Abstract – Prewashed raw (unbleached) and bleached 100 % linen fabrics were flat screen printed with pastes Tubivis DRL 300 or Tubvinyl 235, a flame retardant agent for cellulosic articles Apyrol CEP addition and pigment Bezaprint Green BT. Half of the printed fabrics were after-washed. The burning characteristics of raw and bleached, and the same printed and printed, after-washed fabrics were tested. The best performance in flame retardancy was achieved for bleached linen printed with Tubivis DRL 300 paste and for after-washed raw linen fabric printed with both pastes.

Keywords – Linen fabric, printing, flammability reduction.

I. INTRODUCTION

Linen fabrics are popular as home textiles. Nevertheless linen fabrics are flammable. Reduction of flammability of textiles has been increased by governmental legislations in different countries (1). Human safety issues play a leading role in the mainstream world security, ensuring the prevention of accidents that can cause injuries to human health (2), environment and possessions.


The use of flame retardants (FR) is a one of the most common strategies used to improve the fire performance of textiles and other materials (4).

The global market for FR chemicals is valued at 6.1 million USD in 2014 and is expected to reach 14.32 million USD by 2022 at a compound annual growth rate (CAGR) of 11.25 %. Factors that drive the market include a high demand from current and emerging applications, emerging economies and advancement in technology. Increasing costs and strong government regulations are the major restraints of the market. Construction and automotive industry and other major end-user industries of FR chemicals rise globally (5).

In our previous research continuous coating with commercial printing pastes containing antimony trioxide for improving flame retardancy of local Latvian linen fabrics was used. For all coated and coated after-washed fabrics good flame resistance was observed (6).

The use of printing technologies for treatment of textiles allows reaching different effects on inexpensive textile surfaces. The aim of this research is to investigate burning characteristics of raw and bleached linen fabrics, same as in previous research (6), printed with compositions containing commercial pastes Tubivis DRL 300 or Tubvinyl 235, a permanent organophosphate flame retardant agent for cellulosic articles of protective workwear, decoration articles, upholstery fabrics, bed clothes in hospitals, tent fabrics and similar fabrics made in the padding process (7). Apyrol CEP and pigment Bezaprint Green BT (producer CHT BEZEMA). In most of cases flame retardant cellulosics are produced by chemically after-treating fabrics in the textile finishing process that, depending on chemical characteristics and cost, yield flame retardant properties. In cases of correct treatment, textiles finished with Apyrol CEP are stable during multiple washings and dry cleaning (8).

The printing for flammability reducing is applicable for home textiles: curtains, blinds, upholstery, coverings and wallpapers, airplane and automotive textiles: cars seats, floor carpets etc. (9).

Textile materials are printed using different patterns (raised printing, lowered printing, screen printing) and different techniques (block, roller, flat screen, rotation screen, sublimation) (10).

Colour pigments have been used for printing of textiles for many centuries. They were passed onto the fabric using natural resin. Nowadays, pigment printing market shared of more 50 %. Advantage of the technique is cost-effectiveness and the ecological aspect, because the procedure involves no wet processes (11). In pigment printing, water-insoluble pigments are applied with a heat-curable binder system, followed by drying and curing and the physical properties of the pigment print depend greatly upon the adhesive properties of print binder system (12).

In addition to obtaining decorative pattern on a linen textile by printing, it is also possible to improve the fire resistance.

II. MATERIALS AND METHODS

A. Materials

Plain weave raw (unbleached) 100 % linen fabric with surface density 178 g m⁻² (R0 – Fig. 1 A) and bleached linen fabric with surface density 190 g m⁻² (B0 – Fig. 1 B) from Larelīti Ltd. was used. Raw and bleached linen fabrics were pre-washed before printing in a water solution of washing agent Felosan NOF (CHT R Beitlich GmbH), concentration 2 g L⁻¹, liquor ratio (M) – 30, temperature – 100 °C, time – 60 min with following rinsing in cold/warm water.
substrate using a blade. Drying of printed samples was done at 110–120 °C for 7 ± 1 min and a thermal treatment at 160 °C for 3 ± 1 min was applied.

