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Manufacturing parameters optimization in functional textile dyeing processes

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Abstract

This research is to develop the dyeing parameter optimization model for functional textiles based on the analysis of relationship between the manufacturing parameters in the dyeing process and the dyeing performance. The aim of this research is to minimize the total dyeing cost including the production and energy costs with the consideration of robustness measure and dyeing performance. The first task of this research is to analyze the relationship between the dyeing parameters and dyeing performance by the Central Composite Design (CCD). The result of the CCD is the estimated response surface for the use of our second task of the dyeing parameter optimization to search for the optimal combination of dyeing parameters with a robust performance against the manufacturing variability.

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Keywords: dyeing parameter; parameter optimization; Central Composite Design (CCD); dyeing performance; robust performance

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1. Introduction

The functional textiles market is recently driven by the increasing demand of sportswear, while functional textiles are expensive due to the premium class of textiles. Textile dyeing processes of functional textiles involve various manufacturing parameters including heating temperature, time, heating rate, etc., which are significantly affect the consumed energy and corresponding dyeing costs in a textile dyeing cycle. In the current practice, most dyeing parameters for functional textiles are typically determined by the past experience rather than a scientific methodology. Given a dyeing formulation, various dyeing parameters yield different levels of dyeing performance measures. The engineers experience to determine dyeing parameters of functional textiles may cause the surge of dyeing costs or the loss of dyeing quality. For example, an inferior dyeing fabric needs to be either re-dyeing or directly dumping away, which causes a significant cost loss in functional textiles dyeing factories. Dyeing processes of functional textiles are involved with a high energy-consuming process since a substantial amount of solution needs to be heated up to a couple of hundreds of Celsius degree followed by a series of washing-off steps to remove the unfixed dissolved oligomers as well as residual auxiliaries. The heating-up and cooling-down processes repeat a couple of cycles before its completion. Until recently, most literature only focuses on the analysis of the dyeing formulation and dyeing performance. For instance, Imada et al. (1992) predict the pH control and auxiliary addition in a dyeing cycle to obtain the optimum exhaustion and fixation curves. Guo and Chen (1994) improve the dyeability of cotton with reactive dye and pretreatment of auxiliaries. Chen (1997) investigates three different types of disperse dyestuffs to enhance color fastness. Jasper et al. (1993) apply the neural network to predicting the concentrations of dyes.

Experiment design is also a well-known method to choose the level of dyeing parameters in a dyeing cycle. Lin et al. (2007) show that the level-dyeing can be obtained by replacing the traditional acid agent by pH sliding agents with an appropriate dyeing temperature. Etemadifar et al. (2014) investigates the effective factors in a dyeing process using one factor at a time (OFT) method. Following OFT, Etemadifar et al. (2014) apply the central composite design (CCD) method for evaluation of the interactive effects of investigated operating factors for wool dyeing. Sinha (2016) applies the response surface methodology (RSM) to searching for the manufacturing parameters in a dyeing cycle to effectively reduce the cost of experiments. Wang et al. (1998) summarize the significant factors to enhance the uniformity of dyeing. These experiment design based methodologies, however, only investigate a discrete set of dyeing parameters rather than a comprehensive search on a continuous space of dyeing parameters. In this paper, we first construct a response between the dyeing parameters and dyeing performance measures in functional textiles dyeing processes followed by the optimization technique to search for the optimal setting of dyeing parameters in a continuous solution space rather than only a bunch of discrete combinations of dyeing parameters. The remainder of this paper is organized as follows. Section 2 describes a typical dyeing cycle followed by two major tasks: response surface between dyeing performance measures and dyeing parameters, and optimization of dyeing parameters. Section 3 summarizes the model and experiments results and we conclude the paper in Section 4.

2. Optimization of dyeing parameters

This section describes a typical dyeing cycle in the functional textiles dyeing processes including a series of heating-up and cooling-down operations. Several critical dyeing parameters affect the dyeing performance of functional textiles. To construct the response between the critical parameters and dyeing performance, the method of experiment design has applied in our paper explained in Section 2.2 followed by the optimization model to optimize the critical dyeing parameters in Section 2.3.

2.1. Dyeing cycle

A dyeing cycle involves a series of temperature variations so that dye molecules have uncut chemical bond with fiber molecules. The temperature variation and dyeing time duration are two major factors affecting the dyeing performance. A typical dyeing cycle of temperature variations and time duration is shown in Figure 1. Dyeing is started at temperature T_L for preparation, then the dye temperature is raised at a fast rate v °C/min to T_1 followed by