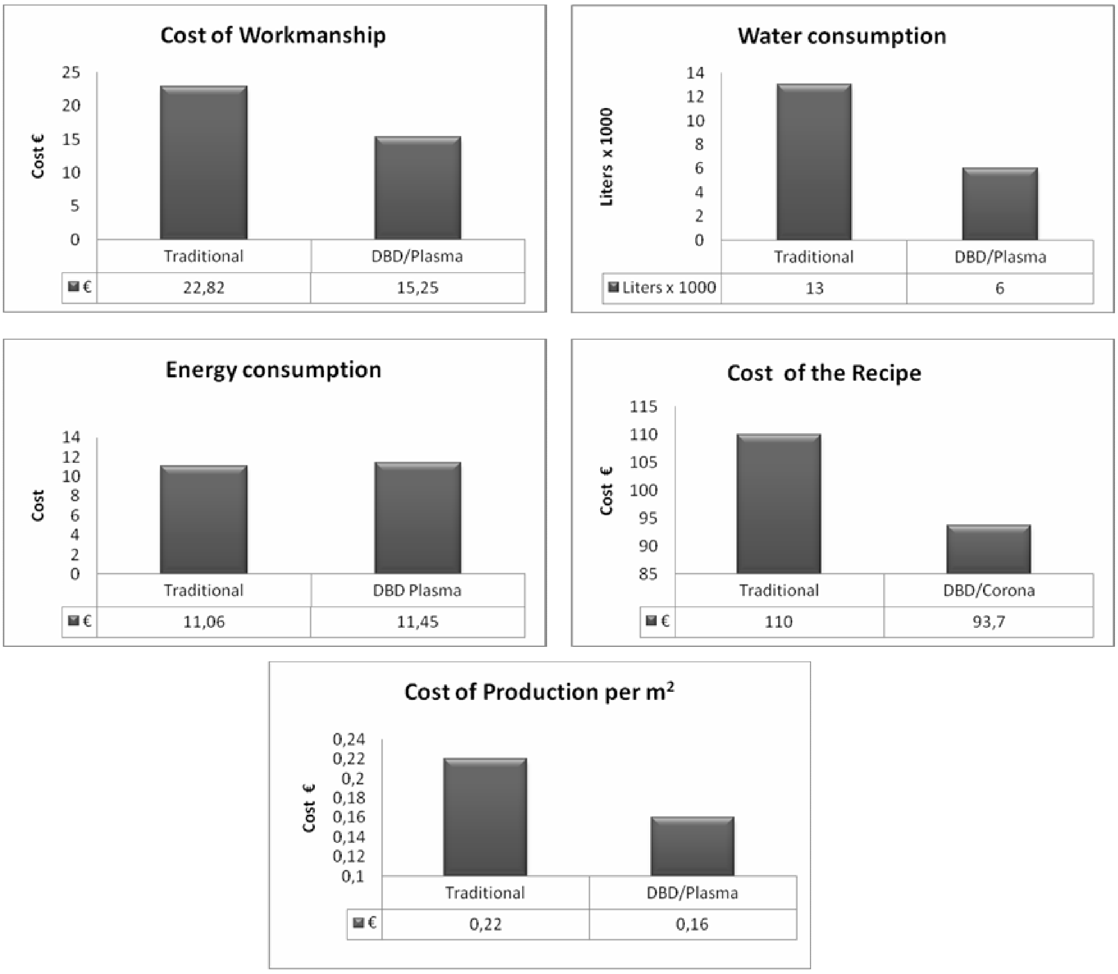
significant set of innovative advances prepared to help the future of textile industry.
This way, DBD technology rushes to prove its potential in the real stage of production. A portuguese-german machine is installed in a portuguese textile industry and a large series of results are presented as the main argument for the adoption of plasmatic atmospheric discharge either in traditional or innovative textile processing. [Carneiro et al., 2004].

