**Weiran Qian[1], Xiaoxiao Qiu[1], Yiqi Guo[1], Xiang Ji[1], Yi Li[2,3], Laili Wang[1,4,*]**

[1] **Zhejiang Sci-Tech University, School of Fashion Design & Engineering,**
Hangzhou, Zhejiang, 310018, China

[2] **Ningbo University, Faculty of Tourism and Culture, Fashion Department of International United Faculty between Ningbo University and University of Angers,**
Ningbo 315201, China

[3] **Ningbo University, Collaborative Innovation Center of Port Economy, East China Sea Institute,**
Ningbo 315211, China

[4] **Key Laboratory of Silk Culture Heritage and Products Design Digital Technology, Ministry of Culture and Tourism,**
Hangzhou, 310018, China,
* Corresponding author e-mail: wangll@zstu.edu.cn

# Chemical Footprint of the Wet Processing of Cotton Fabric

**DOI:** 10.5604/01.3001.0014.8236

**Abstract**
*The chemical footprint (ChF) can identify the harmful effects of discharged chemical pollutants, helping producers to select environmentally friendly chemicals to reduce their negative environmental impact. This paper quantified and evaluated the ChF of the wet processing of cotton fabric with data collected from a dyeing enterprise. The results showed that the discharged sodium hydroxide caused the most severe impact in terms of both human toxicity and ecotoxicity due to the extensive usage and its high toxicity. The discharged sodium carbonate and dimethyl silicone oil also had a greater environmental impact. Comprehensive evaluation of human toxicity and ecotoxicity with a multi-objective grey target decision-making model indicated that the pretreatment process had the most significant impact, followed by the finishing process and dyeing process. More attention should be paid to the pretreatment process, such as the selection of environmentally friendly textile chemicals, in order to reduce the native impacts of the wet processing of cotton fabric.*

**Key words:** *chemical footprint, USEtox, human toxicity, ecotoxicity, grey target decision-making model.*

## Introduction

Cotton is important in the fashion industry because of its excellent flexibility, comfort, fine breathability and washability and various other properties [1]. With the aim of improving the serviceability of cotton fiber and fabrics, there are three major processes involved in the production chain: pretreatment, dyeing and finishing as well as other sub-processes. Specifically, cotton wet treatment, desizing, scouring, bleaching and dyeing are not considered as clean and sustainable processes as they are energy, freshwater, chemical and pollutant intensive [2, 3]. Chemical consumption and chemical pollutant discharge have drawn more and more attention in recent years [4-6]. The chemical footprint (ChF) method has been carried out to quantify and evaluate the environmental impacts caused by chemical consumption and chemical pollutant discharge. ChF was first put forward by Panko and Hitchcock in 2011. It provided an insight into the assessment of potential risks to human life and the environment caused by chemical consumption and chemical pollutant discharge [7].

ChF was first applied in the textile industry by Roos in 2015 [8]. In the past five years, more and more attention has been paid to the application of ChF for the evaluation of toxicity impacts caused by chemical consumption and chemical pollutant discharge in the production of textile products [8-12]. The USEtox model was widely used in these researches. The results showed two kinds of toxicity impacts: human toxicity and ecotoxicity, according to the USEtox model. It was difficult to conclude which kind of textile product or production process has less impact because the units of the two kinds of toxicity impacts were different. This will affect the efficiency of the ChF assessment of textile products. In order to fill this gap, this paper carried out a comprehensive evaluation of the human toxicity and ecotoxicity impacts of three major wet processes (e.g., pretreatment, dyeing and finishing) in cotton fabric production. The multi-objective grey target decision-making model was applied to eliminate the dimensional differences in human toxicity and ecotoxicity. Then it was possible for a comparison of the toxicity impacts caused by the different processes. It is significant for producers to alleviate the toxicity impacts accurately and effectively.

