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New Sustainable Chemistry

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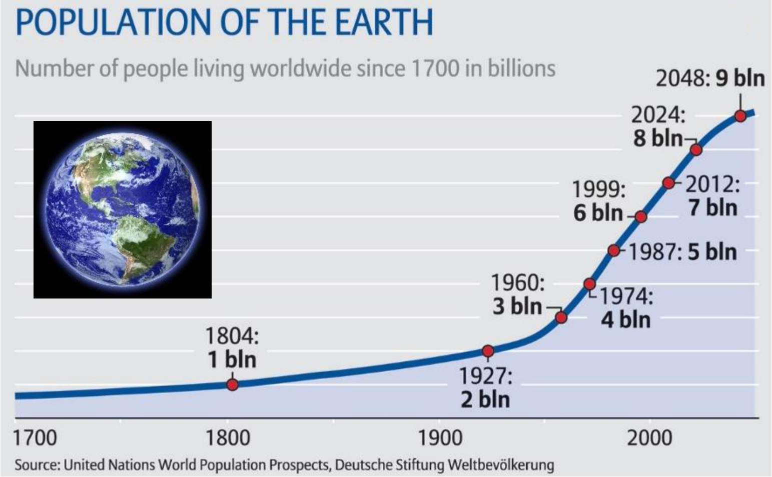
Sustainability Challenges of the Textile & Dyeing Industries – opportunities for innovation