2. DBD PLASMA MACHINE

Figure 1: Industrial prototype installed at Lameirinho factory (Portugal)

DBD treatment consists on the application of an electrical discharge of high voltage (around 10.000 V) through air between two electrodes, using frequencies around 40 kHz, at normal atmospheric temperature and pressure. Discharge on dry cotton fabric can be applied in textile processing allowing to rationalize water, energy and chemicals that are spent in huge amounts within this industry, fulfilling the requisites of the new world ecological demands imposed by environmental concerns.

For the construction of the industrial machine (figure 1), the constructor Softal has designed all the necessary controls and sensors such as tension, humidity, metal impurities, fire, velocity, power of discharge, temperature, cooling of the roller, ozone exhaustion, protection and security of the machine and entrance of clean cooled air. The generator has been designed in accordance with the highly energetic demands of textile substrates. The ceramic electrodes and the backing roller were specially designed for a complete uniform discharge at 4 meters wide running at adequate industrial velocities at a maximum power of 50 kW.
For example, in a batch of 300m cotton fabric vat dyeing, in which a discharge is previously made, it is possible to obtain a cost reduction around 27% and a processing time reduction of 40%.
This DBD plasma treatment allows an increase of the final product quality and an optimization of textile processing in very important aspects either concerning conventional processes or the innovation focused in durability and efficiency of functional finishing. [Carneiro et al., 2004].



Graphic 1: Cost Comparison between traditional process and DBD Plasma process

3. RESULTS

3.1. Chemical and physical effects on cotton fibre

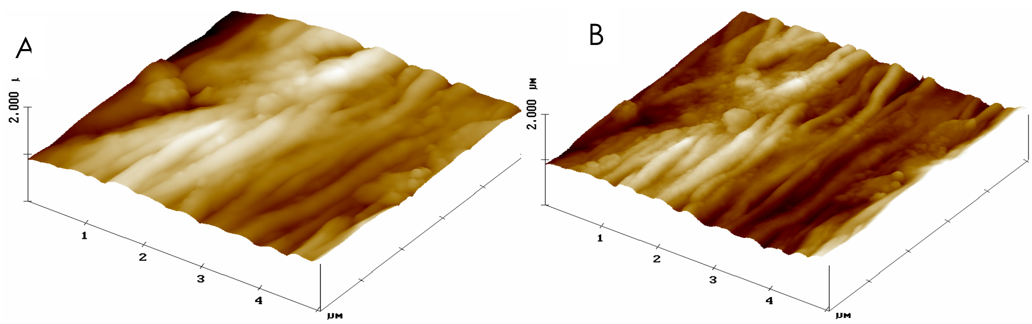
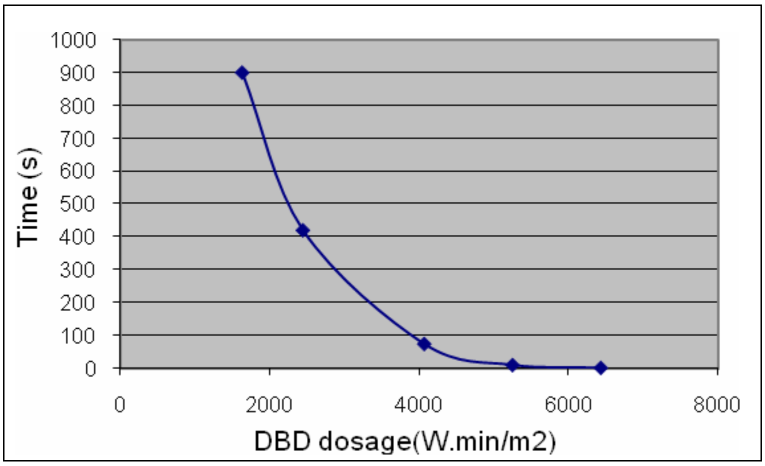


Figure 2: Images obtained with AFM of the cotton fibre before (A) and after (B) DBD plasmatic treatment

Results obtained with X-Ray photoelectron spectroscopy (XPS) have confirmed that the cuticle of cotton fibre has been partially removed. In addition to the channels created (figure 2), several polar groups, as hydroxyl, carboxyl and amine groups, are formed by plasmatic discharge in the surface of the cuticle.