## Methods and data

### Chemical footprint method

The USEtox model describes the migration and transformation of chemical substances in environmental compartments. It is used to calculate the human toxicity and freshwater ecotoxicity impact of chemicals with the help of the corresponding characterisation factor (CF) for chemical substances. CF is derived from the matrix product of fate factors (FF), human exposure factors (XF) and human toxicological effect factors (EF) [13]. The calculation of CF in the USEtox model is described as follows,

$$CF = FF \times XF \times EF \tag{1}$$

FF represents the residence time (in days) of a chemical substance in a specific environmental compartment. It quantifies the decomposition of the pollutant in the environment directly relating to the degradation capacity of a chemical substance in different compartments. EF is explained in terms of the change in pollutant concentration, the proportion of species affected (in $PAF \cdot m^3/kg$) in terms of ecotoxicity, and of the effects of toxic substances on human health for human toxicity (in cases/kg). XF is the exposure factor, which represents the bioavailability of a certain chemical substance in terms of ecotoxicity, and the rate at which pollutants are transferred from the

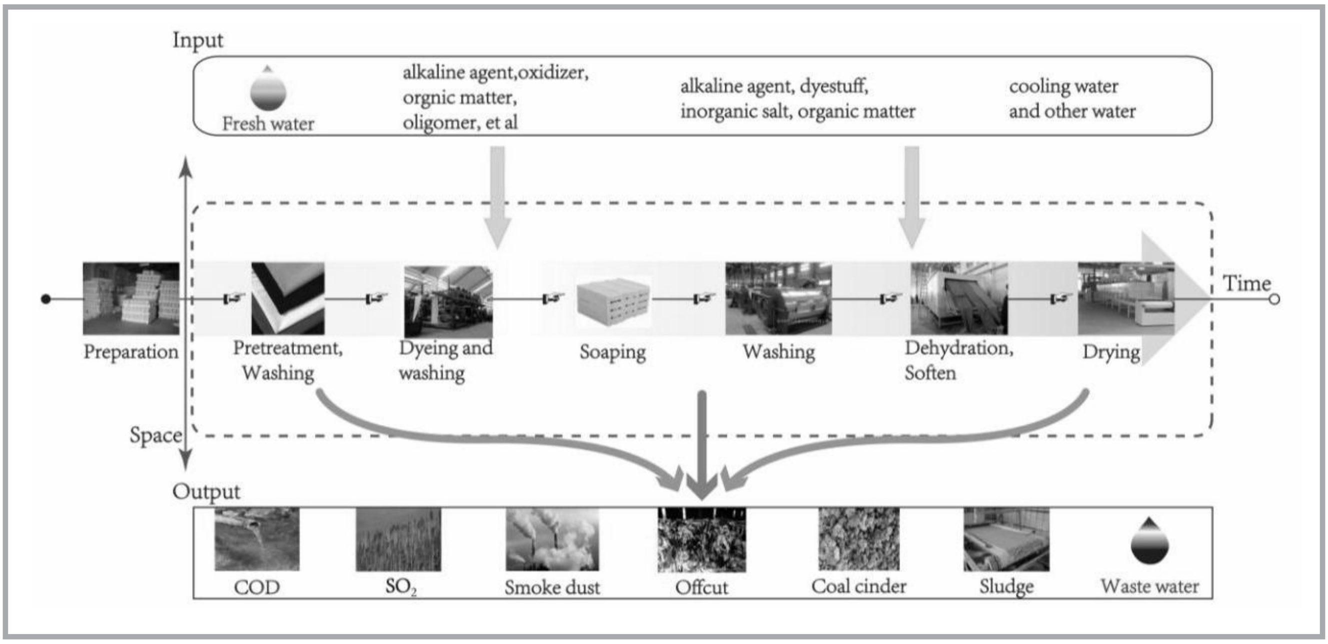


***Figure 1.*** *System boundary of ChF calculation.*

environment to the human body through a series of exposure pathways for human toxicity.

According to the USEtox model, the equation used for ChF calculation of cotton fabric is as follows:

$$ChF = f \times \sum_{i,j} E_{i,j} \times CF_{i,j} \quad (2)$$

ChF is the human or ecological chemical footprint (in Cases or PAF·m$^3$·day), f the correction factor between the USEtox model and ChF, with a value of 290, $E_{i,j}$ the mass (in kg) of substance i discharged into compartment j, and $CF_{i,j}$ represents the characterisation factors of substance i discharged into compartment j (in Cases/kg or PAF·m$^3$·day/kg).

