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Environmental impact assessment of an eco-efficient production for coloured textiles

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ABSTRACT

The textile and clothing industry is one of the world most global industries and constitutes an important source of income and employment for several EU countries. The textile manufacturing process is characterized by high consumption of resources such as water, fuel and a variety of chemicals in a long process sequence generating a significant load on the environment. Therefore, in order to meet the consumers demand of eco-friendly products, more sustainable production processes are under investigation in order to reduce the environmental burdens. The feasibility of these alternative solutions has been demonstrated during the EU BISCOL project proposing a new dyeing process as a global alternative for the conversion of raw materials into competitive eco-viable final products. This has been achieved through the integration of enzymatic synthesis of dyes at semi-industrial scale, textile pre-treatment based on plasma technology and synthesis of new auxiliaries at lower environmental impact. A life cycle assessment has been performed to evaluate the environmental impact associated with the development of new strategies for textile industry in comparison to classical dyeing processes. Results based on primary data from the consortium partners involved in the project show that relevant benefits are achievable with an innovative protocol in terms of reducing energy, water and raw materials consumption.

1. Introduction

With the increasing consumption of manufacturing goods all over the world, product manufacturing systems have come under intense scrutiny with regard to their impact on the environment. The consumption of natural resources has increased dramatically in the last 40 years with little concern for the environmental degradation caused, particularly in the rapidly industrializing countries (Van der Voet et al., 2009; EEA Report, 2005). Every industrial sector and leading companies in each sector are also now being held to account for their impact on human health and the environment. The textile industry has to address such issues within its supply chain as well as its overall production chain, spanning from natural or man-made fibres production to finishing processes (pre-treatment, dyeing, printing, and finishing). At every stage of the textile production, vast amounts of energy, water and chemicals are used to process the textiles and apparel which consumers demand. Within the textile industry, the main consumption of these energy and mass inputs is due to wet processing (preparation process, dyeing process and finishing process). The textile industry also uses large quantities of both electricity and fuels. The share of electricity and fuels within the total final energy use of each country's textile sector depends on the structure of the textile industry in that country. For example, the textile industry accounts for about 4% of the final energy use in manufacturing in China (Marbek resource consultants, 2001), while this share is less than 2% in the U.S. (U.S. DOE, 2006).

Large amounts of water are required for textile processing, dyeing and printing. The daily water consumption of an average sized textile mill having a production of about 8000 kg of fabric per day is about 1.6 million litres (Kant, 2012). 16% of this water is consumed in dyeing and 8% in printing. Specific water consumption for dyeing is at least 40 L per kg of cloth depending on the type of dye used, on the average (US EPA, 1996). Dyeing contributes to 15–20% of the total waste water flow. Water is also required for washing the dyed and printed fabric and yarn to achieve washing

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fastness and bright backgrounds as well as for cleaning the printing machines to remove loose colour paste from printing blankets, printing screens and dyeing vessels (Wasif and Kone, 1996; Vijaraghavan, 1999).

In the last few years, the demand for sustainable clothing from “ethical” consumers, the significant improvements in enforcement of environmental laws by regulatory authorities and better compliance by manufacturers clearly demonstrates a growing recognition of the importance of moving towards a more sustainable model for the textile and clothing industries. Presently there are several European directives to protect the worker and consumer's health such as the Dangerous Substances Directive (67/548/EEC) and REACH & Restrictions on the marketing and use of certain dangerous substances and preparations (azo colourants) Directive (2002/61/EC). With respect to the issues of preventing, reducing and eliminating pollution, other European directives must be mentioned: the Urban Waste Water Treatment Directive (91/271/EEC), the Integrated Pollution Prevention and Control Directive (96/61/EC) and the Water Framework Directive (2000/60/EC).

Today, various fashion brands and retailers are considering options available to design green manufacturing processes of their products. Decisions made at the design phase greatly affect the later decisions that are to be made by the rest of the supply chain. So, in this step there is the greatest potential for changing the impact of the production process, for example, by using low impact dyes and chemicals. Such principles have been embraced by industry leaders as Nike in sportswear and Patagonia in the outdoor equipment and clothing sector (www.nikeresponsibility.com).

Another important aspect is the strong need to establish more sustainable textile processing measurements in the industry. The main objective of these measures should be to minimize and eliminate the most harmful inputs and the most polluting outputs and, very importantly, to reduce the consumption of energy and water which are the primary impacts of the textile processing industry.

