The industrial water footprint of zippers

Yin Zhang, Xiong Ying Wu, Lai Li Wang and Xue Mei Ding

ABSTRACT

Industrial production of apparel consumes large quantity of freshwater and discharges effluents that intensify the problem of freshwater shortage and water pollution. The industrial water footprint (IWF) of a piece of apparel includes the water footprint (WF) of the fabric, apparel accessories (e.g. zipper, fastener, sewing thread) and industrial production processes. The objective of this paper is to carry out a pilot study on IWF accounting for three kinds of typical zipper (i.e. metal zipper, polyethylene terephthalate (PET) zipper and polyoxymethylene copolymer (Co-POM) zipper) that are commonly used for apparel production. The results reveal that product output exerts a remarkable influence on zipper's average IWF. Metal zipper has the largest IWF and followed by Co-POM zipper and PET zipper. Painting, dyeing and primary processing are the top three water-consuming processes and contribute about 90% of the zipper's IWF. Painting consumes the largest amount of freshwater among all processes and occupies more than 50% of the zipper's IWF. In addition, the grey water footprint (WF_{grey}) provides the greatest contribution, more than 80%, to the zipper's IWF. Based on these results, this paper also provides several strategies aimed at water economization and pollution reduction during industrial production of zipper.

Key words | apparel accessories, industrial water footprint, sustainability strategy, zipper

Yin Zhang
Lai Li Wang
Xue Mei Ding (corresponding author)
College of Fashion,
Donghua University,
Shanghai 200051,
China
E-mail: *fddingxm@dhu.edu.cn*

Xiong Ying Wu
Shanghai Entry-Exit Inspection and Quarantine Bureau,
Shanghai 200135,
China

Lai Li Wang
Centre Testing International Co., Ltd, Shanghai Branch,
Shanghai 201206,
China

Xue Mei Ding
Key Laboratory of Clothing Design & Technology (Donghua University),
Ministry of Education,
Shanghai 200051,
China

INTRODUCTION

Freshwater is an alarmingly scarce resource, with more than one billion people in developing nations lacking access to safe drinking water and more than two billion people lacking adequate water for sanitation (Bartram 2008). This scarcity of freshwater is of compelling concern to today's large-scale industrial production, which consumes considerable amounts of freshwater and discharges a large quantity of industrial sewage, and both of these are primary causes of the global water crisis and problems relating to the water environment. Thus, scientifically and effectively evaluating the impact of industrial production on the water environment is the premise and foundation of improving the efficiency of water utilization and management in industrial production, which is very important in relieving the stress on freshwater resources and water pollution.

The water footprint (WF) is an indicator of freshwater use and wastewater pollution that quantifies direct and indirect volumes. It is a multidimensional indicator that shows consumption and polluted water volumes, specified geographically and temporally (Hoekstra *et al.* 2011). As an important practical application on the evaluation of WF, the industrial water footprint (IWF) can reveal the water consumption and effluent discharge in the process of industrial activity and provide the scientific basis to manage and regulate water usage (Jia *et al.* 2012; Huang *et al.* 2013). An increasing number of publications on the WF of industrial products have been added to scientific literature recently. Van Oel & Hoekstra (2012) estimated the WF of paper production based on the case of the USA, considering the country's paper and pulp production sector as a whole. Yin *et al.* (2012) calculated the WF of steel products, and analyzed the actual situation of freshwater resources consumed in the steel industry. Francke & Castro (2013) studied the WF throughout the production line of a soap bar. Unger *et al.* (2013) reported the results of IWF of four Tata Group companies, namely Tata Steel, Tata Chemicals, Tata Power, and Tata Motors, across 12 industrial facilities in India.

The apparel industry increasingly faces water availability and quality issues in its widely distributed supply chain (Wang *et al.* 2013a). Improving environmental performance in the apparel supply chain is critical for the long-term viability of the industry as well as the sustainability of ecosystems

doi: 10.2166/wst.2014.323

and communities. So far, few studies have been devoted to the IWF of apparel products. Wang *et al.* (2013b) applied the concept of IWF to a case study of seven kinds of dyed cotton knits. Franke & Mathews (2013) reported the WF of C&A's cotton supply chain, and the results of the WF accounting showed that the wet processing is of the largest WFs in the cotton clothing supply chain. However, the IWF of clothing accessories (e.g. zipper, buttons and thread) has not been studied. Given that accessories are integral to apparel, the failure to estimate their IWF will lead to incomplete or inaccurate results of apparel's WF.