### Comprehensive assessment of chemical footprint

The multi-objective grey target decision-making model was applied to eliminate the dimensional difference between human toxicity and ecotoxicity in order to conduct a comprehensive assessment of the ChF of wet processing procedures. The optimal weight of two toxicity indexes was resolved based on the Euclidean distance minimisation criterion. The method is as follows [14-16]:

(1) The ChF is a cost index, which follows the principle that the smaller the index value, the better. In order to eliminate the dimensional differences between human toxicity and ecotoxicity indexes, we use the grey range transformation formula:

$$r_i^{(k)} = \frac{\max\{u^{(k)}\} - u_i^{(k)}}{\max\{u^{(k)}\} - \min\{u^{(k)}\}} \quad (3)$$

Where, $0 \le r_i^{(k)} \le 1$, k = 1, 2, represents human toxicity and ecotoxicity, respectively, i =1, 2, 3, the three break-down processes, respectively, $r_i^{(k)}$ the toxicity of process i for the toxicity index k after eliminating the dimensional differences, $u_i^{(k)}$ the chemical footprint of the process i for the toxicity index k, and $\min\{u^{(k)}\}$ & $\max\{u^{(k)}\}$ represent the minimum and maximum chemical footprints for the toxicity index k, respectively.

(2) Based on the optimal value by grey range transformation, the multi-objective grey target centre is determined as follows:

$$r = (\text{mum}\{r^{(1)}\}, \text{mum}\{r^{(2)}\}) \quad (4)$$

(3) The distances between human toxicity (or ecotoxicity) and the best optimal point, namely the bull's-eye distance, are calculated as follows:

$$d_s = \sum_{k=1}^{2} \omega_k \left| r_i^{(k)} - \text{mum}\{r^{(k)}\} \right| \quad (5)$$

Where, i = 1, 2, 3, $\omega_k$ is the weight coefficient of human toxicity (or ecotoxicity), and $\sum_{k=1}^{2} \omega_k = 1$, $0 \le \omega_k \le 1$.

(4) The weight coefficient ($\omega_k$) is the result of the optimal weight of human toxicity (or ecoxicity).

$$\omega_k = \frac{1}{\sum_{k=1}^{2} \frac{1}{\sum_{i=1}^{n} [d_i^{(k)}]^2}} \cdot \frac{1}{\sum_{i=1}^{n} [d_i^{(k)}]^2} \quad (6)$$

Where, $d_i^k = \left| r_i^{(k)} - \text{mum}\{r^{(k)}\} \right|$

(5) The distance between human toxicity (or ecotoxicity) and the multi-objective grey target is calculated as follows:

$$d_p^* = \sum_{k=1}^{2} \omega_k \left| r_i^{(k)} - \text{mum}\{r^{(k)}\} \right| \quad (7)$$

Where, $\omega_k$ is the weight of the evaluation index k. Sequencing of the ChF (human toxicity or ecotoxicity) of each sub-process can be performed according to the value of $d_p^*$. The smaller the value, the lower the environmental impact caused by the chemicals.

### Calculation boundaries and data collection

The calculation boundaries for the ChF of wet processing were focused on from the pretreatment to the dyeing and finishing process, including singeing, mercerising, washing, dyeing, soaping, dehydration, softness and drying, as shown in ***Figure 1***. The dyestuffs and auxiliaries consumed and discharged directly in the processes were considered for ChF calculation. Data were collected from a printing and dyeing enterprise in Kunshan city, Jiangsu Province, China. The toxicity characterisation factor of chemical substances was mainly obtained from the USEtox model. The corresponding physicochemical parameters for chemi-

