INTENSIFICATION OF WET TEXTILE PROCESSING BY ULTRASOUND APPLICATION

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Ultrasound application in dyeing

Project and Partners

INTEXUSA (Piemonte Regional Project)
INnovation in TEXtile productions by UltraSound Application
Dyeing intensification by ultrasonic technologies
and its integration with automatic on-line control

O BEM
CIMI
FLAINOX
ENEA
Politecnico di Torino
Finissaggio di Trivero
Finissaggio e Tintoria Ferraris
ITT - Industria Tessile Tintoria
Goals and scope of the investigation

Development and optimization of US application to improve wet textile operations, particularly dyeing and washing, which could lead to:

- Improve the standard of industrial processes and products through the reduction and/or optimization of the amount used of utilities and chemicals.
- Reduce the specific consumption of water and energy per unit product and the related costs.
- Increase the process efficiency, thus reducing the environmental impact due both to the amount of wastewater and gaseous emissions.
Ultrasound application in dyeing

**Project development**

- Bench scale equipment
- Preliminary apparatus
- Prototype pilot equipment
Preliminary apparatus

1 - DRIVEN CYLINDER
2 - ENLARGING CYLINDER
3 - US TRANSDUCER

Operating characteristics:
- Flat parallelepiped PTZ transducer
- Frequency: 40, 80 or 120 kHz
- Output power: up to 500 W
- Variable fabric velocity
- Fabric to transducer distance: 45 or 105 mm (at same dye-bath ratio)
Prototype plant equipment

Multi-purpose unit suitable to dye hanks, fabric and garments

Operating characteristics:

• Flat transducer (frequency range: 25-120 kHz, maximum output power: 600 W)

• Cylindrical transducer (frequency: 28 kHz, maximum output power: 1000 W)

• 3 US transducer configurations: flat (bottom), flat (lateral), cylindrical (bottom)

• Minimum dye-bath ratio: about 1:10
Dyeing parameters

- Equipment: preliminary apparatus
- Material: pure worsted wool fabric (180 g/m²)
- Fabric velocity: 3 m/min
- Net exposure time to US: 12 min (average)
- Overall dyeing time: 180 min (average)
- Fabric to transducer distance: 45 or 105 mm
- Dye-bath ratio: 1:70 or 1:115
- Dye-bath pH: 5 (acetic acid)
- Operating temperature: 85°C (isothermal)
- Dyestuff class: acid dyes
Dyeing results - Exhaustion curves and kinetics (1)

Comparison between conventional dyeing and US-enhanced dyeing at 500 W, liquor ratio 1:70, 45 mm distance, effect of frequency.
Dyeing results - Exhaustion curves and kinetics (2)

Comparison between conventional dyeing and US-enhanced dyeing, variable power, liquor ratio 1:70, 45 mm distance.
Ultrasound application in dyeing

**Dyeing results - Half-dyeing time**

Half-dyeing time ($t_{1/2}$): time required for the fibre to absorb half of the colorant that could be absorbed at equilibrium.

\[ R_{0.5} = \frac{t_{1/2, US}}{t_{1/2}} \]

Half-dyeing time at liquor ratio 1:70, 45 mm distance, variable power.

<table>
<thead>
<tr>
<th>Ultrasounds</th>
<th>Frequency (kHz)</th>
<th>Power (W)</th>
<th>Final exhaustion (%)</th>
<th>Half-dyeing time (min)</th>
<th>$R_{0.5}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>-</td>
<td>-</td>
<td>76</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>YES</td>
<td>40</td>
<td>500</td>
<td>81</td>
<td>35</td>
<td>0.50*</td>
</tr>
<tr>
<td>YES</td>
<td>80</td>
<td>500</td>
<td>80</td>
<td>40</td>
<td>0.57</td>
</tr>
<tr>
<td>YES</td>
<td>40</td>
<td>250</td>
<td>80</td>
<td>40</td>
<td>0.57</td>
</tr>
<tr>
<td>YES</td>
<td>80</td>
<td>250</td>
<td>77</td>
<td>50</td>
<td>0.71</td>
</tr>
</tbody>
</table>

* $R_{0.25} = 0.56$, $R_{0.65} = 0.53$, $R_{0.95} = 0.54$
Dyeing results - Overall kinetics constant evaluation