The goal of this study is to evaluate the IWF of zippers manufactured by Weixing Co., Ltd by examining different raw materials and production methods along the entire industrial stage. What distinguishes this study is that it can provide zipper manufacturers with suggestions about water economization and pollution reduction in their industrial stage. This study also can enrich the existing WF accounting for different kinds of industrial products, as well as build a data foundation for the accurate calculation of apparel's IWF.

METHODS

General approach

The IWF of three different types of zipper was analyzed from the raw material to the finished product. A zipper is generally distinguished by the material used in the zipper teeth. Three types of zipper (i.e. metal zipper, polyethylene terephthalate (PET) zipper and polyoxymethylene copolymer (Co-POM) zipper) covering the main categories of zipper were studied.

According to the existing studies, the IWF of a product includes direct water use and indirect water use, and has three components: blue water footprint (WF_{blue}, consumption of surface and groundwater), grey water footprint (WF_{grey}, freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards) and virtual water footprint ($WF_{virtual}$, water that is embedded in the inputs; it is not consumed during the processing of the researched products) (Hoekstra *et al.* 2011). Figure 1 shows the components of a product's IWF.

In this study, the functional unit was defined as a piece of representative zipper. The system boundary included the entire industrial stage from the raw material arriving at the manufacturer's premises to packing of finished zipper. In addition to the freshwater input, it also included the consumption of energy (include electricity and fuels), raw materials and auxiliary materials. The system boundary excluded the component which is regarded as making an insignificant contribution (e.g. 'larger than 1 per cent' or 'larger than 10 per cent' when interested in the largest components only), to the overall IWF (Hoekstra *et al.* 2011). Water use associated with the production of agriculture, warehousing, transportation and retailing processes were also excluded from the analysis as they had no contribution to the IWF of the zipper. The system boundary of the zipper's IWF is shown in Figure 2.

Data collection

For each type of zipper, a data inventory was constructed according to the process map provided by the factory. Preference was given to the use of primary activity data that were

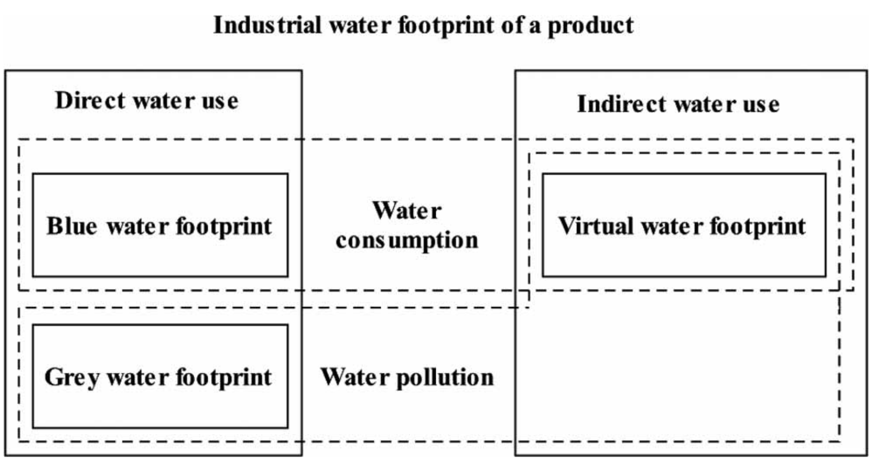

Figure 1 | Schematic representation of the components of IWF.

