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Life Cycle Assessment for the Dyeing and Finishing Process of Organic Cotton Knitted Fabrics

K. Babu Murugesh
Department of Textile Technology
Bapuji Institute of Engineering and Technology
India
kmb6@rediffmail.com

M. Selvadass
Visvesvaraya Technological University
India

ABSTRACT

This paper summarizes the results of the life cycle assessment (LCA) for dyeing and finishing process involved in development of 1 ton, 2/40's, 100% organic cotton single jersey knitted fabrics. Results show that the environmental impact of the dyeing and finishing process of knitted fabrics is primarily due to the method of dyeing process adopted, the dye quantity used to obtain the required color and color strength, electricity and compressed air use, the burning of wood in the industrial boiler for production of steam, the operation of an effluent treatment plant to treat process effluent and transport of chemicals. The environmental impact observed for dyeing fabric in softflow dyeing machine and non-silicate CPB dyeing method remains same, however, the intensity is greatly reduced in non-silicate CPB dyeing method. The environmental impact of finishing process is mainly due to use of softener, burning of wood in boiler for production of steam, use of compressed air and electricity.

Keywords: Life cycle assessment, environmental impact, organic cotton, knitted fabrics, dyeing, finishing

1 Introduction

The knit fabric processing is one of the important industries related with knitted fabric manufacturing operations. Fabric processing is a general term that covers all operations related to scouring, bleaching, dyeing, finishing and printing. This industry sector has massive and undeniable economic value but also causes unprecedented environmental impact that raises sustainability issues (Jayanth et al., 2011; Tufekci, Sivri & Toroz, 2007; Jaya, 2011; Rita, 2012; Mahfuza et al., 2009). Every process and almost every operation within a processing plant has an environmental aspect that should be considered and for which the environmental performance can potentially be improved. The main environmental issues in fabric processing are water use and pollution, energy use and climate change and chemical use (Crem, 2011). Further, the amount of pollutants and waste generated by processing facilities has become an increasing costly problem for manufacturers and a significant stress on the environment (EPPP, 1994).

Recently, buyers are including sustainability issues in their purchasing policies that mainly focus on social issues but also on environmental aspects of the production process. The demand for sustainable clothing, significant improvements in enforcement of environmental laws by regulatory authorities and further compliance by manufacturers clearly demonstrate a growing recognition of the importance of moving towards a more sustainable model for the textile and clothing industry (Dystar, 2010).

The future development of the industry will depend on several factors, including the adoption of Best Management Practices (BMPs) and Environmental Management Systems (EMS) (BMP, 1996; Datta, 2011). The BMPs helps to maximize the efficiency of raw material usage, while minimizing the consumption of energy, water and auxiliary chemicals and the discharge of environmentally damaging materials. The EMS provides the company with an integrated approach to managing and monitoring its environmental effects and complying with environmental regulations. An effective and efficient EMS will provide the company with the opportunity to reduce costs, to reduce its environmental impact, increase efficiency and enhance its reputation.

Life cycle assessment (LCA) (Rebitzer et al., 2004) can be used as part of EMS in order to evaluate environmental performance and also as a tool for identification of significant environmental aspects of products or service of an organization. An environmental aspect is defined as an element of an organization's activities or products or services that can interact with the environment. An aspect regarded significant is the one that has or can have a significant environmental impact (Anna, 2011). An environmental impact is defined as any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's environmental aspects (ISO 14001, 2004). To study the environmental impact of products, an inventory of all material inputs and energy for the product should be prepared along with the emissions to the environment. Subsequently, this life cycle inventory can be used to calculate the size of various environmental impact indicators.

In this paper, the environmental impact analysis for dyeing and finishing process adopting gate-to-gate LCA using Impact 2000+ methodology is presented. The objective of the study is to determine and examine the differences in the environmental impacts of exhaustion & cold pad batch dyeing and finishing process for the production of 1 ton, 2/40's 100% organic cotton single jersey knitted fabrics dyed to three different colors using textile reactive dyes.

2 Research methodology

2.1 Environmental aspects of textile dyeing and finishing processes

Dyeing is the application of desired color (textile dyes) to the fabric whereas, finishing involves a number of processes such as softener padding to impact softness, voluminous handle & hydrophilic character to the fabric, drying to remove moisture and compacting to impact dimensional stability.

- The fabric dyeing process is depended on many factors. These include the fabric state (tubular or open width fabric), the color and color strength to be developed, the dyeing process (batch or semi continuous) adopted, the dyeing technology (exhaust or cold pad batch) adopted, the quantity of material to be dyed, and quality requirements of the dyed fabric.

- The finishing process of dyed fabrics depends on the end use of the fabric and the customer requirements. The most common finishing process involves the use of silicon softener to improve the fabric softness and handle. This is followed by the drying and compacting process.

Exhaust dyeing process using softflow dyeing machine is the most popular and common method used for dyeing of the knitted fabrics. Here, the fabric is rotated in a large volume of dye bath containing reactive dyes, dyebath chemicals and auxiliaries. During this process, the dye gets slowly transferred from a dyebath to the substrate (cotton) that is to be dyed. This method uses a high material to liquor ratio that result in high volume of effluent.

