

Thermal properties of hemp fibre non-woven materials

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Abstract. This review considers the thermal properties analysis of hemp fiber non-woven materials made by three different manufacturing technologies - thermal bonding, needle-punching and hydro-entanglement. For non-wovens development two hemp fibers cultivars grown in Latvia were used – Purini and Bialobrzeskie. Thermal resistance, conductivity and the effects of several parameters on thermal performance are revised.

1. Introduction

Reductions of energy consumption in the building sector are important measures needed, as guided by the new energy policy, EU has to achieve at least a 20 % reduction of energy and greenhouse gas emissions by 2020 compared to the year 1990. In Latvia high hemp straw yields are obtainable with excellent physical and mechanical fibers properties. [1,2] This study is concerned with the non-woven samples development from local hemp dioeciously genotype Purini (P) and the EU registered monoecious variety Bialobrzeskie (B) both farmed in climatic and soil conditions found in Latvia. Their physical and thermal properties testing and comparative analysis are carried out.

2. Materials and methods

Hemp fibres, used for this study were obtained from hemp stems harvested from a trial plot of Latgalian Agriculture Research Centre of Latvia. The harvested hemp stems of both varieties were left for dew retting on the field (4 weeks). Linear density for P is 23.4 Tex, for B is 36.2 Tex. [3]

2.1. Samples developed by thermal bonding technology

The hemp/polyethylene-polypropylene webs with fibers ratio 90:10% were produced by carding technique and non-woven samples were made from these webs by means of thermal bonding, where each sample stayed about 1 minute for each thickness cm of the material at 145° hot air regime.

2.2. Samples developed by needle-punching technology

Non-woven specimens were made from carded webs by means of needle-punching technology performed on 30 cm wide sample needle loom with 36 g regular 3 barb needles. The shank gauge of the needle is 15 – 18 – 42. Penetration depth of needles: 6.4 mm on both sides. Punch density: 75 punches/ cm².

2.3. Samples developed by hydro-entanglement technology

Hydro-entanglement was performed on a seven injector 0.5 m wide machine. Webs were pre-wetted and hydro-entangled using jet strips with a nozzle diameter of 150 µm; pressure 100 bar was applied in



an alternating face and back profile. The conveyor speed was fixed at 5 m/min. During the samples production was observed that filters of hydro-entanglement machine blocked up fast as no special measures were taken to remove water-soluble components and impurities (dust) from hemp fibres. Jet strips nozzles blocking were not observed.

2.4. Thermal bonded, needle-punched and hydro-entangled non-woven samples testing methods

An abbreviation system has been used to describe the samples. 3 needle-punched (N), 3 thermal bonded (T) and 4 hydro-entangled (H) samples for each variety were used to produce the non-wovens corresponding to different thicknesses: N1, N2, N3; T1, T2, T3 and H1, H2, H3, H4. Samples have also been denoted according to the origin of the constituent hemp fiber, i.e. Purini (P) or Białobrzesskie (B). All non-woven samples were conditioned under standard atmospheric condition EN 20139:1992. Standard test methods were utilized for the measurement of non-woven properties. Non-woven thickness was measured according to BS EN ISO 9073-2:1997, where method C was adopted with slight modifications: uniform pressure 0.02 kPa, i.e., 20 grams on 100 cm² for N and T groups samples, for H group samples: 10 grams on 50.2 cm². Surface density (m) was determined according to BS EN 29073-1:1992, modification: test area of the sample was 10 000 mm². The density of the non-woven samples has been calculated by dividing the non-woven surface density by the material volume. Both, thermal resistance (m²·K/W) was measured by using two-plate method: fixed pressure procedure and thermal conductivity (λ), W/(m·K), was calculated according to BS 4745:2005.

3. Results

Through all experiment thermal conductivity (λ) is in the range from 0.028 up to 0.04 W/(m·K), overall difference is 44 %. It can be explained as in general, thermal conductivity depends on the thermal resistance, density, temperature, moisture content, as well as components and porosity [4]. Therefore, the material λ can vary within a relatively wide range.