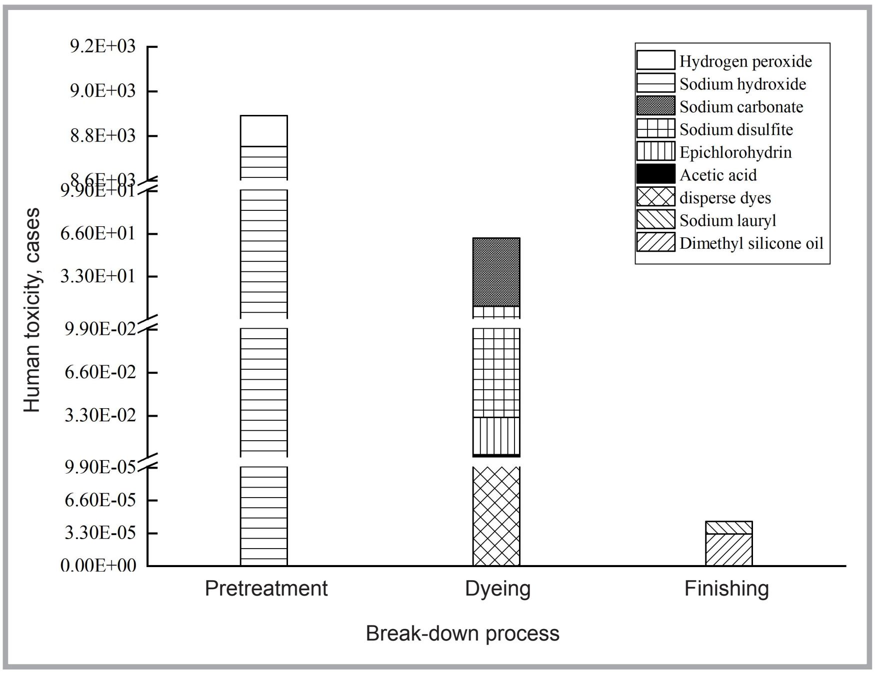


***Figure 2.*** *Human toxicity of wet processing of cotton fabric.*

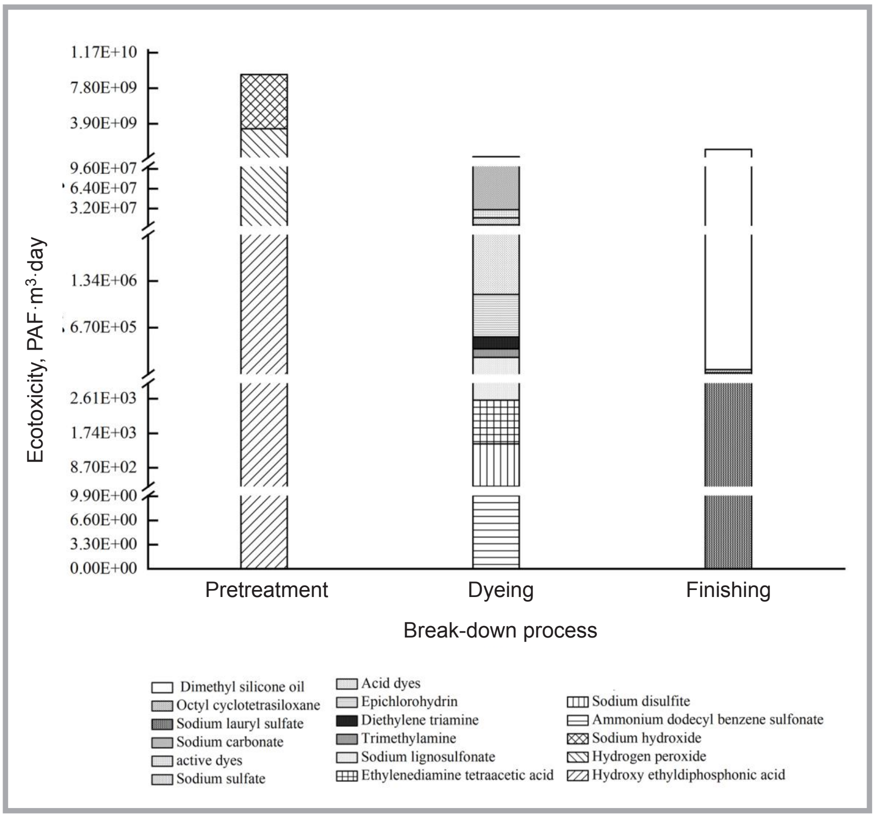


***Figure 3.*** *Ecotoxicity of wet processing of cotton fabric.*

***Table 1.*** *Index for comprehensive evaluation of ChF.*

| Sub-process (i) | Toxicity index, dimentionless | | Bull's eye distance ($d_p^*$) |
|---|---|---|---|
| | Human toxicity ($r_i^1$) | Ecotoxicity ($r_i^2$) | |
| Pretreatment | 0.00 | 0.00 | 1.01 |
| Dyeing | 0.99 | 1.00 | 0.01 |
| Finishing | 1.00 | 0.91 | 0.05 |

cal substances not included in the above databases were collected from other databases, such as the Estimation Programs Interface Suite and Pesticide Action Network Pesticide database. 1200 tons of dyed cotton fabric was chosen as the functional unit.