Cold Pad batch (CPB) dyeing is used for dyeing cotton knitted fabrics. The basic technique is to pad the pretreated ready for dyeing (RFD) fabric with premixed dye liquor. The padding process forces the dyestuff inside the fabric for greater penetration while removing excess dye solution. The fabric is then batched on rolls for 4 to 12 hours. The batching time depends upon the type of dye used, the color and color strength developed. Typically, the batches are covered with a plastic film to prevent carbon dioxide absorption and rotated continuously. While in batching, the dyestuff penetrates and reacts with the fabric, resulting in even, consistent color. After the reaction is complete, the fabric is washed using counter current continuous washing machine.

The environmental aspects of the dyeing and finishing are closely connected to the high volume of process effluent released. This is followed by emissions to air and energy consumption. The effluent is characterized by high total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD) and color that has adverse impact on surface water, ground water and on land. The volume of such effluents often exceeds acceptable standards and the concentration of pollutants is generally high. The impact can be significant when several processing plants are located at one place and discharge effluents into a common source.

In general, the recent environmental policies led the processing industry of knitted fabrics to adopt some environmentally responsible activities such as:

- The use of low impact reactive dyes.
- The use of low liquor ratio softflow dyeing machine.
- The use of non-silicate cold pad batch dyeing technology.
- Adopting good management practices to achieve right first time dyeing.
- Setting up zero effluent plant for treatment of process effluent.

2.2 Process sequences adopted for development of knitted garments

Global Organic Textile standards (GOTS) approved 2/40's, 100% organic cotton super combed hosiery yarn was procured and knitted to gray fabric using a single jersey knitting machine. The gray fabric was sent to a processing mill where it was subjected to pretreatment processes such as demineralization and combined scouring and bleaching process to develop scoured RFD fabric. The RFD fabric was dyed and finished to develop ready to stitch (RTS) fabrics.

The dyeing process involves the use of textile reactive dyes, dyebath chemicals and auxiliaries to obtain the required color and color strength using an exhaust or non-silicate CPB dyeing method. The finishing process involves softener padding, drying and compacting. The finished fabrics are later transported to garment unit for cutting & stitching into garments.

Three samples S1, S2 and S3 was developed after pretreatment process. The dyeing of the S1 and S2 samples was done using a softflow dyeing machine whereas dyeing of the S3 sample was done using a non-silicate CPB dyeing method. The dye recipe used for the dyeing process and the color, color specification and color strength of the dyed fabric is presented in Table 1. The process sequences adopted is presented in Table 2.

Table 1. Dye recipe for dyeing process and color specification / strength of dyed fabric

Sample	Color	Dye	Qty (gpl)	Color specification					Color strength (K/S)
				L	a	b	c	h	
S1	Stone	Remazol Yellow RR Remazol U Caramine RGB Remazol Blue RR	0.1180 0.0546 0.0876	62.30	5.10	5.02	7.16	44.50	0.579
S2	T Blue	Navacron Yellow HRN Navacron Blue HRN Navacron T Blue	0.2100 2.3000 0.4500	37.69	-10.78	-15.46	18.85	235.09	6.302
S3	Red	Remazol U Yellow RGB Remazol U Caramine RGB Remazol Azure CA	6.0000 15.000 3.0000	30.91	29.91	13.14	32.67	23.70	5.886

Table 2. Process sequences adopted in dyeing and finishing

Fabric	S1	S2	S3
Dyeing process	Exhaust dyeing using softflow dyeing machine		Non-silicate CPB dyeing
Finishing	Softener padding		
	Relax drying		Stenter drying
	Compacting & fabric packing		
	Fabric transport		

The methodology of dyeing the three samples S1, S2 & S3 is as follows:

S1 (Stone) – Dyeing (M:L – 1:7) at 60^0 for 45 mins – cold water rinse – acetic acid rinse at 50^0C for 10 mins– soap wash at 80^0C for 20 mins – hot water rinse at 60^0C for 20 mins – cold water rinse for 10 mins– drain and remove fabric from machine for finishing.

S2 (T Blue) – Dyeing (M:L – 1:7) at 80^0 for 45 mins – cold water rinse – acetic acid rinse at 50^0C for 10 mins – soap wash1 at 80^0C for 10 mins – soap wash 2 at 80^0C for 10 mins – hot water rinse at 80^0C for 10 mins – cold water rinse for 10 mins – drain and remove fabric from machine for finishing.

S3 (Red) – Pad dye liquor (M:L – 1:0.8) onto the fabric – batching for 8 hrs. at room temperature – cold water rinse (2 times) – acetic acid rinse at 50^0C – soap wash 1 at 80^0C– soap wash 2 at 80^0C – hot water rinse at 80^0C – hot water rinse at 80^0C – cold water rinse –finishing.

2.3 Life cycle assessment of dyeing and finishing process

LCA was done to determine the environmental impact of the dyeing and finishing process. The goal of the assessment was to determine and compare the environmental impact associated with the dyeing and finishing process in the development of 100%, 2/40's organic cotton single jersey knitted RTS fabrics. The important factors influencing the environmental impact during dyeing and finishing process were also compared.

The study is intended to be a gate-to-gate LCA that includes fabric dyeing and dyed fabric finishing such as softener padding, drying and compacting process. The work presented here has been compiled in combination with the Microsoft Excel and SimaPro software 7.3.2 (Developer) developed by PRe Consultants (PRe: Simapro). The scope of the study is from 'gate-to-gate' that includes all the activities and input/output materials involved in the dyeing and finishing process of organic cotton knitted fabrics to develop three different colors.

The functional unit is defined as the dyeing and finishing of 1 ton, 2/40's, 100% organic cotton single jersey RFD fabrics.