These changes permits the cotton fibre to absorb chemicals dissolved in aqueous baths used in wet processing. [Souto et al., 1996].



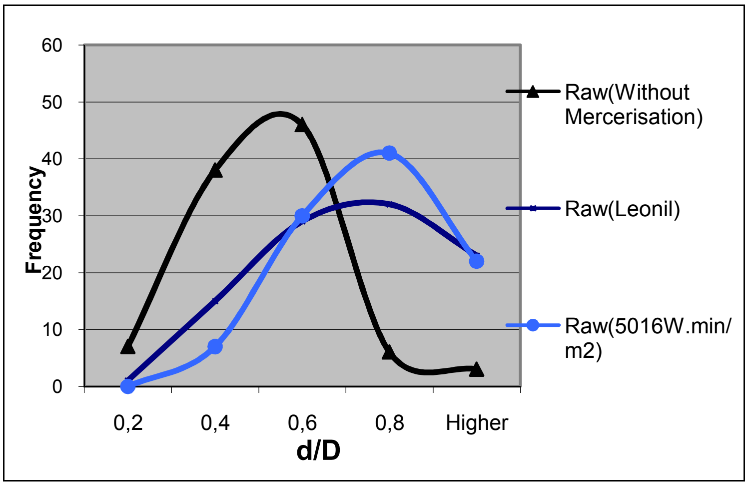
Graphic 2: Time for water drop absorption in raw cotton fibre versus DBD dosage

3.2. Preparation processes

The integration of DBD in the preparation of raw cotton fabrics has been studied, namely in what concerns its influence in desizing for starch products removal, oxidative bleaching and mercerization. Other alkaline operations for hydrophilisation purposes are avoided and significant reduction of pollution in source is then achieved.

3.2.1 Mercerization

The circularity of cotton transversal section illustrates the effect of mercerisation bath in shrinkage and deconvolution of the fibre which mean important morphological changes occurring in tensioned situation. Circularity highly increases in DBD treated materials in correspondence to the increase in mercerisation level.



Mercerisation has been made in a metallic frame, with controlled tension, using a sodium hydroxide bath at a concentration of 300g/L, with and without wetting agent and no cooling procedure.

Graphic 3: Frequency analysis of d/D ratio (perpendicular axis of transversal cross-section) for mercerized and non mercerized raw cotton

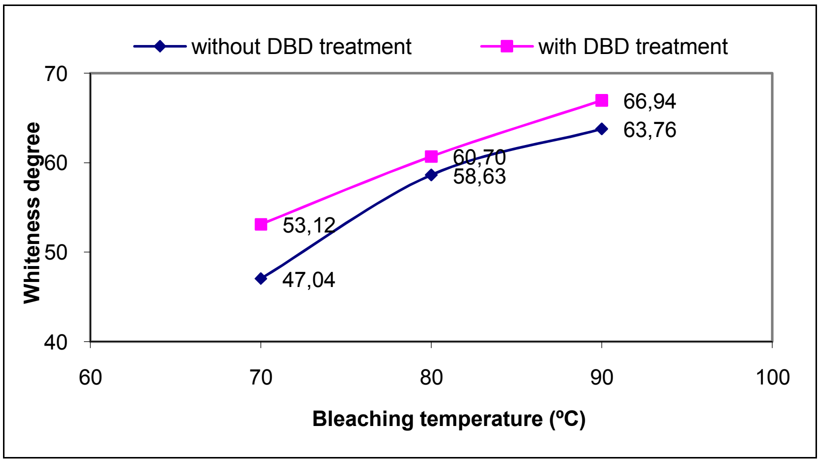
For the raw, desized and bleached fabrics, mercerization effect in circularity of transversal section is higher if a DBD is previously made. A more uniform circularity is shown for plasmatic treated fabrics which means a more uniform mercerization, even if no wetting agent is used. DBD treatment allows the penetration and reaction of sodium hydroxide molecules into cotton fibres core, either in raw, desized or bleached materials.