Necessity for Sustainable Products



2012 - world population 7 billion

2050 - expected to rise to over 9 billion

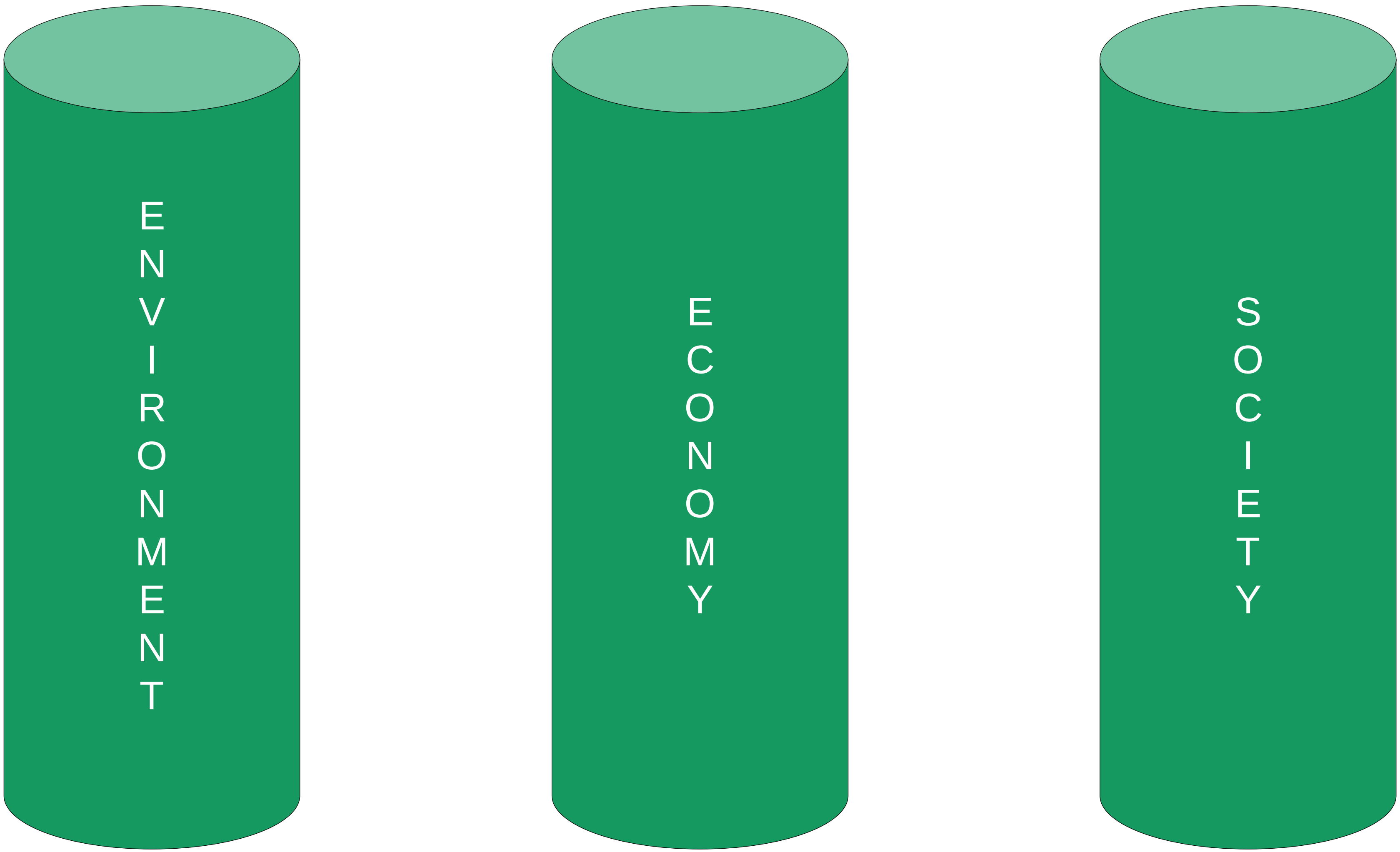
Increases demand

- food, energy, water, resources, chemicals

Increases environmental burden

- pollution
- depletion of finite non-renewable resources (*e.g.* fossil fuels)

Definition of Sustainability



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Sustainability considerations

RAW MATERIALS

ENERGY

WATER

EMISSIONS

Ideal sustainable product

- Provide an **equivalent function** to the product it replaces
- **Performs as well as or better** than the existing product
- Be available at a **competitive or lower price**
- Have a minimum environmental footprint for **all the processes involved**
- Be manufactured from **renewable resources**
- Use only **ingredients that are safe** to both humans and the environment
- **No negative impact** on food supply or water

Textile dyeing processes

Traditional dyeing processes use 5.8 trillion litres water p.a.

~3.7 billion Olympic swimming pools

10-20% dye remains after dyeing (plus other chemicals), leaving potential for wastewater pollution

One fifth of the world's industrial water pollution (World Bank)

391 billion kWh energy for dyeing processes

Innovative technologies needed to reduce, or eliminate, water, energy and auxiliary chemicals in dyeing

Treatment of textile dyeing effluent

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Wastewater discharged from dyeing processes one of biggest contributors to textile effluent

Mainly residual dyes and auxiliary chemicals

>50,000 tpa dye discharged into effluent

Dye Class	Fibre	Loss to effluent (% applied)
acid	polyamide	5-20
basic	acrylic	0-5
direct	cotton	5-30
disperse	polyester	0-10
metal-complex	wool/polyamide	2-10
reactive	cotton	10-50
sulphur	cotton	10-40
vat	cotton	5-20

Treatment of textile dyeing effluent

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Dyeing effluent in a watercourse aesthetically undesirable, but has a more serious environmental impact

High BOD combined with spectral absorption of dye

- Can affect photosynthetic processes
- Reduction in O_2 levels in the water → suffocation of aquatic flora and fauna

Dyestuffs may be also have aquatic toxicity (metals, AOX)

Several methods developed to remove colour from dyehouse effluent

Varying in effectiveness, economic cost, and environmental impact (of the treatment process itself)

Blackburn RS, *Environ. Sci. Technol.* **2004**, *38*, 4905.

Coloration of cotton

Dyeing of cotton primarily conducted using reactive dyes

Despite development of dyes with high fixation, dyeing still uses high quantities of salt, water (and energy), and creates colour pollution

- **Soil too alkaline to support crops**
- **Kills aquatic life**
- **Fresh watercourses turned saline downstream from dyehouses**
- **Difficult to remove from effluent**

- **10-40% dyestuff hydrolysed**
  - Goes down drain
  - Aesthetically unpleasant
  - Blocks sunlight
  - Kills aquatic life
- **Clean effluent**
  - High cost

- **High level in dyeing**
- **Incredible volume in wash-off**
  - Up to 10 separate rinsings
  - High energy consumption
  - 50% total cost dyeing procedure

Traditional Reactive Dyeing Process

1st Stage of Reactive Dyeing

- dye absorbs onto cellulose substrate through hydrogen bonding in aqueous solutions with a high level of electrolyte addition
- dye adsorption onto the fibre is enabled, higher salt leads to better dye uptake

2nd Stage of Reactive Dyeing

- addition of alkali to achieve pH 11 generates covalent bonding between dye and fibre
- however, alkaline environment produces hydroxyl ions in solution which react with the dye to create hydrolysed dye (as much as 40% of the dyestuff may be hydrolysed)
- whilst the hydrolysed dyes have an affinity for the fibre, it is not covalently bonded

