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CONTINUOUS WOOL FABRIC DYEING BY ATMOSPHERIC PLASMA TREATMENT AND PAD IMPREGNATION

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Why to perform a continuous dyeing process?

- ***dyeing repeatability***
  - to attain a fully satisfactory dyeing repeatability
- ***shade uniformity***
  - to reach a high uniformity color shade in the fabric
- ***low lot splitting***
  - *to* decrease lot splitting
- ***high productivity***
  - to reach a high productivity in the dyeing line
- ***low consumption***
  - to optimize dye stuff, water and energy consumption

Which are the main characteristics of this process?

open-width form

the fabric is dyed in a open-width form

padding

the fabric impregnation is realized by padding

recipe formulation

the padding liquor is prepared with conventional dye stuff

operating mode

the process can be carried out in a semi-continuous or continuous mode

Which are the main steps of this process?

1- Plasma treatment

to achieve the required hydrophilicity in the fabric

2- Padding

to obtain a homogeneous and controlled fabric impregnation

3- Ageing

to realize dye diffusion and fixation into fiber

Which are the main advantages given by this process?

- ***high dyeing repeatability***
  - well controlled dyeing conditions - lower lot splitting
- ***high process productivity***
  - fabric speed of about 10 m/min
- ***low water demand***
  - *reduced padding liquor ratio - continuous washing*
- ***low energy demand***
  - reduced water volume – low plasma energy need
- ***implementation of BATs to dyeing***
  - matching the current wool dyeing BAT specification

Process characteristics

up to 200% productivity enhancement

80% of water saving

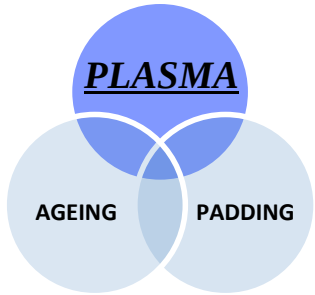
up to 95% of energy saving

	Exhaustion dyeing	Padding after PDAPJ *	Padding after HCAP**
Productivity	70 kg_{fiber}/h	85 kg_{fiber}/h	145 kg_{fiber}/h
Fabric speed	***	6 m/min	10 m/min
Water demand	95 kg_{water}/kg_{fiber}	20 kg_{water}/kg_{fiber}	20 kg_{water}/kg_{fiber}
Energy demand	5600 kJ/ kg_{fiber}	1650 kJ/ kg_{fiber}	300 kJ/ kg_{fiber}

* PDAPJ – Post Discharge Atmospheric Plasma Jet
** HCAP – Hybrid Corona Atmospheric Plasma
*** Overflow dyeing equipment suitable to dye 6 fabric ropes 250 m long

a speed enhancement up to 20 m/min is foreseen

The process step by step – plasma treatment



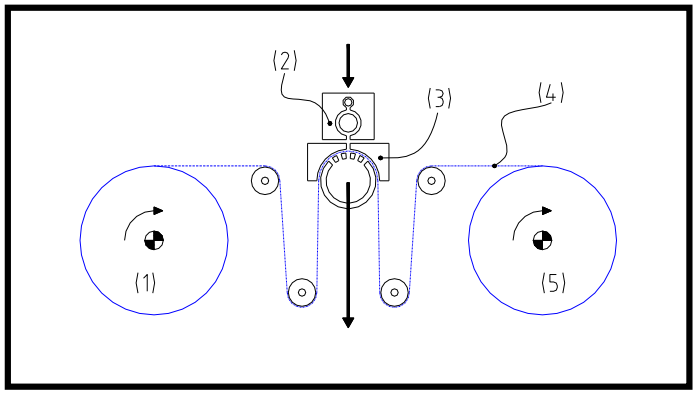
- *PLASMA*
  - *wool hydrophilicity enhancement*
  - *continuous atmospheric equipments*
  - *atmospheric cold plasma*
  - *N_2, O_2, $O_2 + N_2$, air, He, Ar, He+Ar*
  - *no mechanical fiber damage*
  - *high productivity level*
  - *low power and low gas demand*
  - *inexpensive treatment*

The process step by step – plasma PDAPJ equipment

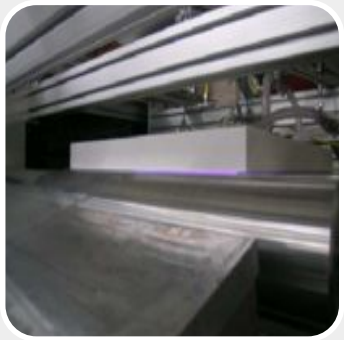
Miniweb 380s (AcXys Technologies)

