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Hemp Fibres for Nonwoven Insulation Materials

Liga Freivalde[1], Silvija Kukle[2], Guntis Strazds[3], [1-3]*Riga Technical University*, [3]*Association of Textile and Clothing Industry*

***Abstract* - This article presents development of nonwoven fabrics of hemp fibres for insulation applications in building industry, created with carding and needle-punching technologies. Two types of retted hemp fibres harvested in 2010 – a local dioecious variety "Purini" and the EU registered monoecious industrial hemp variety "Bialobrzeskie" grown in the Vilani district of Latvia – have been used and compared with their end-product properties. The resulting needle-punched hemp fabrics are characterised to determine their dimensional properties (thickness, weight per unit area), water vapour transmission) porosity, thermal resistance and thermal conductivity to assess their suitability as alternative insulation materials. The influence of hemp variety on fabric properties has also been estimated.**

Keywords – needle-punching, nonwoven insulation materials, hemp fibres.

I. INTRODUCTION

Worldwide, it is observed that attention has increasingly focused on the acquisition of renewable resources which are further used in the development of new sustainable and environmentally friendly materials and products. Naturally derived fibres occupy an increasing proportion among renewable resources, replacing man-made fibres in a wide range of technical applications, including nonwoven products. For now the most important hemp fibre applications are bio-based composites (natural fibre reinforced plastics), as well as construction and thermal insulation materials [1], where the latter is the subject of this article. Nowadays, most houses are better insulated than in the old days when, as a result of poor insulation, a lot of heat was lost. But the inside air quality was in many cases better than now, because of the ability of walls to breathe [2]. Environmental and human health advantages of natural fibres, in this case hemp, in insulation are the following: thermal insulation materials composed of hemp fibres are hygroscopic; low density and generate limited toxic substances during combustion; they are also easily biodegradable and disposable. Hemp is classified as environmentally-friendly natural fibre in processes of cultivation, processing, hemp product exploitation and liquidation. Hemp is also vital to maintaining air by removing carbon dioxide and returning oxygen. But there are also disadvantages like flammability [2]. The bast layer (phloem) of the hemp stalk contains the valuable textile fibres.

Tow of hemp fibres traditionally has been used in insulation tapes between timbers [3] but since 1990s, when hemp was rediscovered throughout the world as an important raw material for bio-based products [1], several types of mats and loose fill insulations of different thickness for common houses have been developed into commercial products [3]. About 3,000 up to 4,000 tonnes of hemp insulation materials are produced annually in the EU. Because of the relatively high price compared to mineral fibre insulation materials, it is hard to achieve bigger sales. The most important growers, manufacturers and users are China and the EU – Germany, France and Great Britain respectively [4].

The area of hemp grown in the world decreases because of high grain prices. Overall in the year 2010 in the EU there were 22 000 ha of hemp, from which in France – 10 000 ha and only 6 000 ha in the year 2011[5].

European flax and hemp short fibres, unlike mineral oil and ploypropylene, after a long period of price stability, have only recently experienced insignificant increase in price, and at present the price is stable – a price rise of less than 10% over seven years, respectively from 2003 till 2010. It is expected in the future that natural fibre prices will definitely stay below 1 €/kg [1]. However, when comparing prices, it must be taken into account that hemp fibre prices vary according to supply, demand and quality [6]. With adequate framework conditions, European hemp has a considerable growth potential [1].

Nowadays, bast fibres insulation forms a small part of the insulation market throughout Europe, e.g. in Germany below 0.5 %. One reason for the relatively small volume is two-to-threefold higher price of bast fibre insulations compared, for example, to the price of mineral wool. On the other hand, typical positive arguments for these insulations are their ecological properties, like a low energy demand in production, potential for recycling, and positive effect on indoor [3].

In Latvia hemp in the historical perspective was grown mainly for food needs, as well as other crop protection against pests. Revival of hemp cultivation for obtaining fibres in Latvia dates from 2008 [7]. In Latvian climate high hemp straw yields are obtainable, fibre proportion reaches 22-25% [8], and the acquired fibres have good physical and mechanical properties [9] – [12]. This study is concerned with the development of nonwoven insulation materials using local hemp varieties based on appropriate specifications and comparative analysis with the EU introduced varieties farmed in climatic and soil conditions found in Latvia.

