DELIVERABLES REPORT

Multipurpose hemp for industrial bio products and biomass
(Ref n. 311849)

D5.8 Report on the suitability of hemp fibre for blow-in insulation

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1. Background and objectives

The concept of the integrated biorefinery of the EU-FP7 project „MultiHemp“ (Ref. 311849) aims the development of a modular biorefinery with choices of various product options depending on market forces. Following this concept, it is necessary to achieve the optimised processing steps and further end use applications for the particular raw material along the production chain.

Beside the long bast fibres which are primarily used for high-tech products like technical textiles or high-tech composites, there are short hemp fibres (bast fibre bundles), shives and “bulk” hemp along these processing lines (Figure 1). Those by-products are seen as innovative reinforcements for injection moulded bio-composites, low-carbon construction materials and insulation products (Figure 1: green circle).

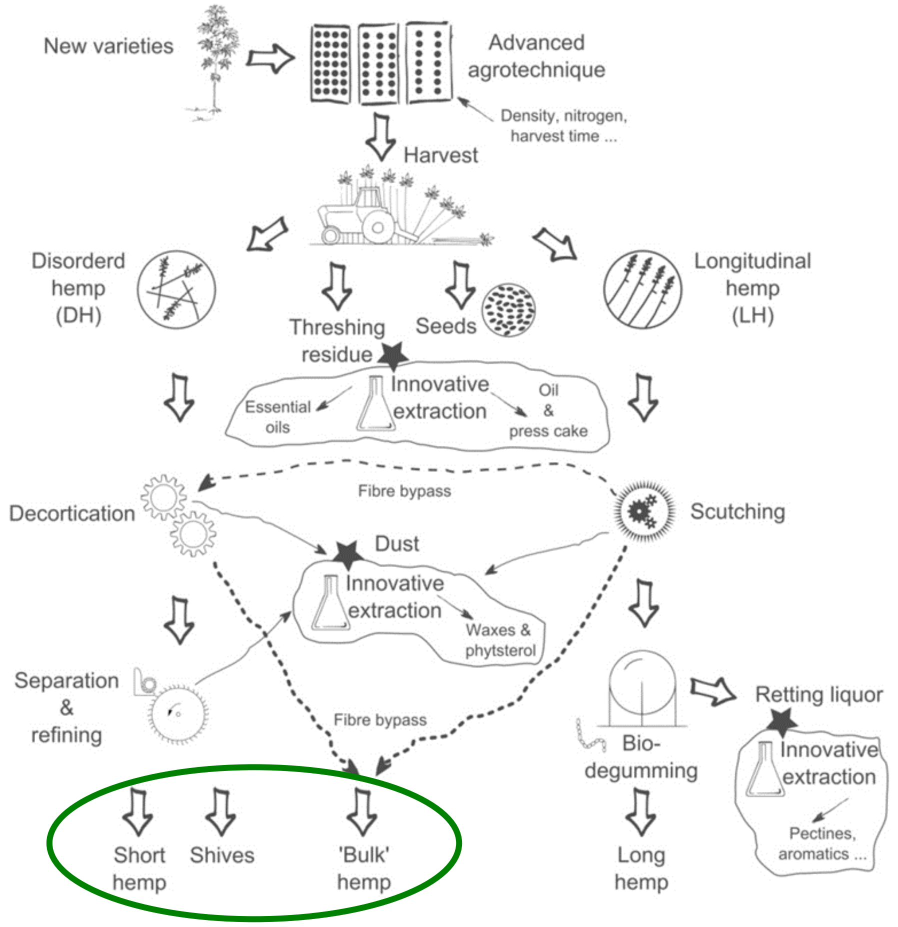

Figure 1: Scheme of the MultiHemp biorefinery concept. Large arrows indicate raw material flow along the production chain; Green circle highlights the by-products within the production chains which are seen as potential materials for insulation products.

Construction and insulation materials are frequently discussed on conferences and in publications regarding to the requirements of EU directive 2010/31/EU, which claims the needs of implementing effective measures for construction and reconstruction of existing buildings to reduce the energy consumption (Zach et al., 2013; Papadopoulos, 2005). Insulation materials made of renewable resources are therefore seen as an alternative material to conventional insulation products. They exhibit low energy consumption during the production, consume a minimum of resources and producing a minimum or hardly any industrial waste compared to materials like mineral fibrous insulating and foam plastics (Murphy et al. 1999).

One principal idea of the MulitHemp project is to evolve a sustainable and environmental friendly alternative to synthetic thermal insulation materials; by developing a blow-in insulation material of by-products within the raw material flow.

For an acceptance towards environmental sustainability and the establishment of a new insulation materials there are requests for technical advantages for the consumer, environmental advantages for society and a competitive price (Murphy et al. 1999). Therefore expert’s knowledge from scientific and industrial sides are necessary. Within this work package the industrial partner Ventimola GmbH & Co. Dämmtechnik KG (Bremen, Germany) is involved for developing a process technology for a blow-in insulation product of hemp. This company is engaged with the development and practical implementation of insulation procedures of loose fill insulation products of cellulose, wood fibres or mineral materials for over twenty years.

Therefore the conventional blow-in process, mostly used for insulation products of mineral wool and cellulose, will be adapted for the new hemp insulation material.

Moreover the blow-in material has fulfil the requirements of structural-physical perceptions regulated in European standards. Those requirements including the mechanical characteristics, thermal insulation, moisture absorption and fire resistance are investigated within this work package.

Beside the investigation regarding to the European standards of the developed blow-in insulation material, there are additional topics related to the MultiHemp biorefinery concept. In order to sustain a sufficient quantity, an economical production at competitive prices for the raw material of the blow-in insulation products, bulk hemp of different production lines should be mixed together. Different varieties, harvesting procedures and location with distinct climatically conditions can influence the material properties. Apart from the hemp variety and location, the harvesting procedure is seen as an important factor, too. Within this task of WP6 samples from two harvesting techniques were used, the classic European hemp harvesting technique and the concept of DunAgro (Oude Pekela). To answer the questions of the possible influence of variety, location, climate and processing on the insulation properties we used hemp from two different locations, two varieties, three different structures and two harvesting techniques to process the “bulk hemp” with a Whirlwind-Mill to different blow-in insulation materials.

