Content of Hemp Fibres and Properties of Nonwovens

Liga Freivalde[1] , Silvija Kukle[2] , [1-2]*Riga Technical University*

Abstract **– Results of fibre content of variety *Bialobrzeskie* before and after hydrothermal treatment with NaOH solution have been compared. The production and properties of hemp nonwovens made by carding and hydroentangling also are reported. The samples of hydroentangled hemp fibers (varieties *Purini*, *Bialobrzeski*) have been characterised to determine their dimensional properties, water vapour transmission, pore size distribution, thermal properties in order to assess their suitability as alternative insulation materials.**

Keywords **– hemp fibre content, insulation materials, nonwovens.**

I. Introduction

Hemp is an annual plant that gives fibres with good mechanical properties. “Hemp” refers primarily to Cannabis sativa L. (Cannabaceae), although the term has been applied to dozens of species representing at least 22 genera [1].

Hemp bast fibres have traditionally been used for textiles, but they can also be used, e.g., for composites, building materials, paper products and packages. For now the most important hemp fibre applications are bio-based composites (natural fibre reinforced plastics), as well as construction and thermal insulation materials [2], where the latter is the subject of this article.

Hemp can be grown in moderate climates and they require relatively low input to give high yields. Bast fibres are suitable for use as insulation materials due to their thermal properties and some ecological features, i.e., biodegradability. However, controlled procedures during harvesting, processing, manufacturing and building are required in order to avoid the risk of negative effects caused by contaminants and moisture. There is an increasing interest in ecological values and renewable materials, promoting, e.g., the use of agro-based materials in the building sector and also in other applications. Hemp fibre use in the manufacturing of insulating materials minimizes damage to the environment as it contributes to reduction in CO^2 emissions [3]; moreover, hemp fibre has low energy demand in production, potential for recycling, and positively affects indoor environment [4].

Hemp can successfully be grown in Latvia, and may in the future it will give the raw material for extensive domestic production of several structural materials. In order to use the natural fibres for manufacturing of more elaborate high-quality materials, fibre properties should be taken into account. Important mechanical properties for design of contemporary products are stiffness, strength, moisture sensitivity. On the basis of the obtained test results, the quality of the fibre can be affected by the way of retting, such conditions as treatment with NaOH solutions, and dependency on concentration.

Also climate conditions and soil content affect fibre properties and further materials made of them. It means that in developing insulation materials, it is important to test locally grown hemp fibres.

Investigation of the qualities of fibre hemp has been promoted by the need to find appropriate applications and production methods for hemp fibres. The thermal performance of bast fibre insulations has been investigated before, but there is a lack of information concerning fibre quality, which affects production chain and information related to hydroentanglement method in fibre hemp processing.

II. Materials and Methods

Hemp fibres used in this study were obtained from hemp stems harvested using a trial plot in Vilani district, Latvia (local dioecious variety “Purini”) and commercial sowing (ES registered monoecious industrial hemp variety “Bialobrzeskie”) in Kraslava district, Latvia. The harvested hemp stems of both varieties were left for dew retting on the field for biological degradation. In order to extract fibres from retted *Bialobrzeskie* hemp stems light modified flax scotching line was used.

For treatment with NaOH solution hemp grown in 2009 was used. Scutched fibres of variety *Bialobrzeskie* were subjected to 2-hour hydrothermal treatment (100^0C) to depolymerize hemicellulose and pectin in the cell walls of fibres combined with mercerization using 1% and 1.5% NaOH solution followed by washing and drying at temperature of 105^0C for two hours. The proportion of long fibres after combing by hand was determined.

