RESEARCH OF TECHNOLOGICAL PROCESS OF HEMP SLAB PRODUCTION

Semjons Ivanovs[1], Adolfs Rucins[1], Oskars Valainis[1], Dana Belakova[2], Edgars Kirilovs [2], Rihards Vidzickis[2]
[1]Latvia University of Agriculture; [2]Riga Technical University, Latvia
valainis@gmail.com

Abstract. Research and practice have shown that alongside with the natural fibres used in textiles they can also be used successfully as composite reinforcements, compounds of building materials, as heat and sound insulation materials. Fibre slabs as well as three-dimensional pressed parts can be produced for application in the construction and furniture industry. The main raw materials are aerobically aged hemp stalks. The samples are made of hemp chips, fastened together using the UF and PF glue. The use of preserved chopped hemp to produce slabs allows using all the stalks and also the leaves and seeds without waiting for their full maturity. That makes harvesting of the raw material independent of the weather. The material can be stored compactly, decreasing changes in the properties of the material, significantly shortening the recycling period and accordingly reducing the energy demand and simplifying the technological process. Research was done to find an innovative production technology of a heat and sound insulating material to be used in construction. During the research a technology was created for a mixture of hemp which involved finding an optimal mulching degree of the hemp stalks, testing the best suited glue (including natural glues) for this operation, testing the impact of the slab thickness on the quality parameters –sound (not described in this article) and heat insulation. The hemp mass for the slab was created from two components – wet (fermented) and dry mass to get a certain degree of moisture. To achieve this result, hemp was cut in the flowering stage, which gave certain advantages, e.g., lower energy consumption and reduced risk of hemp harvesting.

Keywords: hemp harvesting, hemp slab technology, hemp slab production.

Introduction

In the EU countries industrial hemp (*Cannabis sativa* L.) is considered as one of the important renewable resources for the production of a wide range of industrial products (a witness of this is the Resolution of the EU Commission “COM/2008/03/07”) [1]. Specialists have calculated that, by the photosynthesis rate of the organic mass, 1 ha of hemp is equivalent to 4 ha of a forest. The major producers of hemp in Europe are France, Poland, the Netherlands, and Germany. In Latvia massive growing of industrial hemp started since 2009.

The research in the production of slabs from the natural fibrous materials in the world has been carried out by scientists of many countries, using as the basic material the fibre and stalks of hemp, flax, wheat, soya beans, eucalyptus, bamboo, sugar-cane, rice, maize (corn), cotton fibre. Various technologies and binding agents have been applied for the production of slabs achieving slabs of various density and thickness with different physical and mechanical properties intended for various applications [2-5].

Great interest of the practical workers is raised in the use of the hemp stalks for construction and thermal insulation purposes [6]. In Latvia (the LUA) possibilities to use hemp stalks in gypsum slabs were studied [7]. Despite the fact that active research work has been carried out in the world during the recent years in order to create new building materials, the topicality of new thermal insulation materials from the hemp stalks is as high as before.

For instance, a method for the production of lignocellulose chips or fibre slabs has been developed in the USA [8], and a method for the production of composite materials from the hemp sheaves [9]. The hemp sheaves may be mixed with wood chips, thus obtaining a slab from wooden/hemp sheaves [9]. There are slabs made from hemp and flax fibre [10], as well as from the flax sheaves, using phenol-formaldehyde resin as a binding agent [11]. A slab of another type was made without any binding agent, chemically treating the fibres with a 35 % hydrogen peroxide before pressing [12]. The German enterprise “Kosche” manufactures on an industrial scale and offers in the market light furniture slabs from hemp sheaves [13]. A Dutch enterprise makes slabs from flax sheaves already since 1956. Carbamide resin is used in these slabs as a binding agent. The slabs are applied as thermal and acoustic insulation materials; they are by 100 % biodegradable [14]. The American enterprise “TorZo surface” produces slabs by impregnating the hemp fibres with acryl [15].