Plasma treatment makes it possible to have a better mercerisation's degree than the traditional method, even without wetting agent. Mercerisation without wetting agent means much better conditions to recover sodium hydroxide baths, meaning lower costs and less environmental damages. [Carneiro et al., 2005].

3.2.2 Bleaching

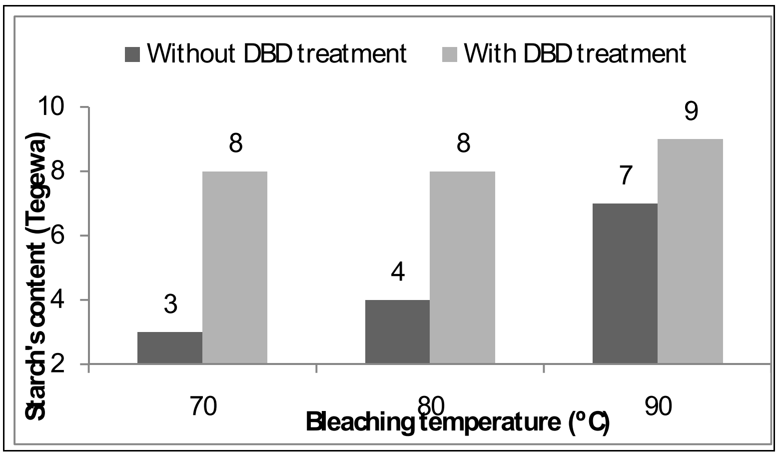
When the bleaching of grey cotton fabrics is made using a long bath oxidative process, the effect of DBD is very positive with:

- An increase in the whiteness degree.
- Final hydrophilicity of bleached cotton fabrics is assured with times for water drop absorption as low as three seconds for lower bleaching temperatures.
- Starch removal is highly improved and this means the possibility to combine preparation phases without any losses in final quality of prepared fabrics.



Long-bath bleaching process with hydrogen peroxide at the temperature of 70ºC, 80ºC and 90ºC have been performed.

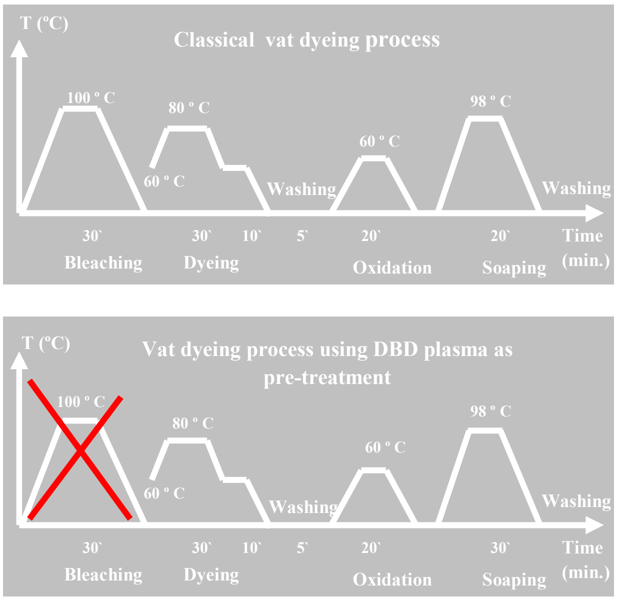
Graphic 4: Whiteness degree for different bleaching temperatures with and without DBD treatment



Graphic 5: Starch's content (TEGEWA scale) for different bleaching temperatures with and without DBD treatment

Preparation can be shortened and improved with high impact in pollution source reduction objectives, assumed as the more convenient policy in the frame of an overall plan to change textile current practices. [Carneiro et al., 2005]

3.3. Dyeing
3.3.1- Vat dyeing



DBD plasma technology applied to vat dyeing enables a complete hydrofilization of raw cotton through oxidation of the hydrophobic layer, making cotton materials ready to be directly dyed, skipping the stages of preparation. The differences between conventional vat dyeing process and the process in which DBD is used, include the total annulation of preparation and a posterior half bleaching instead of the soaping used in classic vat dyeing.