2. Insulation material preparation process

2.1 Structural requirements on insulation material

A determining factor is the settling behaviour or rather the volume stability which depends on mechanical loads such as impacts, constant loads or vibration due to surface shaking caused by traffic and impacts caused by slamming doors. For those reasons the required insulation structure has to be a three dimensional network which exhibit a strong cohesion among the single fibre bundles to avoid settling. This network is increased by spliced and entanglements between fibre bundles. However, this structure influences the handling during the blow-in process due to fine agglomerated fibre bundles avoiding the flowability of the insulation material. This leads to an inhomogeneous distribution of the insulation material and causes cavities which decline the thermal insulation properties (Treml, 2011).

The processing and handling properties of the insulation material are consequently influenced by the manufacturing process.

2.2 Selection of the manufacturing process

The selection of an adequate manufacturing process depends on the further mentioned required structure of the insulation material and on the practicability. For those reasons Ventimola carried out various preliminary grinding and processing test of raw material to get the most convenient process. This includes the pre-processing such as cleaning and sorting of the raw material, which is contaminated with impurities e.g. stones. For homogenizing the cleaned raw material a shredding unit was used.

Following up with the manufacturing process, the further step is the milling process. The use of mills with high acting loads such as stone or hammer mills results in an undesirable large structural damage of the fibre bundles. The consequence is the loss of strength and elasticity of the insulation material. Whirlwind-Mills and refining mills showed the most promising results for an adequate manufacturing process.

The grinding stock e. g. raw hemp material is therefore fed to the Whirlwind-Mill by an inlet box. In the first step of the grinding process the grinding stock is pre-crushed by the rotor of the mill which further conveys the material into the milling zone. The following milling process is mainly caused by collision of the rotating grinding stock. The pre-crushed raw material e. g. fibre bundles and shives collide with each other in an airstream caused by the rotation of the rotor which represents the main grinding process.

This procedure enables the fibrillation of the fibre bundles which is important for the required structural properties. Several pilot tests with different process parameters such as rotational speed and material loading showed the possibility of different fibre bundle sizes with varying length to diameter ratio. Furthermore different processing set-ups with refining mills were carried out to determine the best practice.

2.3 Preparation process

Raw material and straw were generally shredded in advance. Already prepared fibres as well as fibre mix obtained from the cleaning units of the fibre preparation of the Company Planète Chanvre (France) and the Company Dun Agro (Netherlands) were in other cases inserted into the mill directly. The amount of dust content was determined by weighing with a scale (Kern EOB, Kern & Sohn GmbH, max. 300 kg, D = 10 g, Balingen, Germany). Main milling parameters such as rotational speed and material loading were adapted to the required grinding stock. Additional electric power data was collected throughout all grinding experiments in order to compare the environmental impact of this process to already existing process and products.
As a result of the preparation process different configurations of the blow-in insulation material is generated. Two locations (France and Netherlands) divided the materials in two main groups. The difference of the two locations is in this case not the climate condition. Rather, they differ in two harvesting techniques: the classic European hemp harvesting technique and the concept of DunAgro (Oude Pekela).
Furthermore the manufacturing process exhibit three structure of the insulation material. Therefore the test specimen varying in the amount of fibres and shives are labelled as primarily consisting of fibres (F), shives (S) and a fibre-shive-mix (FG).

The labelling of the test specimen includes the location (F/NL), variety (Bialobreskie B and Futura F), structure (F, S, FG) and the number of the sample. As an example, the label F_F_F 10 is a test specimen cultivated in France, the variety is Futura, the structure consists primarily of fibres and the test number is 10.

3. Methodology and measurements

3.1 Settlement characteristics according to ISO/CD 18393

For the investigation on the settlement characteristics the international standard ISO/CD 18393 method A and B and a vibration test in compliance to the proceedings of Vogel (1999) was executed with all test specimens.

Determination of settlement characteristics according to ISO/CD 18393 method A

The test box, open to the top, was made of perforated metal plates and wood (20 mm 3-layer-plates) with interior dimensions of L x W x H = 550 x 550 x 330 mm³.
The test rig consists of a mounting plate, which is excited by an eccentric via a guided pump rod. The box filled with the insulation material is mounted on top of the test rig. The apparatus is to be configured that the box is smoothly moved up 50 mm and subsequently slams down onto a stiff plastic bearing in free fall. This process is repeated 20 times with a dwell time of 0.8 s and a lifting time of 1.2 s.

Test procedure

- The insulation material is blown into the box from above with a blow-in machine (Zellofand M95, X-Floc, Renningen, Germany) and needs to be filled up to the top of the box.
- The blow-in insulation material is weighed with a scale (Kern 440 – 35 N, Kern & Sohn GmbH, max. 400 g, D = 0.01 g, Balingen, Germany) to verify the exact bulk density.

  The bulk density ρ_B was calculated from the ratio between the mass m in kg and the volume V in m³ in compliance of the equation:

  $$\rho_B = \frac{m}{V} \tag{I}$$

  For comparability reasons the achieved bulk density was adjusted to 32-40 kg per cubic metre.
- Determination of the filling level of the insulation material is measured initially of the test procedure at 12 different positions. Usage of a test plate (200 x 200 mm², mass: 204 ± 6 g), which exerts a pressure of 50 Pa onto the insulation material. The test plate is placed carefully on top of the insulation layer and the height is determined by insertion of a centrically guided needle. The height of the insulation material has to be measured with an accuracy of 1 mm. A possible test rig configuration is shown in EN 823 Figure B.1.
- The box is covered by a cover plate and the mounting plate is connected rigidly by e.g. straps.
- For a required sample size 20 shock procedures were executed.

- The height of the settled insulation material after the 20 test cycles is measured again at 12 different positions in a comparable way to the initial determination of the filling level which gives a mean value for continuing calculations according to ISO/CD 18393.

Determination of settlement behaviour according to ISO/CD 18393 method B

Test specimens, which showed promising results during the investigations of the method A, are selected for the settlement behaviour test according to method B.

A test rig was developed based on the proposed minimum dimensions of the ISO/CD 18393 method B (Width: 625 mm, Height: 1000 mm, Depth: 160 mm). The template of the drop and vibration frame is inspired by the work of Vogel (1999). Three spruce wood frames with different internal depths were constructed as a support for various planking materials. The frame is blown-in with a bulk density as described in procedure A. The frame is lifted to the minimum height of 5 cm according to ISO/CD 18393 method B and is dropped with the bottom side of the frame onto a concrete flooring.