Test results of hydro-entangled samples show lower λ values for cultivar P comparing with variety B in all cases except H4 is slightly higher. Differences between cultivars mostly are insignificant, for samples H4 it is only 0.2%, for samples H3 and H2 it is 2%. For samples H1 difference is higher, i.e., 22% (Fig.1).

By comparing hydro-entangled samples with thermal bonded and needle-punched sample groups it can be seen that changes in the thermal conductivity are relatively small, except sample NP2 is noticeably higher than sample TP2 (Fig. 1), compared to the changes in the thicknesses (Fig.2).

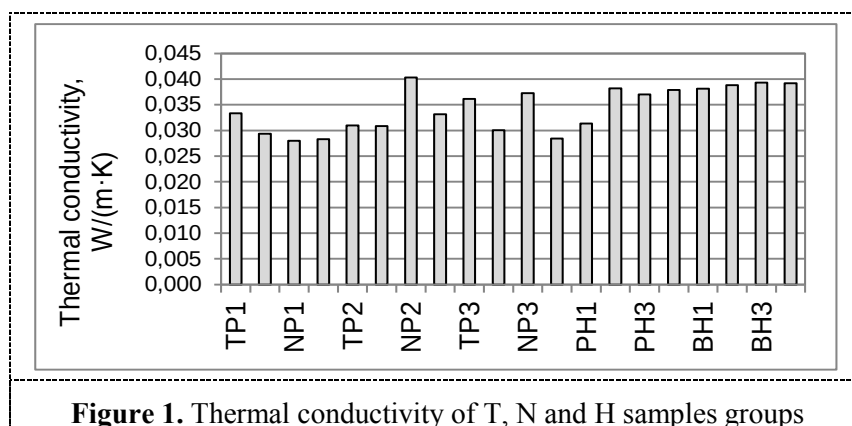
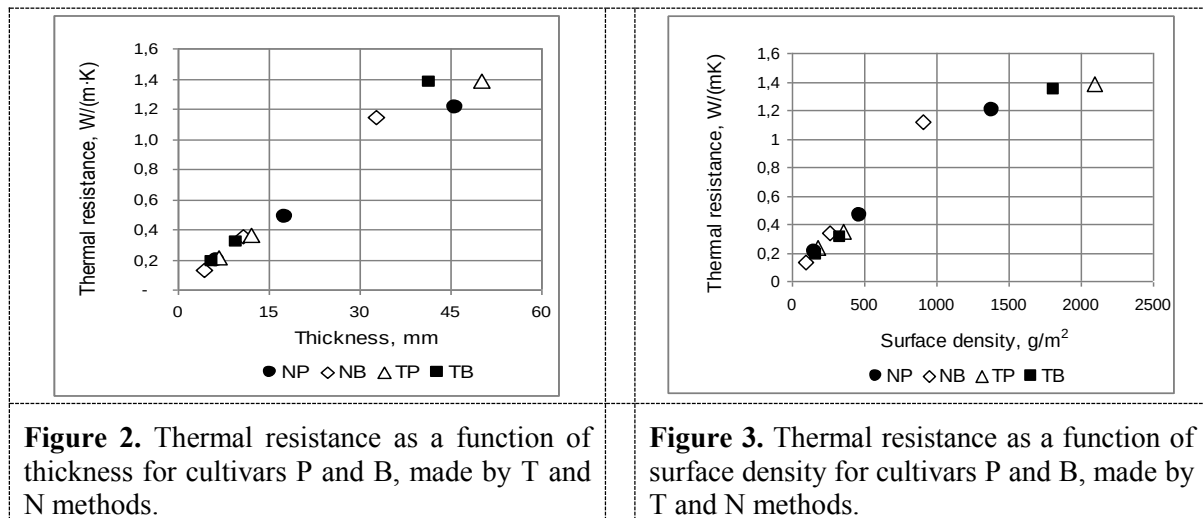


Figure 1. Thermal conductivity of T, N and H samples groups

Throughout the experiment analysis of covariance show strong relationship between thermal resistance and thickness as high correlation take place: $r = 0.99$, correlation between thermal resistance and surface density is slightly lower: $r = 0.94$. Results for relationship among non-woven thermal resistance and thickness (Fig. 2) can be described as linear relationships for thermal bonded $Y_{TP/B}$ as well as needle-punched $Y_{NP/B}$ samples groups (eq. 1-4).



