



**made
with love**

**Better thinking's
perfect t-shirt.**

**Dyeing for a change:
Current conventions
and new futures in the
textile colour industry**



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Introduction

Well, having given ourselves a project title such as 'the perfect t-shirt', we knew that we would often find ourselves in the midst of some real complexity and strife. So it was with this in mind that we tried to make sense world of chaos and confusion that is textile dyes and their environmental impacts. We resisted the urge to bite the desk, and instead painstakingly researched the different options available to us and the pros and cons of each as best we could.

It's been rather complicated: available information has either been thoroughly uninformative, or incredibly scientific (a favourite sentence of ours being 'although D-fructose would appear to be non-reducing, the structure readily undergoes keto-enol tautomerism'). But we've put all the useful information into terms suitable for non-rocket scientists, highlighting as many issues relating to each method as we could, as well as including a few appendices that we found interesting. As always with eco-design, comparing apples with oranges makes it impossible to find a cut-and-dry solution, but at least we're raising awareness about the impacts and viable alternatives and starting a dialogue with people about the issues.

The best way to colour a shirt is, sadly, an area that is often neglected when manufacturers look to make their garments more ecologically sound. It's great to see more and more t-shirts made of organic cotton, but many of their manufacturers have not stopped to consider the environmental impacts of the dyes. Many retailers and producers happily claim that they sell organic shirts, having completely disregarded how their stock has been coloured. The good news is this is beginning to change, with the Soil Association only allowing their logo to be printed on garments that have fibre that was grown, coloured and printed organically. But wanting to take things as far as we can, we want to investigate every option to find out the best choice available. And as you'll see, this area is far from being the best it can be at the moment.

One question we battled with was 'why have a coloured t-shirt in the first place?'. The most effective way to reduce the impact of something is to ask yourself if you need it at all (which, in this instance, is the colour, not the t-shirt). We've decided to offer an undyed option for hardcore eco-types, but for people who feel more pressured by the conventions of fashion, we've decided to produce a colourful option, and for those who want to look perfect for business and more formal occasions, we're going to offer a black one.

What follows is a breakdown of the available information that was relevant to the fabric we'll be using, which may well be cotton, linen, viscose or some combination of the above. There are a number of options for a producer wishing to minimise their impact: from improving conventional methods, to using somewhat greener natural dyes, to learning from traditional, ancient methods. We've tried to keep as many product and company names in as possible so anyone reading this for work can follow up leads. And, as per usual, if you disagree with any of the above or have any interesting thoughts, comments or constructive criticism relating to the issues, we'd love to hear from you. Just drop us a line at perfect@betterthinking.co.uk.

Why the issue of dyes needs to be addressed

Although they may produce cheery-looking, colourful garments, conventional dyeing processes are extremely polluting, so much so that the manufacture and use of synthetic dyes are two of the world's most polluting industries. Conventional dyes present extreme health risks to those working with them and to those who wear them, as well as damaging the environment in a number of ways.

So how can conventional chemically based dyes affect you, the end user? In some people they can lead to skin rashes, nausea, difficulty breathing, irregular heart beat, and seizures, as well as leading to behaviour and learning difficulties for some children. The dyeing process generally involves a range of toxic chemicals such as dioxins, which are carcinogenic and possibly disrupt hormones; toxic heavy metals such as chrome, copper, and zinc which are known carcinogens; and formaldehyde, a suspected carcinogen. Some dyes contain heavy metals like copper, chromium or cobalt.

More information is available on the damage conventional dyes do to the environment. For instance, we know we should pay more attention to how to use water more efficiently. Richard Blackburn at the Centre for Technical Textiles, University of Leeds, says that a t-shirt's biggest impact on the environment is through the water it uses. On average, each kilo of finished fabric needs between 80 to 100 litres to dye it. A t-shirt weighs around 200 grams, meaning each one uses 16-20 litres of water. About 80% of conventional direct dye is retained by the fabric; the rest is flushed out from the shirt, polluting the water it enters. Each year, the global textile industry discharges 40,000-50,000 tons of dye into rivers and streams, and, in Europe alone, 200,000 tons of salt (used in the process to even out colour) are discharged every year. Although this waste water can be treated to remove the heavy metals and other toxic chemicals it contains so it can safely be returned to water systems, this does not always happen, and if it does, the process can depend on fossil fuels and more chemicals. The good news is that treatment plants that can recover 95% of dye and 90% of salt have been developed and plan to be used at PREM in Tiripur, India.

Why does it matter that we are releasing this effluent into our rivers and streams? Well, first the selfish reasons: the water we drink is often the water we have discharged, and, according to Dr P Cooper, 'monitoring by the authorities [and] regulatory bodies is by no means totally effective'. Some harmful dyes lead to algae overpopulating watercourses, preventing adequate levels of sunlight entering the water. This means flora cannot grow, oxygen levels in the water are reduced and the flora and fauna that are there already are suffocated. Salt pollutes freshwater courses, kills fish and makes soil too alkaline to support crops. There are a number of freshwater lakes that have been turned permanently saline by dyeing operations. Colours in the water, especially dark ones, pose prevent sunlight penetrating the water, thereby inhibiting bacteria from carrying out its helpful task of breaking down waste components of the waste water. Heavy metals and chlorine present in effluent may be toxic to aquatic organisms. Almost all dyes take a long time to break down and can be considered ecologically unsound or environmentally hazardous. And, of course, it all looks pretty horrible too.