The system boundaries of gate-to-gate LCA includes:

- The production of reactive dyes, dye bath chemicals and auxiliaries.
- Resources used in the dyeing process such as water, dyes, dyebath chemicals and auxiliaries.
- Finishing of the dyed fabric by padding with softener, drying and compacting.
- Packing of the finished fabrics and transporting the fabric to garment production unit.
- The use of an industrial boiler that is fueled by wood for the production of steam.
- The operation of the effluent treatment plant (ETP) used to treat the process effluent released from dyeing.
- The transportation of the chemicals used in dyeing process, washing process and the use of wood in the boiler for production of steam.

The life cycle inventory represents the main part of the whole study and is mainly concerned with the data collection. The primary data for the three selected colors was collected during dyeing and finishing of knitted fabrics at the sampling stage in a processing mill using exhaust dyeing method with softflow dyeing machine and non-silicate CPB dyeing method. The data collected was then converted for 1 ton fabric with the help of mill personal. The inventory data is summarized in Table 3. The data for production of the reactive dyes, chemicals and auxiliaries used in the dyeing process and the energy consumption was obtained and consolidated from various literatures. The data for the effluent treatment plant used to treat the process effluent was obtained from the industry contacts and from the literature. The inventory database present in SimaPro software 7.3.2 was also extensively used. The inventory data analysis was done using life cycle inventory assessment methodology IMPACT 2002+ (Mark, Michael, An, Marisa, 2008).

Table 3. Inventory data of dyeing & finishing process for 1 ton knitted fabric

Products	Unit	S1 (Stone)	S2 (T Blue)	S3 (Red)
Fabric processed	kg	1000	1000	1000
Dyeing				
Reactive dye 1	kg	0.8260	1.4700	4.8000
Reactive dye 2	kg	0.3822	16.1000	12.0000
Reactive dye 3	kg	0.6132	3.1500	2.4000
Wetting agent	kg	3.5000	3.5000	0.4000
Stabilizer	kg	14.0000	14.0000	1.6000
Lubricating agent	kg	7.0000	7.0000	-
Sodium sulphate	kg	210.0000	560.0000	-
Sodium carbonate	kg	35.0000	140.0000	16.0000
Sodium hydroxide	kg	-	-	2.8000
Acetic acid	kg	3.5000	3.5000	1.3125
Soap, at plant	kg	14.0000	28.0000	10.5000
Water, softened,	kg	41728.6786	55254.7800	21748.1875
Water (boiler)	kg	4108.1600	5135.2000	1320.0000
Electricity	kWh	90.4167	175.6667	177.5179
Compressed air	m3	50.3125	97.7500	18.4000
Transport, lorry 3.5-7.5t	tkm	1723.8679	2455.4995	783.6126
Heat, hardwood logs	MJ	17731.55803	22164.44754	5697.3576
Effluent treatment	kg	41917.5	55931.5	21700.0
Squeezer & softener pad				
Silicon softener	kg	24.0000	24.0000	24.0000
Acetic acid	kg	0.8000	0.8000	0.8000
Water, softened	kg	800.0000	800.0000	800.0000
Electricity	kWh	15.5523	15.5523	15.5523
Compressed air	m3	5.7500	5.7500	5.7500
Relax / stenter drying				
Electricity	kWh	73.7143	73.7143	134.0353
Water (boiler)	kg	685.714286	685.714286	2880.0000
Heat, hardwood logs	MJ	2959.6663	2959.6663	728.6400
Compacting				
Polypropylene sheet	kg	2.5000	2.5000	2.5000
Electricity	kWh	143.438222	143.438222	143.438222
Compressed air	m3	5.7500	5.7500	5.7500
Water (boiler)	kg	778.525437	778.525437	778.525437
Heat, hardwood logs	MJ	3360.255921	3360.255921	3360.255921
Dyed fabric transport				
Transport, lorry 3.5-7.5t	tkm	311.00	311.00	311.00

2.4 limitations

The limitations of the study are as follows:

- All samples are dyed to obtain trichromatic colors with different dyes having different colors. Since no inventory data is available for all the dyes, we have taken the inventory of one dye for all colors.
- In effluent treatment plant, the use of alum is not taken into account. About 452 kg of alum is required for treatment of 150KL of textile effluent.
- The land and building used for processing plant is not taken into account.
- The life cycle part of the processing machines is not taken into consideration.

3 Results and Discussions

The process sequence and the environmental impact for the dyeing & finishing process of samples S1, S2 and S3 knitted fabrics is presented in Tables 4, 5 and 6 respectively.

Table 4. Environmental impact of dyeing and finishing (S1) process for 1 ton fabric