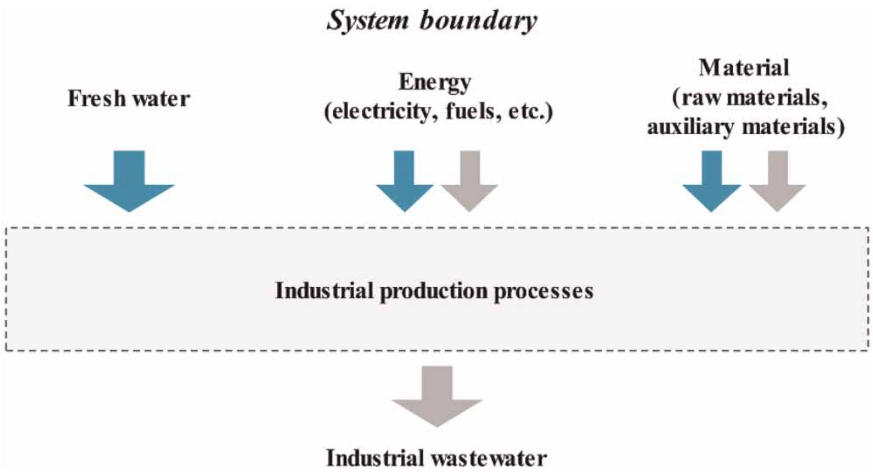

Figure 2 | System boundary of zipper's IWF.

collected from the processes owned, operated or controlled by the organization, and secondary data were used for inputs where primary activity data were not been obtained. In this study, the data collected directly from the factory consist of inputs to the processes (the consumption of freshwater, energy and materials) as well as outputs from the processes (the volume of discharged industrial wastewater and concentrations of water pollutants). In cases where the same factory was used to produce a range of different products, including products that were unrelated to this study, the water used to produce each product was determined using a rational basis that depended upon the extent of water metering in the plant.

For $WF_{virtual}$ (i.e. the WF of energy and materials used in the manufacture of zippers), WF factors were obtained from competent sources, such as authoritative publications, and peer-reviewed papers (Zhang *et al.* 2013). Table 1 presents WF factors for energy and materials.

Since the variability in production processes is dynamic and not necessarily the same between months or years, the IWF of a zipper is not constant. In this study, we calculated the zipper's IWF in three recent years (i.e. 2010, 2011 and 2012).

Industrial water footprint calculation

WF_{blue} of a processing step can be calculated as Equation (1):

$$WF_{proc,blue} = \text{blue water evaporation} + \text{blue water incorporation} + \text{lost return flow} \quad (1)$$

where the 'lost return flow' refers to the water that does not return to the same catchment area. We made the assumption that the manufacturer returns its effluents into the same catchment in this study. Thus, the 'lost return flow' is assumed to be zero. The WF_{blue} of the zipper can be calculated by the difference between water intake and wastewater discharged from a procedure.

Table 1 | WF factors for energy and materials

Energy/Materials	Unit	WF factor
Electricity	$m^3/kW \cdot h$	10.15×10^{-3}
Coal	m^3/t	7.01
Metal product	m^3/t	82.85
Dye	m^3/t	570.66
Textile auxiliaries	m^3/t	201.66
Packaging material (plastic product)	m^3/t	29.27
Paper product	m^3/adt (air dry ton)	10,567.39

WF_{grey} is an indicator of water pollution and can be calculated as Equation (2):

$$WF_{proc,grey} = \frac{L}{C_{max} - C_{nat}} = \frac{Effl \times (C_{effl} - C_{act})}{C_{max} - C_{nat}} \quad (2)$$

where L is the pollutant load, calculated as the effluent volume (*Effl*) multiplied by the difference between the concentration of the pollutant in the effluent (C_{effl}) and the actual concentration of the intake water (C_{act}). C_{max} is the ambient water quality standard for the corresponding pollutant, and C_{nat} is its natural concentration in the receiving water body. The WF_{grey} is determined by the chemical oxygen demand, which is the most critical pollutant, as it is the one associated with the largest pollutant-specific WF_{grey}. The maximum allowable concentrations in ambient water (C_{max}) refer to the national standard (i.e. GB 3838-2002 Surface Water Environment Quality Standard).

$WF_{virtual}$ refers to the amount of water, including the water consumed and polluted, implied in the energy and materials used in the zipper production process. $WF_{virtual}$ can be calculated as Equation (3):

$$WF_{proc,virtual} = \sum_{i=1}^{n} M_i k_i \tag{3}$$

where M_i is the consumption of energy or materials i, and k_i is the corresponding WF factor of energy/materials i ($i = 1, 2, \ldots, n$).

In this paper, the three components are reported separately because their costs are obviously different from each other. The total IWF is calculated by summing the three components according to Equation (4):

$$IWF = WF_{proc,blue} + WF_{proc,grey} + WF_{proc,virtual} \tag{4}$$

RESULTS AND DISCUSSION

Based on the methodology and data collected in the preceding sections, the average IWF of zippers was calculated, regardless of product type. The IWF of different processes as well as different components (i.e. WF_{blue}, WF_{grey} and $WF_{virtual}$) was also calculated and assessed.