Valdeperas modification of Cegarra-Puente equation:

\[
\ln \left( -\ln \left( 1 - \frac{E_t^2}{E_\infty^2} \right) \right) = \alpha \ln K t
\]

\[K_{40\text{kHz}} = 0.0143 \text{ min}^{-1}\]
\[K_{\text{NO US}} = 0.0078 \text{ min}^{-1}\]

\[K_{40\text{kHz}} / K_{\text{NO US}} \approx 2\]
related to \( R \approx 0.5 \)
## Dyeing results - Color fastness

### Color fastness to domestic washing (UNI EN ISO 105 C01)

<table>
<thead>
<tr>
<th>Ultrasounds</th>
<th>Frequency (kHz)</th>
<th>Power (W)</th>
<th>Degradation</th>
<th>Staining on wool</th>
<th>Staining on cotton</th>
</tr>
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<tbody>
<tr>
<td>NO</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4-5</td>
<td>5</td>
</tr>
<tr>
<td>YES</td>
<td>40</td>
<td>500</td>
<td>3-4</td>
<td>4-5</td>
<td>5</td>
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<tr>
<td>YES</td>
<td>80</td>
<td>500</td>
<td>4-5</td>
<td>4-5</td>
<td>5</td>
</tr>
<tr>
<td>YES</td>
<td>40</td>
<td>250</td>
<td>4</td>
<td>4-5</td>
<td>5</td>
</tr>
<tr>
<td>YES</td>
<td>80</td>
<td>250</td>
<td>4-5</td>
<td>4-5</td>
<td>5</td>
</tr>
</tbody>
</table>

Identical values were obtained for perspiration (UNI EN ISO 105 E04) and rubbing (UNI EN ISO 105 X12).

Color fastness to artificial light (UNI EN ISO 105 B02) did not show any difference between conventional dyeing and US-enhanced dyeing.
Dyeing results - Mechanical properties

Determination of the bursting strength by sphere method (UNI 5421)

Bursting strength and distension for repeated measurements related to:
- a) Untreated,
- b) 6 hours treated.

<table>
<thead>
<tr>
<th>Test</th>
<th>Strength (daN)</th>
<th>Distension (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39.6</td>
<td>3.779</td>
</tr>
<tr>
<td>2</td>
<td>38.9</td>
<td>3.715</td>
</tr>
<tr>
<td>3</td>
<td>40.2</td>
<td>3.739</td>
</tr>
<tr>
<td>4</td>
<td>40.7</td>
<td>3.755</td>
</tr>
<tr>
<td>5</td>
<td>39.6</td>
<td>3.743</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Strength (daN)</th>
<th>Distension (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37.9</td>
<td>3.650</td>
</tr>
<tr>
<td>2</td>
<td>38.4</td>
<td>3.726</td>
</tr>
<tr>
<td>3</td>
<td>38.9</td>
<td>3.699</td>
</tr>
<tr>
<td>4</td>
<td>38.6</td>
<td>3.777</td>
</tr>
<tr>
<td>5</td>
<td>39.5</td>
<td>3.816</td>
</tr>
</tbody>
</table>

Average values demonstrated no mechanical damage occurring in the fabric properties.
Dyeing results - SEM analysis

SEM analyses were carried out on the fabric to detect any fiber structural modification.

Comparison of the wool fibers: a) Untreated, b) 6 hours treated.
Conclusions and comments

- Application of US increased the dyeing kinetics, especially at low frequencies, helping the overall mass transfer of the dyestuff to the fiber.

- Influence of dye-bath ratio: better performance was obtained at lower dye-bath ratio. In this view the prototype is expected to provide excellent results.

- Influence of US frequency: 40 kHz generated the best results. Even better results are expected by operating at lower frequency.

- Influence of US power: the results demonstrates that only a part of the energy given to the transducer is effective to enhance the kinetics of dyestuff mass transfer.

- Influence of the fabric to transducer distance: increasing the distance causes a reduction of the US effect.

- Color fastness evaluation does not show noticeable differences between US-treated and non-treated samples.

- No mechanical damage of the fabrics was observed during 6 hours of direct treatment by US.
Acknowledgments

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