Both hemp varieties used for hydroentanglement method, were sown in the trial plot on 13th May, 2010. Due to differences in flowering time, cultivar *Purini* was harvested on 7th September, cultivar *Bialobrzeskie* – on 16th September. Both hemp biotype farming conditions were similar: active nitrogen fertilizer doze was 60 kg/ha; seeding norm was 70 kg ha^{-1}; the harvested hemp stems of both varieties were left for dew retting on the field (4 weeks). Average stem length of cultivar *Purini* – 1.35m, of variety *Bialobrzeskie* – 2.70 m. Straw yield of cultivar *Purini* (P) was 8.07 t/ha, for variety *Bialobrzeskie* (B) – 18.22 t/ha; bast fibre yield was 23.9% for cultivar P, 32.1 % for B. Linear density for P was 23.4 Tex, for B – 36.2 Tex. Moisture content of fibres found in the range was 9.2%–9.3 %. Before carding, fibres were pre-cut to 5–10 cm in length. Parallel-laid webs were prepared by carding where fibres were disentangled and mixed to create a homogeneous web. Specimens were made from these webs by means of hydroentangling technology.

Hydroentanglement was performed on a seven injector 0.5 m wide machine. Webs were pre-wetted and hydroentangled using jet strips with a nozzle diameter of 150 μm; jet strips at pressure of 100 bar (10 MPa) were applied in an alternating face and back profile. The conveyor speed was fixed at 5 m/min. The fibres were entangled, intertwined and interlaced with each other to produce a coherent structure. Immediately after hydroentangling, a large fraction of interstitially held water in the nonwoven is mechanically removed by suction, but because hemp is cellulosic, the water content remains very high even after mechanical extraction and through-air drying is required [5].

Four nonwoven variants hydroentangled (H) from fibres of each variety are labeled as follows with reference to the original web basis weights (g/m^2) used to produce the fabrics: H100, H120, H140 and H160. Samples were also denoted according to the origin of the constituent hemp fibre, i.e., Purini (P) or Bialobzeskie (B).

The mechanical and physical properties of obtained samples were determined according to internationally accepted standards: 1) Fabric thickness, mm (BS EN ISO 9073-2:1997), where method B was adopted with slight modifications: uniform pressure of 0.02 kPa, i.e., 10 grams on 50.2 cm2; 2) Fabric mass per unit area, g/m^2 (BS EN 29073-1:1992, ISO 9073-1:1989), modification: test area of the sample was 10 000 mm^2 instead of 50 000 mm^2. 3) Maximum pore size mean value, μm (fluid displacement method was used, where the materials are exposed to a certain pressure to expel the liquid from the pores). 4) Water vapour transmission, % (BS EN ISO 12572:2001), glass dishes were used. 5) Thermal resistance, m2·K/W, (BS 4745: 2005, ISO 5085-1:1989, ISO 5085-2:1990), two-plate method was used: fixed pressure procedure; 6) Thermal conductivity (k), W/(m·K), k=d/R, where d – the thickness, R – the thermal resistance, (BS 4745: 2005, ISO 5085-1:1989, ISO 5085-2:1990), 7) Nonwoven density, kg/m^3, 8) web weight (ww), grams.

III. Results and Discussions

A. *Hemp Fibre Bundle Content*

Plant fibres are constituted by three structural polymers (the polysaccharides cellulose, and hemicelluloses and the aromatic polymer lignin), as well as by some minor nonstructural components (i.e., proteins, extractives, minerals). Bast fibres from hemp contain ~67% cellulose, ~16% hemicellulose, 3.3% lignin and 0.8% pectin [6]. The purpose of retting is the decomposition of the pectin substances, by which fibre bundles are attached to surrounding bark matrix and the woody core. This will facilitate the subsequent mechanical separation of the fibre bundles from the rest of the stem.

As in hemp fibre unit cells with diameter of 15-50 microns are connected by lignified pectins, the basis of hemp processing lies in loosening and dissolving this bond using different methods. Hydrothermal treating depolymerizes the hemicelluloses and pectins into lower molecular aldehydes and phenolics [7], which are polymerized under high temperatures. It is supposed that hydrothermal treating combined with mercerization using NaOH influence fibre content and mechanical properties, as well.

Table 1 shows the comparative data of long and short fibre content without treatment and with two different NaOH solution concentrations during hydrothermal treatment. After treatment with 1% NaOH solution, long fibre content decreased only by 1.9%, with the increase in concentration by 0.5% long fibre content decreased seriously by 10.3% (Table 1).