Another reason synthetic dyes are a problem is because they are made from finite resources, such as petroleum. Even with more sustainable dyes that are more inherently carbon neutral, such as plant based ones, there's room for improvement – they're used in factories that run off fossil fuels and require products and additional agents to be transported long distances.

There's so much wrong with the industry as it is now, any improvement from any manufacturer should be encouraged. But what's the most perfect way to do it?

Part One: Traditional Dyeing Methods

Generally, the textile industries use synthetic dyes, which fall into a number of categories: direct dye, vat dye, sulphur dye and reactive dye. Here's what I can tell you about the environmental impacts of each:

Direct dye

Direct dyes are so-called because they colour cellulose 'directly', which benefits the environment by eliminating the need for a mordant (the chemical fixing agent lots of other dyes need). They're most often used for fashion clothing, and are popular because they are cheap, easy to apply, very light fast, and available in a wide range of bright colours.

However, the process requires types of salts that concern experts so much they have recommended substitutes must be found. Energy is needed to heat the dyebath to boiling point. The waste water from this process contains salt, dye-fixing agents and between 5% to 20% of the original added amount of dyestuff.

Azo dyes are a type of direct dye that are made from a nitrogen compound. They are usually red, brown, or yellow, and make up about half of the dyes produced. They are known to give off a range of carcinogenic particles and have hence been banned by several EU countries.



Some of the colours available through direct dyeing

Vat dye

Certain dyes, such as indigo, are classed as vat dyes. To make these dyes soluble, alkali and a powerful reducing agent need to be added. Vat dyes are some of the most wash-fast on cotton, but they are very expensive due to the complicated dyeing procedures they require, and hence are only used for high-quality clothes. The effluent from this process contains between 5% to 20% of the residual dyestuff, as well as reducing agents, oxidising agents, detergents and salts.

Of all of the conventional dyeing methods, vat dyeing appears to be one of the least environmentally impactful, while at the same time producing high quality results. The chemicals involved in the process fall into the two least environmentally impactful categories of the chart in Appendix 2.



Sulphur dye

Sulphur dyeing is a relatively cheap method of obtaining good colour strength and acceptable fastness of dyeing. It's often used for low cost fabrics and garments such as working clothes. 70,000 tonnes of sulphur dyes are used annually, with just one colour, Sulphur Black 1, making up 20-25% of the dyestuff market for cotton. Environmentally speaking, it's free from heavy metals and other nasties, so it's not too bad when compared to reactive dyes, except for the fact that 90% of all sulphur dyes make use of sodium sulphide, which makes the process's effluent more toxic than any other's. This discharge endangers life and possibly alters its DNA, corrodes sewage systems, damages treatment works and often leads to high pH and unpleasant odours. This effluent also contains between 30% to 40% of the dye that was originally added to the bath, as well as alkalis and salt.

Progress to make this process more environmentally sound has been made, such as minimising or eliminating the amount of sodium sulphite in the dye, with limited results. However, Hydrol, a by-product of the maize starch industry, is an effective substitute of sodium sulphite, producing a black colour but using one third of the sodium sulphide required for sulphur black dyeing. It has also been found that sugars can be used as a sustainable, non-toxic alternative to some of the sulphide-based reducing agents, whilst providing results of a comparable or superior standard. However, it seems these treatments are not currently commercially available.

Reactive dye

Fibre-reactive dyes are synthetic dyes that directly bond with the garment fibres, rather than merely remaining as an independent chemical entity within the fibre. The benefits: these dyes are easy to apply and are available in a wide range of colour and wash-fast bright colours. The fixation or absorption rate of low-impact dyes is at least 70%, creating less waste water runoff than conventional dyeing processes. Reactive dyes are applied at relatively low temperatures (30°C compared to the 100°C needed for direct dyes), saving energy, and require controlled amounts of salt and alkali. Recent advances have created fibre-reactive dyes with colours that are brighter and richer, and they provide excellent colourfast properties.

Low-impact reactive dyes have been developed, which have been classified by the EU as eco-friendly. They contain no heavy metals or other known toxic substances, and do not need mordants. The high cost of this dye becomes an environmental advantage, as it is cheaper to reclaim dye from its effluent rather than discharge it all and start from scratch. The water can also be recycled. The dye cycle is shorter than it is for other dye processes, meaning less water, salt and chemicals are needed. The entire process normally occurs at a pH of around 7.0, meaning no acids or alkalis need to be added to the water. It's really hard to find out the names of these low-impact reactive dyes and who's using them, but the Dandelion Clothing Company seems to be one of the companies using them.

The disadvantages: like other environmentally damaging dyes, these dyes are made from synthetic petrochemicals. The process requires very high concentrations of salt (20%-80% of the weight of the goods dyed), alkali and water. Even if the unfixed dye is reclaimed, the effluent from this process can still contain high concentrations of salts, surfactants and defoamers, and are strongly alkaline. It's also quite expensive, whereas conventional dye is cheap. This process' effluent normally contains salt, alkali, detergent and between 20% to 50% of dye used. As reactive dyes currently make up 50% of world dye consumption, more knowledge on how to improve upon this method is needed.