## Results and discussion

### Human toxicity impact

***Figure 2*** shows the human toxicity impact per functional unit in the wet processing of selected cotton fabric. According to the results displayed in ***Figure 2***, the total ChF (i.e., human toxicity) was 8.95E+03 Cases. The pretreatment process (e.g., oxygen bleaching, mercerising, washing) exhibited the greatest impact on human toxicity, accounting for 99.30% of the total ChF, followed by the dyeing process and finishing process. There was a great demand for sodium hydroxide in the pretreatment process as it plays a significant role in mercetisation. In addition, hydrogen peroxide also accounted for a large proportion of the ChF of the pretreatment process.

Sodium carbonate presented the highest proportion of the ChF of the dyeing process, followed by sodium disulfite, epichlorohydrin and acetic acid. Dimethyl silicone oil and sodium lauryl sulfate, used as a softener and oil-removing agent in the finishing process, had the lowest impact, owing to the combination of their relatively little quantity used and the small value of human toxicity.

### Ecotoxicity impact

The ecotoxicity impact per functional unit of selected cotton fabric was calculated and is shown in ***Figure 3***. It can be seen that the pretreatment process contributed the most to the ecotoxicity impact, accounting for 87.21% of the total ChF. This was caused by the large amount of sodium hydroxide and hydrogen peroxide used in the pretreatment process as well as their large characterisation factors. The dyeing process contributed the least to the ecotoxicity impact, with a ChF value of 2.708E+08 PAF·$m^3$·day, despite the largest number of chemicals used in this process. Sodium carbonate had the largest ecotoxicity impact, accounting for 88.88% in the dyeing process. In the finishing process, dimethyl silicone oil generated the largest ecotoxicity impact, due to its relatively larger ecotoxicity characterisation factor.

**Comprehensive assessment of impacts**

A comprehensive impact evaluation system for human toxicity and ecotoxicity was established according to ***Equations (3)-(7)***. The weight of each evaluation indicator was calculated and the target distance of each index was obtained, shown in ***Table 1***.

As shown in ***Table 1***, the order of distance $d_p^*$ of the three sub-processes are as follows: pretreatment > finishing > dyeing. This means that the comprehensive toxicity impact of the pretreatment process was the largest, followed by the finishing process and dyeing process.

The traditional pretreatment process in the cotton fabric wetting process required a large number of chemicals, which created a large ChF for human toxicity, shown in ***Figure 2***. For example, sodium hydroxide and hydrogen peroxide used in the pretreatment not only aggravated sewage treatment processes but also caused severe environmental damage. To minimise the toxicity impacts caused by alkali, a new refining enzyme process was introduced. Biotechnology not only removed the impurities in cotton fabric but also required less sodium hydroxide, thus achieving cleaner and more sustainable production [17-19]. Furthermore, other auxiliary technology, such as ultrasonic technology and supercritical carbon dioxide fluid have been introduced for greater enzyme efficiency [20-22].

From the results of the aforementioned comparative assessment, the finishing process had the second largest comprehensive toxicity impact. As depicted in ***Figure 3***, besides sodium hydroxide, the toxicity impact caused by soaping and softening agents in the finishing process should not be underestimated. Currently, in order to adhere to the requirements of cleaner production, an increasing number of environmentally friendly textile chemicals have been produced, replacing the highly toxic chemicals that have been generally used in the production processes. For example, environmentally friendly softeners containing functional groups with special functions have been developed with the intention of reducing the water consumption and retention time of toxic polymers in the environmental compartments, thus reducing or eliminating the toxicity effects [23-25]. As to the dyeing process, the application of cleaner dyestuff with advanced technology should be taken into account. Microwave irradiation and supercritical carbon dioxide have potential application for cleaner cotton fabric dyeing, representing a significant advancement in the textile dyeing process [26-28].

