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The Influence of Physical Factors on Wool Fibre Colour Changes

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Wool fibre has it native colour, but it changes during storage, scouring, dyeing, bleaching, decatizing and other finishing processes. The aim of this work was to investigate the influence of physical factors such as temperature and humidity on the colour of wool fibres which differed in their initial colours. The data of investigations showed that treatment of wool fibre at relatively low temperature, i. e. 85 °C, and higher temperature i. e. 165 °C, changed wool fibre colour. Dry and especially wet wool fibres changed their colours more intensively prolonging heating time. Light wools remained lighter and after heating comparing with the yellowest wool. However, light wools had more propensity to yellow during heating.

Keywords: wool fibre, colour, yellowness, physical factors.

1. INTRODUCTION

Wool fibre has it native colour. Some wools are lighter some are more pigmented. Pigmented wool fibre contains an excessive amount of melanin responsible for its black or brown colour [1].

Cameron and Stobart established that there were differences in the yellowing propensity of the Rambouillet sheep breed [2]. There was no correlation between fibre diameters and the yellowing propensity observed. This study implies that there is a genetic predisposition for wools to develop a yellow colour, there appears to be sufficient variability that selection against the propensity to yellow would decrease the incidence of natural yellowing in fleeces.

Wool colour is not stable and it changes during storage [1, 3], scouring, dyeing [4], bleaching, decatizing [5, 6] and other finishing processes. The factors, which are damaging and make influence on wool fibre colour are temperature, amount of humidity, mechanical action, chemicals, duration of treatment [5, 7]. Even unsheared wools are damaged of sun, humidity, mechanical actions [7], etc. By reason of this, colour, porosity, elasticity, softness, strength, dye ability of wool fibre change [8].

The intensity of wool fibre structure and physical properties negative changes may be reduced using some chemicals and appropriate conditions of finishing processes. The dependence of physical properties of keratin fibres upon their structure changes occurring during oxidative bleaching with or without nonionic and slightly cationic surfactants was investigated [9]. It was noticed that slightly cationic surfactant used in bleaching solution reduced the damage of hair fibres and enhanced dye exhaustion in dyeing.

Wool yellowing has been of a great interest within the textile industry [2]. This phenomenon is undesirable. Discoloured or especially yellow wool's cannot, for example, be used in pastel shade apparel. Any reduction in yellowness of wool fibre would potentially improve the acceptability of the wool to processors (and thus increase the price).

The study of wool fibre one-week water bath incubated at 40 °C or incubated overnight at a higher temperature showed that the bacteria presented in raw wool played a significant role in colour biodegradation during storage [1].

Wool yellowing can be produced by irradiation and by thermal treatments exceeding 100 °C [10]. Several papers were published on this, but the mechanism of colour formation has not yet been firmly established [10 – 15].

Thermal and hydrothermal yellowing is a chemical process and appears irreversible. The yellow colored chromophores form due to decomposition of cysteine, tyrosine and oxidation of tryptophan [7, 10, 11, 14, 15]. Colour changes are induced by the superheated steam and they become more distinct with higher temperatures (120, 130, 140, 150 °C) and longer exposure times (30, 60, 120, 180, 240 s) [13]. Above 150 °C, damage of the wool fibres becomes more severe, because wool fibre yellowed. Wet wools yellow more intensive than dry ones.

McMullen and Jachowicz [11] have investigated thermal treatments on human hair when the temperature ranges from 130 °C to 160 °C for extended periods of time (5 – 15) min or 15 s. Hunter colorimetry was employed to quantify thermally induced colour changes in hair. They estimated an increase in the yellowness of white and Piedmont hair or simultaneous yellowing and darkening of bleached hair.

Montazer *et al* [1] investigations with pigmented wool showed that the oxidative/reductive bleaching process produced wool yarns with better optical properties.

Wool fibre changes it colour during UV irradiation as well [16]. The variation of yellowness index was observed when wool fibre was exposed to 20, 50 and 80 hours of UV irradiation. It was noticed a sharp increase in yellowness values after 20 hours of UV irradiation. When the duration of exposure was increased from 20 hours to 50 hours for all treated wool samples yellowness index changed almost insignificantly. The values of lightness of exposed to UV irradiation wool fibres varied conversely to values of yellowness indexes.