Fortunately, research is being undertaken in this area, and a number of companies have produced products that improve on its impacts. It's been found that, by pre-treating cotton with 120g of phosphate buffer per kg of fabric, no salt or alkali is needed in the dyeing process as the process can occur at a neutral pH. It also means the amount of water required can be halved and the whole dyeing process can be significantly reduced, presenting additional benefits in the form of cost savings. Compared to the other chemicals used to dye fabric the conventional way, this is a relatively low concentration, and its high exhaustion value means the effluent would only contain it in small proportions, making it a much greener alternative.

By pre-treating cotton with Jarasol 391 and dyeing it with Jarasol water-soluble sulphur dyes, the need for salt or alkali is considerably reduced. However, it has poor colour fastness. A new dye system developed by Uniqema is slightly inferior in terms of colour fastness, but vastly superior in environmental terms: it requires no salt, no alkali,



considerably less water consumption (30% of the current standard), less processing time, minimal effluent, possibility of recycling dyebaths, deeper shades and higher light fastness values makes the system a highly viable, greener alternative. But since we don't want to postpone our t-shirt production waiting for it to be released, we need to keep looking...

Other progressive products: Procion T and Kayacelon reactive dyes have higher fixation rates than many reactive dyes, reducing the dye content in the effluent. In addition, the effluent is neutral even without treatment. Cellulose blends can be dyed using only one dye bath, consuming less water.

Bifunctional, also known as mixed, dyes require shorter dye procedures. Because of their increase fixation properties, the salt requirement is reduced to almost half. As well as consuming fewer chemicals in the first place, it also means there is less in the effluent. A further improvement on the above is Cibacron LS; a dyestuff which requires one quarter of the salt required by its conventional counterpart, substantially reducing the salt load on the effluent. The fixation rate is 20% better than other alternatives, and the colorant load in the effluent is reduced by half.

Monforts and Zeneca have developed an even more environmentally sound process that it calls Econtrol. The process is a continuous one, i.e. it happens 24 hours a day. Urea, sodium silicate, soda ash, sodium hydroxide or salt are eliminated from this process, and the amount of sodium bicarbonate required is about 5% of its previous levels. Excellent results are reported to have been achieved. The effluent contains between 4 and 5% of what is currently emitted by state-of-the-art technology.

Part Two: Improving on conventional techniques

There are a few new, environmentally aware methods of colouring fabric that do not involve natural dyes. These are documented below...

The recycled t-shirt



Muji recycled yarn t-shirts

Inspired by the Muji recycled yarn t-shirt, which is made from the ends of huge fabric rolls, we investigated a t-shirt made from the unwound yarn of old t-shirts. Although it is technically possible, the recycled t-shirt may not be commercially feasible. Circular spun t-shirts, which do not have seams down the sides, can be unwoven using a piece of machinery available in the UK to provide a piece of yarn long enough that, when linked to other long yarns, could be knitted into a new t-shirt. However, most t-shirts have seams, meaning finding enough circular woven t-shirts of the quality and colour we need may be prohibitively expensive. Maybe we should make our t-shirt shirt on a circular spinner so they can be unravelled at the end of their lives...

Closed loop principles

If this project were entitled 'the perfect jumper', this closed loop method of dyeing would be perfect. Developed by Climatex according to the principles of super eco-gurus McDonough and Braungart (they of the pioneering 'Cradle to Cradle' approach), the system's already in operation, forming an important part of Looolo's biodegradable textile story. Remainders from the dye baths are purified, recycled and reused entirely, so pollutants are never released into the outside world. And as well as being super-eco, the colours produced are super-cheerful too. But for us, the drawback is that these methods can only be used to dye organic wool, ramie (a member of the linen family) and viscose. Cotton, linen and cellulose have different characteristics which mean we cannot use this method for our t-shirt. An organic merino wool t-shirt could be dyed using this method, but as we feel our first perfect t-shirt will be made from vegetable fibre, partly because there are ethical issues involved in the production of merino wool, we can't currently pursue this method.