II. MATERIALS AND METHODS

Raw materials – hemp fibres used for this study were obtained from hemp stems harvested from a trial plot – a local dioeciously genotype "Purini" and the EU registered monoecious industrial hemp variety "Bialobrzeskie" in the Vilani district of Latvia. The harvested hemp stems of both varieties were left for dew retting on the field for biological degradation. Field retting is a natural process for fibre production from hemp, which depending on weather conditions, results in fibres of variable quality. During this process fungi and yeasts colonise the hemp and produce polysaccharide-degrading enzymes, which macerate and disrupt the parenchyma cells [13].

In preparation for carding, fibres were pre-cut to 6 till 10 mm in length. Parallel-laid webs were prepared by carding wherein fibres were disentangled and mixed to create a homogeneous web. Nonwoven specimens were made from these webs by means of needle-punching, which is the process where fibres are engaged by the needle barbs [14]. Needle-punching was performed on 30cm wide sample needle loom with 36 g regular 3 barb needles made by Foster. The needles are arranged in offset lines like a chess board. The shank gauge of the needle is 15 – 18 – 42. Penetration depth of needles – 6.4 mm on both sides. Punch density – 75 punches/ cm^2.

Average web dimensions used for needle-punching were 0.6 x 0.4 m. The single-layered fabrics were combined to produce the multi-layered nonwovens. The aim of developing multi-layered needle-punched structures was to obtain the desired thickness with a limited number of fibres. As a result, it must be taken into account that fabric density increases by increasing web weight and depth of penetration. The increase in needle penetration depth results in a deeper inter-locking and entanglement of fibres, as a higher number of barbs penetrates the web and, therefore, a higher compaction of the web and a reduction in thickness occur, which causes the increase in fabric density [15]. It follows that the material properties may vary depending on the type of fabric preparation web – either being used by one or more layers in order to obtain a uniform thickness.

In this article an abbreviation system has been used to describe the samples. Three needle-punched (N) samples for each variety are used to produce the fabrics corresponding respectively to different thicknesses: N1, N2 and N3. Samples have also been denoted according to the origin of the constituent hemp fibre, i.e. Purini (P) or Bialobrzeskie (B).

Wherever possible, standard test methods have been used for the measurement of fabric mechanical and physical properties, such as thickness, fabric mass per unit area, fabric density, porosity, water vapour transmission, thermal resistance and thermal conductivity. All fabric samples have been conditioned under standard atmospheric condition which has a relative humidity of 65 ± 2 % and a temperature of 20 ± 2 °C for at least 24 hours before testing (BS EN 20139:1992; ISO 139:1973 Textiles– Standard atmospheres for conditioning and testing).

Fabric thickness (mm) of the nonwoven fabrics obtained have been measured according to BS EN ISO 9073-2:1997, where the method B has been adopted with slight modifications: uniform pressure 0.02 kPa, i.e. 20 g on 100 cm^2.

Samples have been weighted using a balance with the accuracy of 10^{-3} g in order to determine the mass per unit area, g/m^2 according to BS EN 29073-1:1992, ISO 9073-1:1989, modification: test area of the sample has been 10 000 mm^2 instead of 50 000 mm^2. The density of the nonwoven fabrics has been calculated by dividing the fabric mass per unit area by the material volume.

Water vapour transmission (%) has been obtained according to BS 7209:1990, by using the water method. Metal dishes containing distilled water have been used, and the periodic weighings determine the rate of water vapour movement through the sample [16].

Thermal resistance ($m^2 \cdot K/W$) has been measured according to BS 4745: 2005, ISO 5085-1:1989, ISO 5085-2:1990 by using the two-plate method: fixed pressure procedure. Samples of the fabric to be tested were 330 mm in diameter.

Thermal conductivity (W/ (m·K)) – K, has been calculated from K=d/R, where d – thickness, R – thermal resistance, (BS 4745: 2005, ISO 5085-1:1989, ISO 5085-2:1990).

Porosity has been obtained from the ratio of the fabric density and the fibre density which is expressed in percentage [16], where density of hemp fibre is 1,48 g/cm^3, respectively 1480 kg/m^3 [3], [6].

III. RESULTS AND DISCUSSION

A summary of the test data for each fabric is given in Table 1, which compares values for both types of hemp variety.