The purpose of the work: to study technological solutions of harvesting industrial hemp in order to obtain green chopped mass under Latvian conditions, including the impact of the harvesting times upon the cutting (chopping) process. To carry out investigations in the pressing technology of insulation slabs from hemp at their various proportions of density and components, as well as to determine their impact upon the thermal insulation properties of the slabs.

Materials and methods

A production technology of slabs from a hemp mixture was worked out (Fig. 1), as well as a methodology for preparation (chopping, dosing of the components, mixing and pressing) of the hemp mixture.

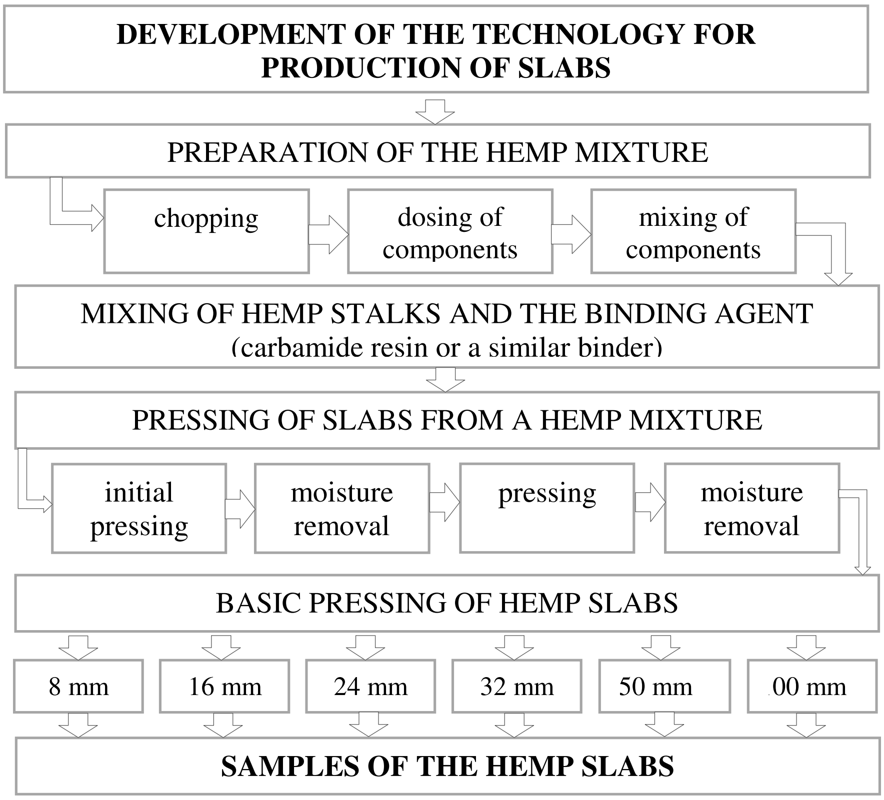
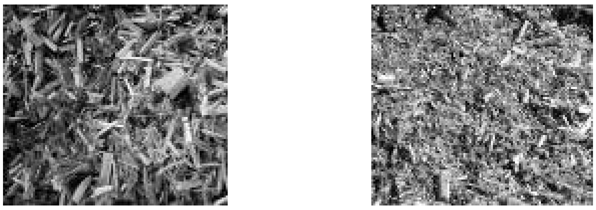


Fig.1. **Scheme of the slab production technology**

In contrast to the use of hemp in order to produce fibre (in textile industry, etc.), the lowest strength of the fibre of one component has no essential importance for the production of slabs, and there is no necessity to wait for the maximum strength of the fibre at its full maturity in autumn. Harvesting of the hemp component for technical needs takes place at the beginning of autumn when there are favourable conditions for drying by atmospheric air [16]. The most essential precondition for quality silage is to shorten the initial stage of preservation as much as possible by squeezing air from the mass, thus achieving sooner the desired anaerobic conditions. Important factors are also the maturity degree of the preserved mass of plants, the moisture content in the particles, their cross section and length, quick filling of the silo, substantial packing and immediate careful sealing of the silo after it is filled [17; 18]. The production technology of the raw material by using the dry and the moist component is less dependent on the weather conditions, which shortens considerably the recycling cycles, reduces their energy intensity and simplifies the slab production technological process [19].