Average IWF

Figure 3 presents the average IWF and product output per month for zippers without considering the product type. It can be seen that from January to June, the average IWF of zipper decreased gradually with the product output increasing. From July to December, the average IWF changed slightly with the decreasing of monthly product output. The average IWF is the largest in January while it is the smallest in July. In contrast, the collective primary data shows that the production in January is the smallest while it is the largest in July. Since average IWF is calculated based on monthly consumption of freshwater and monthly total product output, it indicates the overall stability of the freshwater consumption per unit product in its industrial stage. The former comes from all the freshwater-consuming sources of production processes, such as painting or dyeing.

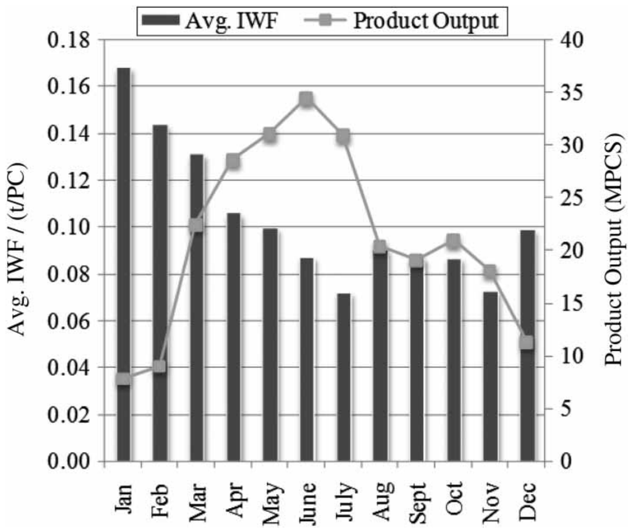

Figure 3 | Average IWF and product output per month of zipper (PC: piece; MPCS: million pieces).

The latter would be affected by production order, plan and efficiency. Therefore, measures could be adopted to achieve an optimal balance between monthly freshwater consumption and monthly total production, and consequently to decrease zipper's IWF.

IWF of processes

Figure 4 shows the percentage of different production processes in the total IWF of metal zipper, PET zipper and Co-POM zipper, respectively. We can see that the metal zipper has the largest IWF, followed by Co-POM zipper and PET zipper. This is due to the different processes applied in the production, their varying water consumption, the diverse chemicals used and their environmental toxicity.

It also can be seen that the percentage of a process' contribution to the total IWF varies significantly among different production processes for the three types of zipper. For zipper products, painting, dyeing and primary processing are the top three freshwater-consuming processes, which totally contribute about 90% of their IWFs. Painting is a production process that uses a huge amount of water to color some parts of the zipper, such as the slider. What's more, this process is the main source of industrial wastewater containing pollutants to be assimilated. Therefore, painting consumes the highest amount of water among all processes and occupies more than half of total IWF, as seen in Figure 4. The dyeing of the zipper's tape also needs large volumes of freshwater and discharges wastewater with high concentrations of water pollutants

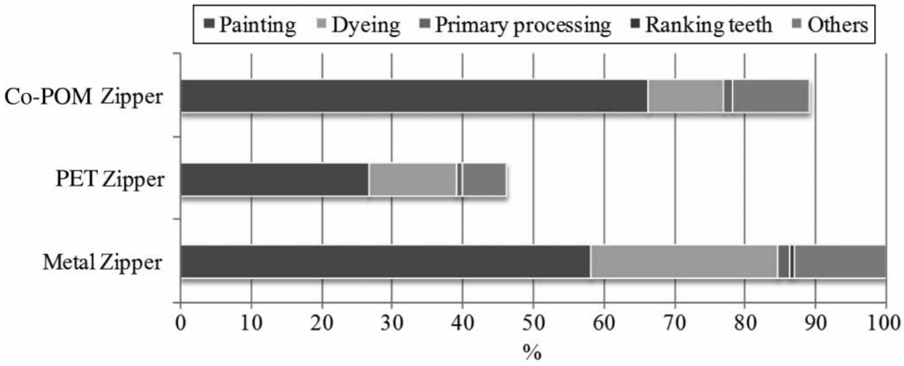

Figure 4 | IWF percentage of the different production processes.

caused by dyes and auxiliaries. Also primary processing is inefficient. It occupies a relatively high percentage of all the processes in the total IWF except painting and dyeing. Therefore, fully understanding the utilization of water resources and discharge of industrial wastewater in these three production processes could provide a basis for minimizing water consumption in the industrial stage of zipper products.