Traditional Reactive Dyeing Process

Wash-off of Reactive Dyeings

- reactive dyeings require a multistage wash-off process after dyeing involving various aqueous rinses and washing to remove hydrolysed dye and achieve the characteristic high colour fastness
- wash off and subsequent effluent treatment can account for up to 50% of the total cost of reactive dyeing
- high levels of electrolyte causes dye molecules to aggregate making the hydrolysed molecules difficult to remove
- several wash off processes are needed, the first 2 are mainly to dilute the electrolyte levels, subsequent stages remove the hydrolysed dye from the substrate to achieve the high colour fastness required
- the wash off process uses large volumes of water, high energy levels to raise the water temperature for efficient washing as well as increasing greatly the time taken for dyeing and reducing productivity

Use of Dye Transfer Inhibitors (DTI)

Novel DTI Wash-off Process

- water and energy are the biggest issues in dyeing of textiles
- DTIs have long been used in domestic laundry detergents for holding soils and dye molecules in suspension and preventing re-deposition onto the textile
- existing and developmental DTIs were used to remove unfixed hydrolysed dyes following the reactive dyeing of cotton
- the objective was to drastically reduce the wash off procedure, reduce energy, time, cost and gain a substantial sustainability benefit

The Process

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Recommended Dyeing and Wash-off Method

- Fabric, reactive dye and sodium sulphate added to water (10:1 solution to fibre ratio), held at 50 °C for 20 min, temp raised 1.5 °C/min to 80 °C and held for 30 min.
- Sodium carbonate added to change pH to 10.5 and held at 80 °C for 60 min. Fabric then removed.
- Fabric washed-off according to Dye Manufacturer instructions using **6-stage** process.

Recommended Dyeing Method and DTI Wash-off Process

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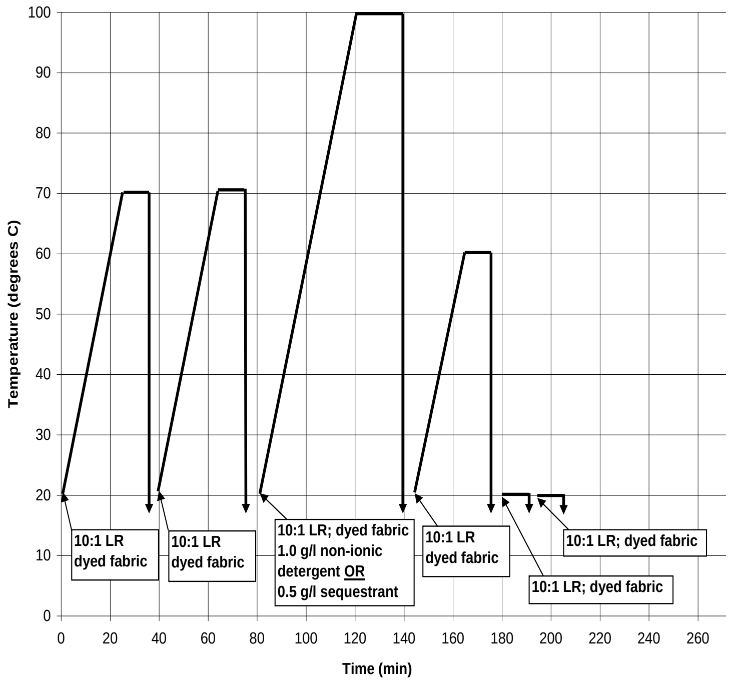
- Sodium carbonate added to change pH to 10.5 and held at 80 °C for 60 min. Fabric then removed.
- Fabric washed off in a **3-stage** process

i. washed in water (10:1 solution to fibre ratio) at 20 °C for 10 min. Wash bath then emptied