Impact category	Unit	Dyeing	Squeezer & softener pad	Relax drying	Compacting	Transport	Total
Carcinogens	kg C2H3Cl eq	106.8180	1.0680	1.2401	2.6397	1.1801	112.9459
Non-carcinogens	kg C2H3Cl eq	307.8141	0.7017	8.4983	10.8263	1.7148	329.5553
Respiratory inorganics	kg PM2.5 eq	10.0669	0.0501	0.2647	0.3360	0.1778	10.8955
Ionizing radiation	Bq C-14 eq	93118.7568	1137.2543	1459.1192	1991.4625	2318.3143	100024.9071
Ozone layer depletion	kg CFC-11 eq	4.3885E-04	5.8793E-05	1.3800E-06	1.9396E-06	2.2853E-05	5.2381E-04
Respiratory organics	kg C2H4 eq	2.6131	0.0278	0.0426	0.0605	0.1072	2.8512
Aquatic ecotoxicity	kg TEG water	604686.2570	3490.5655	51139.2936	59102.1992	10856.3181	729274.6334
Terrestrial ecotoxicity	kg TEG soil	186521.9976	598.7201	19134.7854	21869.3850	6756.8131	234881.7013
Terrestrial acid/nutri	kg SO2 eq	184.1249	1.0883	4.0746	5.2533	5.3189	199.8600
Land occupation	m2org.arable	286.7423	0.5268	32.9548	37.6246	2.5688	360.4172
Aquatic acidification	kg SO2 eq	58.8761	0.3160	0.7260	1.0589	0.8259	61.8030
Aquatic eutrophication	kg PO4 P-lim	1.1567	0.0117	0.0291	0.0371	0.0168	1.2514
Global warming	kg CO2 eq	12243.1033	75.5960	71.6625	135.5898	146.0293	12671.9810
Non-renewable energy	MJ primary	142163.4991	1540.9284	828.7308	1629.9465	2517.6096	148680.7144
Mineral extraction	MJ surplus	36.6287	1.6218	0.8622	1.0568	1.3623	41.5317

Table 5. Environmental impact of dyeing and finishing (S2) process for 1 ton fabric

Impact category	Unit	Dyed fabric	Squeezer & softener pad	Relax drying	Compacting	Transport	Total
Carcinogens	kg C2H3Cl eq	149.5640	1.0680	1.2401	2.6397	1.1801	155.6919
Non-carcinogens	kg C2H3Cl eq	414.3561	0.7017	8.4983	10.8263	1.7148	436.0973
Respiratory inorganics	kg PM2.5 eq	13.8763	0.0501	0.2647	0.3360	0.1778	14.7048
Ionizing radiation	Bq C-14 eq	137217.9685	1137.2543	1459.1192	1991.4625	2318.3153	144124.1197
Ozone layer depletion	kg CFC-11 eq	5.7883E-04	5.8793E-05	1.3800E-06	1.9396E-06	2.2853E-05	6.6379E-04
Respiratory organics	kg C2H4 eq	3.6396	0.0278	0.0426	0.0605	0.1073	3.8777
Aquatic ecotoxicity	kg TEG water	809819.4248	3490.5655	51139.2936	59102.1992	10856.3347	934407.8178
Terrestrial ecotoxicity	kg TEG soil	249107.8491	598.7201	19134.7854	21869.3850	6756.8576	297467.5973
Terrestrial acid/nutri	kg SO2 eq	255.9612	1.0883	4.0746	5.2533	5.3190	271.6963
Land occupation	m2org.arable	382.7316	0.5268	32.9548	37.6246	2.5688	456.4065
Aquatic acidification	kg SO2 eq	82.2024	0.3160	0.7260	1.0589	0.8259	85.1293
Aquatic eutrophication	kg PO4 P-lim	1.6520	0.0117	0.0291	0.0371	0.0168	1.7467
Global warming	kg CO2 eq	16878.4208	75.5960	71.6625	135.5898	146.0303	17307.2995
Non-renewable energy	MJ primary	199766.3168	1540.9284	828.7308	1629.9465	2517.5923	206283.5148
Mineral extraction	MJ surplus	59.1437	1.6218	0.8622	1.0568	1.3622	64.0467

Table 6. Environmental impact of dyeing and finishing (S3) process for 1 ton fabric

Impact category	Unit	Dyeing	Squeezer & softener pad	Stenter drying	Compacting	Transport	Total
Carcinogens	kg C2H3Cl eq	56.8928	1.0680	0.9925	2.6397	1.1801	62.7731
Non-carcinogens	kg C2H3Cl eq	156.3368	0.7017	4.3463	10.8263	1.7148	173.9260
Respiratory inorganics	kg PM2.5 eq	5.4004	0.0501	0.1292	0.3360	0.1778	6.0934
Ionizing radiation	Bq C-14 eq	51809.4997	1137.2543	944.5106	1991.4625	2318.3153	58201.0423
Ozone layer depletion	kg CFC-11 eq	2.1872E-04	5.8793E-05	1.0274E-06	1.9396E-06	2.2853E-05	3.0333E-04
Respiratory organics	kg C2H4 eq	1.4321	0.0278	0.0231	0.0605	0.1073	1.6507
Aquatic ecotoxicity	kg TEG water	267668.2069	3490.5655	14486.2083	59102.1992	10856.3347	355603.5146
Terrestrial ecotoxicity	kg TEG soil	75103.0081	598.7201	4971.5107	21869.3850	6756.8576	109299.4816
Terrestrial acid/nutri	kg SO2 eq	98.1128	1.0883	2.1042	5.2533	5.3190	111.8776
Land occupation	m2org.arable	113.1902	0.5268	8.5181	37.6246	2.5688	162.4285
Aquatic acidification	kg SO2 eq	34.6721	0.3160	0.6005	1.0589	0.8259	37.4734
Aquatic eutrophication	kg PO4 P-lim	0.7519	0.0117	0.0141	0.0371	0.0168	0.8317
Global warming	kg CO2 eq	6586.8637	75.5960	113.3417	135.5898	146.0303	7057.4216
Non-renewable energy	MJ primary	77532.4270	1540.9284	1157.6440	1629.9465	2517.5923	84378.5381
Mineral extraction	MJ surplus	24.1573	1.6218	0.3666	1.0568	1.3622	28.5648

The results show that environmental impact of dyeing knitted fabrics using exhaust dyeing method is high compared to that of the non-silicate CPB dyeing method. Further, it is observed that environmental impact for the development of light color is less compared to that of dark color. The environmental impact of the finishing process involving softener padding and compacting process is similar for all the dyed fabrics whereas that of drying process varies.