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The aim of this work was to investigate the influence of physical factors such as temperature and humidity on the colour of wool fibres which differed in their structures and initial colour.

2. EXPERIMENTAL

Materials. Three fabrics (*1F, 2F, 3F*) of pure merino wool fibre were used for the studies. They differ in their linear densities of the yarns, in area densities, warp and weft settings (accordingly S_1 and S_2) as well. The structure of *1F* was: linear density 34 tex, area density 123 g/m^2, S_1 and S_2 were 210 dm^{-1}; *2F* – 129 tex, 353 g/m^2, S_1 and S_2 were 130 dm^{-1}; *3F* – 150 tex, 406 g/m^2, S_1 and S_2 were 100 dm^{-1} respectively. The weave of all fabrics was plain. These all fabrics were called untreated *1F, 2F* and *3F* fabrics.

Procedures. *Wet heating at 85 °C.* Wool fabrics were treated in the oven at 85 °C and 100 % relative humidity for 20, 40 and 60 min.

Dry heating at 165 °C. All dry wool fabrics were heated at 165 °C between two metallic plates for 1, 2 and 4 min.

Wet heating at 165 °C. Wool samples were moistened with distilled water and after water elimination they had 35 % – 45 % of w.w. water inside. Wet wool samples were heated between metallic plates at 165 °C for 1, 2 and 4 min.

Tests. The changes of wool fibre colour during different treatments were evaluated by measuring colour coordinates in digits and calculating values of Yellowness Index *YI*. "Spectraflash SF450X" (Datacolor International spectrophotometric system) device was used for colour coordinates estimation. It was measured *CIELAB* colour space coordinates such as: lightness L^*, yellowness b^*/blueness $-b^*$, redness a^*/greenness $-a^*$, hue H, croma C and the total colour difference ΔE (*Delta E*). Illuminant D_{65} and 10° observer were employed during measurements. Five measurements were performed and the average values of colour coordinates were calculated.

The total colour difference ΔE was calculated according to the following equation [17, 18]:

$$\Delta E = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2}\ , \quad (1)$$

where ΔE (*Delta E*) is the total colour difference, ΔL^* is the lightness difference, Δa^* is the redness difference, Δb^* is the yellowness difference. All differences of colour coordinates were calculated between treated and untreated samples. L^*, b^*, a^*, C, ΔE are given in NBS units and H in degrees [17].

Yellowness Index *YI* (%) was calculated according the following equation:

$$YI = 100\,(1.28X - 1.06Z)/Y; \quad (2)$$

where X, Y, Z are the colour coordinates of the sample. They were measured using the spectrophotometer mentioned above.

The absolute deviations of all colour parameters of examined samples didn't exceed 0.3 NBS units. The standard deviations didn't exceed 2.5 %.

3. RESULTS AND DISCUSSION

The untreated wool fibres *1F, 2F, 3F* differed in their intensity of yellowness, which was expressed by Yellowness indexes *YI* and yellowness b^* (Figs. 1 and 2). The *YI* of untreated *1F* was 24.1 %, of *2F* was 25.4 %, *3F* was 41.5 %. The b^* value of untreated *1F* was 12.3, of *2F* was 12.8, *3F* was 19.4.

The data of wool fibre yellowing during heating at 85 °C for 20, 40 and 60 min are presented in Figs. 1 and 2. The values of Yellowness Indexes *YI* show that untreated wool fibre fabric *1F* was light and it remained light after 20, 40 and 60 min of heating. The values of yellowness b^* of *1F* (Fig. 2) were lower than that of others fibres. *2F* fabric yellowed prolonging treatment time. Yellowness changes show the data of *YI* and yellowing b^*. The *YI* values of *2F* fibre increased respectively for 20 min 1.88 %, for 40 min 3.2 % and for 60 min 2.52 % comparing with untreated *2F*. Significantly higher *YI* values were calculated for untreated *3F* wool fabric than that for *1F* and *2F*. It was noticed a little decrease of *YI* values after 20 min and 40 min of heating. However, *3F* fibre yellowed prolonging treatment time to 60 min (Figs. 1 and 2). These results sustain the theory, which announce, that wool fibre yellows more intensive prolonging steaming time and this shows that chemical structure of wool fibre changes [5].