The harvesting time has essential impact upon the stalk cutting capacity of the chopper and the productivity of the process. In 2014 experiments were made in three terms with a 12 day interval: on August 11 (at the start of flowering), August 23 (in a stable stage of early flowering) and on September 4 (in a full flowering stage when some stalks develop seed buds). During the harvest on September 4 the hemp fibre often wind around the operating parts of the chopper because now it has become durable (its breaking strength was by 39-45 % higher than on August 11), therefore, it does not submit to chopping. During this time of harvesting the pieces of the chopped mass with uncut fibre (the core part of the stalks being chopped) are often found constituting 5-6 % of the total mass and sometimes reaching a length up to 170 mm (under normal conditions it is 12 mm) [20].

The preparation process of the components of the hemp material is carried out in certain proportions in which the preserved and the dry components are mixed (Figure 2).



a) b)

Fig. 2. **Components of the hemp material:** a – chopped stalks; b – preserved component

The dry component is formed from the cut hemp stalks, which are dried using solar energy. Before the use the long stalks are chopped ≈ 1 cm long (Figure 2, a) by the guillotine. Mixing of the dry and the preserved materials (Figure 2, b) ensures the required moisture for a more qualitative mixing of the components with the binding agent.

According to the conducted calculations (Table 1), for the proportion of the mass of the dry and the preserved components 1:3, there were taken 2/3 of the preserved component and 1/3 of the dry component, which were manually mixed. To achieve a homogeneous structure of the hemp mixture, its screening was made through a calibrated 20x20 mm sieve, screening at first the preserved hemp component and after that the corresponding dry hemp component. As a binding agent there was synthetic carbamide-formaldehyde resin glue (UF) KLEIBERIR 871.0 used, which is at present the most widely applied binding agent used for gluing together sheets of plywood, boards and various wooden products.

Mixing of the dry (Figure 2, a) and the preserved (Figure 2, b) materials ensures the necessary moisture, so that more qualitative mixing and primary disintegration of the components could take place in the extruder.

After plastification two-stage disintegration follows. At the first stage, primary disintegration of the mixture proceeds in the extruder (Figure 3). The stalk cutting process takes place between the screw conveyor and the refining discs; the geometric design of the screw conveyor ensures increase in the pressure in the transportation direction that extrudes the mixture through the discharge outlet into the disk refiner (Figure 4).

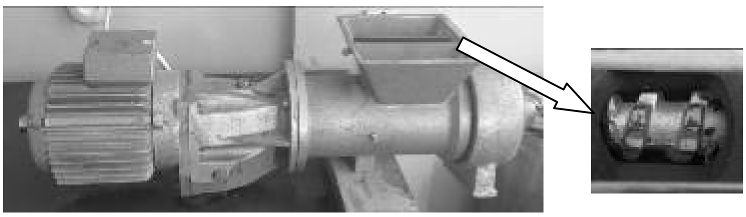


Fig. 3. **Extruder for disintegration of the hemp mass**

Fig. 4. **Disk refiner of the extruder**

The second disintegration takes place in the disk refiner (the distance between the refining surfaces is 3-5 mm); as a result, soft crushing of the preservative takes place.

In order to make each slab, a binding agent is used. It is calculated depending on the mass of the dry fraction of hemp to be pressed in the proportion indicated in the technical specification by the producer of the UF resin glue.

The fleece material is put into the press (Figure 5, b), and the pressing process of the slab starts, which is controlled according to the preset pressing mode (Table 1).

a) b)

Fig. 5. **Press for pressing the fleece material:** a – pressing equipment; b – pressing chamber

The slabs are pressed according to the preset height indicated for the particular experiment in Table 1 with the help of a heat press (Fig. 5) and the width and length of the pressed slabs, in their turn, are 300x300 mm, determined by the dimensions of the press.