The environmental impact related to the dyeing process is primarily due to use of water and energy consumption. These are a function of the color strength developed, dyeing technique adopted, operating practices and the type of machinery used. The batch dyeing process adopting softflow dyeing machine in S1 and S2 dyeing process operates at higher material to liquor ratio. This result in high consumption of chemicals and auxiliaries that are dosed based on the volume of the water used. It also leads to higher water and energy consumption in the form of steam.

The environmental impact of dyeing process S2 is high compared to S1 process. This is because of the higher amount of dyes used to get dark color strength. The quantity of reactive dye used to obtain required color strength / ton fabric in S1 dyeing process is

1.8214 kg compared to 20.720 kg used in S2 dyeing process. Further, additional soaping and rinsing is required to remove unfixed dye from the fabric. The S2 dyeing process uses 55254.80 lt of process water and 5135.20 kg of steam. Similarly, S1 dyeing process uses 41728.6786 lt of process water and 1408.16 kg of steam. Hence, S2 dyeing process requires additional water (32.41%) and steam (25.00%) to dye 1 ton of fabric compared to S1 dyeing process. The high volume of dyeing effluent requires additional resources for operation of effluent treatment plant that increases the environmental impact.

The environmental impact for the dyeing of sample S3 is drastically reduced compared to that of S1 and S2. The lower environmental impact observed can be attributed to the non-silicate CPB dyeing method adopted that enables dyeing to take place with lower water and energy consumption compared to conventional exhaust dyeing process. The dyeing process S2 & S3 use nearly same quantity of dye to develop different color but when the environmental impact is compared, it is observed that S3 dyeing process results in lower environmental impact compared to S2 dyeing process. This is because S3 dyeing process uses only 21748.19 lt of water and 1320 kg of steam / ton fabric. Hence, when compared with that of the S2 dyeing process, it can be observed that the water (60.64%) and steam (74.30%) consumption is reduced greatly. This also reduces the volume of the effluent released to the ETP and hence, reduces the load on operation of the ETP that reduces the environmental impact drastically.

Dyeing using the CPB method is an established and reliable process for obtaining very good dyeing results with minimum use of resources (Stephan & Jurgen, 2006; Khatri, Memon, Khatri & Tanwari, 2011). It can help to achieve significant water and carbon savings in fabric production compared with the conventional processes using exhaust dyeing (Ray, 2011). The salt addition is totally eliminated. The non-silicate CPB dyeing method is developed without the use of silicates which is normally used to increase the pad liquor stability and to prevent carbonization. This technology makes the CPB dyeing process cleaner, faster and improves the fabric quality. The benefits of silicate free CPB process includes improved wash off properties resulting in water and energy savings, increased diffusion and penetration of dye due to longer fixation times, no risk of alkaline hydrolysis so that the fabric can be neutralized before soaping and lower electrolyte content in the effluent since no salt is used. The lower electrolyte content of liquor reduces the substantively of the hydrolyzed dye stuffs, which is therefore easier to wash off. This results in lower energy and water consumption in the washing process.

In general, the energy and water consumption in the dyeing process is not only due to the result of material to liquor ratio used but also due to discontinuous nature of the dyeing process, especially with regard to operations such as heating, washing and rinsing. Furthermore, shade matching can also be responsible for higher water and energy consumption. Shades which are difficult to match may require repeated shade addition with cooling and reheating between each addition. All these increases the amount of effluent generated which is released into effluent treatment plant where it is treated. Since volume of effluent is high, the load on effluent treatment plant is also high. This increases the energy and chemical consumption of effluent treatment plant which in turn increases the environmental impact.

The environmental impact in percentage for the dyeing process of sample S1 & S2 is presented in Tables 7 & 8. The dyeing process adopted for the development of samples S1 and S2 is similar except for the color developed and hence the environmental impact of the two samples differs only in the dyeing stage.

From Tables 7 & 8, the major source of environmental impact in the dyeing process is due to use of the reactive dyes, use of the electricity, burning of the wood in the boiler for production of steam, the use of effluent treatment plant for treatment of dyebath effluent and transportation of various reactive dyes, dyebath chemicals and auxiliaries used in the dyeing process. Further, it can be observed that the environmental impact due to use of the reactive dyes and other dye bath chemicals/auxiliaries is very less compared to the overall environmental impact of the dyeing process.