TABLE I
PHYSICAL PROPERTIES OF NEEDLE-PUNCHED FABRICS

Test	Variety Purini			Variety Bialobrzeskie		
	PN1	PN2	PN3	BN1	BN2	BN3
Fabric thickness, mm	6,5	17,7	45,7	4,4	10,6	32,7
Fabric mass per unit area, g/m^2	153	468	1385	91	258	908
Fabric density, g/m^3	21,9	26,5	30,3	20,7	24,5	27,8
Porosity, %	98,5	98,2	98,0	98,6	98,3	98,1
Water vapour transmission, %	69,2	57,1	28,0	74,3	54,4	26,8
Thermal resistance, m^2K/W	0,24	0,44	1,23	0,16	0,32	1,15
Thermal conductivity, W/m K	0,028	0,040	0,037	0,028	0,033	0,028

Fabric weight, thickness and density are interrelated physical parameters of needle-punched nonwoven fabrics produced by using carding. The needling action causes simultaneous changes in both density and thickness [15].

Relationships between fabric mass per unit area and thickness for both varieties are very similar and can be described as non-linear relationships (equations 1-2), which can be seen in Table 1 and Figure 1. By increasing fabric mass, thickness is growing nonlinear. If comparing both varieties, fabric mass per unit area and material thickness for all samples are higher for the variety Purini. These differences between varieties are due to the fact that by making webs with a carding machine the same number of fibres has been used, but after carding the web weight has been higher for the variety Purini. For the variety B more fibres were wasted in the middle of carding process.

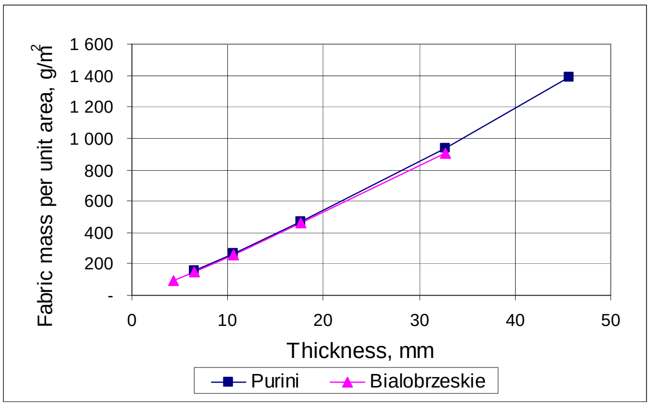

Fig. 1. Fabric mass per unit area as function of thickness.

$Y_{PM} = 0{,}114\ x^2+25{,}496\ x-17{,}543$ (1)
$Y_{BM} = 0{,}0784\ x^2+25{,}956\ x-24{,}557$ (2)

Heat transfer through material is conduction. The thermal conductivity, fabric bulk density, porosity and fabric architecture are material structural parameters affecting heat transfer [16].

From Table 1 and Fig.2., it is apparent that the thermal conductivity Y_{PC} and Y_{BC} multiplied by 100 for both hemp varieties is described by nonlinear functions (equations 3-4) of needle-punched fabric thickness within following borders 0.028 – 0.04 W/(m·K) for the variety Purini and 0.028 – 0.033 W/(m·K) for the variety Bialobrzeskie. Thermal conductivity is affected by the fabric thickness for both varieties Y_{PC} and Y_{BC}, but the trends are not consistent: the thermal conductivity in the PN group has remained about Y_{PC} = 35% despite a large change in the fabric thickness of over 39 mm. The thermal conductivity of the BN samples, Y_{BC} was found to be more than a half lower than that of PN samples (Y_{PC}=17%), where changes in the fabric thickness are over 28 mm.

The thermal resistance of both varieties of needle-punched fabrics shows the tendency to follow the growth of fabric thickness.

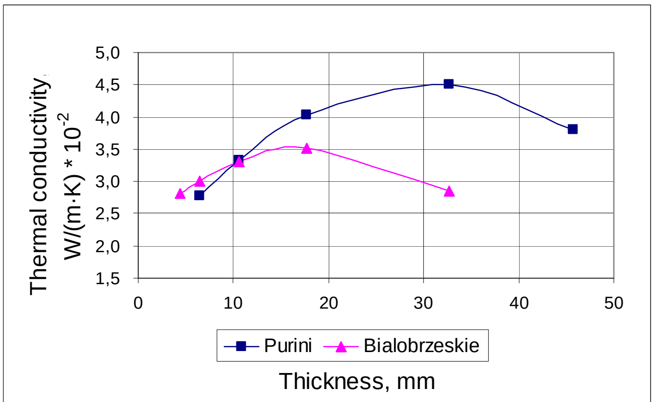

Fig. 2. Thermal conductivity, W/(m·K) as a function of thickness.