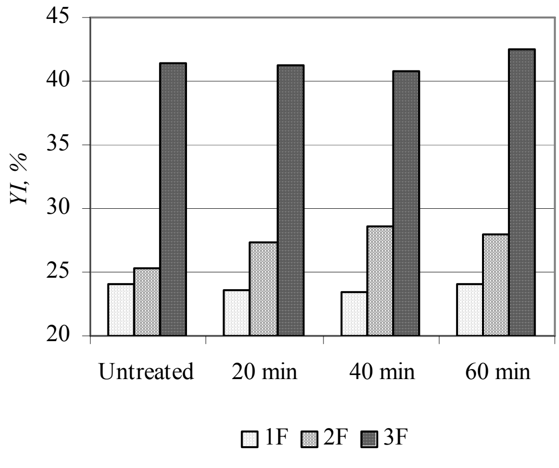

Fig. 1. Yellowness Indexes *YI* of wool fabrics treated at 85 °C

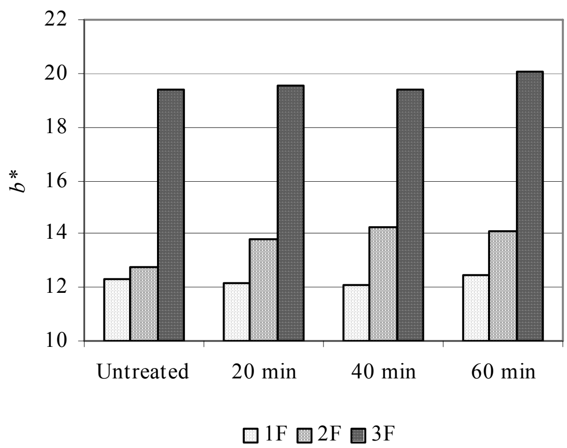

Fig. 2. Yellowness b^* of wool fabrics treated at 85 °C

The data of wool fibre lightness L^* are resented in Fig. 3. The L^* of untreated *1F* was 85.5, of *2F* was 83.1, of *3F* was 76.1. During heating the L^* varied in opposite to *YI* and b^* (Figs. 1 and 2).

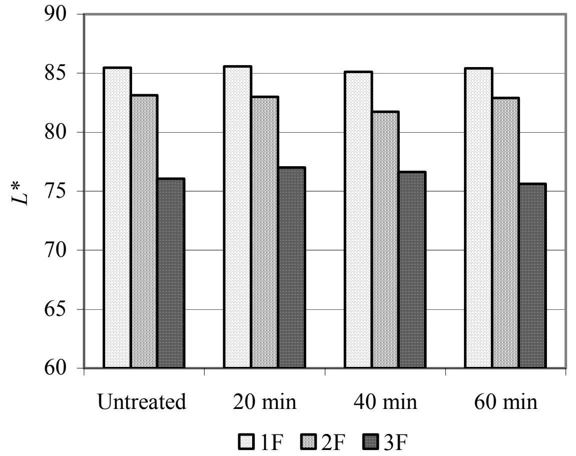

Fig. 3. Lightness L^* of wool fabrics treated at 85 °C

The total colour difference *Delta E* of wool fibre colour changes after heating 20, 40 and 60 min compared with corresponding untreated fibre is presented in Fig. 4. The data show that heating at 85 °C for 20, 40 and 60 min slightly influenced to total colour changed of *1F* fibre comparing with others. *Delta E* values of fibre *2F* are higher due to more intensive wool fibre yellowing (b^* values) and loss of lightness L^* particularly after 40 min of heating.