Vibration test in compliance to the proceedings of Vogel 1999

The following test procedure of the vibration test refer to the investigations as stated in Vogel (1999) which take into account the influence of the vibrations in buildings caused by traffic, airplanes and railroads. Therefore, two rotating exciters are mounted directly opposed to each other on a test case in order to generate the required sinusoidal vibration. The rotating exciters provide a frequency of 65 Hz and a defined load of 17.7 kN which applies the required acceleration of 15 m/s².

3.2 Fire behaviour according to DIN EN 4102

For the fire behaviour investigations a gabion cage for the edge flaming procedure was constructed according to DIN EN 4102-1. The gabion cage was filled manually with a bulk density of 32 to 38 kg/m³. A measurement mark was mounted in 150 mm height from the bottom of the test specimen.

The nozzle burner was 45 ° inclined relatively to the horizontal and the height of the flame was at least about 20 mm. During the measurement time of 15 s, and after further 5 s observation time, flames or rather burned material must not exceed the measurement marks.

A test series include five test specimens. The data of the five tests will be averaged for further evaluation.

3.3 Thermal insulation according to DIN EN 12667

In accordance to DIN EN 12667 the thermal conductivity λ in (W/(m*K)) of selected samples of the hemp blow-in insulation material were tested by means of a guarded hot plate device. Therefore a custom-made frame, (Figure 2 B) in which the samples were filled in manually with a required bulk density of 35 kg/m³, was developed.

To calculate the bulk density, following the equation I, a scale (Kern 440 – 35 N, Kern & Sohn GmbH, max. 400 g, D = 0.01 g, Balingen, Germany) was used to weigh the mass of the filled blow-in insulation material.

Samples were stored for 24 h at 20 ± 3 °C and 50 % relative humidity in a climate chamber (Vötsch-Klimaschrank Typ VCL 4003, Vötsch Industrietechnik GmbH, Balingen-Frommern, Germany). The thermal conductivity was calculated in accordance with equation (II):

$$\lambda = \frac{\phi d}{A(T_1 - T_2)} \tag{II}$$

(ϕ: heat flow in W; d: sample thickness in mm; A: measuring zone in mm²;
T_1: Temperature of the heating plate in K; T_2: temperature of the cooling plate in K)

The testing time was defined by a minimum of five hours to guarantee a steady-state heat flow. The temperature difference between the heating plate with an absolute temperature of 40 °C and the cooling plate with an absolute temperature of 25 °C was adjusted by 15 K. The guarded hot plate device was constructed after arrangement c) with two symmetrically arranged test specimen and a circular measuring zone. The measuring zones were providing four (heating plate) or rather three (each cooling plate) thermal elements for the heat flow measurements. The experimental set-up is shown in Figure 2 A.

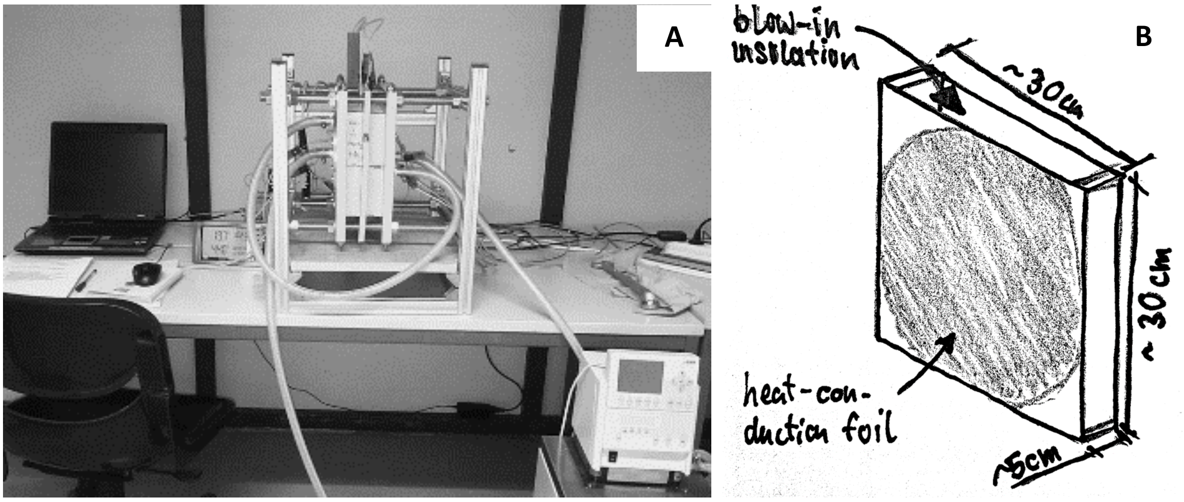

Figure 2: The experimental set-up with the guarded hot plate device and the water cooling system (A). The sketched custom-made frame with the dimension and the heating-conduction foil (B).

3.4 Hygrothermal performance/water absorption according to DIN EN ISO 12571/ DIN EN 1609 method A

Hygrothermal investigations of the blow-in insulation material were carried out by using a climate chamber (Vötsch-Klimaschrank Typ VCL 4003, Vötsch Industrietechnik GmbH, Balingen-Frommern, Germany) according to DIN EN ISO 12571. Determining the mass test specimens were weighted with a scale (Kern 440 – 35 N, Kern & Sohn GmbH, max. 400 g, D = 0.01 g, Balingen, Germany). The minimum of the required test specimen mass was 10 g. According to the test procedure the samples were first dried to a constant mass with a temperature of 105 °C. The relative humidity was successively increased starting with the least. The increments of the relative humidity were 33, 40, 55, 65, 80, and 90 %, respectively. Before increasing the relative humidity the test specimen was weighed to determine the moisture absorption. Within the test procedure only the absorption curve was investigated.

The determination of the short term water absorption by partial immersion was done according to DIN EN 1609 method A. For the investigation the tap water was acclimatised by ambient temperature of 23 ± 5 °C. The test specimens were filled in a costum-made frame and immersed 10 ± 2 mm with the entire underside in the acclimatized water. After 24 h ± 30 min the samples were taken out and placed onto a drainer. The excess water could drop off for 10 ± 0.5 min.