$Y_{PC} = -0{,}003x^2+0{,}188\ x+1{,}675$ (3)
$Y_{BC} = -0{,}004\ x^2+0{,}1308\ x+2{,}307$ (4)

By carrying out a water vapour tests, the specimen is sealed over the open mouth of a test dish which contains distilled water. At specific time, weighings of the assembled dish are made and the rate of water vapour permeation through the specimen is determined as the mass of water lost from the dish. The water vapour permeability index is calculated by expressing the water vapour permeability of the fabric as a percentage of the water vapour permeability of a reference woven fabric which is tested in a similar manner, concurrently and alongside the test specimen. [17].

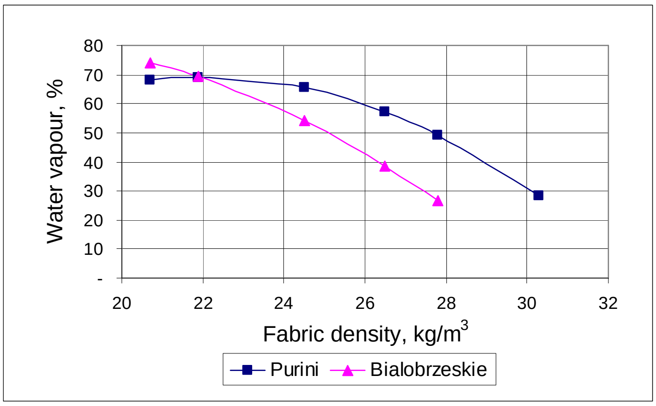

Fig. 3. Water vapour transmission as a function of density.

$Y_{PW} = -0{,}596\ x^2+26{,}233\ x-219{,}45$ (5)
$Y_{BW} = -0{,}431x^2+14{,}176\ x-34{,}516$ (6)

Relationship among fabric density and water vapour is nonlinear which is described as a second-degree polynomial (equations 5 and 6). As shown in Fig.3, water vapour decreases faster for the variety Bialobrzeckie. By increasing material density, the water vapour decreases rapidly. Water vapour changes significantly if comparing the results for the lowest and highest density. For the variety P difference in density is 39% and in water vapour is 147 %. For the variety B, when difference in fabric density is 34%, water vapour changes within 177%. By comparing both varieties, P has 4% higher average density and 30% lower water vapour than the variety B.

The relationships between density and porosity of both varieties are linear (equations 7-8).

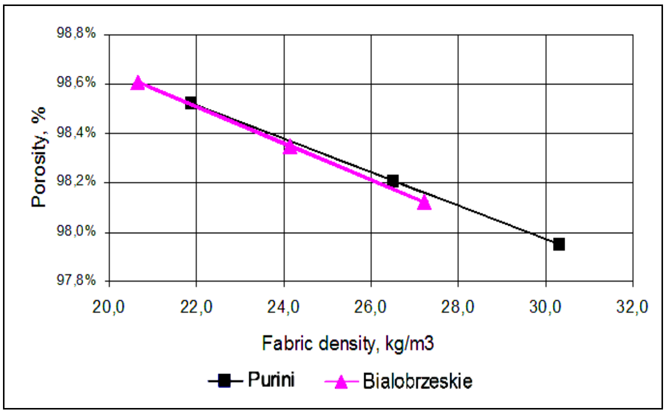

Fig. 4. Porosity as function of fabric density for varieties Purini and Bialobrzeskie.

$$Y_{PP} = -0,0007x+1 \quad (7)$$
$$Y_{BP} = -0,0007x+1 \quad (8)$$

As it is seen from Table 1 and Fig.4, fabric porosity decreases by increasing material density. But reduction is not large if comparing borders for both varieties – for the variety P where the lowest density is 23.5 kg/m3 and the highest – 30.3 kg/m3, change in the pore quantity is only 0.3 %. For the variety B, where density, in general, is lower than for the variety P, namely between 20.7 kg/m3 and 27.8 kg/m3, and porosity is slightly higher – it varies within 0.5 %. This could be explained by the fact that the fibre hardness of the variety B is higher and therefore the process of needle-punching is complicated.