Table 7. Environmental impact in percentage for S1 dyeing process

	Carcinogens	Non-carcinogens	Respiratory inorganics	Ionizing radiation	Ozone layer depletion	Respiratory organics	Aquatic ecotoxicity	Terrestrial ecotoxicity	Terrestrial acid/nutri	Land occupation	Aquatic acidification	Aquatic eutrophication	Global warming	Non-renewable energy	Mineral extraction
Reactive Dye VSRL	0.31	0.13	0.49	0.83	1.98	0.67	0.30	0.20	0.45	0.05	0.84	1.71	0.22	0.39	2.14
Wetting agent	0.10	0.01	0.14	0.17	0.13	0.46	0.01	-0.06	0.11	2.44	0.10	0.21	0.06	0.10	0.47
Stabilizer	0.92	0.07	0.19	0.22	46.36	1.04	0.15	0.07	0.24	0.01	0.22	0.61	0.24	0.64	0.59
Lubricating agent	0.56	0.02	0.19	0.30	0.15	1.23	0.03	-0.07	0.18	0.02	0.12	0.31	0.13	0.27	0.81
Sodium sulphate	0.63	0.26	0.78	4.88	1.95	0.58	0.76	0.66	0.74	0.14	1.06	2.29	0.77	1.30	5.95
Sodium carbonate	0.32	0.13	0.23	1.13	0.89	0.28	0.35	0.34	0.30	0.08	0.24	0.87	0.28	0.47	3.56
Acetic acid	0.04	0.01	0.03	0.23	0.22	0.18	0.06	0.05	0.03	0.01	0.04	0.15	0.04	0.13	0.29
Soap	0.13	-0.01	0.49	0.49	0.29	1.31	-0.08	-0.44	0.34	8.07	0.18	0.85	0.18	0.16	1.30
Water (process)	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.50
Water (boiler)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Electricity	0.50	0.57	0.50	0.49	0.12	0.38	0.24	0.11	0.47	0.11	0.56	0.47	0.61	0.52	0.30
Compressed air	0.02	0.01	0.03	0.32	0.04	0.01	0.05	0.05	0.03	0.00	0.03	0.13	0.03	0.05	0.10
Heat, hardwood logs	4.51	13.75	13.33	7.00	1.29	7.92	49.48	60.93	10.98	68.32	4.66	12.75	0.53	0.94	12.57
Transport	6.12	3.09	9.79	13.80	28.87	22.75	9.95	20.08	16.01	4.97	7.78	8.07	6.61	9.82	20.61
Effluent treatment	85.8	81.96	73.81	70.12	17.70	63.17	38.66	18.06	70.11	15.77	84.18	71.59	90.28	85.21	50.76

Table 8. Environmental impact in percentage for S2 dyeing process

	Carcinogens	Non-carcinogens	Respiratory inorganics	Ionizing radiation	Ozone layer depletion	Respiratory organics	Aquatic ecotoxicity	Terrestrial ecotoxicity	Terrestrial acid/nutri	Land occupation	Aquatic acidification	Aquatic eutrophication	Global warming	Non-renewable energy	Mineral extraction
Procion reactive dye	3.77	0.92	2.32	2.95	6.84	2.67	1.62	1.59	2.55	0.31	3.31	4.30	1.48	2.67	7.62
Wetting agent	0.07	0.01	0.10	0.12	0.10	0.33	0.01	-0.04	0.08	1.83	0.07	0.14	0.05	0.07	0.29
Stabilizer	0.65	0.05	0.14	0.15	35.15	0.75	0.11	0.05	0.17	0.01	0.16	0.42	0.18	0.46	0.37
Lubricating agent	0.40	0.01	0.14	0.20	0.11	0.88	0.02	-0.05	0.13	0.02	0.09	0.22	0.09	0.19	0.50
Sodium sulphate	1.19	0.51	1.51	8.83	3.94	1.11	1.52	1.31	1.42	0.29	2.03	4.28	1.49	2.46	9.82
Sodium carbonate	0.92	0.38	0.66	3.07	2.70	0.81	1.05	1.02	0.87	0.23	0.69	2.44	0.82	1.33	8.81
Acetic acid	0.03	0.01	0.02	0.16	0.17	0.13	0.05	0.04	0.03	0.01	0.03	0.10	0.03	0.09	0.18
Soap	0.19	-0.02	0.71	0.67	0.43	1.88	-0.12	-0.66	0.49	12.10	0.26	1.18	0.26	0.22	1.61
Water (process)	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.41
Water (boiler)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Electricity	0.69	0.82	0.70	0.64	0.18	0.53	0.35	0.16	0.65	0.16	0.78	0.64	0.86	0.72	0.37
Compressed air	0.02	0.02	0.04	0.42	0.06	0.02	0.07	0.07	0.03	0.00	0.04	0.17	0.04	0.07	0.12
Transport	6.23	3.27	10.12	13.34	31.17	23.27	10.58	21.42	16.41	5.30	7.93	8.05	6.83	9.95	18.19
Heat, hardwood logs	4.02	12.77	12.09	5.93	1.22	7.11	46.18	57.03	9.87	63.98	4.17	11.16	0.48	0.83	9.73
Effluent treatment	81.78	81.24	71.45	63.50	17.91	60.51	38.52	18.05	67.29	15.77	80.45	66.89	87.38	80.91	41.95

The environmental impact in percentage for the S3 dyeing process is presented in Table 9. It shows the environmental impact is similar to S1 & S2 dyeing process but the percentage varies.

