Water-Free Decolorization of Disperse-Dyed Polyester via Supercritical CO_2

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Motivation



Fig. 1.: German-Dutch DeDye-ReDye Consortium

Why decolorization of PES matters

Polyester (PES) makes up ~59 % of global fibre production (2025), yet less than 1 % of clothing material is currently recycled fibre-to-fibre. The EU Strategy for Sustainable and Circular Textiles creates regulatory pull for high-quality textile-to-textile recycling. The key technical barrier: Residual colorants limit recyclates to dark or mixed-colour applications and reduce their market value. Conventional decolorization routes (back-stripping, dissolution–precipitation, depolymerization) require large amounts of water and energy and use hazardous chemicals.[1, 2]

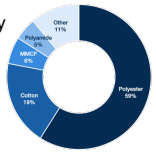


Fig. 2: Global fibre production [Textile Exchange (2025)]

Approach & Project Goals

DeDye-ReDye: a water- and chemical-free route with supercritical Carbon dioxide

Supercritical CO_2 (critical point: 31 °C, 73 bar) combines gas-like diffusivity with liquid-like solvating power. Literature reports 79–85 % decolorization of PES at ~120 °C and 25 MPa, but no scalable, techno-economically validated process exists yet. [1,2,3,4]

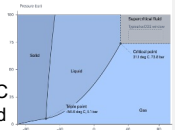


Fig. 3.: Pressure-Temperature Diagram of CO_2

DeDye-ReDye aims to:

- overcome the critical barrier as disperse dyes are built for high fastness, which makes them hard to remove;
- correlate dye molecular properties (chromophore, size, molecular weight, pH stability, fastness type) with $scCO_2$ extraction efficiency;
- develop a scalable $scCO_2$ technology for decolorizing PES textiles;
- enable high-quality recycling without water or harmful chemicals;
- close the loop for textile-to-textile recycling.

Materials & Methods

Defined HT-dyeing

- 100% PES woven fabric (210 g/m²)
- 100% knitted fabric (100 g/m²)
- Exhaust dyed at 1/1 standard depth at 130–135°C, 45 min)
- followed by reductive clearing

Table 1: Selection of disperse dyes

Sample	Color Index	Molecule size	Energy	Chromophore	Molecular weight [g/mol]	pH stability
1.1	Disperse Yellow 64	small*	low	Chinophthalon	368,2	3-9
1.2	Disperse Red 60	small*	low	Anthrachinon	331,3	3-10
1.3	Disperse Blue 56	small*	low	Anthrachinon	349,1	3-9
1.5	Disperse Yellow 198	large**	high	Azo	423,0	3-6,5
1.6	Disperse Orange 30	large**	high	azo	450,3	3-8
1.7	Disperse Red 177	large**	high	azo	438,5	3-6
1.8	Disperse Blue 73	large**	high	Anthrachinon	376,4	3-9
1.9	Disperse Blue 79:1	large**	high	Azo	625,4	4-6
1.14	Disperse Blue 284	medium**	high	Azo	465,4	4-5

* 130°C, 45 min ** 135°C, 60 min

$scCO_2$ extraction

- Pressure 100-350 bar
- Temperature 100-130°C
- Extraction time 45-75 min.
- co-solvent flow 1,38-5 ml/min.
- CO_2 flow 5-25 g/min.

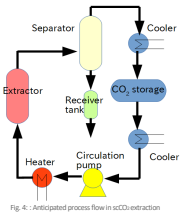


Fig. 4: : Anticipated process flow in $scCO_2$ extraction

Assessment

- Decolorization by colorimetry (L*a*b*, K/S, ΔE*)
- Topography by laser confocal microscopy
- Fastness after dyeing, de-dyeing and re-dyeing to ISO norms

Results

Correlation dyestuff character and decolorization effect

Table 2: Decolorization results

Sample	Color Index	Chromophore	Dyed sample	Decolorized sample	Decolorization CIE L*a*b* [%]	Decolorization K/S value [%]
1.1	Disperse Yellow 64	Chinophthalon			92,4	99,5
1.2	Disperse Red 60	Anthrachinon			89,6	99,8
1.3	Disperse Blue 56	Anthrachinon			70,1	97,9
1.5	Disperse Yellow 198	Azo			95,5	99,7
1.6	Disperse Orange 30	Azo			90,7	99,4
1.7	Disperse Red 177	Azo			86,1	99,3
1.8	Disperse Blue 73	Anthrachinon			69,1	97,8
1.9	Disperse Blue 79.1	Azo			85,8	99,7
1.14	Disperse Blue 284	Azo			87,5	97,6
1.15	Disperse Blue 60	Antrachinon			90,4	99,5
1.16	Disperse Violet 26	Antrachinon			91,1	99,6

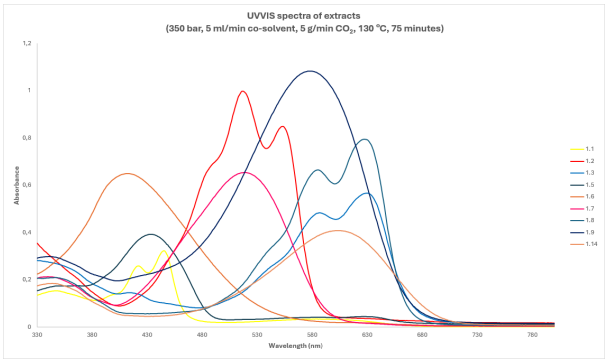


Fig. 5: : UVVIS spetra of extracts of all dyes

Conclusion & Outlook

- Proof-of-concept trials confirm substantial, reproducible colour removal without aqueous steps or hazardous chemicals.
- Ongoing experiments show a possible dependence of extraction efficiency on dye molecular structure, indicating which dye classes suit $scCO_2$ decolorization best.
- $scCO_2$ decolorization offers a closed-loop-compatible, water-free pathway for polyester recycling, eliminating aqueous effluent and hazardous auxiliaries.
- Linking dye structure to process performance provides the process intelligence needed for industrial implementation.
- Next steps will be parameter optimization for decolorization of all dyes to > 90 % and transfer to recycled PES, scale-up, LCA and cost analysis

References
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