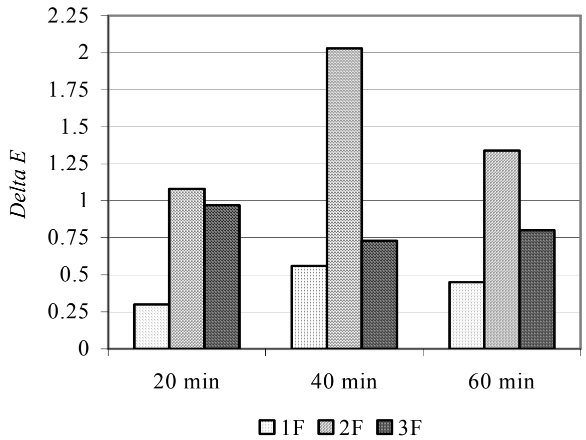

Fig. 4. The total colour difference *Delta E* of wool fabrics treated at 85 °C

All dry wool fibre fabrics were treated at 165 °C for 1, 2 and 4 min. The data of investigations presented in Figs. 5 and 6 show, that the surfaces of *1F* and *2F* wool fibres exhibit the yellow colour containing particles intensively when the time of treatment was prolonged. The *YI* value of *1F* after 4 min heating at 165 °C grew 5.35 %, of *2F* it grew 3.75 % and of *3F* it was almost the same as of *3F* untreated. It is obviously from Figs. 5 and 6 that after 1 min and 2 min of heating *YI* and b^* values of *3F* decreased comparing them with of *3F* untreated and 4 min treated. It could be, that yellow particles were slightly affected (bleached) of heat. However, prolonging treatment time to 4 min *3F* wool fibre yellowed to the same intensity as of *3F* untreated. Conversely to *YI* and b^*, after 1 min and 2 min of heating the L^* values (Fig. 7) increased, after 4 min they decreased due to *3F* wool fibre yellowed. Lightness L^* of *1F* slightly declined prolonging treatment time, however it was not noticed the changes in L^* of *2F*.