The colours available using Looolo's closed loop dye system

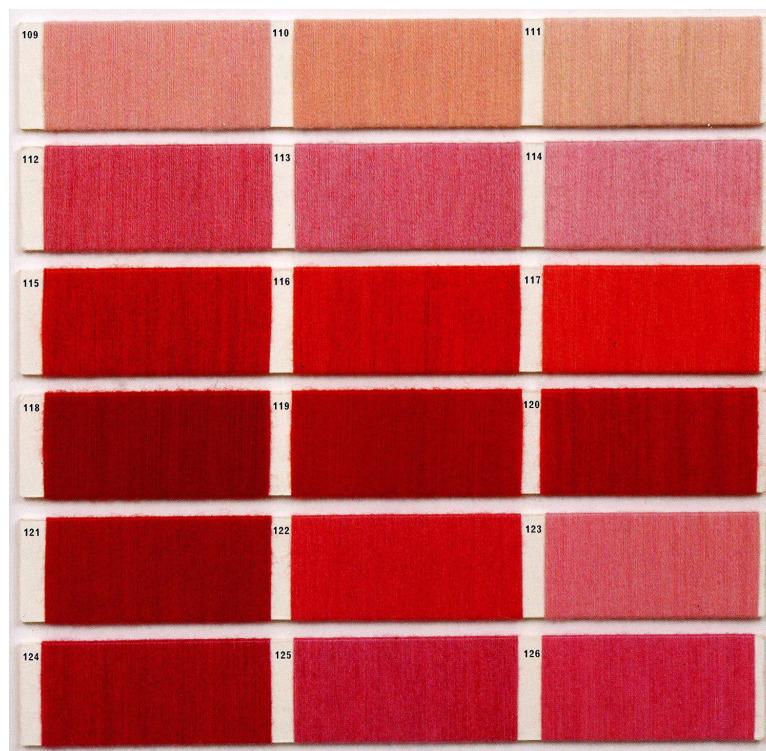
Part Three: Natural colours

Natural colour doesn't just mean dyes derived from natural sources: it can also mean naturally coloured cotton, or cotton left undyed. Sunbleaching is an extremely environmentally sound method of brightening undyed cotton. The natural colours industry has been eclipsed by synthetic dyes, which claim to be cheaper and more effective, but advocates say natural dyes are available in a huge range of bold, fade-resistant colours and are thus a viable alternative. But research is needed to make them truly viable: there is still doubt as to their performance and supplies are currently extremely limited. However, as more people become concerned with the environmental effects of synthetics, more money is being put into research and setting up the infrastructure needed, improving the situation all the time.

Natural dyes

Natural dyes - colour from plant and animal sources - provide alternatives to the complex world of chemical dyes. Although fundamentally more environmentally sound - they can be grown organically and are inherently carbon neutral - they come with some drawbacks, including the reliance on chemicals to bond the colour to the fabric, a large amount of water still being needed in the colouring process, and further investment and time needed to let the industry and technology reach its full potential. There's an interesting debate here - this dyeing method may not be perfect now, but if we support it and highlight how good it could be given the right investment, we could help move it towards being the perfect colour solution.

So first the advantages: far from being an inferior alternative to synthetic dyes, it has been argued that synthetics dyes 'give a rather shallow experience... Natural dyes reacquaint us with a high quality sensory experience'. The five classic dyestuffs are madder, cochineal, weld, cutch and indigo, and these can be used to create almost every colour you'd care to mention, with the exception of certain electric blues and fluorescent colours. They are all plant dyes, with the exception of cochineal, which is derived from insects. It is said that these five dyes yield strong colours, are resilient to fading, are also relatively fast and available.



Vibrant colours from natural dyes



Natural dyes can offer real social benefits. As they are crops they boost the economy of developing nations, providing sustainable livelihoods for rural people, especially women. They also can make a country's textile industry more competitive, as it can grow the crops for the dyes themselves, reducing production costs by eliminating the large expense of chemical imports.

Originally, weld comes from Europe but the others are native to the tropical world, but indigo, which comes from woad, is being grown in the UK, and can clearly be grown in similar climates, meaning the amount of transport the t-shirt would be responsible for would be reduced.

By-products of the crop, such as organic compost and fuel, could provide environmentally sound alternatives to other products. It also offers the potential to regenerate the natural environment by increasing soil variety. Natural dyes could increase permanent forest cover and planting of native tree species to preserve biodiversity. And the learning from improving natural dyes could extend beyond the textile industry: they could improve the environmental friendliness of biodegradable plastics and packaging, as well as making cosmetics, bath products and food safer for individuals.

However, there are a number of disadvantages to natural dyes in their current form. Although they sound like a better alternative to conventional dyes, and bound to make the ecologically-minded feel better when they look at the label, natural dyes are not necessarily safer or more ecologically sound than synthetic dyes.

Just because the dye itself is natural, it doesn't mean that the crop is sustainable. Pesticides may have been used on the crop and it may be genetically modified or irrigated unsustainably. Some colours come from forest products, depleting valuable natural resources. Also, other substances used in the colouring process may well be environmentally damaging. The colourful cotton in the pictures above has been mercerized, that is, treated with harmful caustic soda. Cutch does not need a mordant, but madder, cochineal and weld all do, and indigo is a vat dye, requiring dissolving in alkaline solution before it is useful. Also, the amount of water used, considered to be the biggest environmental impact of dyeing, hasn't been taken into account. Some of the effluent from the natural dyeing process may be just as harmful as that used in conventional processes. And despite being natural, these dyes aren't necessarily safe, as in the case of poison ivy and toxic mushrooms. Proper health and safety equipment must be supplied and workers need to be trained properly so they treat the dyes and mordants with respect.

And despite what some people are saying, the performance of the dye is questionable, with some detractors saying they can be less permanent, more difficult to apply and wash out more easily. The variability of the colour will need to be turned into a selling point of the t-shirt, by making people feel proud to own something that is unique.

The use of natural dyes will almost certainly make the garment more expensive, firstly, because large quantities of land and raw material are required to obtain the same depth of colour that a synthetic one would obtain. Both growing and applying the dyes are time-consuming, increasing cost. Natural dyes take at least twice as long as synthetic dyes to get a result, and using natural dyes on vegetable fabric will be more costly still, as it is more resistant to taking up good strong colours than animal fibres are, and slower, longer treatments often give better results.

And then there's the problem of availability: with perhaps the exception of indigo, the most common dyeing crop, crops grown for are dye are almost non-existent. This shouldn't be too much of a problem for us, as we want to do a relatively small dye run, but a global t-shirt company would have extreme difficulty making vast improvements to the environmental impacts of their dyeing processes because the supply, and the infrastructure to apply it, doesn't exist at that scale.