Table 9. Environmental impact in percentage for S3 dyeing process

M9A Dyed fabric	Carcinogens	Non-carcinogens	Respiratory inorganics	Ionizing radiation	Ozone layer depletion	Respiratory organics	Aquatic ecotoxicity	Terrestrial ecotoxicity	Terrestrial acid/nutri	Land occupation	Aquatic acidification	Aquatic eutrophication	Global warming	Non-renewable energy	Mineral extraction
Reactive Dye VSRL	6.05	2.65	9.63	15.65	41.85	12.97	7.14	5.27	8.97	1.28	15.02	27.72	4.34	7.53	34.15
Wetting agent	0.02	0.00	0.03	0.04	0.03	0.10	0.00	-0.02	0.02	0.71	0.02	0.04	0.01	0.02	0.08
Stabilizer	0.20	0.01	0.04	0.04	10.63	0.22	0.04	0.02	0.05	0.00	0.04	0.11	0.05	0.13	0.10
Sodium carbonate	0.28	0.12	0.19	0.93	0.82	0.23	0.36	0.39	0.26	0.09	0.19	0.61	0.24	0.39	2.46
Sodium hydroxide	0.00	0.00	0.05	0.00	0.00	0.01	0.03	0.00	0.06	0.00	0.06	0.00	0.05	0.07	0.00
Acetic acid	0.03	0.01	0.02	0.16	0.17	0.13	0.05	0.05	0.02	0.01	0.02	0.08	0.03	0.09	0.17
Soap	0.19	-0.02	0.68	0.67	0.43	1.79	-0.13	-0.82	0.48	15.34	0.23	0.97	0.25	0.22	1.48
Water (process)	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.39
Water (boiler)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Electricity	1.84	2.21	1.81	1.73	0.48	1.35	1.08	0.53	1.72	0.55	1.86	1.42	2.22	1.88	0.90
Compressed air	0.01	0.01	0.02	0.21	0.03	0.01	0.04	0.05	0.02	0.00	0.02	0.07	0.02	0.03	0.06
Transport	5.23	2.76	8.29	11.27	26.33	18.87	10.22	22.67	13.66	5.72	6.00	5.64	5.59	8.18	14.21
hardwood logs	2.72	8.70	7.99	4.04	0.83	4.64	35.91	48.62	6.62	55.61	2.54	6.30	0.32	0.55	6.12
Effluent treatment	83.41	83.54	71.23	65.25	18.38	59.67	45.22	23.22	68.11	20.68	74.00	57.02	86.87	80.89	39.84

The use of effluent treatment process contributes greatly to the overall environmental impact. The effluent treatment plant uses a number of chemicals and electrical energy for treatment of dyeing process effluent. The chemicals include lime, ferrous sulphate, ferric chloride, acrylamide, hydrochloric acid and antiscalant agents. It also generates sludge that goes the land fill for disposal. Therefore, the volume of effluent released into the ETP plays an important role in the overall environmental impact since high volume of effluent released into the ETP will require additional quantity of resources that will increase the environmental impact.

The environmental aspects of the finishing process are due to the softener padding, drying and compacting. The softener padding and compacting process remains same for all the fabrics whereas the drying process varies depending on the fabric state and type of machine used. Relax drying machine is used for tubular knitted fabrics whereas stenter drying machine is used for open width knitted fabrics. The environmental impact in percentage for S1/S2/S3 finishing process involving softener padding and compacting process is presented in Table 10. It shows that the use of silicon softener results in highest environmental impact in softener padding & squeezer process whereas the environmental impact of the compacting process is mainly due to electricity use.

Table 10. Environmental impact in percentage for S1/S2/S3 finishing process

Impact category	Softener padding & squeezer					Compacting
	Silicone softener	Acetic acid	Water softened	Electricity	Compressed air	Electricity (IND)
Carcinogens	90.22	0.93	0.05	8.61	0.18	100.00
Non-carcinogens	54.75	1.49	0.09	43.07	0.61	100.00
Respiratory inorganics	80.73	1.50	0.03	17.14	0.61	100.00
Ionizing radiation	85.81	4.31	0.04	6.89	2.96	100.00
Ozone layer depletion	99.43	0.38	0.00	0.16	0.03	100.00
Respiratory organics	89.78	3.94	0.02	6.11	0.15	100.00
Aquatic ecotoxicity	89.13	2.56	0.06	7.26	0.98	100.00
Terrestrial ecotoxicity	88.69	3.61	0.07	5.81	1.81	100.00
Terrestrial acid/nutri	84.57	1.35	0.02	13.57	0.48	100.00
Land occupation	88.42	1.05	0.06	10.29	0.19	100.00
Aquatic acidification	79.95	1.53	0.02	17.90	0.60	100.00
Aquatic eutrophication	87.19	3.31	0.02	8.02	1.45	100.00
Global warming	80.97	1.50	0.03	16.98	0.53	100.00
Non-renewable energy	88.38	2.77	0.01	8.30	0.54	100.00
Mineral extraction	96.83	1.51	0.21	1.18	0.27	100.00

The Environmental impacts in percentage for relax drying (S1 / S2) and stenter drying (S3) process is presented in Table 11. In shows that the use of wood in boiler for production of steam for heating in relax drying machine and electricity consumption contributes greatly to overall environmental impact. In case of stenter machine, electrical energy consumption is the major source of environmental impact.

Table 11. Environmental impacts in percentage for relax drying (S1 / S2) and stenter drying (S3) process

Impact category	Unit	Relax drying			Stenter dyeing
		Electricity	Water (for boiler)	hardwood logs	Electricity
Carcinogens	kg C2H3Cl eq	35.15	0.04	64.81	100.00
Non-carcinogens	kg C2H3Cl eq	16.86	0.01	83.14	100.00
Respiratory inorganics	kg PM2.5 eq	15.37	0.00	84.63	100.00
Ionizing radiation	Bq C-14 eq	25.45	0.03	74.52	100.00
Ozone layer depletion	kg CFC-11 eq	31.41	0.12	68.48	100.00
Respiratory organics	kg C2H4 eq	18.87	0.01	81.11	100.00
Aquatic ecotoxicity	kg TEG water	2.35	0.00	97.65	100.00
Terrestrial ecotoxicity	kg TEG soil	0.86	0.00	99.14	100.00
Terrestrial acid/nutri	kg SO2 eq	17.18	0.01	82.82	100.00
Land occupation	m2org.arable	0.78	0.00	99.22	100.00
Aquatic acidification	kg SO2 eq	36.93	0.01	63.06	100.00
Aquatic eutrophication	kg PO4 P-lim	15.28	0.01	84.71	100.00
Global warming	kg CO2 eq	84.89	0.02	15.09	100.00
Non-renewable energy	MJ primary	73.14	0.02	26.84	100.00
Mineral extraction	MJ surplus	10.52	0.35	89.14	100.00

