Journal of Cleaner Production 148 (2017) 415–421

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Short communication

Optimizing a laundering program for textiles in a front-loading washing machine and saving energy

Wei Bao [a], R. Hugh Gong [b], Xuemei Ding [a, c, *], Yue Xue [a], Pengfei Li [a], Weichao Fan [a]

[a] College of Fashion and Design, Donghua University, Shanghai 200051, China
[b] Textiles, School of Materials, University of Manchester, Manchester M13 9PL, UK
[c] Key Laboratory of Clothing Design & Technology, Ministry of Education, Donghua University, Shanghai 200051, China

ARTICLE INFO

Article history:
Received 13 November 2016
Received in revised form
14 January 2017
Accepted 28 January 2017
Available online 3 February 2017

Keywords:
Laundering program
Optimization
Energy reduction
Soil removal

ABSTRACT

The laundering process has significant environmental impact due to the consumption of energy, water and chemicals. This paper optimized an energy-saving laundering program, especially for shirts or other underwear by efficient experiment design to balance the temperature, main wash time and mechanical action. As a result, energy consumption after optimization is around 1/3 lower than the original, and at the same time, detergency and the rate of fabric abrasion are basically the same as the original. What's more, compared with original program, no additional chemicals or water is used. This finding can help the washing machine manufacturers to optimize washing procedures and it will significantly reduce the environmental impact of washing machines.

1. Introduction

Washing clothes and other home textiles is one of the most widespread housework in the world (Pakula and Stamminger, 2010). The laundering process has significant environmental impact due to the consumption of energy, water and chemicals (Fig. 1). According to statistics, electricity consumption of washing machines accounts for 6.4% of total residential electricity in EU-27 (Bertoldi and Atanasiu, 2009). In addition, Life cycle assessment studies on clothes (Chen and He, 2014), detergents (Saouter and Van Hoof, 2002) and washing machines (Yuan et al., 2016) show that the "use" period is usually the most energy-demanding period during these products' life cycle.

Drum-type washing machines, which are more popular to consumers, use less water than impeller-type ones. However, they are often associated with hot water and longer mechanical agitation, which causes more energy consumption. Experimental tests showed that energy used to heat up the wash load accounts for more than 78% when temperature is above 40 °C (Mozes et al., 1998) in laundering process. In 2010 the average washing temperature in Germany was 46 °C (Hauthal, 2012). Lowering the washing temperature is an effective way to save energy, but it may decrease the clean performance.

According to the Sinner Circle (Fig. 2), a laundering procedure is a result of the synergistic actions between temperature, duration, mechanical action and chemical action (Hauthal, 2012), so it is important to balance these parameters for sustainable washing procedures without lowering other washing performances, such as cleaning effect and fabric damage. Several studies have investigated the effects of washing conditions on washing performance and the consumption of electricity and water. Lowering the temperature and prolonging the washing time led to a remarkable decrease of the energy consumption while the cleaning performance remained the same (Janczak et al., 2010). However, fabric damage was not considered. In fact, prolonging wash time can easily cause fabric damage, so it is an important performance aspect to consider. Some studies optimized parameters to save energy by increasing detergent or disinfecting agents. Honisch er al. concluded that the loss of hygiene effectiveness caused by temperature reduction can be compensated by increasing the wash cycle time and/or use of a detergent with activated oxygen bleach (Honisch et al., 2014). Fijan er al. optimized a laundering program to achieve more energy-saving by a transformation from thermal to chemo-thermal action, at the same time ensure disinfection (Fijan et al., 2008). Altenbaher er al. implemented an optimal low-temperature laundering procedure, which decreased energy consumption while

* Corresponding author. Present address: 1882, West Yan an Road, Shanghai, China.
E-mail address: fddingxm@dhu.edu.cn (X. Ding).