Natural indigo

However, despite these drawbacks, it's worth bearing in mind that they are preferable to the current convention of synthetic dye use. There are also some organisations working to improve on the performance and impacts of naturals. A full range of natural colours is available from Allegro Natural Dyes. Genencor International have developed a biosynthetic indigo, that eliminates harmful aniline, formaldehyde and cyanide contained in its conventional form. A project that sounds exceptionally exciting is The Colours of Nature. One of a handful of remaining natural dyeing units in the world, it specialises in indigo dyeing, and is entirely focused on environmentally friendly, vegetable dyeing process. Their dyeing process treats the yarn with a high alkaline soap instead of caustic soda, and uses plant extracts that not only do not harm humans, but may improve their health. For example, the tannin used as a mordant is a powerful antiseptic, the turmeric revitalises the skin and the indigo is relaxing. The water used in each stage is treated and then recycled for agricultural use. With some development, this dyeing process could be used for medium sized industrial production runs.

Naturally coloured (colour-grown) cotton

Of 6,000 cultivated cotton varieties, 40 are coloured, providing a range of colour including mocha, tan, grey, brown, black, mahogany, red, pink, blue, green, cream and white. However, due to their short fibre length which is unsuitable for industrial milling, these varieties are somewhat obscure.

The only naturally coloured cotton with a fibre length long enough to mill was developed by Sally Fox and is called FoxFiber. It's available in shades of green, beige, brown and blue and is sold by Vreseis Ltd. It's grown organically but we don't yet know whether it is irrigated sustainably. Naturally brown cotton is grown in Peru, Ecuador, Central America, Mexico and Southeastern USA, so it could have some social benefits, but not as many as it would if it was grown elsewhere, such as West Africa. We're not yet sure how viable it would be to begin growing a FoxFiber crop in West Africa: more investigation along these lines will be needed should we decide to pursue this route.



Naturally colored cotton

Sunbleaching

Just like the sun lightens peoples' hair during the summer, direct sunlight can also naturally bleach cotton. It works by destroying the molecules that colour the fabric, and was used in earlier times before we had chemical bleaches. A small disadvantage: just like people who've had too much sun get brittle hair and wrinkly skin, sunbleached fabric has an aged appearance. The process is also slower than other processes, as the cloth needs to be left in direct sunlight for about 36 hours, meaning it could be more time-consuming and hence more expensive. But the huge advantage is that it's probably the simplest process this report covers, requiring no complicated equipment or other substances, or transport to specialist facilities. It could be a highly viable option for our t-shirt but as very little information is available on it, we should carry out some tests to see how it well it really works.

Undyed

A report from the CBI on environmentally sound production clearly states: 'the best option is not to dye the fabric.' Eco-logic dictates that the less processes the t-shirt goes through, the more environmentally sound it is. An undyed t-shirt completely cuts out the colouring process, meaning the footprint of dyeing the undyed t-shirt is a big fat (somewhat predictable but worth mentioning). And by simplifying the production process, an undyed t-shirt is cheaper for the customer and presents less headaches for us. It's just a case of showing people that bright colours carry a cost and that at this stage it's ethically preferable to wear an undyed shirt.



Part Four: Other aspects of the dyeing process and how we can improve environmental impacts

Regardless of what dye type a producer chooses, there are several ways to reduce the impacts of the dyeing elsewhere in the process. Even using conventional methods, dye and water can be used more efficiently by planning the run better, putting more yarn in one dye bath and avoiding making up a full dye bath for a small lot of yarn. Darker dyes can be added to dye baths previously used for lighter colours, enabling chemicals to be re-used, or water that has been previously used to rinse light colours can be used as influent to wash or dye darker colours. It may be worth rethinking the fabric that will be dyed: for instance, bamboo fabric accepts and holds dye well, meaning dyefixing agents such as heavy metals and formaldehyde are not necessarily needed.

One of the most reliable and environmentally friendlier methods of dyeing is pad-batch dyeing, also known as the exhaustion method. It can be used for cotton, rayon and blends. The fabric is dyed, the excess is squeezed out and the fabric is stored. After two to twelve hours, it is washed. This method offers advantages in the form of waste reduction, simplicity and speed. The use of salt is practically eliminated, and in some situations water consumption is reduced by 90%. Energy consumption is reduced by 75%. Dyes, chemicals, labour and floor space are also reduced.

Automatic dispensation is an innovation that reduces wastage by precisely calculating the amount of dye to be used and colour matching to combine previously used dyes. Processing times are improved, colour matching is more precise and smaller lots can more easily be dyed. The automated process also protects workers from the health risks of handling hazardous chemicals. The benefits of reducing the amount of chemicals needed has a synergetic effect: less fossil fuel is required to produce and transport them, and less appears in the effluent, meaning it is easier to clean.

Fibre, yarn or cloth?

Although the colour can be added at either the fibre, yarn or cloth stages of the production process, it is best to add it at the yarn stage, both for environmental and aesthetic reasons. Dyeing at the fibre stage requires more water and can absorb the colour unevenly. Cloth often sticks to itself, meaning it doesn't take the dye or mordant evenly. Both processes involve a less efficient dye process as they need a larger dye bath with less material in it, and more thorough rinsing at every stage to remove any loosely attached mordant and dye.