Type of insulation	Fibre raw material	Bulk density (kg/m^3)	k (or λ) (W/m K)
—	Flax	—	0.040–0.046
Mat	Flax	5–50	0.038–0.075
—	Flax	20–100	0.035–0.045
—	Flax and hemp	25–40	0.050
Mat	Flax and hemp	39	0.033
Mat	Flax and hemp	19	0.060
Mat	Hemp, retted	5–50	0.040–0.082
Mat	Hemp, green	5–50	0.044–0.094
Loose-fill	Hemp, frost-retted	25–100	0.040–0.049
—	Hemp	20–45	0.040–0.060
—	Glass wool	20–50	<0.040
—	Glass wool	18–50	0.050
Mat	Stone wool (mineral wool)	5–50	0.035–0.071
—	Stone wool (mineral wool)	15–300	0.037–0.050
—	Stone wool	30–60	0.050
—	Cellulose	30–45	0.041–0.050
Loose-fill	Cellulose (recycled paper)	30	0.041
—	Cellulose (wood fibre)	30–60	0.050

—, not provided.

Fig.5. Thermal conductivity of traditional and perspective insulation materials [18].

The thermal conductivity in the range of 0.028 – 0.04 W/(m·K) of insulation materials made of hemp fibres by needle-punching technology is compatible with that of conventional insulation materials. However, the variation between the K values of all insulation materials varies, e.g. in relation to bulk density (Fig.5). The relationship between density and K is not linear and it varies between different studies [18].

IV. Conclusions

It has been an exploratory study intended for utilizing hemp fibres for developing thermal insulation for buildings, particularly for walls and roofs.

A thermal insulation is defined as a material with low heat conductivity whose main function is to minimize heat transfer. Bast fibres can fulfil this function because of their porous structure, small diameter, and a low fibre bulk density – for hemp it is 1.48 g/cm3 comparing with glass fibres, where it is 2.6 g/cm3, which leads to a lot of air between the fibres in the insulation.

The production of multi-layered samples by combining nonwoven fabrics through the needle-punching process has been explored. The thermal resistance and conductivity results obtained for these fabrics are promising for the intended end-use.

For construction purposes a material is defined as insulating if its thermal conductivity is less than 0.065 W/mK. A typical mineral wool has thermal conductivity in range of 0.035-0.040 W/mK, wood 0.21 W/mK, air 0.026 W/mK. The developed hemp fibre needle-punched materials have excellent insulation performance due to optimal thermal insulation properties, where λ is 0.028 – 0.040 W/mK for the tested variety P and 0.028 – 0.033 for the variety B, which leads to decrease in energy needed to heat the building. This result is consistent with the requirements related to the natural insulating materials, where thermal conductivity is equal to 0.040 - 0.045 W/m· K .

As fibres of fabric Bialobrzeskie are coarser, more rigid, with less elasticity than P fibres, there is higher weight loss during carding process; as a result, fabric thickness and mass per unit area are lower for the variety Bialobrzeskie.

Good water vapour permeability of a large thickness range allows including needle-punched non-woven hemp fibre materials for natural breathing packet formation for household, industrial and construction use.

Hemp nonwoven insulation can be used as an alternative material for glass wool or mineral wool insulation materials in environmental protection aspect, as well as inner humidity regulation in buildings.

In addition, natural fibres are combustible without residues while glass fibres are not. In consequence, incineration with energy recovery is a favourable end-of-life option as an alternative to recycling. However, natural fibres have also disadvantages, for instance, the increased moisture absorption, flammability.

The obtained results show an opportunity to develop the local Latvian hemp genotype Purini and the industrial hemp variety Bialobzeskie registered in the EU into the insulation applications with a high added value, used in the construction industry.