http://dx.doi.org/10.1016/j.jclepro.2017.01.161
0959-6526/

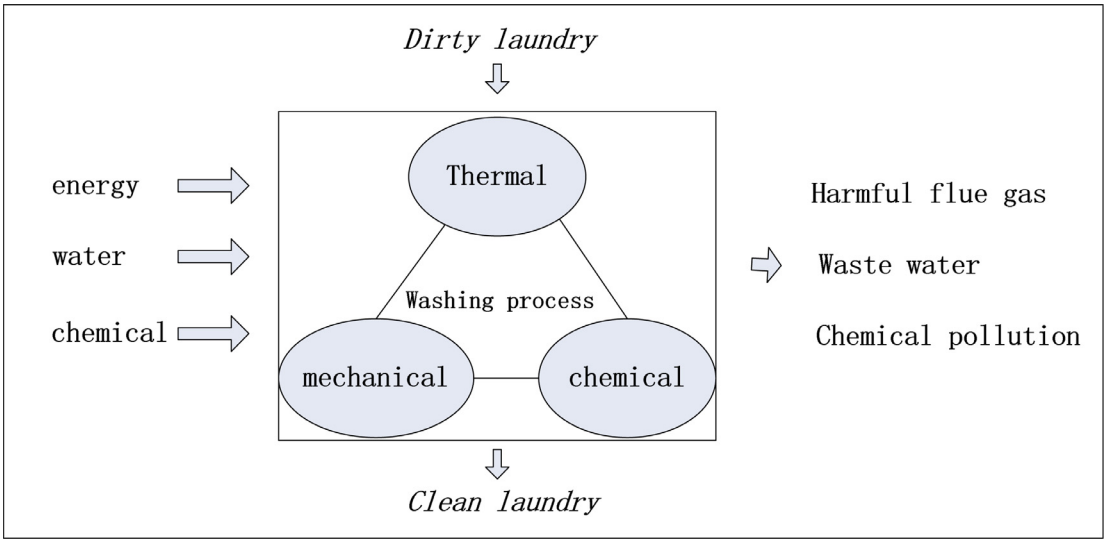

Fig. 1. Environmental impact of laundering process.

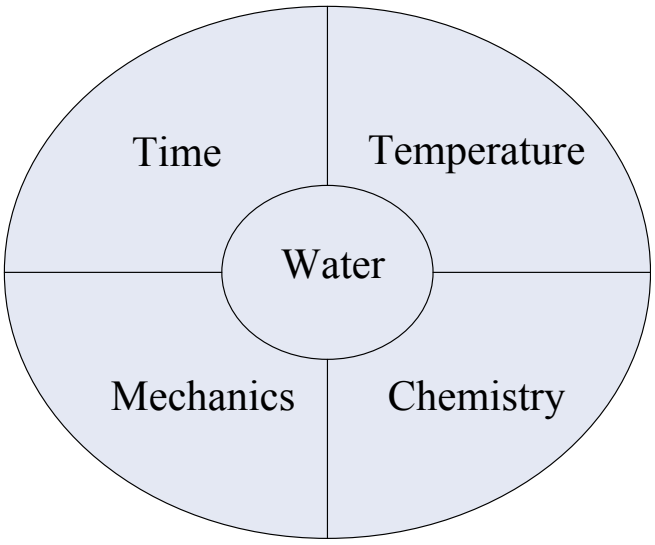

Fig. 2. The sinner circle (Hauthal, 2012).

reaching an adequate disinfection effect with somewhat higher dosages of chemicals and with lower damages to the textiles (Altenbaher et al., 2011). Although these programs decrease energy consumption, more chemicals were used. Han er al. identified the optimal washing methods in terms of washing efficiency and electricity consumption. To this end, the mechanical action by the washing machine's agitation and the chemical action by detergents were investigated (Han et al., 2015), but the energy and pollution caused by chemical production were not taken into account.

This research aimed at optimizing a sustainable laundering program which can reduce energy consumption without additional chemicals. The cleaning efficiency and fabric abrasion damage are also considered.

Of the contaminates in the clothes, those from the human body are the most common accounting for up to 70% of the total. Sebum is the largest part of dirt in a wash (Johansson and Somasundaran, 2007). Therefore, in this research sebum stain test strips were used to determine cleaning performance. This means that this program is more suitable for washing underwear and shirts.

2. Experimental part

In this study, the influences of parameters on washing performances are obtained through experimental study and the optimum parameter combination is also found.

2.1. Preparation of materials

Sebum stain test strips (GB/T 13174-2008) were purchased from China Research Institute of Daily Chemical Industry, which were cut to 6 × 6 cm^2 swatches. The thread removal material used (Wang et al., 2014) was polyester fabric, whose thread count was 23 ends/cm and 19 picks/cm. The fabric was cut to 5 × 5 cm^2 pieces. The test load was composed of three cotton shirts and one piece of cotton base load (GB/T 8629-2001), which together was 1/4 of full load. And the size of each piece of cotton base load is 92 × 92 cm^2. A commercial liquid type detergent (Chaoneng, Nice group Co., Ltd, China) was used. The main ingredients of the detergent included coconut oil soapstock, anionic surfactant, nonionic surfactant and detergent builder. In the experiment, the detergent usage is 20 mL, which is the recommended dosage by the supplier. The washing machine used in the study was a drum-type washing machine (2.8 kg, Xiao Ji Internet Science & Technology Co., Ltd, China) with adjustable parameters. The standard washing machine used was Wascator FOM71 CLS from Electrolux co., Ltd.

2.2. Design of experiment (DOE) and laundering procedures tested

JMP is a computer program for statistics developed by the JMP business unit of SAS Institute. In this paper, JMP's custom designer is used to design experiment.

(1) Parameters

The aim of this research is to develop a program with lower energy consumption but without increased dosage of chemicals or water consumption. Therefore, the dosage of detergent and bath ratio are fixed parameters. The following parameters are modified: mechanical action (wash speed, on time and off time), wash temperature and main wash duration (the time used to heat up is included in the main wash duration). The detailed parameters and levels are shown in Table 1.