TABLE I

Results of Fibre Content of Variety *Bialobrzeskie* before and after Hydrothermal Treatment with NAOH Solution

Untreated, combed			Treated, combed					
			NaOH 1 %			NaOH 1,5 %		
Fibres, grams		Dust, grams	Fibres, grams		Dust, grams	Fibres, grams		Dust, grams
Long	Short		Long	Short		Long	Short	
12.7	7.7	3.6	8.77	7.45	0.68	8.43	8.65	0.64
52.9%	32.1%	15.0%	51.9%	44.1%	4.0%	47.6%	48.8%	3.6%

B. *Hydroentangled Nonwoven Materials*

A summary of test results of the hydroentangled samples of hemp variety *Purini* and *Bialobrzeskie* are given in Table 2.

TABLE II

Tests Results of Purini and Bialobrzeskie Hemp Fibre Nonwovens

No.	Test Parameter	*Purini* nonwovens				*Bialobrzeskie* nonwovens			
		PH100	PH120	PH140	PH160	BH100	BH120	BH140	BH160
1.	Thickness,	2.1	2.71	2.9	3.32	2.68	2.71	3.27	3.74

	[mm]								
2.	Mass per unit area, [g/m^2]	206	269	337	378	185	232	292	305
3.	Pore size, [µm]	-	266.1	-	167.6	-	226.8	-	129.1
4.	Water vapour transmission, [%]	97	98.8	95.1	95.5	97.3	97.3	84.6	85.2
5.	Thermal resistance, [m^{2}K/W]	0.067	0.073	0.076	0.084	0.070	0.071	0.093	0.094
6.	Thermal conductivity, [W/(m·K)]	0.031	0.037	0.038	0.040	0.038	0.038	0.035	0.040
7.	Web weight [g]	56.5	70	89	98.6	41.7	50.8	68.3	82.4
8.	Density, [kg/m^3]	98.1	99.3	116.2	113.9	69.0	85.6	89.3	81.6

Original fibre amounts used to produce the webs by carding were the same for both varieties: 100, 120, 140 and 160 grams. However, web weight after carding was higher for variety *Purini* as there was higher weight loss during carding process for variety *Bialobrzeskie* (23%). The web weight after carding was in the range from 56.5 to 98.6 g for P and 41.7 to 82.4 for B (Table 2. and Fig.1).

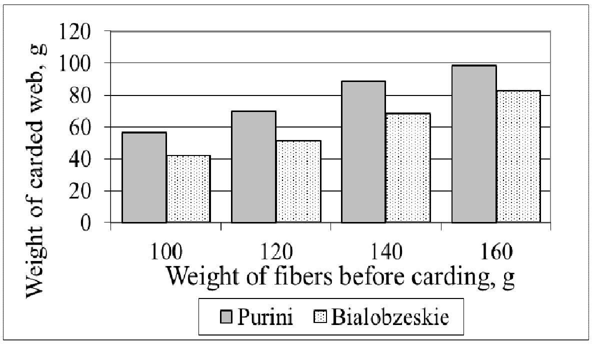

Fig. 1. Weight of carded web, grams.

Also the fabric mass per unit area for webs after hydroentangling showed the same coherence between varieties – B samples were lighter than P samples. As seen from Table 2 and Fig. 2, fabric mass per unit area for P fabrics was in the range of 206–378 g/m^2 in contrast to the B fabrics, where it was from 185 to 305 g/m^2.

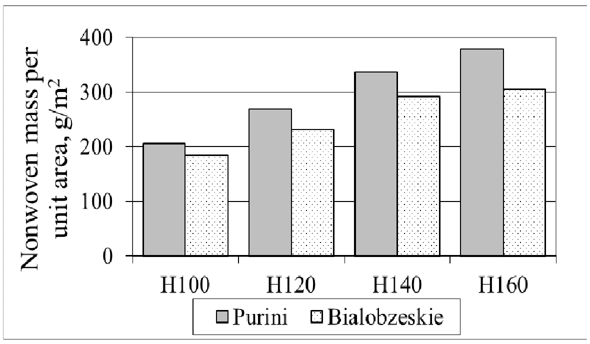

Fig. 1. Nonwoven mass per unit area, g/m^2.