## Conclusions

Due to the increasing emphasis on cleaner production, this paper took the initiative and calculated and evaluated the human toxicity and ecotoxicity of the wet processing of selected cotton fabric based on ChF methodology. Moreover, in the light of the unit difference between the two kinds of toxicity impacts, the novelty of this paper is that the multi-objective grey target decision-making method was introduced to obtain a comprehensive toxicity evaluation.

The results of this study showed that the pretreatment process was the greatest contributor to both human toxicity and ecotoxicity because of the use of sodium hydroxide. Sodium carbonate and dimethyl silicone oil occupied the largest proportion of ChF in the dyeing process and finishing processes, respectively. Furthermore, the comprehensive evaluation of human toxicity and ecotoxicity confirmed that pretreatment process had the most significant impact, followed by the finishing process and dyeing process.

In the light of our calculated results, it is of great importance to highlight the scarcity of calculated results concerning gaseous chemical pollutants (e.g., volatile organic compounds, nitrogen oxides, and sulfides, etc). This is important to fill the knowledge gap to compile a more comprehensive assessment of chemical footprints. As far as the necessary measures for decreasing the human toxicity and ecotoxicity caused by the textile industry, utilisation of environment-friendly textile dyes and auxiliaries and effective wastewater treatment technology should be paid considerable attention.

## Acknowledgements

*The authors are grateful to the Zhejiang Provincial Natural Science Foundation (LY21G030004, LY20G030001), the National College Students Innovative Entrepreneurial Training Program of China (202010338017), and the Fundamental Research Funds of Zhejiang Sci-Tech University (2021Y008) for providing funding support to this research.*

## References

1. Gokce Y, Aktas Z, Capar G, et al. Improved Antibacterial Property of Cotton Fabrics Coated with Waste Sericin/Silver Nanocomposite. *Materials Chemistry and Physics* 2020; 254: 123508.
2. Baydar G, Ciliz N, Mammadov A. Life Cycle Assessment of Cotton Textile Products in Turkey. Resources Conservation & Recycling 2015: 104: 213-223.
3. Harane RS, Adivarekar RV. Sustainable Processes For Pre-Treatment Of Cotton Fabric. Textiles and Clothing Sustainability 2017; 2(1): 1-9.
4. Kan CW, Lam CF, Chan CK et al. Using Atmospheric Pressure Plasma Treatment for Treating Grey Cotton Fabric. *Carbohydr Polym* 2014; 102(1): 167-173.
5. Dong X, Gu Z, Hang C, et al. Study on the Salt-Free Low-Alkaline Reactive Cotton Dyeing in High Concentration of Ethanol in Volume. *Journal of Cleaner Production* 2019; 226: 316-323.
6. Ayele M, Tesfaye T, Alemu D, et al. Natural Dyeing of Cotton Fabric with Extracts from Mango Tree: A Step Towards Sustainable Dyeing. *Sustainable Chemistry and Pharmacy* 2020; 17: 100293.
7. Panko J, Hitchcock K. Chemical Footprint Ensuring Product Sustainability. [2012-10-04]. http://chemrisknano.com/chemrisk/images/stories/Chemical_Footprint_Ensuring_Product_Sustainability.pdf.
8. Roos S, Posner S, Jönsson C, et al. Is Unbleached Cotton Better Than Bleached? Exploring the Limits of Life-Cycle Assessment in the Textile Sector. *Clothing and Textiles Research Journal* 2015; 33(4): 448-459.
9. Roos S, Holmquist H, Jonsson C, et al. USEtox Characterisation Factors for Textile Chemicals Based on a Transparent Data Source Selection Strategy. *International Journal of Life Cycle Assessment* 2018; 23(4): 890-903.
10. Tian ZJ, Wang LL, Li Y. Calculation and Assessment of Chemical Footprint of Textiles and Apparel. *Silk* 2019; 56(1): 33-37.
11. Yi L, Yan L, Qing H. Chemical Footprint of Textile and Apparel Products: An Assessment of Human and Ecological Toxicities Based on USEtox Model. *The Journal of the Textile Institute* 2020; DOI: 10.1080/00405000.2019.1710907.
12. Qian JH, Qiu YY, Yang YD. Accounting and Evaluation of Chemical Footprint of Cotton Woven Fabrics. *Industrial Textila* 2020; 71(3): 209-214.
13. Hauschild MZ, Huijbregts M, Jolliet O, et al. Building a Model Based on Scientific Consensus for Life Cycle Impact Assessment of Chemicals: The Search for Harmony and Parsimony. *Environmental Science & Technology* 2008; 42: 7032-7037.
14. Luo D, Wang X. The Multi-Attribute Grey Target Decision Method for Attribute Value within Three-Parameter Interval Grey Number. *Applied Mathematical Modelling* 2012; 36(5): 1957-1963.