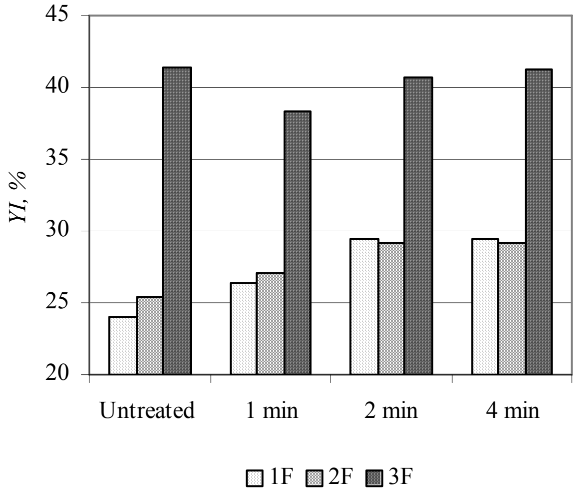

Fig. 5. Yellowness Indexes *YI* of dry wool fabrics treated at 165 °C

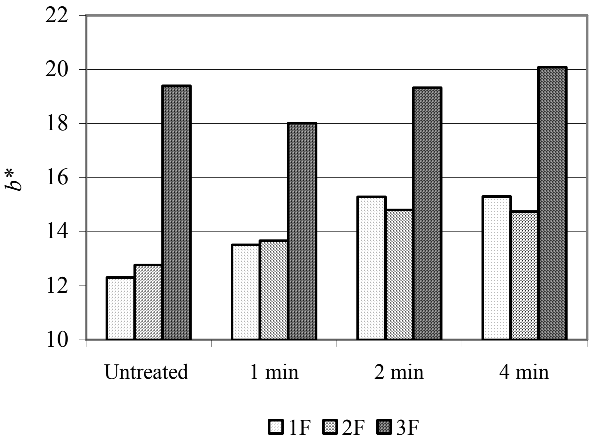

Fig. 6. Yellowness b^* of dry wool fabrics treated at 165 °C

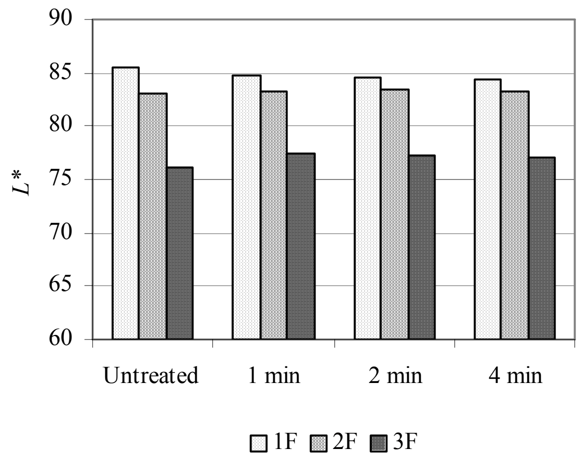

Fig. 7. Lightness L^* of dry wool fabrics treated at 165 °C

The data of total colour difference *Delta E* of dry wool fibre treated at 165 °C (Fig. 8) show intensity of colour changes comparing with corresponding untreated wool sample. The treatment conditions influenced on the total colour changes of all examined wool samples. Prolonging treatment time colour changes of *1F* were more significant. *2F* fibre, especially when wool fibre was more heated 2 min and 4 min at 165 °C. It could be due to *1F* fabric was thinner comparing with *2F* and *3F*, therefore the temperature of 165 °C could penetrate into the deeper layers of the fabric and elementary fibres and to form more yellow particles.

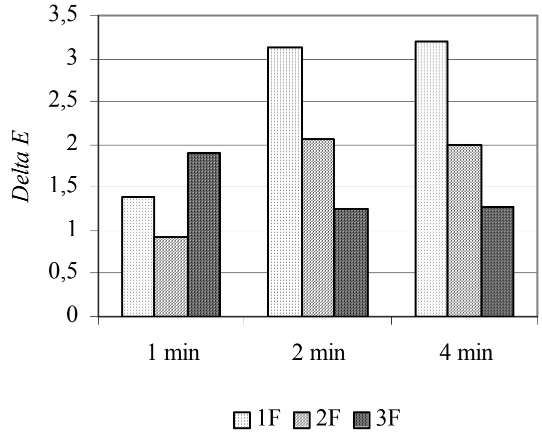

Fig. 8. The total colour difference *Delta E* of dry wool fabrics treated at 165 °C

The values of Yellowness Indexes *YI*, yellowness *b** and lightness *L** of *1F, 2F* and *3F* samples after wet heating at 165 °C are presented adequately in Figs. 9 – 11.

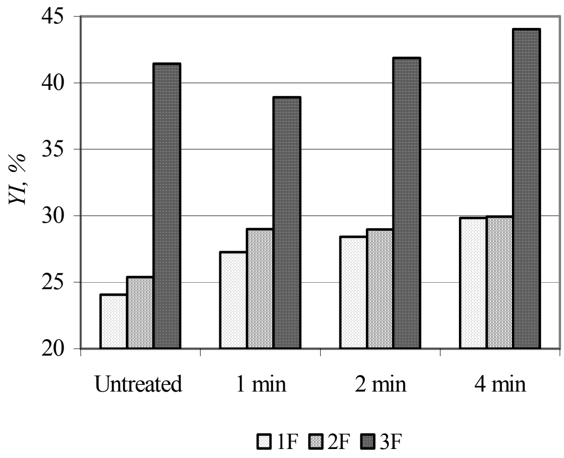

Fig. 9. Yellowness Indexes *YI* of wet wool fabrics treated at 165 °C

The tendencies of *YI, b** and *L** changes during wet heating are very similar to appropriate dry wool fibre. However the values of *YI* and *b** are a little bit higher comparing with dry heating (Tables 1 and 2). The reason of this is more harmful conditions of treatment due to the water inside the fibre. Cottle [12] and Schwartze *et al* [13] estimated that dry wool is more resistant to heating than wet wool. Schwartze and McKinnon [12] noticed that wool fibre yellowed more intensive at 100 °C when it was wet. McMullen and Jachowicz [11, 15] estimated that wool fibre yellows during boiling in the water. The yellow colour chromophores form due to changes in cysteine, tyrosine or tryptophane.