C. After-washing.

For half of the printed raw and bleached linen fabrics 5 washing cycles in solution of sodium carbonate (3 g L⁻¹) and washing agent Felosan NOF (5 g L⁻¹) in distilled water at M 30, 40 °C for 15 min with following rinse in cold/warm water, according to ISO 105-C10:2006 was used.

D. Burning Test.

Each of 6 received samples (14 pieces – 8 vertically and 6 horizontally, 200 × 160 mm) were tested in accordance to LVS EN ISO 15025:2003 for protective clothing – test for limited flame spread to the surface (horizontal test) and the bottom edge (vertical test) of fabric, before and after 5 washing cycles. The burning tests were done in Latvian Centre of Certification (LATsert).

III. RESULTS AND DISCUSSION

Prewashed raw (Fig. 1 A) and bleached (Fig. 1 B) Latvian linen fabrics were printed manually using the flat screen method. Commercial synthetic thickener Tubivis DRL 300 or dispersion-based adhesive Tubivinyl 235 with permanent organophosphate flame-retardant for cellulosic textiles Apyrol CEP and pigment Bezaprint Green BT were used for printing. The right side of the fabrics was with a decorative print (Fig. 2 A, Fig. 3 A, Fig. 4 A, Fig. 5 A). Pushing on the left side fabrics printed with synthetic thickener Tubivis DRL 300 was slightly noticeable (Fig. 2 A, Fig. 3 A), while pushing of the flock adhesive Tubivinyl 235 was observed vastly through the fabric printing paste (Fig. 4 B, Fig. 5 B).

The changes of the printing quality of samples after 5 washing cycles were not noticeable.

The results of burning tests showed (Table II) that the raw and bleached linen fabrics burned completely and formation of thermal degradation product debris was observed. The raw linen printed with Tubivis DRL 300 paste burned completely, while after 5 washing cycles the right side of the raw linen printed with same paste did not burn, if the horizontal flame applying method was used, but using the other method the fabric burned completely.

The afterglow time of this fabric was 8–10 s. This is 6.4–8.8 times shorter than for the raw linen without print. Debris was observed.

For bleached linen printed with Tubivis DRL 300 flame did not reach the top of the sample and flame extinction was observed after 12–18 s, but for the same after-washed fabric flame extents after 16–40 s depending on the method of flame application.

The afterglow time of bleached linen fabrics was 1–2 s. This was 40–29 times shorter (B/TubivisDRL300) than for bleached linen without printing and for after-washed fabrics the afterglow time was 80–58 times shorter (B/Tubivis DRL300/W). Debris was not observed.

### TABLE I

**DESIGNATION OF SAMPLES**

<table>
<thead>
<tr>
<th>Designation</th>
<th>Pre-washing</th>
<th>Printing</th>
<th>After-washing</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>--</td>
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</tr>
<tr>
<td>B0</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>R-TubivisDRL300</td>
<td>x</td>
<td>--</td>
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<tr>
<td>B-TubivisDRL300</td>
<td>x</td>
<td>--</td>
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</tr>
<tr>
<td>R-TubivisDRL300_W</td>
<td>x</td>
<td>Tubivis DRL300</td>
<td>--</td>
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<tr>
<td>B-TubivisDRL300_W</td>
<td>x</td>
<td>x</td>
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<tr>
<td>R-Tubivinyl235MC</td>
<td>x</td>
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<tr>
<td>B-Tubivinyl235MC</td>
<td>x</td>
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<tr>
<td>R-Tubivinyl235MC_W</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>B-Tubivinyl235MC_W</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**B. Printing**

Commercial synthetic thickener for pigment printing Tubivis DRL 300 or screen-printable dispersion based adhesive Tubivinyl 235 with addition of permanent organophosphate (chemical composition was not given), flame-retardant for cellulosic textiles Apyrol CEP (stable during multiple washings and dry cleaning) with proportion of chemicals in printing paste (1:2) and pigment Bezaprint Green BT (2 w.t.% of paste) was mixed manually (producer of all chemicals was CHT BEZEMA).