Table 1

Pressing modes of the fleece material

Temp. of the heating surfaces of the chamber, *T* ºC	**Pressing modes**							
	Cycle 1		Cycle 2	Cycle 3		Cycle 4	Cycle 5	
upper/lower	*H*1, m	*t*1,sec.	*t*2, sec.	*H*3, m	*t*3, sec.	*t*4, sec.	*H*5, m	*t*5, min
130/130	0.2000	30	20	0.1100	30	20	0.1000	30
130/130	0.1000	30	20	0.0550	30	20	0.0500	30
130/130	0.0640	30	20	0.0352	30	20	0.0320	30
130/130	0.0480	30	20	0.0264	30	20	0.0240	30

Before pressing of the fleece material starts, the upper and the lower surfaces of the heating plates are heated to temperature (*T*), and at the pressing times from (*t*1) to (*t*5) moisture suction is switched on. The pressing mode consists of five cycles, each cycle having a definite pressing time and distance between the heating surfaces of the press. In Cycle 1 the fleece material is pressed to thickness (*H*1) and held for time (*t*1). In Cycle 2 the press is relieved for time (*t*2) in order to remove from the pressed slab the wet steam accumulated in it. In Cycle 3 the fleece material is compacted to thickness (*H*3) and held for time (*t*3). In Cycle 4 the press is relieved for time (*t*4). In Cycle 5 the fleece material is pressed to the required thickness (*H*5) and held for time (*t*5). During the last cycle the steam is removed from the compacted sheet with the highest intensity, therefore, time (*t*5) of pressing moisture suction is continued for 15 min.

Results and discussion

The conducted studies of the hemp stalk harvesting indicated suitability of the presented variant in practice, high efficiency of the processes (the capacity of the combine harvester Claas Jaguar 840 (Figure 6, a) reached 21 $t \cdot h^{-1}$, and that of the packer USM-1 – 80 $t \cdot h^{-1}$).

a) b)

Fig. 6. **Harvesting of the hemp stalks:** a – combine harvester Claas Jaguar 840;
b – mass of the chopped hemp stalks

The average length of the fraction of the chopped mass obtained during the experiments was 12 mm (Figure 6, b). For further storage the stalk mass was placed by means of a compactor-packer USM-1 into hermetically sealed polyethylene envelopes (tunnel bags) with a density not less than 300 – 400 kg·m^{-3}. In such a package without air presence slight fermentation of the biological lactic acid mass takes place (the acidity of the mass is pH 4.6-5.0). As a result of the process, oxygen is consumed, and carbon dioxide is formed which ensures self-preservation of the mass. Therefore, no special preservatives had to be used. Consequently, the biomass obtained from the chopped hemp stalks can be used also for production of biogas on rural electric power plants. The green hemp mass can be stored using other materials, too, for instance special silos or trenches, the main precondition being that the necessary density and airtightness are ensured.

The production of slabs from the hemp mixture, as well as the preparation of this mixture (chopping, dosing of its components, mixing and pressing) was carried out according to an elaborated methodology and a technological scheme (Figure 1).

As an example, the obtained experimental data are shown (Figure 7) about the variations in the thermal conductivity of the slab depending on the density of the pressed slabs.