4 Conclusions

The results show that the environmental impact of the dyeing and finishing process of knitted fabrics is primarily due to the method of dyeing process adopted, the dye quantity used to obtain the required color and color strength, electricity and compressed air use, the burning of wood in the industrial boiler for production of steam, the operation of an effluent treatment plant to treat process effluent and transport of chemicals. The environmental impact observed for dyeing fabric in softflow dyeing machine and non-silicate CPB dyeing technology remains same, however, the intensity is greatly reduced in non-silicate CPB dyeing method. The environmental impact of finishing process is mainly due to use of softener, burning of wood in boiler for production of steam, use of compressed air and use of electricity.

In general, the non-silicate CPB dyeing technology helps to reduce environmental impact drastically by reducing water and energy consumption compared to the conventional exhaust dyeing process using softflow dyeing machine. It also reduces the process effluent that has to be treated in an effluent treatment plant. The processed fabric also shows high quality that helps to achieve greater customer satisfaction.

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References

Anna, L. (2011). Environmental life cycle assessment as a tool for identification and assessment of environmental aspects in environmental management system (EMS) part 1: methodology. The International Journal of Life Cycle Assessment, 16, 178-186.

BMP. (1996). Manual for Best Management Practices for Pollution Prevention in the Textile Industry. Retrieved October 1, 2012, from http://infohouse.p2ric.org/ref/02/01099/0109900.pdf

Crem, B. V. (2011). Sustainability issues in the textiles sector: Environment. CBI Market Information Database. Retrieved October 1, 2012, from www.cbi.eu

Datta, R. M. (2011). Textile industry: beneficiary of environmental management system. 2nd International Conference on Environmental Science and Technology. IPCBEE, 6.

Dystar. (2010). Sustainability in textile processing, Key elements of sustainability in the textile supply chain. Dystar Textile Services – Ecology Solutions. 9.

EPPP. (1994). Environmental Pollution Prevention Project. Case study-Pollution Prevention Assessment for a Textile Dyeing Facility serving fabric manufacturers. Retrieved October 1, 2012, from http://pdf.usaid.gov/pdf_docs/PNABX815.pdf

ISO 14001, 2004 (E), Environmental management systems - Requirements with guidance for use. 2. Retrieved September 29, 2012, from http://www.cait.cn/ISO14000/biaozhun/bzwj/200808/P020081104476975314192.pdf

Jaya, R. (2011). Assessment of water quality of River Bandi affected by textile dyeing and printing effluents, Pali, Western Rajasthan, India. International Journal of Environmental Sciences, 2(2).

Jayanth, S. N, Karthik, R, Logesh, S, Srinivas, R. K, Vijayanand, K. (2011). Environmental issues and its impacts associated with the textile processing units in Tiruppur, Tamilnadu. 2nd International Conference on Environmental Science and Development, IPCBEE, 4.

Khatri, Z, Memon, M. H, Khatri, A, Tanwari, A. (2011). Cold Pad-Batch dyeing method for cotton fabric dyeing with reactive dyes using ultrasonic energy. Utrasonics Sonochemistry, 18(6) 1301-1307.

Mahfuza, S, Sultana, M, Shahidul, I, Ratnajit, S & Al-Mansur M. A. (2009). Impact of the Effluents of Textile Dyeing Industries on the Surface Water Quality inside D.N.D Embankment, Narayanganj. Bangladesh journal of scientific and industrial research, 44(1), 65-80.

Mark, G, Michael, Oele, Schryver, A. D, Marisa, V. (2008). SimaPro Database Manual Methods library. Impact 2000+, 28-39.

Pre: Simapro 7.3.2. Pre Consultants, B.V. Plotterweg, 12, 3821, BB Amersfoort, The Netherlands.

Ray, S. (2011). Leading manufacturer demonstrates lower carbon and water fabric using the new Greenhouse Gas Protocol Product Standard. Wah Fung Group, Beijing, Retrieved September 26, 2012, from http://www.wfg.com.hk/sys/images/files/WF_Press_v1_4.3_ML.pdf

Rebitzer, G, Ekvall, T, Frischknecht, R, Hunkeler, D, Norris, G, Rydberg, T, Schmidt, W. P, Suh, S, Weidema, B. P & Pennington, D. W. (2004). Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. Environment International, 30(5), 701-720.

Rita, K. (2012). Textile dyeing industry an environmental hazard, Natural Science, 4(1), 22-26.

Stephan, K and Jurgen, S. (2006). Cold Pad Batch dyeing and washing of knitwear, Benninger AG, Uzwil, Retrieved September 26, 2012, from http://www.benninger.ch/uploads/media/CPB_Dyeing_Washing_Knitwear_English_23_05_06.pdf

Tufekci, N, Sivri, N & Toroz, I. (2007). Pollutants of Textile Industry Wastewater and Assessment of its Discharge Limits by Water Quality Standards, Turkish Journal of Fisheries and Aquatic Sciences 7, 97-103.