- Plasma jet technology
- Two coaxial electrodes generate the plasma
- Continuous treatment in a roll-to-roll system

- Working pressure: atmospheric
- Process gas: Nitrogen (350 ÷ 700 NL/min)
- Fabric width: 0.4 m
- Fabric speed: up to 20 m/min
- Electrical power: 3 ÷ 5 kW



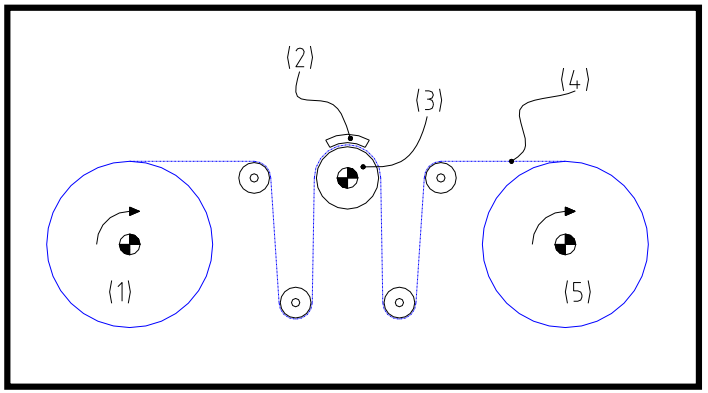
The process step by step – plasma HCAP equipment



HCAP (Arioli S.p.A.)

- Hybrid corona plasma technology
- Two radial electrodes generate the plasma
- Continuous treatment in a roll-to-roll system

- Working pressure: atmospheric
- Process gas: not required
- Fabric width: up to 2.0 m
- Fabric speed: up to 20 m/min
- Electrical power: 0.2 ÷ 1.0 kW



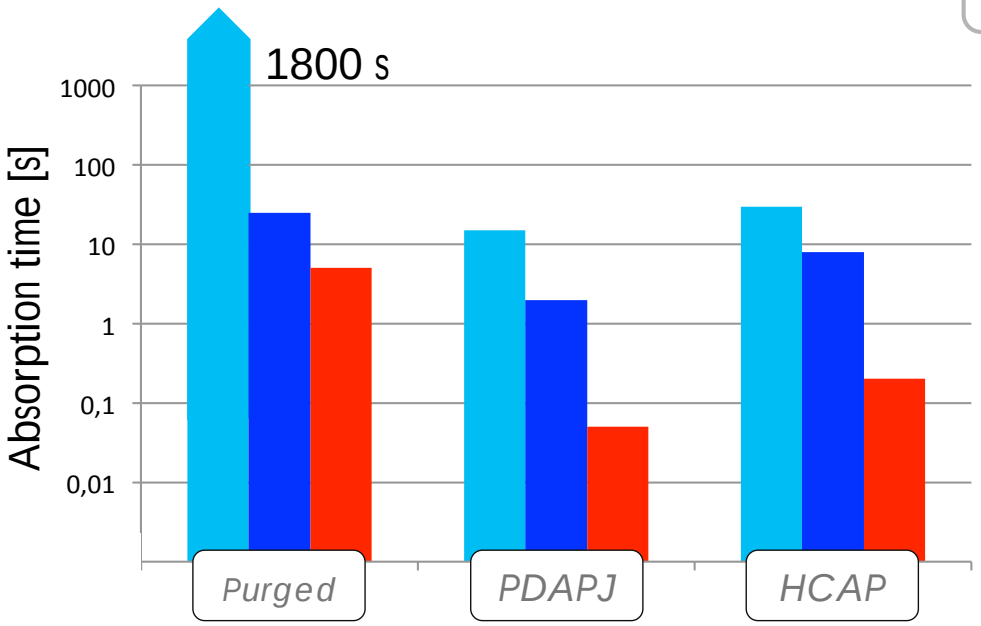
The process step by step – plasma functionalization

plasma enhances wool hydrophilicity

hydrophilicity allows a prompt impregnation

fast fabric impregnation allows padding

Wool fabric
drop absorption time

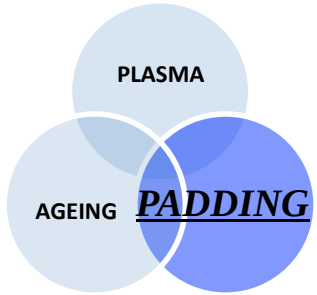


	PDAPJ	HCAP
Fabric speed	6 m/min	10 m/min
Power	4000 W	200 W
SPEEL*	665 J/m^2	20 J/m^2
Gas flow	400 NL/min	---