Test specimens were weighed by a scale before and after the procedure. For the calculation of the water absorption W_p in kg/m² equation III was used

$$W_p = \frac{m_{24} - m_0}{A_p} \tag{III}$$

(m_{24}: mass after dipping in g; m_0: mass before dipping in g; A_p: lower bounding surface in m²)

3.5 Shirley fineness measurements

A fast fineness measurement device called Shirley tester was used to carry out the fibre fineness measurements. The air permeability through a fixed mass of fibres (4 g) is recorded at two different stages of compression (PL + PH) to estimate the fibre fineness.

4. Results and discussion

4.1 Insulation material preparation process

The pre-processing such as cleaning and sorting of the raw material, which was contaminated with impurities, was more difficult than expected. Technically unprocessed raw material provided by the hemp suppliers was partly contaminated by stones of different sizes. The raw material was therefore sorted manually by hand. Smaller pieces of stones which were covered of stalks and leaves could not be sorted. This leads to standstill of the process, repairs and exchanges of grinding and crushing knifes as well as other components of the conveyance were necessary.
To enhance the entire process a sorting machine should be constructed.

4.2 Settlement characteristics according to ISO/CD 18393

Settling, bulk density, settled density are depict in the table 1 The samples that comply with the required standards were selected for further investigation such as thermal insulation, moisture absorption and fire behaviour. The research of the drop and vibration frame did not show significant differences compared to the results of procedure A. Therefore only the results regarding to ISO/CD 18393 are shown in table 1.

Table 1: Results of the settlement characteristics according to ISO/CD 18393. The settlement and the selection ratio was used for selecting samples for further investigations. The name of the variety Bialo is an abbrevation for Bialobreszki and Futura for Futura 75.

test number	location	variety	structure	name	frequency	bulk density	settlement	settlement density	selection ratio
					in Hz	in Kg/m3	in %	Kg/m3	S/Ps
10	F	Bialo	S	F_B_S	52	35.62	6.45	37.92	1.00
14	F	Bialo	FG	F-B-FG	51	40.17	6.67	42.85	1.00
15	F	Bialo	FG	F-B-FG	51	38.49	5.80	40.72	1.00
19	F	Futura	F	FBS	55	35.83	2.51	36.73	1.00
21	F	Futura	F	FFF	52	36.08	1.79	36.73	1.00
39	NL	Futura	S	NL-F-S	52	39.16	3.99	40.72	1.00
44	NL	Bialo	S	NL-B-S	52	41.32	5.88	43.75	1.00
56	NL	Bialo	S	NL-B-S	51	37.88	5.88	40.11	1.00
71	NL	Bialo	F	NL-B-F	52	40.74	3.65	42.23	1.00
82	NL	Futura	FG	NL-F-FG	52	37.25	7.58	40.07	1.00
111	F	Bialo	F	F-B-F	52	27.64	0.70	27.84	1.00
116	NL	Futura	FG	NL-F-FG	53	41.32	6.06	43.83	1.00
124	NL	Futura	F	NL-F-F	52	37.88	6.67	40.40	1.00

4.3 Fire behaviour according to DIN EN 4102

The results of the fire behaviour are depicted in table 2. The test specimens reaching the measuring mark at 150 mm were discarded. It is noticeable that samples with a higher amount of shives exhibit a higher reaction to fire and a stronger afterglow compared to samples with a higher content of fibres or rather fiber/shive mixtures.

Table 2: Results of the fire behaviour according to DIN EN 4102 of the selected test specimens.

test number	location	variety	structure	name	extension in mm after 5 sec.	height in mm	width extension	afterglow	independently extinguishment
10	F	Bialo	S	F_B_S	40	150	strong	very strong	yes
13	F	Futura	S	FFS	40	160	strong	very strong	yes
14	F	Bialo	FG	F-B-FG	25	130	slightly	slightly	yes, fast
15	F	Bialo	FG	F-B-FG	30	140	slightly	slightly	yes, fast
19	F	Futura	F	FBS	35	70	slightly	slightly	yes
21	F	Futura	F	FFF	20	55	slightly	slightly	yes
39	NL	Futura	S	NL-F-S	45	170	strong	very strong	yes
44	NL	Bialo	S	NL-B-S	35	150	very strong	very strong	yes
56	NL	Bialo	S	NL-B-S	45	170	strong	very strong	yes
71	NL	Bialo	F	NL-B-F	30	75	slightly	slightly	yes, fast
82	NL	Futura	FG	NL-F-FG	25	60	very slightly	slightly	yes, fast
111	F	Bialo	F	F-B-F	30	60	slightly	slightly	yes, fast
116	NL	Futura	FG	NL-F-FG	20	50	very slightly	slightly	yes
124	NL	Futura	F	NL-F-F	35	60	slightly	slightly	yes

Further explanation might be in the lower density of the shives. Neuhaus (1994) declares that a higher density of timber results in a retarding behaviour of inflammation. Additionaly, carbonized surfaces retard inflammation due to the lower thermal conductivity. Fibres getting in contact with the flame initially carbonise and do not inflame adjacent fibres unlike the shives.

The ratio between the surface/volume is another influencing factor. A higher ratio results in a higher degree of flammability (Neuhaus, 1994). The fine fibres with a high surface/volume ratio easily ignite and carbonise. Further the carbonised surface retards the inflammation due to the lower thermal conductivity of carbon.

In general it is appreciable that all samples were not treated with a fire retardant. Comparable blow-in insulation materials such as wood fibres or cellulose show a substantially higher reaction to fire and cannot pass the test without using a fire retardant treatment. Therefore it is expected that a treatment with a fire retardant of the investigated test specimen could further decrease the reaction to fire. Further it might be reasonably assuming that the investigated hemp material could show comparable results in reaction to fire with smaller amounts of fire retardants than conventional insulation materials. This will lead to economic and ecological advantages.

4.4 Thermal insulation according to DIN EN 12667

The investigations of the thermal insulation properties were carried out with the use of a custom-made frame. The results of the thermal conductivity were influenced by the frame and had to be corrected. To determine the influence of the frame or rather to identify the observational error, a preliminary test series were executed to estimate a regression line as a correction curve with conventional insulation products (Table 3). In the case of Supafil®, HK33®, wood fibres and cellulose the required or rather specific bulk density of the manufacturer was used.