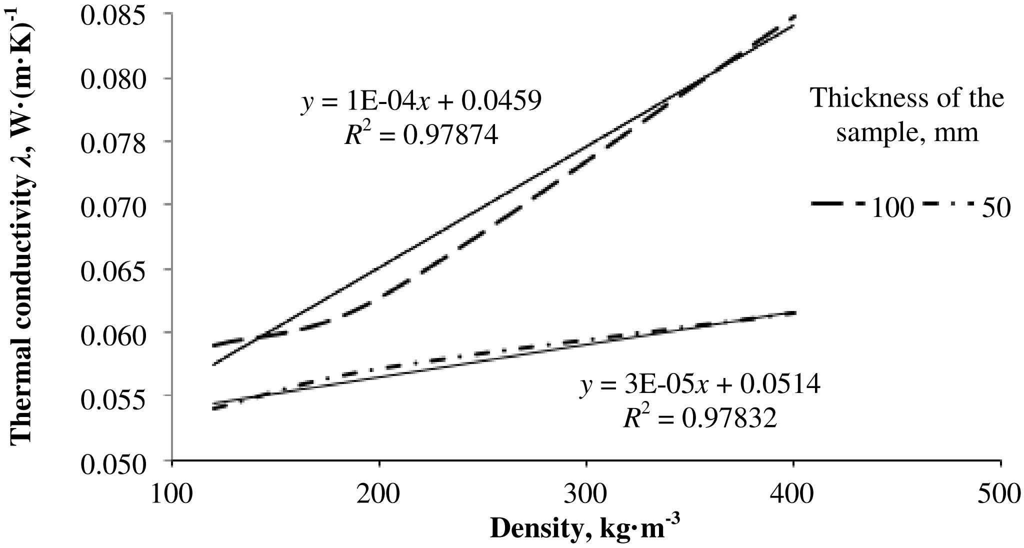


Fig. 7. **Thermal conductivity of a slab depending on its density**

As it is evident from the results (Figure 7), the thermal conductivity of the samples of 50 mm thick slabs varies within the limits from 0.054 to 0.06147 W·(m·K)$^{-1}$. Their thermal conductivity is by 14 % less than that of the samples with a density of 200 kg·m^{-3} which consist of 50 % chopped sheaves with the size of the fraction 10-20 mm, moisture 10 %, and which are mixed with the green mass of the preserved chopped hemp stalks with the size of the fraction 10 mm, moisture content 60 %, in contrast to the slabs with density 400 kg·m^{-3}.

On the other hand, the thermal conductivity of the samples, 100 mm thick, of slabs with the same composition (Figure 7) varies within the limits from 0.059 to 0.08477 W·(m·K)$^{-1}$; namely, the thermal conductivity of the slabs with a thickness of 200 kg·m^{-3} is by 44 % less than the thermal conductivity of the slabs with density 400 kg·m^{-3}.

In order to determine thermal conductivity of a slab depending on its thickness, experiments were carried out at the density of its mass 200 kg·m^{-3} with two flych compositions (Figure 8, Variant 1, Variant 2).

Composition (Variant 1): 1/3 of the dry fraction consisting of chopped sheaves, the size of the fraction approximately 10-20 mm, moisture 10 %, and 2/3 of the green mass of the preserved chopped hemp stalks, the size of the fraction 10 mm, moisture 60 %, powdered synthetic carbamide-formaldehyde resin glue (UF) KLEIBERIR 871.0 being used as a binding agent.

Composition (Variant 2): 1/3 of the dry fraction consisting of 50 % dry green mass of the chopped hemp stalks, the size of the fraction 10 mm, moisture 15 % and 50 % chopped sheaves, the size of the fraction 10-20 mm, moisture 10 %, mixed with 2/3 of the green mass of the preserved chopped hemp stalks, the size of the fraction 10 mm, moisture 60 %, synthetic carbamide-formaldehyde resin glue (UF) KLEIBERIR 871.0 being used as a binding agent.

As it is evident (Figure 8, Variant 1), the thermal conductivity of a slab depending on its thickness varies within the limits 0.05159-0.06274 $W\cdot(m\cdot K)^{-1}$, which is by 22 %. Increasing the thickness of the slabs (Figure 8, Variant 2) from 50 to 100 mm, the coefficient of thermal conductivity increases in the range from $\lambda = 0.05639$ to $\lambda = 0.06737$ $W\cdot(m\cdot K)^{-1}$, which is by 19 %.