Cleaning up the effluent more effectively

As all dyeing processes currently involve some of the dye being flushed into the effluent, attention should be given to the best way of cleaning the effluent. At the moment, substances like alum are used, which are not environmentally friendly. Natural polymers such as locust bean gum, guar gum and cassia gum have been shown to be highly effective at cleaning effluent whilst being much kinder to the environment, due to being derived from renewable plant sources. Its efficiency is not affected by the pH or chemical makeup of the water, avoiding the need for additional agents. Effective removal of dye from wastewater means the water can be reused, as the only thing that may remain is an ionic charge. Although this attempts to solve the problem created by dyes at the end of the process, rather than curing it at its root as a better solution might, this may improve the situation in the short term before more environmentally aware colours and machinery are widely available.

Part Five: Other chemicals used in the dyeing process

Even though what you are now reading is one of the most comprehensive reports on dyes on the web, it still doesn't tell the whole story. Detergents, stain removers, sequestering agents, printing gums, fixing agents and bleaches are all used to complement dyes to make sure the best colour possible is achieved. Here's a quick rundown on the information we found. For some brief notes on some other processes and their effects, see Appendix 6.

Scouring

In order for the dye and mordant to fix well to the fabric, before dyeing, the material needs to have all dirt, wax, oil and grease completely removed, in a process called 'scouring'. Wool and silk can be scoured using soap flakes. Cotton and linen require boiling in a washing soda and acetic acid solution.

Agents to alter water pH

It is generally thought that it is best to use neutral water to dye with. Rain water used to be collected for this purpose, but with today's problem of acid rain, rain water may not be suitable. Washing soda (sodium carbonate), household ammonia or chalk can be added to increase alkalinity, or acetic acid or clear vinegar can be added to make the water pH neutral.

Mordanting

Mordants are used to improve the bond between the dye and the fabric, as well as extending the range of hues that can be obtained from the dyestuff. To make the mordant take better, an 'assistant' can be added, which may mean less mordant is needed. The main problem is that typical mordants are based on heavy metals which are extremely toxic, causing environmental problems and presenting health threats to workers if not properly trained.

The main mordants are alum, tin, iron, chrome and copper: alum is non-toxic but is an irritant if inhaled, chrome is poisonous and can provoke an allergic reaction to anyone with sensitive skin, copper is poisonous and has little effect on vegetable fibres, tin is poisonous and an irritant and, despite being used in small quantities, iron is harmful if ingested.

Mordants can be obtained from plants, such as oxalic acid which is found in rhubarb leaves, alum which comes from clubmoss, and tannin from oak galls and sumac leaves. As a general rule, the weight of the mordant and the weight of the yarn to be dyed are the same.

It takes around 6-8 litres of water to mordant enough yarn for one t-shirt by hand. Vegetable fibres take longer to prepare than animal fibres, making the former's preparation process more expensive. Vegetable fibres also usually need to be treated with tannic acid before and after scouring.

Salt

Manufacturers add salt to the dye process to make it takes to the yarn more slowly, and hence more evenly. Just to remind you, irresponsibly discharged salt pollutes freshwater courses, kills fish and makes soil too alkaline to support crops. There are a number of freshwater lakes that have been turned permanently saline by dyeing operations.

There are ways of improving operations, however. Glauber's Salt is easier to recover than common salt, as well as improving dyeing results. It costs around 2p per kg of salt recovered by the PREM salt and water recovery plant in Tiripur, India, or 0.4p per t-shirt. It costs about 35p to recover a litre of water using the plant, increasing the price of a white t-shirt by less than a tenth of penny and a coloured one by 0.5p.



Mercerization

Mercerized cotton is cotton treated under tension with sodium hydroxide, also known as caustic soda. This has the effect of strengthening the fibres, improving their ability to take up dye and making the fibres lustrous, giving the cotton a silk-like quality. Unfortunately, caustic soda is corrosive, and must be disposed of with care, as it is a poison.

Printing

The environmental impact of textile printing is a whole other world of pain we have yet to delve into. However, it is worth mentioning that most t-shirts that claim they are environmentally friendly are printed in exactly the same way as conventional, environmentally harmful ones. Conventional inks contain white spirit to make them thick enough to use, as well as urea, ammonia solution and thickener agent. Even eco-friendly water-based dyes use a certain amount of white spirit.

Printing inks should never be disposed of down the drain as they heavily pollute water systems. More responsible printers clean all of their equipment using nothing but rags, which are then taken away to be cleaned and recycled by a specialist company, such as Rentokil. However, it is a minority of printers who actually do this, or even filter their waste, as few are monitored.

But progress is possible: T-Shirt and Sons, an environmentally aware fairtrade t-shirt printer used by Greenpeace and Glastonbury Festival, have just been certified as the UK's first printer to offer organic print. The only textile printer in the UK to be certified by the Soil Association, they are leading the pack by a long, long way. Some further investigation may be needed if we decide produce a printed shirt: although vastly preferable to what is on offer from conventional printers, some of their inks still contain heavy metals, but their service offers us great starting point.