* *SPEEL : Specific Electric Energy Load*

Water at 20 °C → Pad liquor at 20°C → Pad liquor at 85°C

The process step by step – padding



PADDING

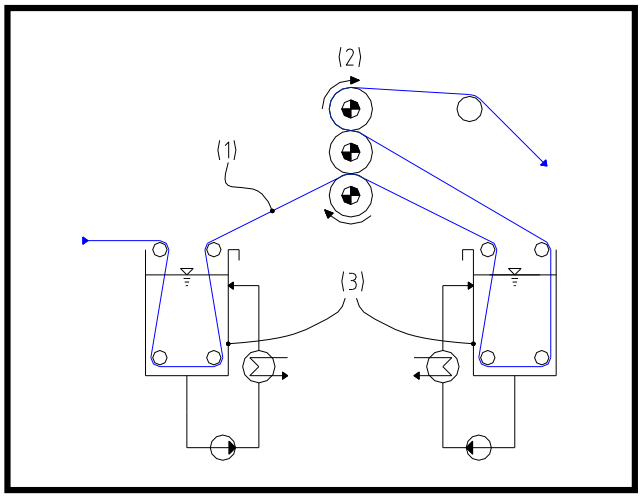
- *high impregnation uniformity*
- *single impregnation and squeezing action*
- *fabric speed up to 10 m/min*
- *standard dyestuff*
- *water and energy saving*
- *continuous equipment*
- *high production level*
- *high dyeing repeatability*
- *easy engineering of the process*

The process step by step – padding equipment

F3C Lab pad mangle (TMT Manenti srl)

- Double squeezing pad mangle
- Two separated liquor troughs
- Two liquor heating and mixing systems

- Fabric width: 0.600 m
- Fabric speed: up to 10 m/min
- Squeezing pressure: up to 100 kg_F/cm^2
- Liquor temperature: up to 85 °C



The process step by step – padding

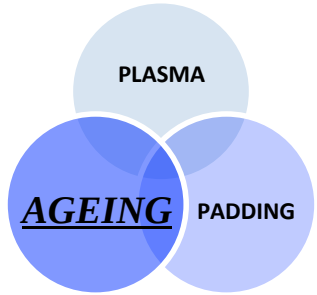
Padding operating conditions

- *fabric speed: 6 ÷ 10 m/min*
- *single squeezing action*
- *squeezing pressure: 25 kg_F/cm^2*
- *liquor temperature: 85 °C*
- *impregnation length: 0.40 m*
- *fabric pick-up: ≈ 50 % w/w*

Tested pad liquor - main features

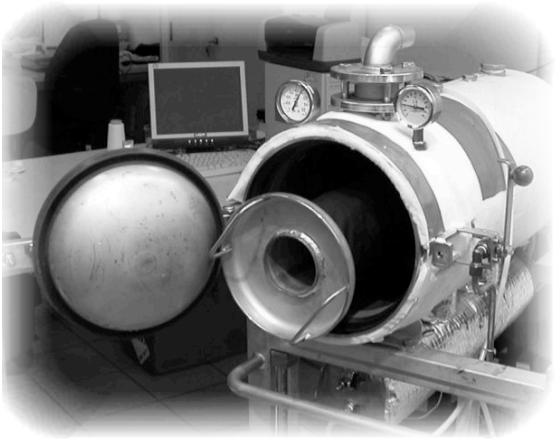
1- metal-complex and acid dyes (max total amount ≈ 100 g/L)
2- acetic acid (pH ≈ 4.9)
*3- wetting agent (≈ 0.1 % w/w)_*

The process step by step – ageing

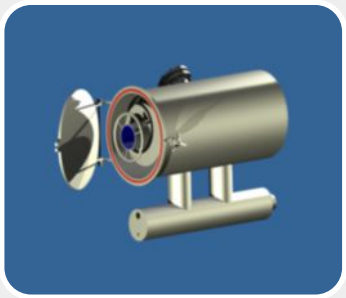


AGEING

- *dyestuff diffusion into fiber*
- *fabric beam or open-width form*
- *semi continuous equipment*
- *thermally conditioned vessel*
- *variable ageing time*
- *high fastness values*
- *no mechanical fiber damage*
- *repeatability*



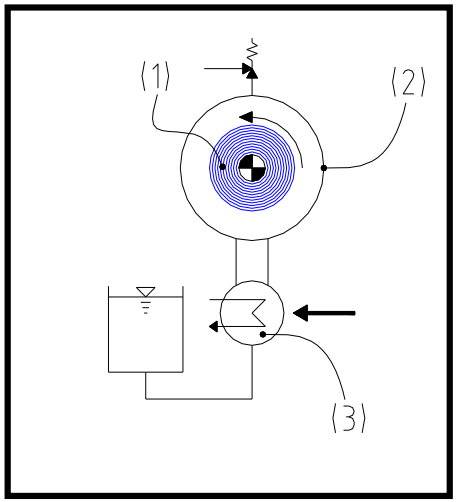
The process step by step – ageing equipment



Ageing vessel (Obem S.p.A.)