IWF of components

Figure 5 presents the percentage of different components of the total IWF of metal zipper, Co-POM zipper and PET zipper, respectively. The total IWF of the three types of zippers are all dominated by the WF_{grey} component, which occupies more than 80% of total value. Therefore, reducing WF_{grey} appears to be a way to lower the total IWF. WF_{grey} is influenced by the significant discharge of wastewater and the high concentration of water pollutants. In order to achieve a smaller WF_{grey} for zipper production factories, several measures should be taken to minimize the wastewater discharge effectively. For example, the wastewater reuse network should be designed to make maximal reuse of wastewater. From a production viewpoint, the use of dyes and auxiliaries in the production processes, especially dyeing and printing, should be minimized while maintaining product quality.

$WF_{virtual}$ also occupies a certain proportion in the total IWF of zipper products, as seen in Figure 5. This illustrates that implied water use in the energy and materials used in the production process plays an important role in the total water consumption, and indicates the potential water economization opportunity. In addition, comparing the percentages of the three components, one also can see that the share of WF_{blue} compared to the share of WF_{grey} or $WF_{virtual}$ is extremely small. Nevertheless, it should not be neglected, since it may have local impacts.

CONCLUSIONS

IWF evaluation of clothing accessories is becoming a key point to raise competition and realize sustainable development for apparel enterprises and the textile industry. Key

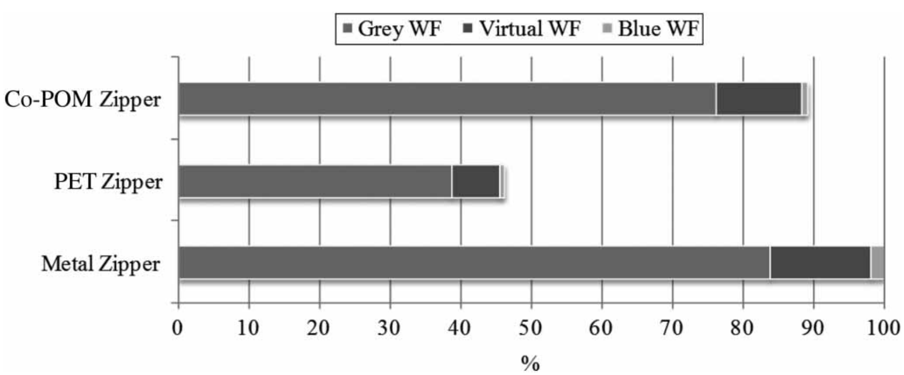

Figure 5 | Percentage of WF_{blue}, WF_{grey} and $WF_{virtual}$ in the total IWF.

factors in the evaluation include clear and detailed accounting of the WF relevant to the entire industrial stage and the inclusion of each production process's WF.

With this approach in hand, we focused on the case of zippers manufactured by Weixing Co., Ltd. The zipper's important position in apparel makes this a well representative analysis for the case of clothing accessories. Our analysis has brought several key findings to light. First, product output exerts a significant influence on the average IWF without considering product type. Therefore, some measures should be adopted to achieve the good balance between freshwater consumption and total production, and consequently to decrease a zipper's IWF. In practical terms, such measures may include adjusting the production order, production plan and production efficiency. Secondly, for the three kinds of typical zipper in this study, metal zipper has the largest IWF followed by Co-POM zipper, and PET zipper the least. The variation of their IWF indicates that replacing metal zippers by PET zippers could well be a more sustainable choice. Thirdly, painting, dyeing and primary processing are the top three water-consuming processes, which contribute about 90% of zipper's IWF. Painting consumes the highest amount of water amongst all processes and occupies more than half of the total IWF. In this sense, zipper manufacturers who seek to reduce the IWF of products they offer to consumers will need to become increasingly engaged in these three production processes, especially painting. Furthermore, the percentages of blue, grey and virtual components in the total IWF shows that the WF_{grey} accounts for the greatest contribution to a zipper's IWF: more than 80% of total value. Considering that WF_{grey} always lies in the numerous discharges of wastewater and the high concentration of pollutants, an important strategy for sustainability should be minimizing the wastewater discharge and reducing the extensive use of dyes and auxiliaries in production processes, such as dyeing and printing. Any reduction in the discharge of wastewater or the use of fertilizers would be reflected in a smaller IWF.