Empirical regression models are linear:

$$Y_{TPR} = 0.0388 + 0.0269d_1, \quad (1)$$

$$Y_{TBR} = -0.0022 + 0.0333d_2, \quad (2)$$

$$Y_{NPR} = 0.0316 + 0.0258d_3, \quad (3)$$

$$Y_{NBR} = -0.027 + 0.0358 d_4, \quad (4)$$

$$Y_{TPR} = 0.1308 + 0.0006m_1, \quad (7)$$

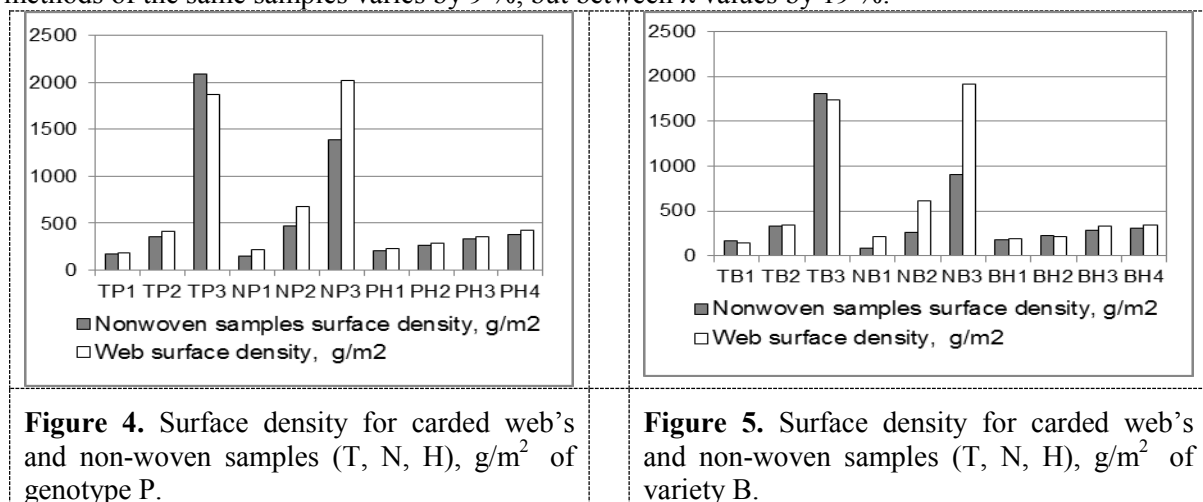
$$Y_{TBR} = 0.0708 + 0.0007m_2, \quad (8)$$

$$Y_{NPR} = 0.0873 + 0.0008m_3, \quad (9)$$

$$Y_{NBR} = 0.0255 + 0.0012m_4 \quad (10)$$

where design factors d_1 , d_2 , d_3 , d_4 represent non-woven thickness (mm); m_1 , m_2 , m_3 , m_4 - surface density (g/m^2), response variables Y_{TPR} – thermal resistance of thermal bonded (TP, TB) and needle-punched (NP, NB) samples of both varieties.

By comparing thicknesses of TP1 and NP1 samples, which are respectively 6.7 mm and 6.5 mm, it can be seen that changes between methods are minor, only 2%. Meanwhile differences of surface density (Fig.4) are more significant - 13 % (172 g/m^2 for TP1 and 153 g/m^2 for NP1). Density between methods of the same samples varies by 9 %, but between λ values by 19 %.