As seen from Table 2 and Fig. 3, the nonwoven thickness for variety P was in the range of 2.1 till 3.32 mm, where for variety B nonwovens it varied from 2.68–3.74 mm. Sample H120 thickness for both varieties are the same: 2.71 mm, but in all other cases, P fabrics are thinner than B nonwovens.

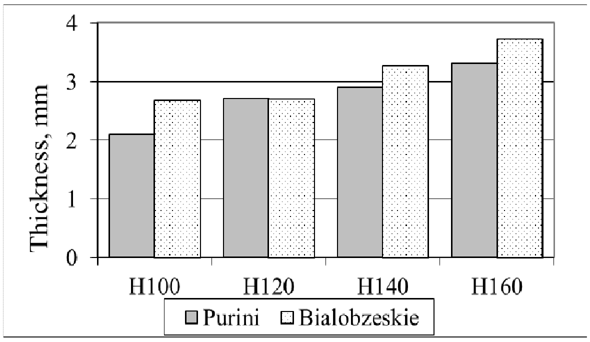

Fig. 3. Nonwoven thickness, mm.

The density of the nonwovens depends directly on material weight, thickness and area, as density can be obtained by dividing the nonwoven mass per unit area by the material volume. Density for samples of variety P varied from 98.1–116.2 kg/m^3, where for B samples it was from 69 to 89.3 kg/m^3 (see Table 2 and Fig. 4), and it was nonlinear for both varieties. The relationship between density and thermal properties is not linear and it varies between different studies [8].

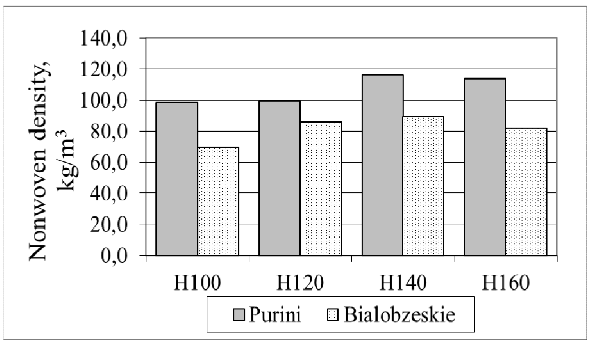

Fig. 4. Nonwoven density, kg/m^3

The thermal conductivity of insulation made of bast fibres is compatible with conventional insulation. However, the variation between the conductivity values of insulation varies, for example, in relation to bulk density and to thickness.

As seen from Table 2 and Fig. 5, the thermal resistance of *Purini* nonwovens within the experiment changed relatively slowly, increasing by 25.4%, because the nonwoven thickness increased by 58.1%. The overall thermal resistance of *Bialobrzeskie* nonwovens was more sensitive to the increase in nonwoven thickness than in the Purini – nonwoven thermal resistance increased by 34.3% with the increase in the nonwoven thickness only by 39.6%.

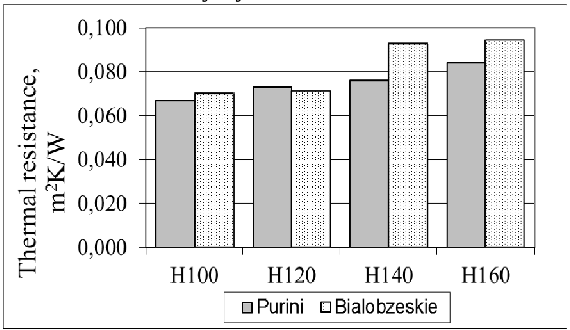

Fig.5. Nonwoven thermal resistance

Heat transfer through material is conduction. The thermal conductivity, nonwoven bulk density, porosity and nonwoven architecture are material structural parameters affecting heat transfer [9].