Table 3 Measured values in W/(m k) and manufacturer information in W/(m k) for the correction with the regression line of the reference sample.

reference sample	mean (n)	standard deviation	manufacturer information	
PMMA	0.2228 (3)	0.0017	0.19	(Evonik, 2013)
Styrodur®	0.0698 (2)	0.0014	0.034	(BASF, 2016)
Supafil® hydrophob	0.0665 (2)	0.0006	0.034	(Knauf, 2016)
HK33®	0.0637 (1)	-	0.033	(Haupt, 2017)
wood fibre	0.0703 (1)	-	0.038	(Steico, 2016)
cellulose	0.0650 (3)	0.0025	0.038	(Isocell, 2013)
OSB 3	0.1377 (3)	0.0006	0.1028	(Sonderegger, 2009)

The coefficient of determination R^2 with a value of 0.998 shows the high linearity of the correction curve (Figure 3). This indicates the possibility to correct the results with the regression line.

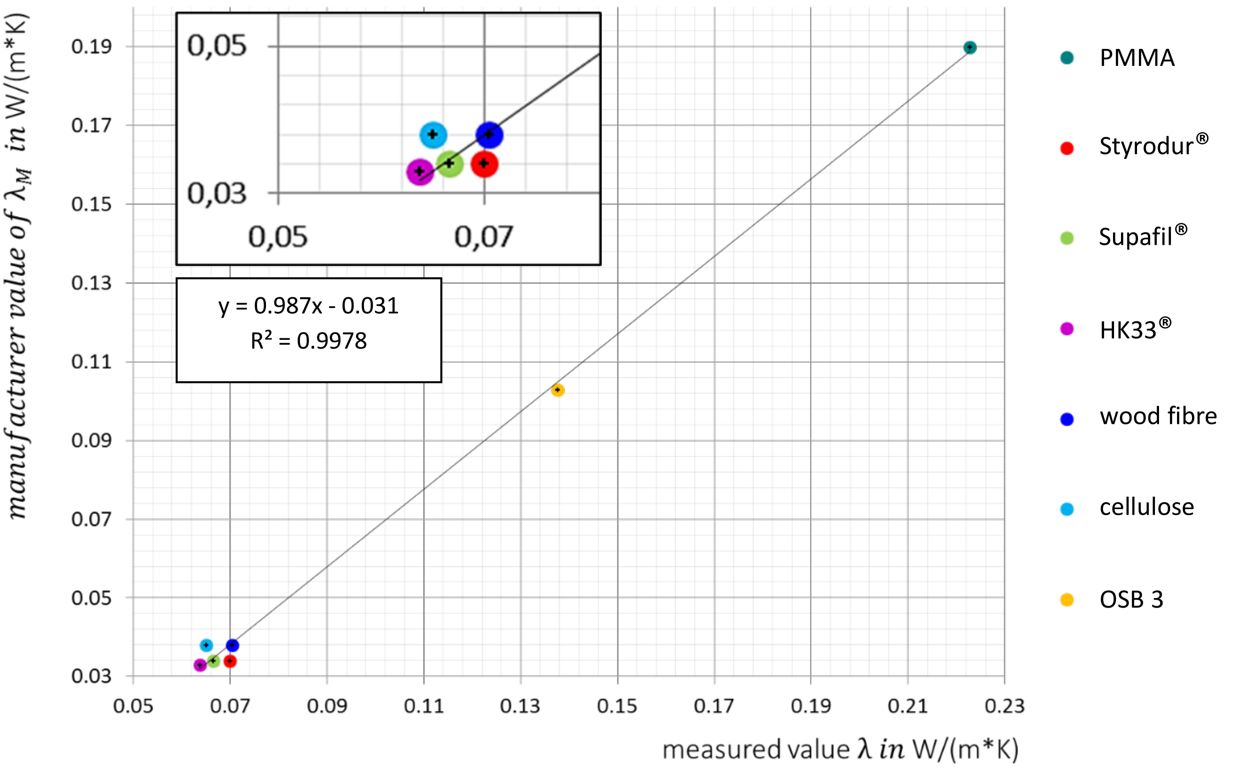

Figure 3: Regression line as a correction curve with conventional insulation products. The coefficient of determination R² with a value of 0.998 indicates the well-adjusted correction curve. Black framed graph section gives a detail scene of the results of HK33® (purple), wood fibre (blue), cellulose (light blue), Supafil® (green) and Styrodur® (red).

The correction method is illustrated in the black framed box in Figure 4 with black arrows. Values of the measured thermal conductivities λ_m are mirrored along the regression curve to receive the corrected thermal conductivities λ_c.
The targeted range of thermal conductivity is highlighted within the red box in Figure 4. It can be observed that the thermal insulation results of the test specimens with the fibre-shive-mix exhibit the lowest values. Those range between 0.0376 and 0.0482 W/(m*K).

An explanation of the different results, which is clearly represented in Table 4, of the groups is seen in the settlement behavior. After the test procedure, it was observed that test specimens with primarily contents of fibers and shives showed a higher settlement behaviour. This leads to a hollow space or rather cavities in the upper part of the frame. Following Cammerer (1995) relevant influence of thermal convection is induced with cavity size greater than 8 mm and temperatures higher than 10 °C, which increase the thermal conductivity.