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Liga Freivalde, Education: Riga Technical University, Faculty of Material Science and Applied Chemistry/ Institute of Textile Materials Technologies and Design. Specialization: material technology and design (Bachelor's degree, 2007). Specialization: Material design and technology (Master's degree – Mg.sc.ing., 2009).
Work experience: 1) Riga Technical University –Researcher, address: 14, Azenes Str., Kipsala, LV – 1048, Riga, Latvia. 2) "Fausta Dizains" Ltd., occupation - Interior Designer; 3) Private house building company "High Castle and Architecture", occupation - Interior Designer - Technician; 4) Latvian Chamber of Crafts, occupation – Conference Organizer, Office Manager. Current interests: renewable raw materials, hemp fibre properties, their use in innovative material development (insulation materials). Previous research interests: RTU Training Corp in Kipsala, 18, Azenes Str., reconstruction and improvement of spatial quality.
Address: 14, Azenes Str., LV – 1048, Riga, Latvia, Phone: + 371 67089256 liga_freivalde@inbox.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: Design Theory & Practice; Market, Material & Processes Research Plan Designing, Organization, Methods of Data Processing and Interpretation; Nanotechnologies.
Work Experience: 1997 – Present: Head of the Professors' Group of Technology and Design of Textile Products , Faculty of Material Sciences and Applied Chemistry. Riga Technical University, the Institute of Textile Materials Technologies and Design
1994 – Present: RTU Professor; 1965 – 1968: Production Engineer at the Production Association "Rigas Tekstils"; 1981 – 1994: Assistant Professor, Leading Researcher, RPI/RTU; 1968 – 1981: Assistant, Aspirant, Senior Lecturer, Department of Mechanical Technology of Fibre Materials of Apparatus Building Faculty at Riga Politechnical Institute.
Memberships in professional societies: 1. Member of International Scientific/Programme Committee of International Textile, Clothing & Design Conferences "Magic World of Textiles" (Croatia) 2005- present.
2. Member-Expert of Doctoral Committees of Kaunas University of Technology, Lithuania (2000 – 2004)
3. Coordinator of cooperation with Reutlingen University of Applied Sciences, Germany (2002 – present).
4. Membership of "Textile Museums" and "Slavic Studies", USA. (1995-present).

Guntis Strazds, Education: Production Engineer, Speciality – Fibre Material Technologies, Riga Technical University (1965) and St. Petersburg Institute of Textile. Dr.habil.sc.ing. degree in textile technology (1989).
Work experience: 1) 1994 - present: President of the Textile and Garment Industry Association of Latvia. Address: 2, Elizabetes Str., LV – 1010, Riga, Latvia. 2) 1997 - present: Valmiera Glass Fibre- Council Member. 3) 1994 – 2005: "Lauma" - Chairman of the Council.
Current research interests comprise use of natural fibres (flax and hemp) in the textile, construction and car production industries.
Address: 2, Elizabetes Str., LV – 1010, Riga, Latvia. Ph: + 371 67089256, E-mail: stragu@latnet.lv.

Līga Freivalde, Silvija Kukle, Guntis Strazds. Neaustie kaņepju šķiedru siltumizolācijas materiāli
Šajā rakstā atspoguļota kaņepju šķiedru neausto materiālu paraugu attīstība siltumizolācijas lietojumiem celtniecības nozarē, kas veidoti ar kāršanas un cauradatošanas 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 tiek testēti, lai noteiktu to izmēru īpašības (biezums, svars uz laukuma vienību), ūdenstvaiku caurlaidības, siltuma pretestības un siltuma vadītspējas, 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, Гунтис Страздс. Конопляное волокно для изоляционных нетканых материалов
Эта статья отражает развитие нетканых материалов, сделанных из конопляного волокна, применяемых для теплоизоляции в строительной индустрии, созданных при помощи чесания и иглопробивной технологий. Два типа конопляного волокна - местный сорт, выращенной в Латвии 2010 году, конопли местного генотипа «Пурини» и коммерчески доступный, в ЕС зарегистрированный и в Польше селекционированный сорт, однодомной промышленной конопли "Биалобрзеские" были использованы в исследовании и сравнении конечных свойств продукта. Полученные образцы материалов конопляного волокна проходили тестирование для определения их физических свойств (толщина, вес на единицу площади), паропроницаемость, термостойкость и теплопроводность для того, чтобы оценить их пригодность для использования в производстве альтернативных теплоизоляционных материалов. Были оценены различные эффекты сортов конопли на свойства материала. Полученные результаты термического сопротивления и теплопроводности для этих тканей являются перспективными для предполагаемого конечного использования. Хорошая паропроницаемость позволяет включить нетканые материалы, сделанные из волокна конопли, 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.