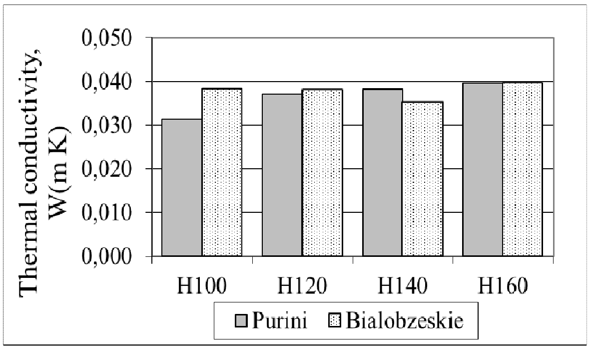

Fig.6. Nonwoven thermal conductivity

Thermal conductivity (k) was obtained from results of materials thickness (t) and thermal resistance (R) from equation $k = t/R$. The thermal conductivity of the hydroentangled nonwovens containing *Purini* fibres increased linearly, whereas no such trend was evident for the *Bialobrzeskie* nonwovens (Fig. 6). For *Purini* group, an overall increase of 29% in the thermal conductivity was observed by increasing nonwoven thickness from 2.1–3.3 mm, for Bialobrzeskie it increased only by 12% if thickness was in the range from 2.7–3.7 mm. However, for each type of samples, the results were very similar or even the same. Nonwoven samples of hemp variety P showed mean values of thermal conductivity in the range of 0.031–0.040 W/(m•K), but the mean values of thermal conductivity of B nonwoven samples were from 0.035–0.040 W/(m•K), which comparing to other commonly used insulation materials (see Tab. 3) showed good indicators.

TABLE III

PROPERTIES OF SOME COMMONLY USED INSULATION MATERIALS

Insulation type	Density, kg/m^3	Thermal conductivity, W/(mK)
Mineral wool	13–180	0.030–0.045 [10-11]
Polystyrene	18–80	0.025–0.041 [10]
Cork	105–120	0.038–0.050 [12]
Wood wool	50	0.038 [12]

It is apparent from Table 2 and Fig. 7 that water vapour transmission is nonlinear for both varieties. Different

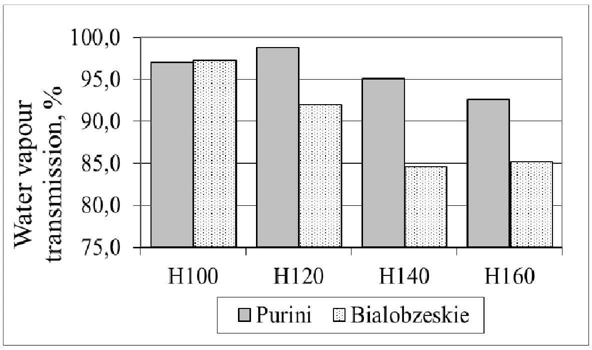

Fig.7. Nonwoven water vapour transmission, %

disposition of test results can be explained by differences in such properties of elementary fibre/ small fibre bundles as diameters, elasticity, flexibility: if B is a source of highly technical and hard fibres, P fibres are softer, more flexible, and, as a result, are better at hydroentanglement exposure by creating a capillary structure, through which water vapour moves quite well through the thicker layers, too.

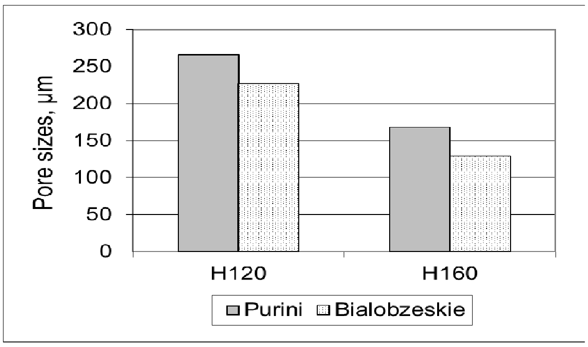

Fig.8. Nonwoven pore sizes, µm.

The porous structure of the bast fibres, small diameter and the low bulk density, leading to trapping of a large amount of air between the fibres in the material, makes them suitable for thermal insulation. Table 2 and Fig. 8 report the pore dimensions of samples produced at H120 and H160. The pore sizes of *Purini* nonwoven samples were found to be up to 17% higher than those composed of *Bialobzeskie* variety. As expected, an increase in water pressure, which increased the specific energy consumed by the web, decreased the pore size by up to 30% due to the increased compaction and fibre entanglement.