Figure 3: Re-design of textile vat dyeing with the incorporation of DBD plasma treatment

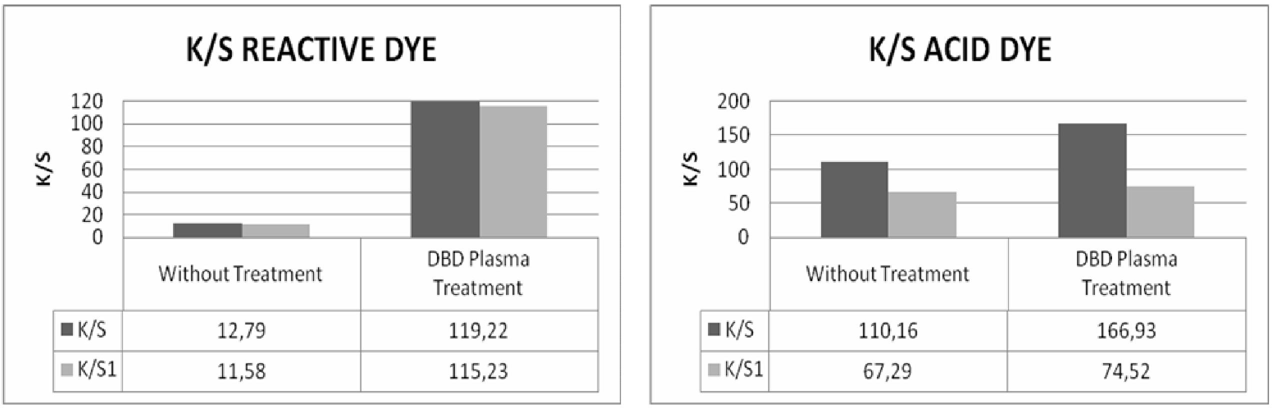
Table1: Vat dyeing colorimetric results

Colorimetric Evaluation							
Dyeing	**Preparation**	**K/S (St Dev)**	**L***	**a***	**b***	**C***	**hº**
C.I. Vat Blue 66 (0,8%)	**DBD**	2,50 (0,09)	54,95	-5,04	-26,60	27,07	259,28
	Bleaching	3,07 (0,12)	51,99	-3,56	-28,66	28,88	262,91
C.I. Vat Blue 66 (3%)	**DBD**	6,81 (0,23)	40,83	-2,17	-30,01	30,09	265,87
	Bleaching	5,92 (0,25)	43,32	-2,78	-30,79	30,92	264,85
C.I. Vat Blue 66 (6%)	**DBD**	10,9 (0,32)	34,68	0,05	-31,67	31,67	270,09
	Bleaching	7,50 (0,24)	39,83	-1,36	-31,59	31,62	267,53