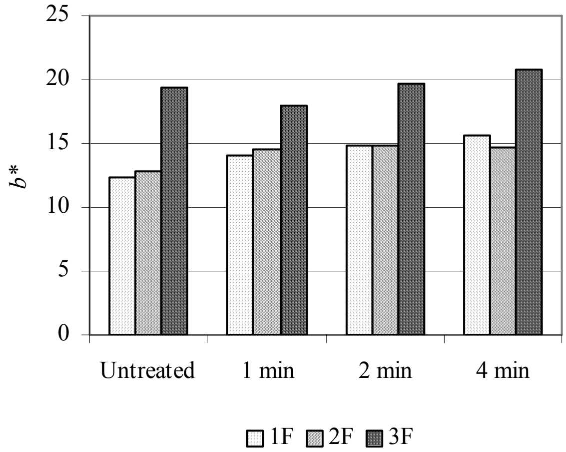

Fig. 10. Yellowness *b** of wet wool fabrics treated at 165 °C

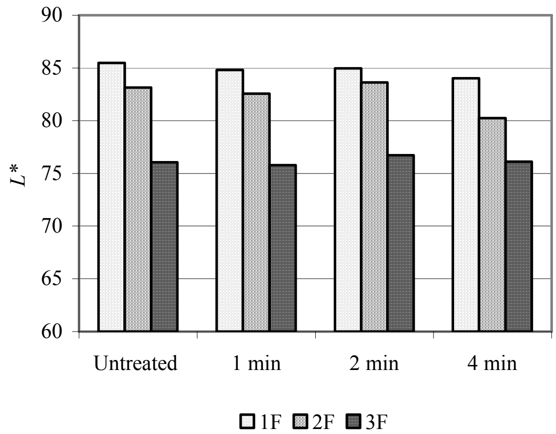

Fig. 11. Lightness *L** of wet wool fabrics treated at 165 °C

Table 1. Δ*YI* (%) between treated at 165 °C and untreated samples

Treatment time	*1F*		*2F*		*3F*	
	dry	wet	dry	wet	dry	wet
1 min	2.32	3.2	1.65	3.6	-3.07	-2.53
2 min	5.35	4.36	3.74	3.58	-0.70	0.42
4 min	5.36	5.76	3.75	4.54	-0.14	2.59

Table 2. Δ*b** between treated at 165 °C and untreated samples

Treatment time	*1F*		*2F*		*3F*	
	dry	wet	dry	wet	dry	wet
1 min	1.21	1.83	0.9	1.7	-1.39	-1.48
2 min	2.98	2.56	2.03	2.02	-0.08	0.33
4 min	2.99	3.26	1.97	1.98	0.68	1.37

The data of *Delta E* presented in Fig. 12 show that the lighter untreated (*1F* and *2F*) wool fibre was the total colour changes were more evident after wet heating 1, 2 and 4 min at 165 °C degree. Untreated *3F* fibre was the yellowest of all untreated wool fibres. However, it had a smaller potential to yellow and to change the total colour during wet heating comparing with *1F* and *2F* wool fibres.

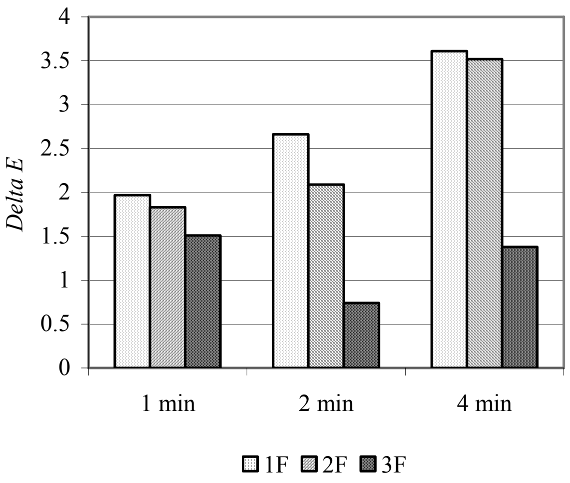

Fig. 12. The total colour difference *Delta E* of wet wool fabrics treated at 165 °C

Cottle's [19] results of investigations showed very similar tendencies. He concluded that highly resistant wools are white and remain white after environmental challenge by heat and humidity. Susceptible wools may be white or yellow to varying degrees depending on natural conditions, but they will further discolour when subjected to a challenge.