IV. CONCLUSIONS

For both viewed varieties long fibre content reduced significantly by increasing NaOH concentration in hydrothermal treatment process, which must be followed in selecting processing modes. After treatment with 1% NaOH solution, long fibre content decreased only by 1.9%, with the increase in concentration by 0.5% long fibre content decreased seriously (10.3%).

The production of samples made by hydro-entanglement technology has been studied in the present article. The mass per unit area of nonwovens obtained from *Purini* cultivar increased linearly by 83% as the web weight after carding increased by 75%. By contrast, the mass per unit area of the nonwovens obtained from *Bialobrzeskie* cultivar increased nonlinearly by 65% when web weight increased by 98%. The B fibre losses during carding were 23% higher in comparison with cultivar B. The water vapour transmission of the nonwoven samples obtained from *Purini* cultivar was up to 8.7% higher and pore sizes were found to be up to 17% higher than those composed of the Bialobrzeskie variety. Differences between test results of cultivars can be explained by distinctions in such properties of elementary fibre/ small fibre bundles as linear density (for cultivar P the average is 23.4 Tex and for cultivar B 36.2 Tex), elasticity, flexibility: if B is a source of highly technical and hard fibres, P fibres are softer, more flexible, and, as a result, are better at hydroentanglement exposure by creating a capillary structure, through which water vapour moves quite well through the thicker layers, as well. Good water vapour permeability of a relatively large thickness range (2.1–3.32 mm for cultivar P and 2.68–3.74 mm for cultivar B) allows including hydroentangled hemp fibre nonwovens in natural breathing packet formation for household, industrial and construction applications. The thermal resistance and conductivity results obtained for these nonwovens are promising for the intended end-uses as they have excellent insulation properties. Better thermal conductivity results were shown by cultivar *Purini*, where λ was in the range of 0.031–0.040 W/mK with nonwoven thickness of 2.1–3.32 mm and density of 98.1–116.2 kg/m^3 in comparison with variety *Bialobrzeskie*, where λ was slightly higher in the range of 0.035–0.040 W/mK with thickness of 2.68–3.74 mm and density of 69–89.3 kg/m^3. These values have been compared to the thermal conductivity of typical mineral wool, cellulose insulation, cork and other insulation materials (see Table 3). These results are consistent with the requirements related to the natural insulating materials, where thermal conductivity is equal to 0.040–0.045 W/m·K. The obtained experimental results have shown that hydroentanglement technology is suitable for hemp fibre processing, which allows obtaining nonwoven insulation materials with predefined properties according to the intended use. Main physical properties of hydroentangled hemp nonwovens correlate well between each other and are subjected to mathematical modelling, thereby there is an opportunity to carry out only a few tests and calculate all other indicators.

The obtained results have shown an opportunity to develop the local Latvian hemp genotype *Purini* into the fibre hemp variety for temperate climate zones suitable for a wide range of potential applications that could be processed into high added value products not only by means of traditional but also advanced high productivity technologies.

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ACKNOWLEDGEMENTS

This research has been supported by the European Social Fund within the project "Support for the Implementation of Doctoral Studies at Riga Technical University".

Liga Freivalde, Education: Riga Technical University, Faculty of Material Science and Applied Chemistry/ Institute of Technology and Design of Textile Materials. Specialization: Material Technology and Design (Bachelor's degree, 2007). Specialization: Material design and technology (Master's degree, 2009).
Work experience: 1) Riga Technical University – Researcher, address: Azenes Str. 14, Kipsala, LV–1048, Riga, Latvia. 2) "Fausta Dizains" Ltd., – Interior Designer; 3) Private house building company "High Castle and Architecture" – Interior Designer/ Technician. Current interests: renewable raw materials, hemp fibre properties, their use in innovative insulation material development. Previous research interests: RTU Training Corp in Kipsala, Azenes Str. 18, reconstruction of spatial quality.
Address: Azenes Str. 14, Riga, LV–1048, Latvia.
Phone: + 371 67089256, e-mail: liga.freivalde@rtu..lv

Silvija Kukle, Education: Riga Technical University, specialization: Mechanical Technology of Fibre Materials; Qualification: Engineer Technologist (1965). Candidate of Technical Sciences (Moscow Textile