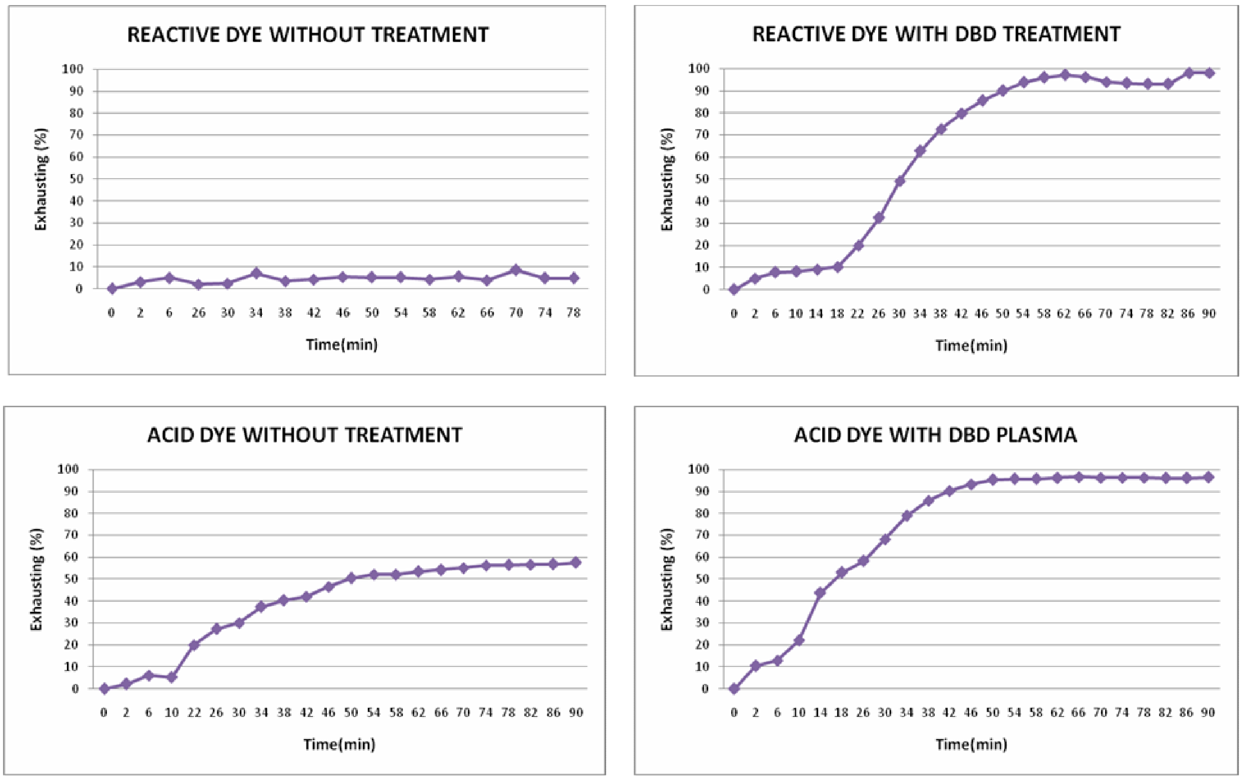
In this colorimetric evaluation study of the uniformity of fabrics dyed with vat dyes and pre-treated with DBD plasmatic discharge were made 300 measurements according with an industrial method used to measure the uniformity.
The process where plasmatic treatment is used as a pre-treatment in raw cotton vat dyeing in comparison with the classical method, has a coloristic income on darker colors and, in general, the dispersion of the colorimetric evaluation was improved. [Souto et al., 2007].

3.3.2 Acid and reactive dyeing of polyamide
It is possible to accomplish excellent results in dyeing with reactive and acid dyes in polyamide 6.6 treated with plasma discharge. The surface modification of the polyamide fibre after DBD plasma treatment permits to obtain very fast

colors with reactive dyes, where a covalent liaison is proved to resist to a strong urea extraction (graphic 6). It is possible to obtain complete bath exhaustion, (graphic 7) in dyeing processes for acid and reactive dyes with DBD plasma treatment.



Graphic 6: K/S comparison results for polyamide 6.6 samples with and without DBD treatment. *K/S1 – Values obtained after extracting treatment (solution 50% Urea; 100º C; time-30 minutes).



Graphic 7: Exhaustion of acid and reactive dyes in polyamide 6.6 with and without DBD plasma treatment.

3.4. Printing

With a plasmatic discharge made previously to pigment paste application a better adhesion is promoted when an acrylic/vynilic binder is used and so wet rubbing fastness increases one point, which means a significant improvement in final quality.

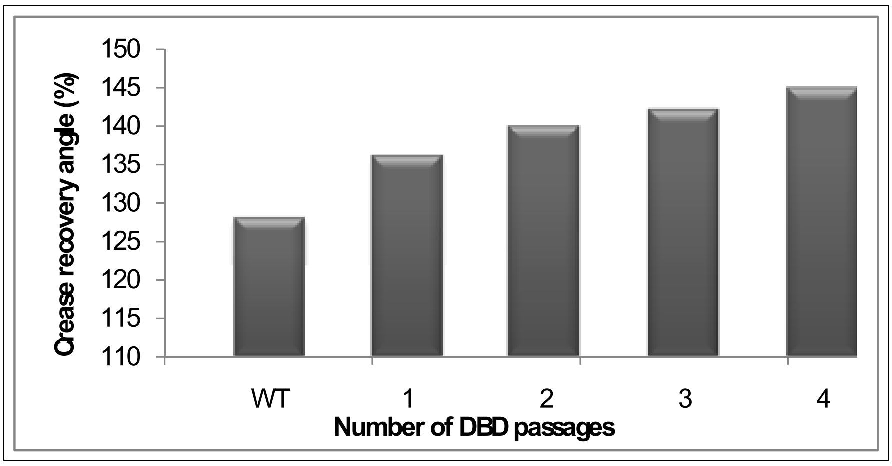
Table 2: Rubbing fastness (ISO 105 X 12) of printed cotton fabric (paste Italoquímica with pigment Italprint Blue RGS)

