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Supercritical CO_2 Technology in Resource-effective Production of Functional and Smart Textiles ⋆

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Abstract

The purpose of this work was to investigate the potential application of $scCO_2$ dyeing technology to produce functional and smart textiles. Selected dyes and functional agents were applied to polyester fabric using the $scCO_2$ impregnation technique. The effects of the processing variables on the functional and colour performances were explored. The results showed that $scCO_2$ is a viable technique to produce functional polyester fabric in a resource-efficient and eco-friendly way. Dyed polyester fabric with additional functionalities such as antimicrobial, antioxidant, UV protection, and UV sensing properties were realised. The fabrics developed have demonstrated desirable colour and functional properties without affecting each other confirming compatibility. Moreover, the functional fabrics exhibited the required durability and fastness properties sufficient for various applications. This research project contributes towards widening the application of the supercritical CO_2 dyeing technique and paves a way for sustainable production of functional and smart textiles in a resource-efficient and eco-friendly way.

Keywords: Supercritical CO_2; Functional and Smart textiles; Antimicrobial; Antioxidant; UV protective textile; Textile UV-sensor; Curcumin natural dye; Chitosan biopolymers; Photochromic textiles

1 Introduction

Functional clothing is a domain of textiles that are designed to deliver specific functions to the users in addition to their usual wearing purposes. Functional textiles encompass areas like

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protective textiles, medical textiles, industrial textiles, sports textiles, automotive textiles, and packaging textiles. In recent times, functional and smart textiles have emerged as a growth field. The market for functional clothing is predicted to reach 244.6 billion USD by 2025 and the global smart textile market size is expected to reach 5.5 billion USD by the same year [1]. Among the textile fibres used for smart and functional textile applications, polyester and viscose (rayon) fibres are the basic and most used ones [2]. The worldwide production volume of textile fibres has increased from 23.94 million metric tons in the year 1975 to 98.5 million metric tons in 2017. Among these, about 53.7 million metric tons (54.5%) were polyester (PET) fibres and the volume is estimated to increase in the coming years [3]. These statistics clearly show that smart and functional textiles are one of the most important fields in the textile industry and polyester is the most important textile fibre in the production of functional and smart textiles.

These functional textiles are mainly manufactured by conventional dyeing and/or finishing process or incorporating various functional finishing agents into the textile structure during the fibre production process. However, the conventional wet textile processes; particularly the dyeing and finishing processes consume a huge amount of water, chemicals, and energy. It is estimated that 100–150 liters of water are required to produce 1 kg of finished textile, on average [4]. This, in turn, results in a huge amount of wastewater discharge which causes large scale water pollution, one of the global environmental problems. The wastewater discharge of the textile wet processing industry lies between 40 and 300 m^3 per ton of finished textiles [5]. This wastewater discharge is contaminated with dyes, finishing agents, salt, alkalis and acids, auxiliary chemicals, and other solvents. A large amount of unfixed dyes and finishing chemicals leaves the process in which the exact amounts depends on the type of dyes or functional agents and the process used. In conventional polyester dyeing, it is estimated that approximately 5-10% of the dye is lost and ends up in the effluent [6, 7]. According to the World Bank estimate, 17 to 20% of industrial water pollution comes from textile dyeing and finishing operations [8]. This is a huge problem posing a serious threat to the flora and fauna and due to this the textile industry is mostly criticized for its role in environmental pollution.

To solve these issues, the textile industries have focused on the use of alternative eco-friendly techniques and agents to minimize waste generation and reduce toxic chemicals. In this regard, more emphasis has been given to the development of cleaner, cost-effective, and value-added textile products to solve the issues related to health and the environment. Not only the product but also the methods of production of the future itself must bring technological innovation and sustainability for possible advancements while keeping the balance of nature. Thus, the textile industries have focused on the use of green technologies as an alternative to conventional textile wet processing to promote sustainable production and reduce waste generation. Some of the important green technologies and renewable natural materials such as biopolymers, enzymes, and natural dyes used for sustainable textile production have been reviewed by [9]. As discussed in the review, some of the green technologies adopted recently include, supercritical CO_2, microwave, plasma, ultrasound, and electrochemical reduction of dyes.

The use of environmentally friendly supercritical CO_2 as a dyeing medium has shown promising results owing to many advantages over conventional systems [10]. Supercritical CO_2 dyeing has several advantages such as it does not require any water, surfactants, or dispersing agents, and does not involve drying at the end of the procedure. It is non-toxic, non-flammable, inexpensive, chemically inert under many conditions, and easily manageable critical conditions. It was shown that the $scCO_2$ dyeing process is not only environmentally superior to aqueous dyeing but also economically [11]. Due to these attributes, it has been given considerable attention and the