Institute, 1977), Doctor of Engineering Sciences (RTU, 1991), Dr.habil.sc.ing. (RTU, 1993). Professional interests: market, material & processes research plan designing, organization, methods of data processing and interpretation, nanotechnologies.
Work Experience: since 1997 – Head of the Professors' Group of Technology and Design of Textile Products, Faculty of Material Sciences and Applied Chemistry, RTU; since 1994 – Professor at RTU.
Membership in professional societies: Member of International Scientific/Programme Committee of International Textile, Clothing & Design Conferences "Magic World of Textiles" (Croatia), since 2005;. Coordinator of cooperation with Reutlingen University of Applied Sciences, Germany (since 2002).

Līga Freivalde, Silvija Kukle. Kaņepju šķiedru saturs un neausto materiālu īpašības
Šajā rakstā atspoguļota kaņepju šķiedru apstrāde, izmantojot NaOH šķīdumu, kas ietekmē šķiedru saturu un to mehāniskās īpašības, kā arī neausto materiālu paraugu izgatavošanu un īpašību testēšanu siltumizolācijas lietojumiem celtniecības nozarē, kas veidoti ar kāršanas un caurstrūklošanas tehnoloģiju. Pētījumos tika izmantotas Latvijā audzētas divu veidu kaņepju šķiedras un salīdzinātas to gala produktu īpašības - vietējā divmāju šķirne „Pūriņi", kas audzētasViļānu rajonā, un ES reģistrēta vienmāju rūpniecības šķirne "Bialobrzeskie", audzēta Krāslavas rajonā. Iegūtie cauradatotie kaņepju šķiedru materiāli testēti, lai noteiktu to izmēru īpašības (biezums, svars uz laukuma vienību), ūdenstvaiku caurlaidība, siltuma pretestība un siltuma vadītspēja, lai tādējādi novērtētu to piemērotību izmantošanai alternatīvu siltumizolācijas materiālu izgatavošanā. Tika novērtēta arī kaņepju šķirnes ietekme uz materiāla īpašībām. Testēto neausto materiālu iegūtie siltumpretestības un siltumvadītspējas rezultāti ir daudzsološi attiecībā uz paredzētajiem gala lietojumiem. Labas ūdenstvaiku caurlaidības īpašības salīdzinoši lielā biezuma diapozonā ļauj iekļaut cauradatotos neaustos kaņepju šķiedru materiālus dabīgi „elpojošu" pakešu veidošanai sadzīves, rūpniecības un celtniecības vajadzībām. Iegūtie rezultāti liecina, ka ir iespēja attīstīt Latvijas vietējo kaņepju genotipu „Pūriņi" izolācijas lietojumiem ar augstu pievienoto vērtību izmantošanai celtniecības nozarē.

Лига Фрейвалде, Силвия Кукле. Содержание волокон конопли и свойства нетканых материалов.
В статье отражен процесс обработки конопляного волокна с использованием NaOH и создания при помощи чесания и гидроструйчатой технологии нетканых материалов, пригодных для теплоизоляции в строительной индустрии. Проведено исследование и сравнение свойств конечного продукта, полученного с использованием двух типов конопляного волокна - конопли местного генотипа «Пурини», выращенной в Латвии 2010 году, и зарегистрированного в ЕС польского селекционированного сорта промышленной конопли "Биалобрзеские". Полученные образцы материалов проходили тестирование для определения их физических свойств (толщина, вес на единицу площади), паропроницаемость, термостойкость и теплопроводность и для оценки их пригодности для использования в производстве альтернативных теплоизоляционных материалов. Было оценено влияние сортов конопли на свойства материала. Полученные результаты термического сопротивления и теплопроводности этих тканей свидетельствуют о перспективности использования предлагаемого продукта. Хорошая паропроницаемость позволяет включить нетканые материалы, сделанные из волокна конопли, в материалы для естественного образования воздухопроницаемого пакета для бытовых, промышленных и строительных нужд. Полученные результаты показывают возможность развивать теплоизоляционные технологии с высокой добавленной стоимостью при использовании латвийского генотипа конопли «Пурини» в строительной отрасли.