Conclusion

Having found out all the information we could, the decision making process still seemed overly complex: no matter which method of conventional dyeing chosen, they still seem environmentally unsound. Natural dyes present some benefits, but have many drawbacks in the forms of availability, water usage and the environmentally unsound additional chemicals they require.

We have learnt an incredible amount though, and have some really exciting avenues to explore further. Whatever dyeing method we decide is right for the perfect t-shirt, you can rest assured it will have the same uncompromising attention to detail and integrity as all of our other investigations carried out so far for the project.

If you'd like us to keep you up-to-date with developments just send an email to perfect@betterthinking.co.uk. We hope you found this report useful and wish you the best of luck with your own endeavours. Remember, a little better thinking goes a long way!

Appendix 1: Pollution Capability of some of the Chemicals/Products used in the Textile Industry

| General Chemical Type | Difficulty of Treatment | Pollution Category |
|--|--|---------------------------|
| Alkalis Mineral acids Natural salts Oxidising agents | Relatively harmless inorganic pollutants | 1 |
| Starch sizes Vegetable oils, fats and waxes Biodegradable surfactants Organic acids Reducing agents | Readily biodegradeable Moderate to high BOD | 2 |
| Dyes & fluorescent brighteners Fibres & polymeric impurities Polyacrylate sizes Synthetic polymer finishes Silicones | Dyes and polymers difficult to biodegrade | 3 |
| Wool grease PVA sizes Starch ethers and esters Mineral oil Surfactants resistant to biodegradation Anionic and non-ionic softeners | Difficult to biodegrade Moderate BOD | 4 |
| Formaldehyde and N-methylol reactants Chlorinated solvents and carriers Cationic retarders and softeners Biocides Sequestering agents Heavy metal salts | Unsuitable for conventional biological treatment Negligible BOD | 5 |

Appendix 2: Type of Pollution Associated with Various Colouration Processes

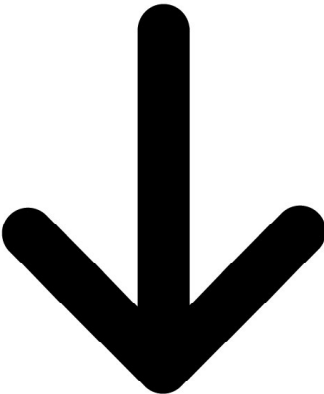
| Fibre | Dye Class | Pollution Category* | Type of Pollution |
|-----------|-------------------|---------------------|--|
| Cotton | Direct | 1 3 5 | Salt Unfixed Dye (5-30%) Copper Salts Cationic Fixing Agent |
| | Reactive | 1 3 | Salt, Alkali Unfixed Dye (10-40%) |
| | Vat | 1 2 | Alkali, Oxidising Agent Reducing Agents |
| | Sulphur | 1 2 | Alkali, Oxidising Agent Reducing Agents |
| Wool | Chrome | 2 5 | Organic acids Heavy metal salts |
| | 1:2 Metal Complex | 2 | Organic acid |
| | Acid | 2 3 | Organic acid Unfixed dye (5-20%) |
| Polyester | Disperse | 2 5 | Reducing agent Organic acid Carriers |

*1 being the lowest, 5 being the highest

Appendix 3: Effluent characteristics from the textile industry

| Process | Effluent Composition | Nature |
|-------------|---|---|
| Sizing | Starch Waxes Carboxymethyl cellulose (CMC) Polyvinyl alcohol (PVA) Wetting agents | High in BOD, COD |
| Desizing | Starch CMC PVA Fats Waxes Pectins | High in BOD, COD, SS, Dissolved Solids (DS) |
| Bleaching | Sodium hypochlorite Chlorine Sodium hydroxide Hydrogen peroxide Acids Surfactants Sodium silicate Sodium phosphate Short cotton fibre | High alkalinity, high SS |
| Mercerising | Sodium hydroxide Cotton wax | High pH, low BOD, high DS |
| Dyeing | Dyestuffs urea Reducing agents Oxidizing agents Acetic acid Detergents Wetting agents | Strongly coloured, high BOD, DS, low SS, heavy metals |
| Printing | Pastes Urea Starches Gums Oils Binders Acids Thickeners Cross-linkers Reducing agents Alkali | Highly coloured, high BOD, oily appearance, SS |
| Finishing | Inorganic salts, formaldehyde | Slightly alkaline, low BOD |

Appendix 4: Wellford's Spectrum of Greening

| Superficial change | Strategy | Ideology |
|---|---|-------------|
|  | 1 Add-on pollution control | Reactive |
| | 2 Technological fix | |
| | 3 Environmental auditing | Proactive |
| | 4 Integrated environmental management systems | |
| | 5 Product stewardship/LCA | Ethical |
| | 6 Partnerships | |
| | 7 Environmental cost accounting | Explorative |
| | 8 Design for sustainability | |
| | 9 Auditing for sustainability | Creative |
| Fundamental change | 10 Economic, social and cultural changes | |

Appendix 5: 38 Good Ideas for Cleaner Production During Wet Processing of Cotton

Process Modification

- a) Control and monitoring of chemical and water consumption in continuous processes.
- b) Controlling machine cleaning with a timer for water consumption.
- c) Efficient removal of print pastes from buckets, squeegees and screens before washing these items.
- d) Applying softeners to fabric by spraying at the stenters, rather than at the jets.
- e) Counter current washing/rinsing on continuous machines.
- f) Control water addition to screen and squeegee washing by timers.