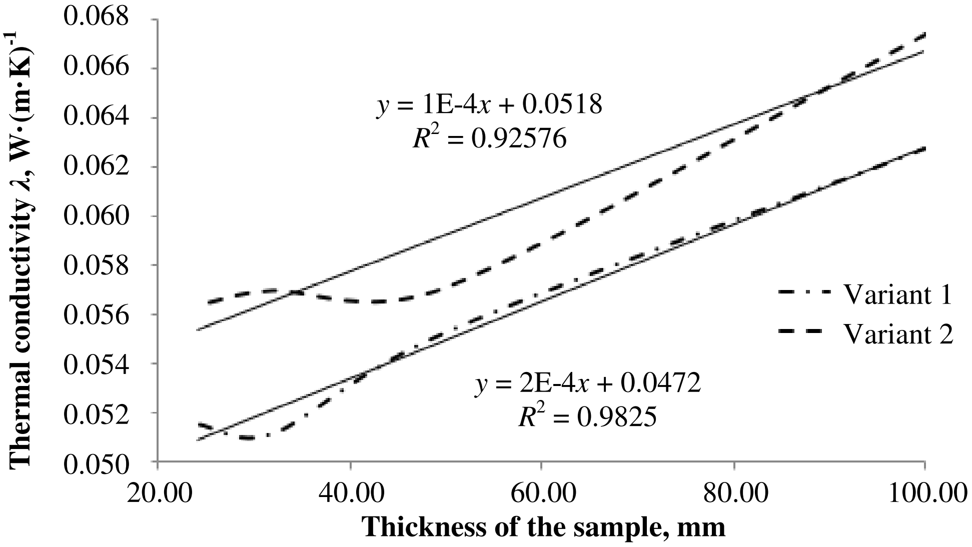


Fig. 8. **Thermal conductivity of a slab depending on its thickness**

If the two composition variants are compared (Figure 8), then the coefficient of thermal conductivity of the slab with a 100 mm thickness increases within the limits from $\lambda = 0.06274$ to $\lambda = 0.06737$ $W\cdot(m\cdot K)^{-1}$, which is by 7 %; the coefficient of thermal conductivity of the slab with a 50 mm thickness increases within the limits from $\lambda = 0.05529$ to $\lambda = 0.05712$ $W\cdot(m\cdot K)^{-1}$, which is by 3 %; the coefficient of thermal conductivity of the slab with a 32 mm thickness increases within the limits from $\lambda = 0.05119$ to $\lambda = 0.05700$ $W\cdot(m\cdot K)^{-1}$, which is by 11 %; the coefficient of thermal conductivity of the slab with a 24 mm thickness increases within the limits from $\lambda = 0.05159$ to $\lambda = 0.05639$ $W\cdot(m\cdot K)^{-1}$, which is by 9 %.

The coefficient of thermal conductivity in the investigated samples of slabs produced from a mixture of a mass of chopped preserved dry hemp was in the range 0.05159-0.06737 $W\ m^{-1}K^{-1}$. On the whole, this is a rather good indicator for a dry insulation material. Lesser values of the coefficient of thermal conductivity for glass wool are about 0.05 $W\cdot(m\cdot K)^{-1}$, mineral wool – about 0.45 $W\cdot(m\cdot K)^{-1}$ and foam plastic – about 0.034 $W\cdot(m\cdot K)^{-1}$. However, these materials have lower compression strength, shear and tension. Like with the other similar thermal insulation materials, increase in the density of the slabs from hemp increases the coefficient of thermal conductivity (when the density of slabs is increased from 200 to 400 $kg\cdot m^{-3}$, the coefficient increases by 14 %) (Figure 8). Besides, like the other materials from hemp, slabs have good ecological properties [21]. It is intended to continue investigations in the optimisation of the composition and the production conditions of slabs from hemp.

Conclusions

1. Forage choppers (combine harvesters) can be used for harvesting and chopping hemp stalks. The harvesting time has essential impact upon the cutting possibilities of the chopper and the efficiency of the process. Under favourable conditions the harvesting time of the hemp mass with simultaneous chopping is the early stage of flowering.
2. Other materials may also be used for storing the green mass, for instance, special silos or trenches, the main precondition being to ensure the required density and airtightness.
3. The use of the hemp mixture for production of slabs allows full usage of the entire stalk.