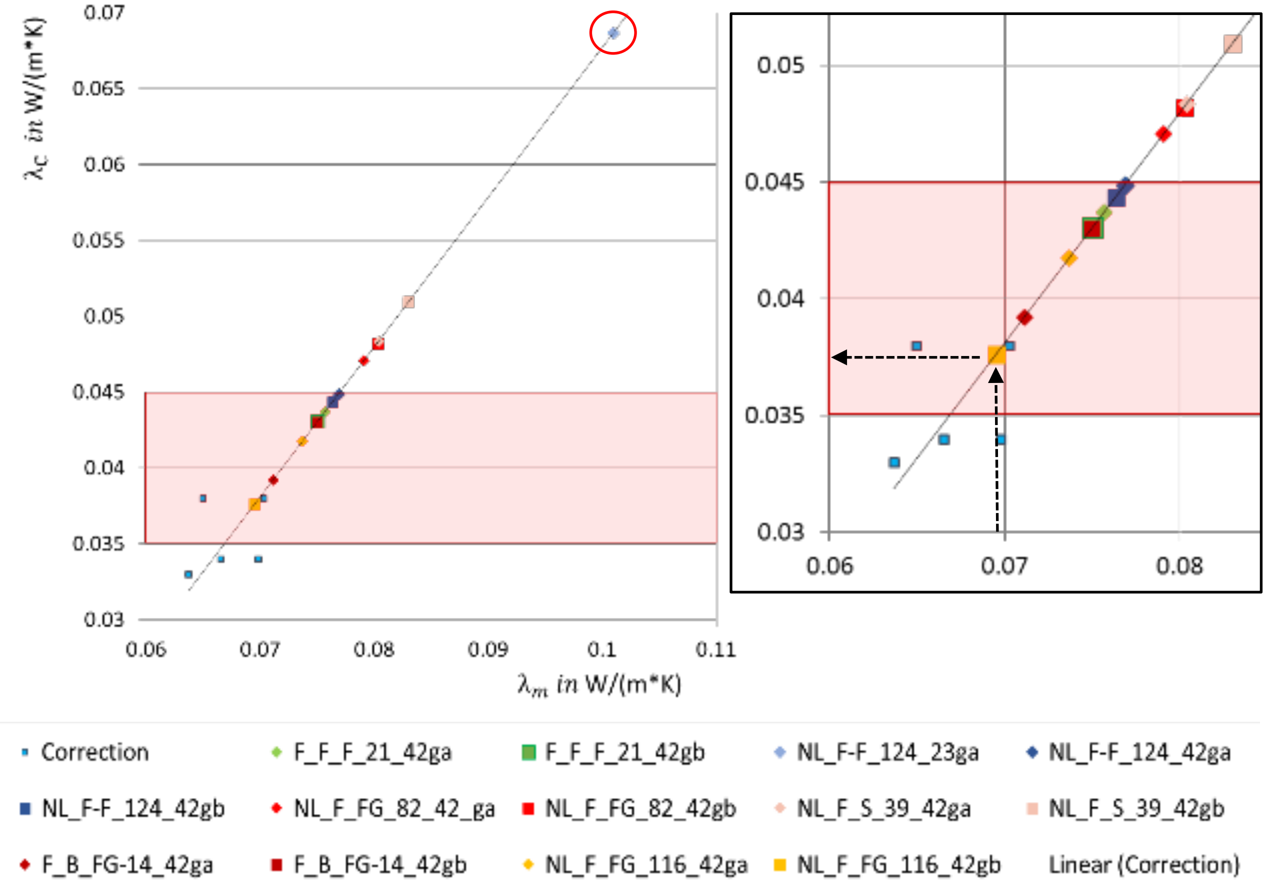

Figure 4: Results of the corrected thermal conductivities λ_c. Red box highlight the targeted range of thermal conductivity. Correction method is illustrated in the black framed box with black arrows.

Table 4: Results of the corrected thermal conductivities λ_c. Yellow box highlight the insulation materials of fibre/shive mix.

test specimen	λ_m	λ_c
F_F_F_21_42ga	0,0757	0,0437
F_F_F_21_42gb	0,0750	0,0431
NL_F_F_124_23ga	0,1010	0,0687
NL_F_F_124_42ga	0,0769	0,0449
NL_F_F_124_42gb	0,0763	0,0443
NL_F_FG_82_42ga	0,0791	0,0470
NL_F_FG_82_42gb	0,0803	0,0482
F_B_FG_15_42ga	0,0711	0,0392
F_B_FG_15_42gb	0,0750	0,0430
NL_F_FG_116_42ga	0,0737	0,0417
NL_F_FG_116_42gb	0,0695	0,0376
NL_F_S_39_42ga	0,0804	0,0484
NL_F_S_39_42gb	0,0830	0,0509

Beneath the influence of settlement behaviour it is possible to see the dependence of the bulk density. In Figure 4 the red circle highlight the sample with a bulk density of 19 kg/m³. The lower bulk density is prone to mechanical loads and vibration due to the loose three dimensional network of single fibre bundles. This leads to hollow spaces, cavities and to a greater settlement behaviour which ends up in an increase of the thermal conductivity.

4.5 Hygrothermal performance/water absorption according to DIN EN ISO 12571/ DIN EN 1609 method A

The results of the hygrothermal performance according to DIN EN ISO 12571 are depicted in Figure 5. The courses of the lines are showing the absorption behaviour of different relative humidity. Each dot is the equilibrium moisture content of one test sample at a specific humidity which depends on the material properties. In order to see the differences within location the lines are drafted in different shades, red shaded lines are samples from French and blue shaded lines are samples from the Netherlands. The line types are indicating the different structure composition such as continuous lines for the fibre-shive-mix, dotted lines show primary fibres and dashed lines represent primary shives samples.

It is noticeable that all lines are running in a comparable S-course which is increasing at a relative humidity of 55 %. Following Treml (2011) the increasing course at higher relative humidity of the absorption curve is related to increasing capillary condensation.

To compare the location, it is observed that red shaded samples from France show slightly higher moisture absorption compared to samples from Netherlands, except the test specimen F_B_F_111 (yellow dotted line).

Regarding to the samples from France it can be observed that the fibre-shive-mix results in the highest moisture absorption followed by the sample mainly consisting of shives. The lowest moisture absorption of the French samples exhibits the primary fibre consisting test specimen.
In case of the Netherlands samples the fibre-shive-mix results similarly to the France test specimens in higher moisture absorption behaviour. However, a clear differentiation between mainly consisting fibre or rather shives sample is not possible due to overlapping curves.
Different contents of fibre and shives or rather contamination of dust and measurement inaccuracies could influence the results. This leads to an overlapping of the absorption lines and make it difficult to see significant differences. Therefore the results of the water absorption are taken into account for the discussion.