Thickness for the samples PH2 and BH2 are equal: 2.7 mm. Difference between densities as well as surface densities is 16 %. It can be explained due fact that for webs processing by carding was used the same amount of entering fibers, but after carding the web weight and respectively also web surface density was higher for variety P (Fig. 4, 5). For variety B 29% more fibers went to the waste in the carding process, thence less fiber and non-woven surface density appeared (Fig.5). For the samples

BH1 and BH2 difference between surface densities and densities is 25.4 %. As the thickness 2.7 mm is equal for both samples it leads to different fiber congestion (Fig.5). Changes between thermal properties are insignificant: 0.8 %. Thermal resistance for samples PH1, PH2, BH1 and BH2 is 0.07 m²K/W. Slightly higher values are for PH3 and PH4, i.e., 0.08 m²K/W. For BH3 and BH4 it is 0.09 m²K/W. For P group samples, by increasing thickness, thermal resistance values grows gradually, but for B group samples thermal resistance develop by leaps reaching a certain thickness (Fig.6, 7).

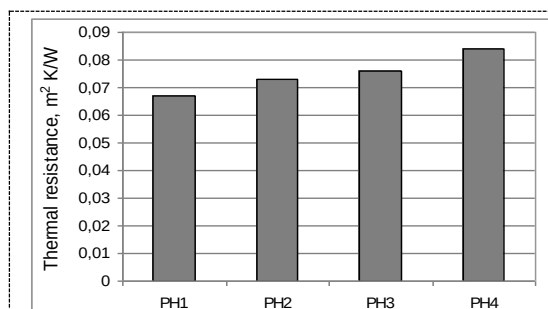


Figure 6. Thermal resistance for cultivars P and B made by hydro-entangling method.

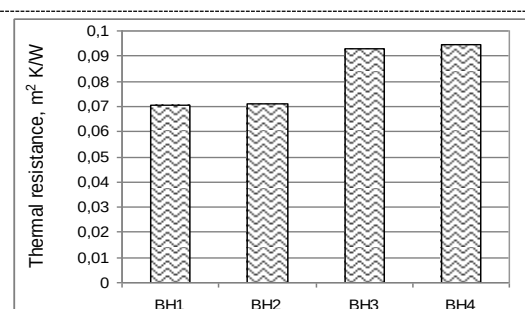


Figure 7. Thermal resistance for variety B made by hydro-entangling method.

The trend within experiment shows that thermal resistance of non-wovens of all technologies (T, N, H) and both varieties increased with non-woven thickness and surface density increase (Fig.2, 3, 6, 7).

4. Conclusions

Thermal properties of non-woven samples of technical hemp fibers made through the thermal bonding, needle-punching and hydro-entanglement technologies were explored in this study. For thermal bonded non-wovens thermal resistance is in the range: 0.20-1.39 m²K/W, λ : 0.0294 - 0.0361 W/m·K, density: 25.7- 41.7 kg/m³ for cultivar P and 0.19-1.38 m²K/W; 0.029 – 0.031 W/m·K, 29.6 - 43.8 kg/m³ for variety B. For needle punched non-wovens thermal resistance is 0.24 - 1.23 m²K/W, λ is 0.028 - 0.040 W/m·K, density 23.6 - 30.3 kg/m³ for variety P and for variety B: 0.16-1.15 m²K/W, 0.028- 0.033 W/m·K, 20.6-27.8 kg/m³. For hydro-entangled samples thermal resistance is 0.067-0.084 m²K/W, λ 0.031-0.039 W/m·K, density 98.1-116.2 kg/m³ for P; 0.071-0.094 m²K/W, 0.0379-0.0392 W/m·K, 68.5-85.9 kg/m³ for B. These results shows the same or better thermal properties than other commonly used thermal insulation materials, e.g., mineral wool with λ 0.030-0.045 W/m·K, if density is 13-180 kg/ m³. By comparing hydro-entangled samples with thermal bonded and needle-punched, it can be seen that changes in the thermal conductivity are relatively small, except sample NP2 is noticeably higher than sample TP2, compared to the changes in the thicknesses.

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