- Thermally conditioned vessel
- Homeo-thermal device
- Beam revolving device

- Temperature: up to 98 °C
- Fabric width: 0.4 m
- Fabric length: up to 50 m
- Revolving speed: up to 20 rpm
- Electrical power: 1.5 kW



The process step by step – ageing

ageing temperature higher than fiber glass transition temperature

high temperature promotes dye diffusion

fabric beam revolving avoids liquor percolation

Ageing operating conditions

- ❑ *temperature: 90 ÷ 95 °C*
- ❑ *time: 5 ÷ 10 hours*
- ❑ *beam revolving speed: ≈ 10 rpm*

Perspective: ageing time reduction to 2 ÷ 3 hrs

Dyeing results

1- Color fastness

to verify the dye diffusion and fixation degree

2- Color shade

to measure the dyeing characteristics of padding

3- Mechanical tests

to verify the process applicability

Dyeing results - fastness

padded fabric fastness is fully comparable with the fastness obtained by exhaustion

	Standard exhaustion dyeing		Padding after PDAPJ		Padding after HCAP	
Perspiration	Acid sweat	Alkali sweat	Acid sweat	Alkali sweat	Acid sweat	Alkali sweat
Stain on wool	5	5	5	5	5	5
Stain on acrylic	5	5	5	4	5	5
Stain on polyester	4	5	4/5	4/5	4	4
Stain on nylon	4/5	4	4	4	4	3
Stain on cotton	4	5	4	4	4	3/4
Stain on acetate	5	5	5	5	4	3/4
Rubbing						
Dry	5			5		5
Wet	4			4/5		4
Light						
Xenon arc lamp	4/5			4/5		4/5

Fastness evaluation according to reference rules. Perspiration: UNI EN ISO105–E04.
Rubbing: UNI EN ISO 105–X12. Light: UNI EN ISO 105–B02.

Color: *blue navy (dyes amount: ≈ 4 % w/w)*

Dyeing results – shade evaluation (first shot)

colorimetric tests confirmed the possibility to achieve deep color

	Light source	ΔE	ΔL	ΔC	ΔH	evaluation
Sample # 1	D65/10	1.445	1.377	0.226	-0.376	paler, bluer, greener
Sample # 2	D65/10	1.412	1.309	0.390	-0.360	paler, bluer, greener

Reference: *exhaustion dyed fabric –* ***Color:*** *black (dyes amount: ≈ 5 % w/w)*

better color matching is easily obtainable by recipe correction

accurate fabric pick-up measurement is required

padding dyestuff consumption matches exhaustion dyeing consumption

Dyeing results – mechanical properties

fabric maintains its mechanical properties during the process

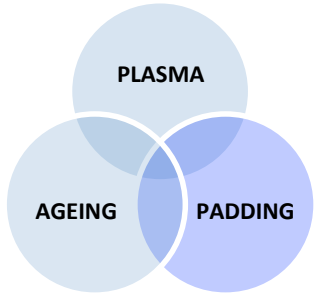
Breaking strength and elongation

	Untreated		After plasma		After ageing	
	warp	**weft**	**warp**	**weft**	**warp**	**weft**
Load [kg]	38.9	23.7	39.7	23.5	38.7	23.3
Elongation [mm]	19.9	31.7	19.9	30.2	19.2	31.5

Breaking strength and elongation measured according to ASTM D5035.

plasma treatment and ageing does not damage fibers

Conclusions



- *the process feasibility has been demonstrated*
- *the process environmental sustainability has been demonstrated by its low energy and water demand*
- *the technology transfer of wool padding to industry is immediately possible*

Perspectives

- *enhancing fabric speed up to 20 ÷ 25 m/min*
- *reducing ageing time from 5 ÷ 10 hours to 2 ÷ 3 hours*
- *performing an exhaustion to pad liquor recipe transfer at industrial scale*

THANKS FOR YOUR KIND ATTENTION

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