Treatment	Back Staining		Staining	
	Dry	Wet	Dry	Wet
Without DBD treatment	5	3-4	4	1-2
With DBD: 4 passa. + printing + fixation	5	4	4-5	2-3
With DBD: Printing + 4 pass. + fixation	5	4-5	4-5	2-3
With DBD: 4 pass. + printing + 4 pass. + fixation	5	4-5	4	2-3

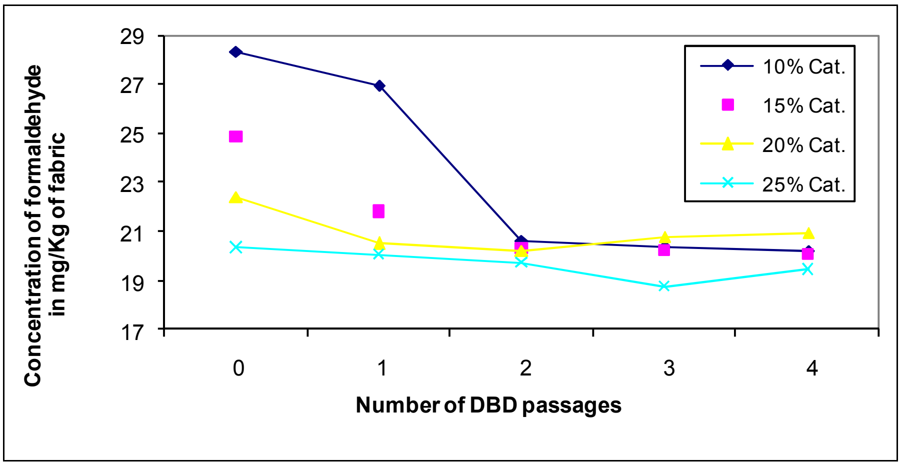
3.5. Finishing

3.5.1 Non-ironing

Significant improvement of crease recovery angle is achieved if DBD treatment is made before no-iron finishing with a cross linking resin of low formaldehyde level. A positive effect is also felt in formaldehyde release, even using less catalyzing agent.



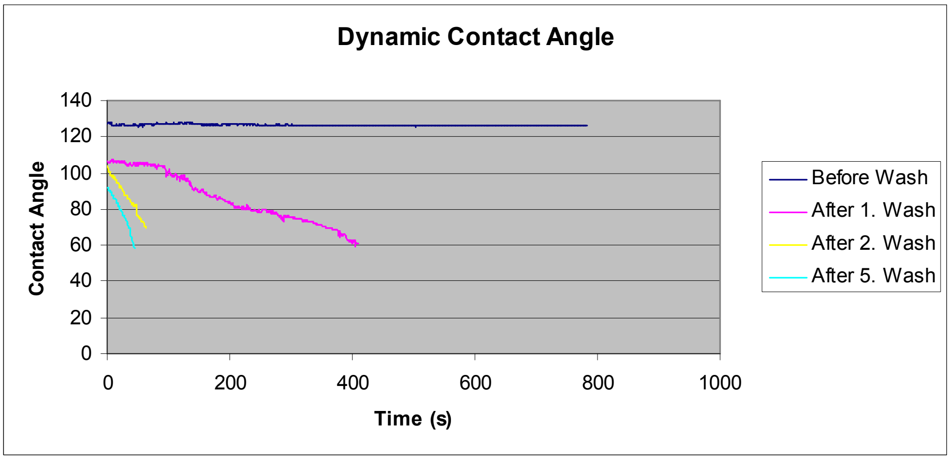
Graphic 8: Crease recovery angle for different DBD passages, after no-iron finishing with reticulation resins of low formaldehyde content