For all fabrics the same flat screen printing method was used: the print paste was squeezed across the screen mesh onto a
<table>
<thead>
<tr>
<th>Designation of sample</th>
<th>R0</th>
<th>B0</th>
<th>R-Tubirvis DRL100</th>
<th>B-Tubirvis DRL100</th>
<th>R-Tubirvis DRL100/W</th>
<th>B-Tubirvis DRL100/W</th>
<th>R-Tubirvis 235MC</th>
<th>B-Tubirvis 235MC</th>
<th>R-Tubirvis 235MC/W</th>
<th>B-Tubirvis 235MC/W</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flame spreading time till the top of the sample</strong></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal test</td>
<td>8–9 s</td>
<td>10–11 s</td>
<td>14–15 s</td>
<td>Does not reach</td>
<td>13–15 s (right side), 10–12 s (left side)</td>
<td>17 s</td>
<td>12–13 s</td>
<td>14 s (right side), 13–14 s (left side)</td>
<td>17 s</td>
<td>10–11 s</td>
</tr>
<tr>
<td>Vertical test</td>
<td>8–9 s</td>
<td>8–9 s</td>
<td>9–10 s</td>
<td>Does not reach</td>
<td>9 s</td>
<td>14–16 s (right side), 13–14 s (left side)</td>
<td>9–10 s</td>
<td>9–10 s</td>
<td>14–16 s (right side), 13–14 s (left side)</td>
<td>10–11 s</td>
</tr>
<tr>
<td><strong>After burning time</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal test</td>
<td>Burns completely in 50–60 s</td>
<td>Burns completely in 65–70 s</td>
<td>Burns completely in 31–45 s (right side), 47–54 s (left side)</td>
<td>Flame extinction 12–18 s (right side), 13–15 s (left side)</td>
<td>Does not burn 51–55 s (right side), burns 55 s (left side)</td>
<td>Flame extinction 57–60 s (right side), 81–84 s (left side)</td>
<td>Burns completely 75–83 s (right side), 70–78 s (left side)</td>
<td>Burns completely 78–83 s (right side), 33–60 s (left side)</td>
<td>Flame extinction 38–55 s (right side), 68–70 s (left side)</td>
<td>Burns completely 68–70 s (right side), 88–90 s (left side)</td>
</tr>
<tr>
<td>Vertical test</td>
<td>Burns completely in 40–45 s</td>
<td>Burns completely in 40–42 s</td>
<td>Burns completely in 54–57 s (right side), 42–50 s (left side)</td>
<td>Flame extinction 12–15 s (right side), 14–15 s (left side)</td>
<td>Burns completely 53–55 s (right side), 55–67 s (left side)</td>
<td>Flame extinction 49–56 s (right side), 40–46 s (left side)</td>
<td>Burns completely 38–47 s (right side), 55–67 s (left side)</td>
<td>Burns completely 25–30 s (right side), 50–54 s (left side)</td>
<td>Burns completely 58–70 s (right side), 88–90 s (left side)</td>
<td>Burns completely 58–70 s (right side), 88–90 s (left side)</td>
</tr>
<tr>
<td><strong>Afterglow time</strong></td>
<td></td>
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<tr>
<td>Horizontal test</td>
<td>77–82 s</td>
<td>75–80 s</td>
<td>8–9 s (right side), 9–10 s (left side)</td>
<td>2 s</td>
<td>48–50 s (right side), 49–53 s (left side)</td>
<td>1 s</td>
<td>23–38 s (right side), 30–32 s (left side)</td>
<td>17–18 s (right side), 16–18 s (left side)</td>
<td>43–44 s (right side), 42–43 s (left side)</td>
<td>2–3 s</td>
</tr>
<tr>
<td>Vertical test</td>
<td>55–60 s</td>
<td>65–75 s</td>
<td>9 s (right side), 10 s (left side)</td>
<td>2 s</td>
<td>52 s (right side), 51–53 s (left side)</td>
<td>1 s</td>
<td>33–36 s (right side), 33–34 s (left side)</td>
<td>19–20 s (right side), 18 s (left side)</td>
<td>44–45 s (right side), 40–49 s (left side)</td>
<td>2–3 s</td>
</tr>
<tr>
<td><strong>Formation of debris</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Horizontal test</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Vertical test</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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</tbody>
</table>
The afterglow time of the bleached linen fabrics (B/Tubivis DRL300) was 40–29 times shorter than for bleached linen without print and for after-washed fabrics (B/Tubivis DRL300/W) it 80–58 times shorter. Debris not observed for tested samples. For bleached linen printed with *Tubivis DRL 300* no ignition was observed, as measured by the standard EN 1101; this corresponds to 3 class of textile fire resistance (3).