In general, the measurement of parameters affecting the system is essential to establish an understanding of the input–output balance of the textile processing operation. The measurement and control of these inputs and outputs can lead to improved resource productivity, improved eco-efficiency and improved cost-efficiency for the processing system.

To address this goal an in-depth and detailed analysis for the assessment of the potential contribution of different processes to environmental impact issues is necessary and a life cycle approach is favoured, so that displacement of environmental burden by outsourcing is avoided. The life cycle assessment (LCA) methodology represents an effective support in order to highlight the critical points of industrial processes (Nieminen, 2003; Steinberger et al., 2009; Tobler, 2001; Yuan et al., 2013) and opportunities for the improvement of different technological solutions in order to reach and promote eco-innovation and eco-efficiency in the textile sector (Nieminen et al., 2006). A sustainable product is one that is manufactured in a way that considers the social elements of fair trade and human rights of the people involved in the manufacturing chain with the lowest possible environmental burdens (e.g. by making the most efficient use of resources such as water and energy) and to recover raw materials (e.g. by the recycling of as much water as possible or by recovering the heat from wastewater discharges). But equally important, a sustainable product is one which can compete effectively in the global marketplace against less sustainable products.

The world economy is currently facing a severe global economic downturn and European textile market is actually depressed (Curran and Zignago, 2010). Therefore, in order to remain competitive with emerging markets, such as China (E-textile toolbox, 2005; Greer et al., 2010; Tutterow, 1999) and India (Allwood et al., 2006), research and development to foster innovation in the European textile industry context is required. This study presents the outcomes of the research activity developed during the Eco-Innovation European BISCOL project (ECO/09/256112/SI2. 567273) proposing a novel dyeing process as an alternative for a more eco-efficient production of coloured textiles.

2. Materials and methods

2.1. Goal and scope of the study

The textile and apparel industry is a varied sector that involves a huge number of activities, from raw materials production, through their processing in yarns and fabrics, dyeing and finishing operations, up to the final garment sewing. In addition, many satellite activities and spin-offs for the production of a wide range of necessary and auxiliary chemicals and machineries contribute this vast and important manufacturing sector (EUROSTAT, 2013). In the entire textile industry, the dyeing process is the most important in terms of high added value and technical complexity (Jiang et al., 2010). At the same time it is the most consuming and polluting step of the fabric processing chain due to the large amount of energy, water and chemicals required (Kiran-Ciliz, 2003; Moore et al., 2004) and wastewater generated (Ibrahim et al., 2008; Ren, 2000).

The function of the system investigated in this work is the production of coloured woollen fabric.

The up-stream (wool production and fabric manufacturing) and down-stream (garment making, final use and disposal) phases are not included in the study because the focus of the analysis was on the environmental impacts generated by the dyeing process of woollen fabric and the opportunities for reducing those impacts applying new solutions compared to the conventional protocols.

The functional unit chosen in this study is 1 kg of woollen fabric (weight per sqm: 300 g/m^2) as reported in other studies on textile processes (Yuan et al., 2013; Steinberger et al., 2009).

2.2. Overview of the process

A sketch of the dyeing process chain and system boundaries defined for the case study is depicted in Fig. 1. In this study the LCA has been performed as a gate-to-gate analysis focused on the main system units composing the dyeing process, i.e. from the textile purge, through the pre-treatment and dyeing steps, up to the final washing and drying phases (foreground system). The insert traced inside the system boundaries illustrates the in-depth analysis performed for all of the production processes of chemicals (auxiliaries components, biocatalyst, dyestuff) required to accomplish the dyeing process. For the innovative compounds specifically set-up for achieving a lower environmental profile for the innovative process, detailed life cycle inventories have been compiled.

The purge, washing and drying steps for the traditional and innovative approaches were modelled identically and inserted in the analysis in order to evaluate the global environmental burden of the dyeing process. Detailed information about the system units that diversify the new and conventional processes are given in the following section.

2.3. Pre-treatment

In the dyeing process, the pre-treatment phase is done to remove impurities and to modify existing fibres in order to impart the desired aesthetic or functional properties. The hydrophobic nature of the cuticle and the high cross-linking density in the outermost fibre surface creates a natural diffusion barrier which

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