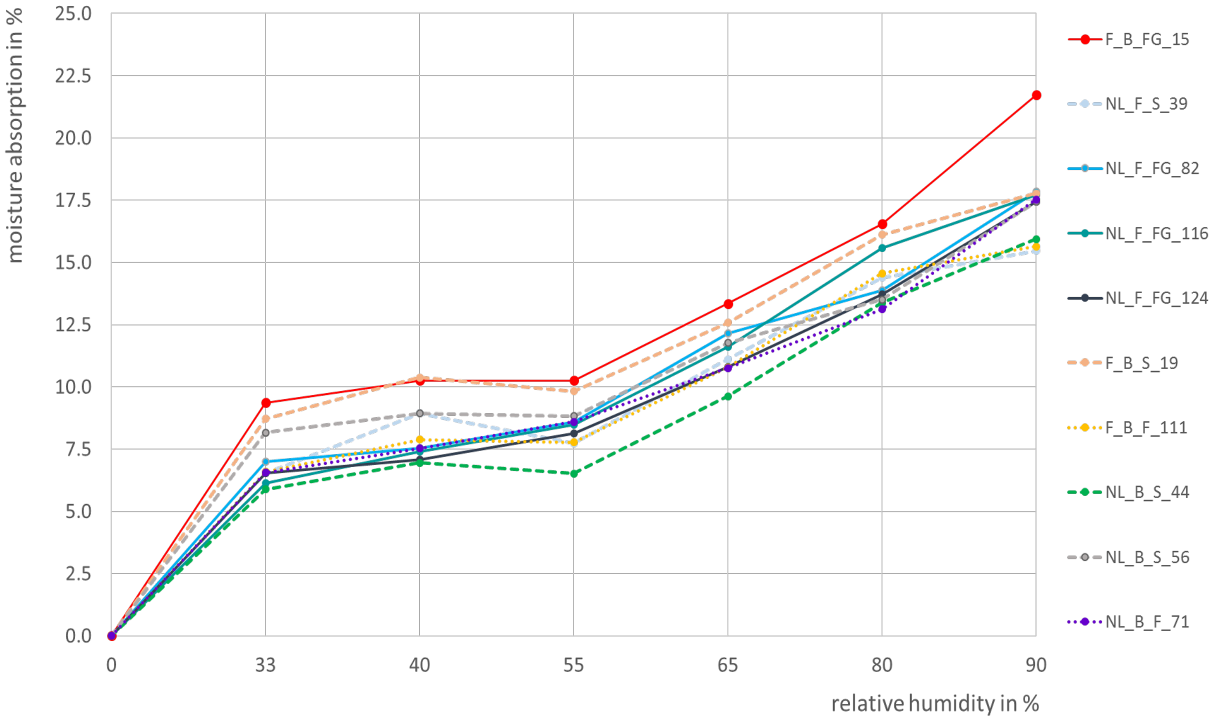

Figure 5: Results of the moisture absorption in % as a function of the relative humidity in % measured during constant temperature of 20 °C in the climate chamber.

The results of the water absorption are represented in Figure 6, which contents the water absorption depending on the bulk density of various samples. It can be seen that test specimens with higher content of shives (S and FG) results in higher water absorption behaviour for both locations. The samples mainly consisting of fibres had the smallest values.

An explanation for this could be the porous structure of the shives which leads to higher capillary attraction. Even when the samples were taken out and placed onto a drainer, the porous structure with cavities or rather pores could hold water.

Furthermore the results of the French test specimens are slightly higher compared to the samples from Netherland which is correlating to the moisture absorption investigations.

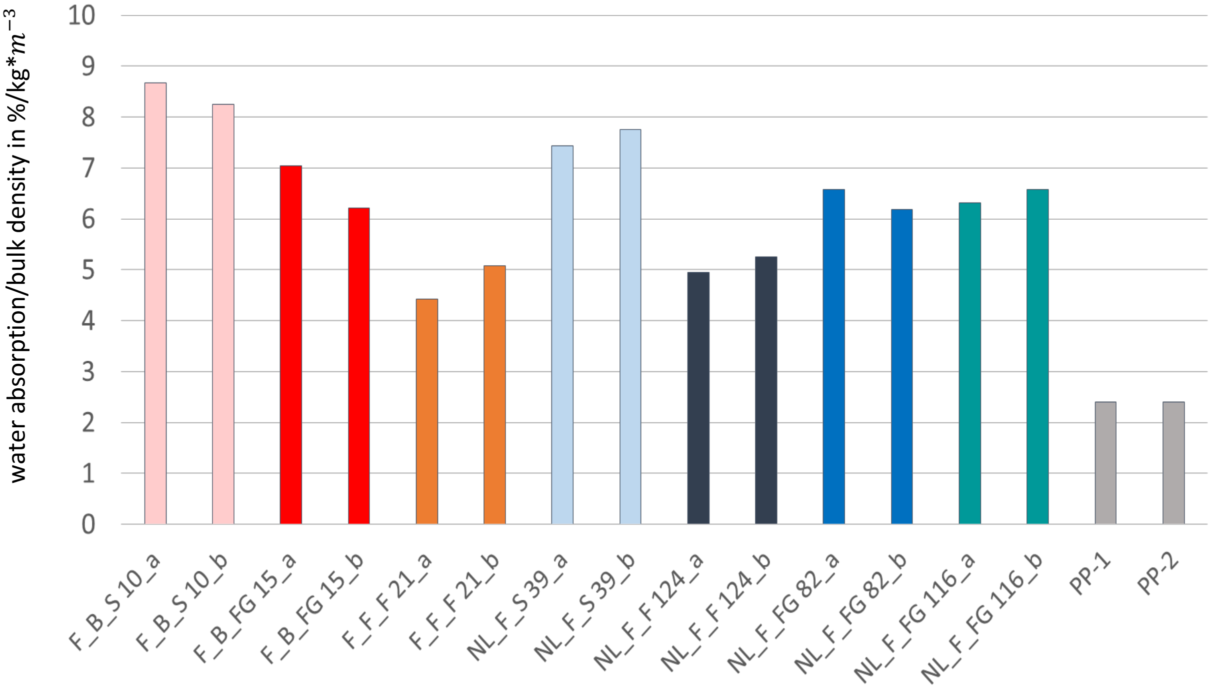

Figure 6: The results of the water absorption depending on the bulk density in %/kg*m^{-3} of different varieties.