![Fig. 2. Printed raw linen (A – right side, B – left side) with flame-retardant *Apyrol CEP* and commercial paste *Tubivis DRL 300*.](image)

Raw linen fabrics printed with *Tubivyl 235 MC* burned completely, but the burning time was 1.4 times longer, while the afterglow time was 2.7–1.8 times shorter than for raw unprinted linen fabric. Flame extinction was observed for the same fabric after 5 washing cycles, afterglow time was ~1.2 times longer than for printed raw linen and ~2.2 times shorter than for raw linen. For raw linen fabrics printed with *Tubivyl 235 MC* paste formation of debris was observed.
Bleached linen fabrics printed with Tubivil 235 MC burned completely, but burning time was 1.1–1.3 times longer and afterglow time was 4.6–3.9 times shorter than for bleached linen without printing. The burning time for the same fabric after 5 washing cycles was ~1.1 times shorter using the horizontal method of flame application and ~1.3 times longer using vertical method. Afterglow time for after-washed fabric was 9–7 times shorter than for printed fabric. Formation of debris was observed for the bleached linen fabric printed with Tubivil 235 MC paste.

IV. CONCLUSION

A decorative pattern with flat screen method and a reduction of flammability of local linen fabrics was achieved with addition of organophosphate flame-retardant Apyrol CEP, commercial paste Tubivis DRL 300 or Tubivil 235 and pigment Bezaprint Green BT.

The best improvement of flame retardancy – flame extinction and reduction of afterglow time for bleached linen printed using Tubivis DRL 300 printing paste – 40–29 times and 80–58 times for after-washed fabric was achieved in comparison to unprinted bleached linen.

For raw linen printed using both pastes the best results were observed after 5 washing cycles, compared to printed raw linen fabrics: for Tubivis DRL 300 printing paste reduction of afterglow time was 6.4–8.8 times shorter. With Tubivil 235 MC paste it was 2.7–1.8 times shorter compared to unprinted raw linen.

The formation of debris or non-combustible products were observed for fabrics printed with both pastes, except for bleached linen printed with Tubivis DRL 300.
ACKNOWLEDGMENT

The author would like to thank Professor, S. Reihmane from Riga Technical University for the support in the research.

REFERENCES


Aina Bernava obtained a Professional Master’s Degree in Material Design and Technology, Riga Technical University in 2011. She is a Master of the Latvian Chamber of Crafts since 2004. She has more than 35 years of experience in design of fabrics and in hand-made weaving. She is a researcher in Riga Technical University, Institute of Polymer Materials since 2014. She was a researcher in ESF Projects connected with functional materials and natural fibers (2009-2012) and in Ltd. MNKC- LIAA Project of Natural Fibre and Flax Fibre Properties (2013-2015).

Address: Paula Valdena Str. 3, LV-1048, Riga, Latvia.
E-mail: aina.bernava@inbox.lv

Aina Bernava, Linu audumu apdrukāšana degamības samazināšanai