Equipment changes

- a) Modify jiggers by making use of sprays and vacuum slots – enhances rinsing efficiency.
- b) Replace high liquor ratio winches with jets.
- c) Install heat exchanges for recovering heat from hot dyebath effluent.
- d) Fit shut-off nozzles onto manually held hosepipes.
- e) Install reversible pumps on printing lines to save unused print paste.

Chemical substitution and/or elimination

- a) Eliminate use of heavy metal based dyes.
- b) Replace mono-reactive dyes with bi-functional ones to increase exhaustion.
- c) Eliminate use of detergents in “washing off” after reactive dyeing.
- d) Eliminate neutralisation with acetic acid after alkaline reactive dyeing.
- e) Avoid bleaching with sodium hypochlorite.
- f) Use enzymes instead of persulphates in desizing.
- g) Avoid use of optical brighteners.
- h) Avoid Sulfapol as a detergent during wool scouring.
- i) Avoid white spirits in print pastes.
- j) Avoid using carriers in polyester dyeing.
- k) Avoid “after chroming” for dyed polyamide or wool.
- l) Avoid use of acetic acid to neutralise after reactive dyeing.
- m) Use biodegradable knitting oil
- n) Do not use resins that release free formaldehyde.

Recycling and/or reuse

- a) Recover indigo after denim dyeing by ultrafiltration.
- b) Size recovery.
- c) Recover and reuse salt after reactive dyeing by reverse osmosis.
- d) Recover heat from stenter exhaust.
- e) Recycle cooling water and condensate.
- f) Reuse dirty water for washing printing buckets, to dampen ash from boilers and cleaning and flushing water.

Housekeeping

- a) Collect all unused print pastes for bulking-up; do not allow dumping of print pastes to effluent drain.
- b) Carry out leak tracing and repairs on water pipes and valves.
- c) Check non-return valves for reverse leakage.

Appendix 6: Unclassified Chemicals Used In Textile Industries

| Product | Contains | Disadvantages |
|---------------------|---------------------------------------|--|
| Detergents | Nonylphenol ethoxylates | Does not biodegrade quickly, breaks down into even more toxic material, highly poisonous to fish |
| Stain remover | Solvents such as carbon tetrachloride | Toxic and carcinogenic, depletes ozone 10 times faster than CFCs |
| Rust stain remover | Oxalic acid | Toxic to humans and aquatic organisms, pollutes water |
| Sequestering agents | Polyphosphates | Banned in Europe but still used in India |
| Printing gums | Pentachlorophenol | Can cause dermatitis, liver & kidney damage. Carcinogenic. Banned in Europe & India |
| Fixing agent | Hydrocarbons | Can cause birth defects, possibly carcinogenic, poisonous to plants and animals |
| Bleach | Chlorine | Irritant, harmful to wildlife |
| Dye | Amino acids | Carcinogenic |



Bibliography

BLACKBURN, R. S. (2004) *Natural Polysaccharides and Their Interactions with Dye Molecules: Applications in Effluent Treatment*

BLACKBURN, R. S. and BURKINSHAW, S. M. (2001) *A Greener Approach to Cotton Dyeings with Excellent Wash Fastness*

BLACKBURN, R. S. and BURKINSHAW, S. M. (2001) *A Greener Approach to Cotton Dyeings. Part 2: Application of 1:2 Metal Complex Acid Dyes*

BLACKBURN, R. S. and BURKINSHAW, S. M. (2002) *Treatment of Cellulose with Cationic, Nucleophilic Polymers to Enable Reactive Dyeing at Neutral pH Without Electrolyte Addition*

BLACKBURN, R. S. and HARVEY, A. (2004) *Green Chemistry Methods in Sulfur Dyeing: Application of Various Reducing D-Sugars and Analysis of the Importance of Optimum Redox Potential*

CENTRE FOR THE PROMOTION OF IMPORTS FROM DEVELOPING COUNTRIES. *Environmentally Sound Production: Improvement Options for the Dyeing and Printing of Textiles* <http://www.cbi.nl/marketinfo/cbi/?action=showDetails&id=285>

COOK, F. L. (1994) *Salt Requirements Put Pressure On Wet Processing Plants*

COOPER, P. (1989) *Are Textiles Finishing The Environment?* www.p2pays.org/ref/39/38474.pdf

THE DANISH ENVIRONMENTAL PROTECTION AGENCY (1999) *Environmental Assessment of Textiles*
<http://www.mst.dk/udgiv/publications/1997/87-7810-838-1/pdf/87-7810-838-1.PDF>

FEREDAY, G. (2003) *Natural Dyes*. London: British Museum Press.

FUJIKI, N. and MACER, R. J. *Bioethics in Asia*. <http://www2.unescobkk.org/eubios/asiae/biae191.htm>

WYNNE, G., MAHARAJ, D., and BUCKLEY, C. *Cleaner Production in the Textile Industry – Lessons From the Danish Experience*. www.nu.ac.za/cleanerproduction/pdfs/Paper_Natcon_final.pdf

UNITED NATIONS DEVELOPMENT PROGRAM. *Sub-Program Justification*. <http://www.undp.org.in/Programme/Environment/natdye/dyejust.htm>

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