4.6 Shirley fineness measurements

Fibre fineness measurements with the Shirley tester are depicted in Figure 7. Fine, or in the case of the investigated test samples a great amount of fine fibres, prevent the air permeability which leads to higher values. A great difference between the values PL and PH can be attributed by compacting the fibres with increasing compression loads within the second compression stage. Therefore (hollow) fibres are affected more to higher compression loads than shives. Regarding to the different contents of fibres and shives, test samples with higher content of fibres result in greater differences. Furthermore samples mainly consisting of shives resulting in lower values due to the greater air permeability.

Test specimens consisting of mainly fibres show the highest values except the sample 10 (F_B_S). A reason could be the contamination with dust within this sample which stops the air permeability and results in an increase of the values. Further the reason for the slight differences between the test samples mainly consisting of shives and the fibre-shive-mix is seen in the greater amount of fibres.

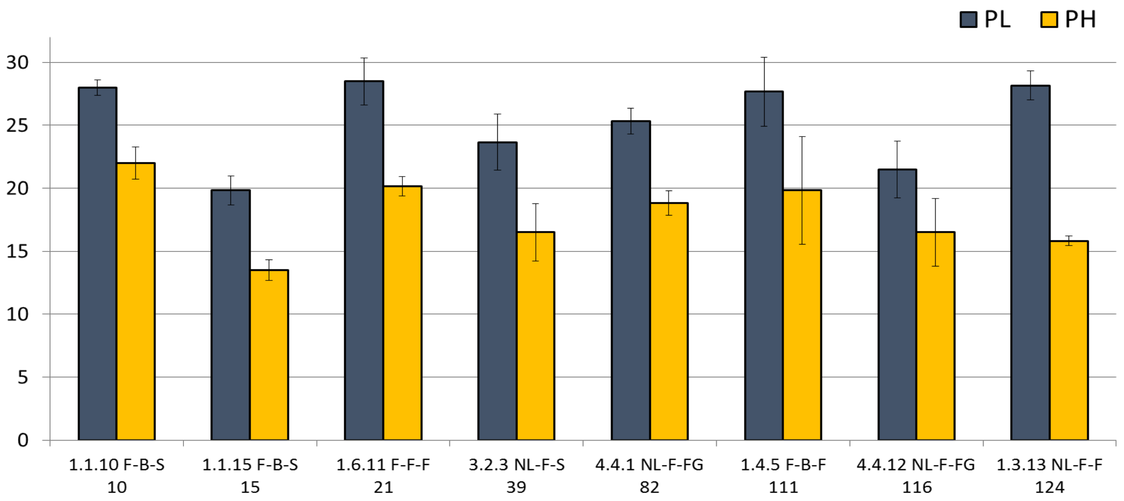

Figure 7: Results of the fineness measurements with the shirley tester of different test specimen.

5. Conclusion and Outlook

The aim of this task within WP6 was to determine the possibility of an alternative blow-in insulation product for the by-product “bulk” hemp along the production chain. Therefore the preparation process and the conventional blow-in process was adapted. Moreover, important structural-physical properties were investigated to characterize the blow-in insulation material. In order to sustain a sufficient quantity of material and an economic production bulk hemp of different production lines should be mixed together. It was therefore analysed if different varieties and location will influence the end product properties.

The investigations show that neither the location nor the variety is influencing the structural-physical properties significantly. Slight differences between the two locations were only observed in the investigations of the moister rather water absorption behaviour.

In the case of the slight differences of the thermal insulation between the various groups, the results are in agreement with the investigations of Murphy (1998) who showed that the influence of the variety on the thermal conductivity is comparatively small. He pointed out that the differences are primarily based on the fineness of the fibres and further concluded that all measures that refine the fibres enhance the thermal conductivity. This explains the differences in thermal insulation behaviour between finer cotton fibres compared to coarse hemp fibres (Murphy, 1998).

During the investigations it was noticeable that fibre-shive-mix samples mostly exhibit the best performances.

Regarding to the results of the settlement behaviour it is assumed that the shives exhibit a supportive effect to the three dimensional network. The network is actually increased by spliced and entanglements between fibre bundles, but it seems that long and buckled shives support this network, too.

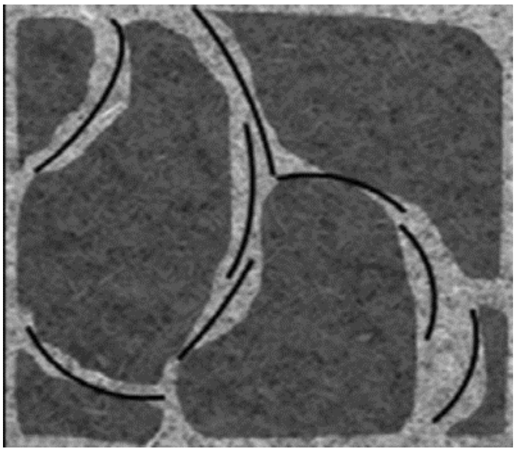

Figure 8: Model conception of the embedded chipped wood in loose fill-in insulation material. Dark colored areas illustrate the agglomerated areas by the chipped wood (adapted fromTreml, 2011).

The results can be compared with the investigations of Treml (2011), which mixed specific chipped wood with conventional loose fill-in insulation, such as cellulose fibres, to enhance the volume stability by simultaneously well thermal insulation properties. The chipped wood hold the fine cellulose in agglomerated areas together and showed supporting functions which reduce the settlement behaviour (Figure 8). This effect occurs even with small amounts of the chipped wood.

It can be concluded that the shives in the fibre-shive-mix samples generating a supporting effect such as the chipped wood and enhance the settlement behaviour.

In relation to the results of the thermal insulation it was expected that the shives are decline the thermal insulation properties. However, regarding to the supporting effect of the shives, the small amount of shives do not affect the thermal properties rather it prevents settling and formation of cavities. Moreover, small amounts of shives are not affecting the moisture or rather the water absorption behaviour significantly.

Considering the results together, the favouring material structure is the fibre-shive-mix, e.g. test specimen 116 or 15, which exhibit structural-physical benefits besides manufacturing and economic advantages.

In conclusion, the developed hemp blow-in insulation can be seen as an alternative of existing renewable insulation materials like cellulose, wood fibres and hemp fibre fleece and act as an impulse for innovative end use application for by-products along a production chain.

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