This is the first study quantifying the IWF of zipper products. By calculating water use across the entire industrial stage, including blue, grey and virtual water components, insights are gained which are valuable to zipper manufacturers. This kind of information highlights the water-intensive production process and ingredients of zipper products, providing a basis for developing strategies and prioritizing actions aimed at reducing freshwater use. The information can also facilitate engagement across the apparel supply chain and a coordinated whole-of-chain approach to water use reduction. But so far, there is no publicly available database for the WF of industrial products and processes. This highlights the critical importance of developing a WF database for industrial products and gathering data to develop benchmarks for specific processes and products. As a consequence, there is a need for further development and improvement of the available database as well as the methodology of IWF.

ACKNOWLEDGEMENTS

The authors would like to thank Weixing Co., Ltd for pushing forward the application of the industrial water footprint method at the corporate level, by deciding to explore what this method can offer to a frontrunner company like Weixing and the industry as a whole. We are also grateful to the National Natural Science Foundation of China for providing funding support to this research through project 71373041, the Ministry of Science and Technology of the People's Republic of China for providing funding support to this research through project 201010041, and to Donghua University for providing funding support to this research through project 'The Fundamental Research Funds for the Central Universities'. Special thanks are extended to anonymous referees and the Editor-in-Chief of this journal for their valuable and constructive comments on the paper.

REFERENCES

Bartram, J. 2008 Improving on haves and have-nots. *Nature* **452** (7185), 283–284.

Francke, I. C. M. & Castro, J. F. W. 2013 Carbon and water footprint analysis of a soap bar produced in Brazil by Natura Cosmetics. *Water Resources and Industry* (1–2), 37–48.

Franke, N. & Mathews, R. 2013 C&A's Water Footprint Strategy: Cotton Clothing Supply Chain. http://www.waterfootprint.org/Reports/CA_Strategy_Final_Report_Formatted 2006.08.2013.pdf (accessed 12 January 2013).

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. & Mekonnen, M. M. 2011 *The Water Footprint Assessment Manual: Setting The Global Standard*. Earthscan, London, UK.

Huang, S. L., Du, C., Li, W. & Wang, L. H. 2013 Research on the theory and method of industrial water footprint. *Ecological Economy* (1), 28–31.

Jia, J., Yan, Y., Wang, C. X., Liang, Y. J., Zhang, Y. J., Wu, G., Liu, X. L., Wang, L. H. & Du, C. 2012 The estimation and application of the water footprint in industrial processes. *Acta Ecologica Sinica* **32** (20), 6558–6565.

Unger, K., Zhang, G. & Mathews, R. 2013 *Water Footprint Assessment Results and Learning: Tata Chemicals, Tata*

Motors, Tata Power, Tata Steel, Tata Quality Management Services. International Finance Corporation, and Water Footprint Network, New Delhi, India.

Van Oel, P. R. & Hoekstra, A. Y. 2012 Towards quantification of the water footprint of paper: a first estimate of its consumptive component. *Water Resource Management* **26** (3), 733–749.

Wang, L. L., Ding, X. M. & Wu, X. Y. 2013a Blue and grey water footprint of textile industry in China. *Water Science & Technology* **68** (11), 2485–2491.

Wang, L. L., Ding, X. M., Wu, X. Y. & Yu, J. M. 2013b Textiles industrial water footprint: methodology and study. *Journal of Scientific and Industrial Research* **72** (11), 710–715.

Yin, T. T., Li, E. C. & Hou, H. J. 2012 Research on water footprint of steel product. *Bao-Steel Technology* (3), 25–28.

Zhang, Y., Chao, H., Wu, X. Y. & Ding, X. M. 2013 Water footprint factor of energy and materials in textile and garment industry. *Dyeing and Finishing* **39** (18), 41–45.

First received 10 February 2014; accepted in revised form 8 July 2014. Available online 23 July 2014