4. CONCLUSIONS

Treatment of wool fibre at relatively low temperature, i. e. 85 °C, and higher temperature i. e. 165 °C, changed wool fibre colour. Dry and especially wet wool fibres changed their colours more intensively prolonging heating time. Light untreated wools *1F* and *2F* and after all treatments of heating remained lighter comparing with *3F*. However, the light wools had more propensity to yellow than the yellowest *3F* wool fibre.

REFERENCES

1. **Montazer, M., Zargaran, M., Rahimi, A.** Depigmentation of Pigmented Wool *Textile Research Journal* 79 (3) 2009: p. 261.
2. **Cameron, B. A., Stobart, R. H.** Improving Wool Color Through Selective Breeds Using Yellowing Propensity Measurements. http://209.85.135.132/search?q=cache:dD4qolfKxFEJ:www.reeis.usda.gov/web/crisprojectpages/213398.html+wool+yellowing&cd=16&hl=lt&ct=clnk&gl=lt (2010.03.23)
3. **Cottle, D. J.** Changes in Wool Colour. Part II: Dumping and Storage *Journal of the Textile Institute* 89 (1) 1998: pp. 10 – 25.
4. **Peters, R. H.** Textile Chemistry (Impurities in Fibres; Purification of Fibre). Amsterdam, London, New York, 1967.
5. **Peters, R. N.** Chemistry of Textile (Physical Chemistry of Dyeing). Part 1. Moscow, Legprombitizdatelstvo, 1989.
6. **Bona, M.** Modern Control Techniques in the Textile Finishing and Making-up. Universidade do Minho, Italy, 1990.
7. **Lewis, D. M.** Wool Dyeing. Bradford, UK, 1992.
8. **Millington, K. R.** The Use of Ultraviolet Radiation in an Adsorbable Organohalogen-Free Print Preparation for Wool and in Wool Dyeing: the Siroflash Process *Journal of the Society of Dyers and Colorists* 114 1998: pp. 286 – 292.
9. **Ragelienė, L., Treigienė, R., Musnickas, J.** Physical Properties Human Hair Dyed Using Nonionic Surfactants *Materials Science* (*Medžiagotyra*) 15 (3) 2009: pp. 277 – 282.
10. **Marschall, R.C., Souren, I., Zahn, H.** Protein Changes After Short Thermal Treatments of Wool Fabric *Textile Research Journal* 12 1983: pp. 792 – 794.
11. **McMullen, R., Jachowicz, J.** Thermal Degradation of Hair. I. Effect of Curling Irons *Journal of Cosmetic Science* 49 (7 – 8) 1998: pp. 223 – 244.
12. **Cottle, D. J.** Changes in Wool Color. Part II: Dumping and Storage *Journal of Textile Institute* 89 (1) 1998: pp. 10 – 25.
13. **Schwartze, J. P., McKinnon, A. J.** Wool Colour Changes in Superheated Steam *Textile Research Journal* 70 (3) 2000: p.p. 205 – 209.
14. **McMullen, R., Jachowicz, J.** Thermal Degradation of Hair. II. Effect of Selected Polymers and Surfactants *Journal of Cosmetic Science* 49 (7 – 8) 1998: pp. 245 – 256.
15. **McMullen, R., Jachowicz, J.** Thermal Degradation and Protection of Hair *Journal of Cosmetic Science* 49 (3) 1998: pp. 190 – 191.
16. **Treigienė, R., Musnickas, J. R.** Influence of UV Exposure on Properties of Wool Fiber Pretreated with Surfactants Solutions *Materials Science* (*Medžiagotyra*) 14 (1) 2008: pp. 75 – 78.
17. **Ingamels, W.** Colour for Textiles. Society of Dyers and Colourists. Bradford, UK, 1993.
18. **McDonald, R.** Colour Physics for Industry. Society of Dyers and Colourists. Bradford, UK, 1997.
19. **Cottle, D. J., Zhao, W.** Changes in Wool Color. Part I: Incubation of Wool to Promote a More Stable Wool Colour *Journal of Textile Institute* 86 1995: pp. 136 – 147.