15. Ren XQ, Zhang HM, Hu RH, et al. Location of Electric Vehicle Charging Stations: A Perspective using the Grey Decision-Making Model. *Energy* 2019; 173: 548-553.
16. Lv LS, Deng ZH, Meng HJ, et al. A Multi-Objective Decision-Making Method for Machining Process Plan and an Application. *Journal of Cleaner Production* 2020; 260: 121072.
17. Buschle-Diller G, Yang XD, Yamamoto R. Enzymatic Bleaching of Cotton Fabric with Glucose Oxidase. *Textile Research Journal* 2001; 71(5): 388-394.
18. Farooq A, Ali S, Abbas N, et al. Comparative Performance Evaluation of Conventional Bleaching and Enzymatic Bleaching with Glucose Oxidase on Knitted Cotton Fabric. *Journal of Cleaner Production* 2013; 42: 167-171.
19. Eren HA, Anis P, Davulcu A. Enzymatic One-bath Desizing – Bleaching – Dyeing Process for Cotton Fabrics. *Textile of Research Journal* 2009; 79(12): 1091-1098.
20. Easson M, Condon B Villalpando A, et al. The Application of Ultrasound and Enzymes in Textile Processing of Greige Cotton. *Ultrasonics London Then Amsterdam* 2018; 84: 223-233.
21. Vankar PS, Shanker R. Ecofriendly Ultrasonic Natural Dyeing of Cotton Fabric with Enzyme Pretreatments. *Desalination* 2008; 230(1-3): 62-69.
22. Liu SQ, Chen ZY, Sun JP, et al. Ecofriendly Pretreatment of Grey Cotton Fabric with Enzymes in Supercritical Carbon Dioxide Fluid. *Journal of Cleaner Production* 2016; 120: 85-94.
23. Pu DJ, Zhong Q, Wang JP. Anhydrous Softening Finishing of Cotton Towel at Low Temperature. *Journal of Zhejiang Sci-Tech University* 2016; 35(3): 327-332.
24. Chen GX. Development Retrospect and Direction Discuss of Fabric Softeners. *Textile Auxiliaries* 2019; 36(2): 9-12.
25. Bansode AS, Pukale DD, Jadhav NL, et al. Sonochemical Enzymatic Esterification of Oleic Acid and Tri-Ethanolamine for a Fabric Softener in Textile Application. *Chemical Engineering and Processing: Process Intensification* 2019; 137: 128-136.
26. Mohammad I, Hongjuan Z, Uzma S, et al. Low Liquor Dyeing of Cotton Fabric with Reactive Dye By an Eco-Friendly Technique. *Journal of Cleaner Production* 2018; 197: 1480-1487.
27. Elmaaty TA, Kazumasa H, Elsisi H, et al. Pilot Scale Water Free Dyeing of Pure Cotton Under Supercritical Carbon Dioxide. *Carbohydrate Polymer Technologies and Applications* 2020; 1, 25 December: 100010.
28. Luo X, White J, Thompson R, et al. Novel Sustainable Synthesis of Dyes for Clean Dyeing of Wool and Cotton Fibres in Supercritical Carbon Dioxide. *Journal of Cleaner Production* 2018; 199: 1-10.



*Received 30.10.2020* *Reviewed 18.12.2020*