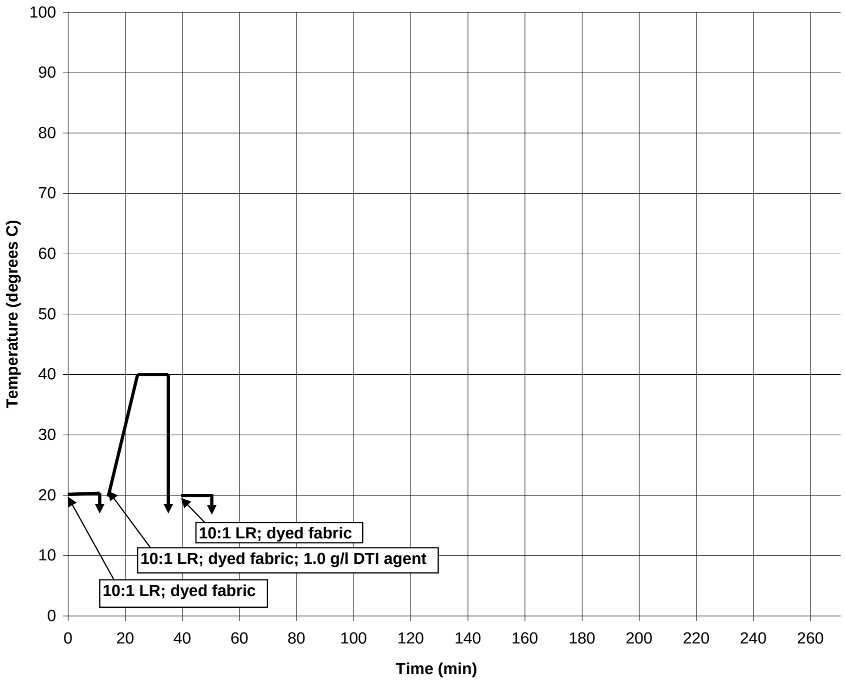
ii. DTI and water added (10:1 solution to fibre ratio) at 40 °C for 10 min. Wash bath then emptied

iii. washed in water (10:1 solution to fibre ratio) at 20 °C for 10 min. Wash bath then emptied

Comparison of the two processes



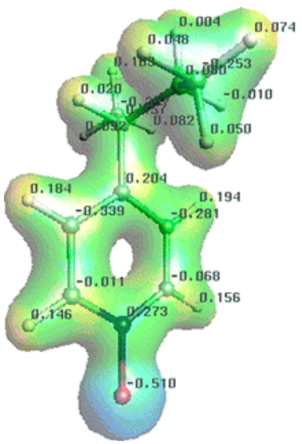
Traditional methodology



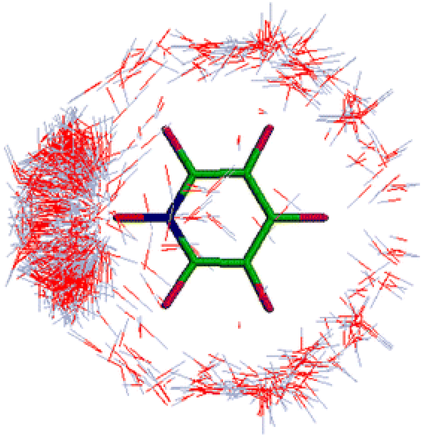
Use of DTIs

Wash-off of reactive dyeings on cotton

- Dye transfer inhibiting (DTI) polymers (used in laundry detergents) were employed to remove unfixed dyes
- Much more efficient, economical and sustainable process developed
- Significantly reduces operation time, water consumption and energy consumption
  - poly(vinylpyridine-*N*-oxide) polymers were the most effective
  - poly(vinylpyridine betaine) polymers also highly efficient



Procedure	Time (min)	Water (L/kg fabric)	Energy (MJ/kg fabric)
Recommended wash-off	250	60	9.21
DTI wash-off	50	30	0.84



Amin MN, Blackburn RS, *ACS Sus. Chem. Eng.* **2015**, *3*, 725.

Grey Scale Rating for Staining to Adjacent Cotton

DTI	C.I. Reactive Red 120		C.I. Reactive Yellow 84		C.I. Reactive Red 141		C.I. Reactive Blue 171	
	20 g dm^{-3} Na_2SO_4	No Na_2SO_4	20 g dm^{-3} Na_2SO_4	No Na_2SO_4	20 g dm^{-3} Na_2SO_4	No Na_2SO_4	20 g dm^{-3} Na_2SO_4	No Na_2SO_4
None	2/3	3	2	3	2	3	2/3	3
Sandozin NIE	3/4	4	3/4	4	3	4	3/4	4
PVP	4/5	4/5	4	4/5	4/5	4/5	4/5	4/5
PVP K-15	4/5	5	4	4/5	4/5	4/5	4/5	4/5
PVP K-30	4/5	4/5	4/5	4/5	3/4	4	4	4
PVP K-90	4/5	4/5	4/5	4/5	4	4	4	4
PVP K-120	5	5	4/5	4/5	4	4/5	4	4/5
Chromabond S-100	5	5	5	4/5	4/5	4/5	4/5	4/5
Chromabond S-403E	5	5	5	5	5	5	5	5
PVNO Classic	5	5	5	5	5	5	5	5
PVNO Europe	5	5	5	5	4/5	5	5	5
Standard wash-off	5	5	5	5	5	5	5	5

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Thank you!

Questions welcome

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