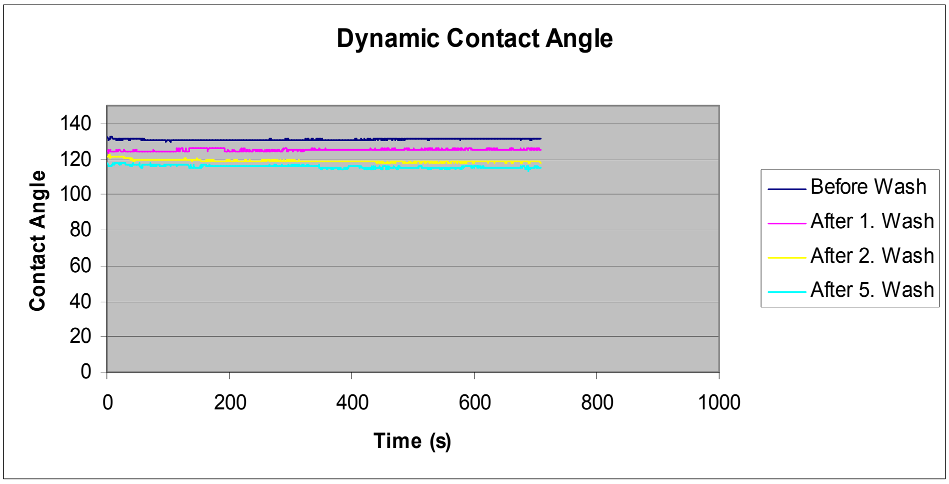
Graphic 9: Effect of the number of DBD passages in formaldehyde release for different catalyst agent concentrations

3.5.2 Water repellency

From graphics 10 and 11, it can be seen that discharged samples still keep their hydrophobic characteristics (mean contact angle is more than 120^0) even after five washings. [Alay et al., 2007].



Graphic 10: Dynamics contact angle measurements of untreated fabrics finished by Baygard AFF 300 % (20 g/L)



Graphic 11: Dynamic contact angle measurements of DBD treated fabrics finished by Baygard AFF 300 % (20 g/L).

3.5.3 Anti bacterial

The effect of plasma DBD on durability of antibacterial agent present in the fabric was studied by using ICP analysis method. DBD treated fabric surface finished by nanosilver compound has more silver element concentration than untreated ones, withstanding up to 30 washings. This result means the possibility of having more economical and ecological solutions for the problems put by reusable garments in medical or hygienical care, namely when compared with disposable ones. [Alay et al., 2007].

Table3: Effect of plasma discharge and repeated washings on silver concentration in samples finished with Silpure FBR-5.

Sample Property	**The concentration of Silver (%)**	
	Before Washings	**After 30 Washes**
With DBD	0.55	0.10
Without DBD	0.27	Below Detection Limit

4. CONCLUSIONS

The german-portuguese DBD plasmatic machine, is giving high standard results regarding quality and economy of textile finishing processes. They mean new opportunities, but also strong tools to face inertia of conventional textile industry.
Innovation is a key point of success, although options for changes must be faced with well defined criteria of impact in factors such as investment, competitiveness, and market needs. The strategy of the textile industry must be balanced between present and future, with clear vision of the meaning of challenges and risks associated to quick and deep alterations.
The DBD machine and associated impact in textile processing were described and quantified merging very meanful results in areas as preparation of cellulosic materials, dyeing and printing of natural and synthetic fibres, optimization of functionalization of textile materials regarding significantly more effective and durable attributes.
This DBD machine is robust and prepared to run controllable operations in aspects such as, worker safety, ambiance protection and product quality.
The present technological offer is very powerful in what concerns the potential to be a rational and adequate answer to achieve gentle implementation and excellent attractiveness towards the textile industry.

5. BIBLIOGRAPHY

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