4. The production technology of the raw material by using the dry and the moist component is less dependent on the weather conditions, which considerably shortens the recycling cycles, reduces their energy intensity and simplifies the technological process of slab production.
5. When the density of slabs is increased from 200 to 400 kg·m^{-3}, the coefficient of thermal conductivity varies within the limits from 0.054 to 0.06147 W·(m·K)$^{-1}$; namely, for the samples of slabs with a density of 200 kg m^{-3} it is by 14 % less than with a density of 400 kg·m^{-3}.
6. Increasing the thickness of slabs with a fleece composition (Variant 1) the coefficient of thermal conductivity increases within the limits from λ = 0.05159 to λ = 0.06274 W·(m·K)$^{-1}$, which is by 22 %, but with a fleece composition (Variant 2) the coefficient of thermal conductivity grows in the range from λ = 0.05639 to λ = 0.06737 W·(m·K)$^{-1}$, which is by 19 %.

Acknowledgements

This publication has been prepared within the framework of the ESF Project "Development of Innovative Technologies for the Preservation and Production of Heat and Cold", contract No.013/0064/1DP/1.1.1.2.0/13/APIA/VIAA/050.

References

1. Cannabis sativa L. Hemp. 2009. pp. 199-200. [online][10.09.2015] Available at: http://eur-lex.europa.eu, 21 April, 2013.
2. Sankari H., Towards best fibre production in Finland: stem and fibre yields and mechanical fibre properties of selected fibre hemp and linseed genotypes. Academic dissertation, ISBN 951-45-9157-7. Helsinki, 2000. 60 p.
3. Hemp Eco Systems/ The Answer is in Nature. [online][10.09.2015] Available at: www. hempecosystems.com.
4. Skujans J., Iljins U., Ziemelis I., Gross U., Ositis N., Brencis R., Veinbergs A. and Kukuts O., Experimental research of foam gypsum acoustic absorption and heat flow, Chemical Engineering Transactions, 19, 2010, pp. 79-84.
5. Kronbergs A., Širaks E., Adamovičs A., Kronbergs Ē.. Mechanical properties of hemp (*Cannabis sativa*) biomass. Environment. Technology. Resources Proceedings of the 8th International Scientific and Practical Conference. vol. 1 Rēzeknes Augstskola, Rēzekne, RA Izdevniecība, 2011, ISSN 1691-5402 ISBN 978-9984-44-070-5, pp. 184-190. [online][10.09.2015] Available at: http://zdb.ru.lv/conferences/4/VTR8_I_184.pdf
6. Barwicki J., Gach S., Koprysz K., Ivanovs S., Adamovics A. and Valainis O. Technical and economical analysis of harvesting and ensilaging of corn grain / Agronomy Research. Vol.12, No.1, 2014. pp. 33-40. [online][10.09.2015] Available at: http://www.claas.co.uk/products/forage-harvesters/jaguar870-840
7. Poisa L., Adamovics A. Hemp (*Cannabis sativa* L.) as an Environmentally Friendly Energyplant // RTU zinātniskie raksti. 13. sēr., Vides un klimata tehnoloģijas. - 5. sēj. (2010), 80.-85. lpp. [online][10.09.2015] Available at: https://ortus.rtu.lv/science/lv/publications/9742;jsessionid= 46EE931D3F818B3B473891B2AC111F88/fulltext.pdf
8. Windsor S.M. Lignocellulosic board, Method of making lignocellulosic board. 09/445.821 United States of America, 1999.
9. Wasylciw W. Hemp hurd composite, Hemp hurd composite panels and method of making. WO00/69607 United States of America, 2002.
10. Eisner K., Kolejak M. Building board from flax and hemp fibers. Poland: Drevo, 1958. pp. 356-360. Vol. 12.
11. Reh R., Osvald A. Contribution to the fire retardant treatment of flax board panels. Slovakia : Committee of Forest Sciences, Polish Academy of Sciences, 1996. pp. 79-83. ISSN 0071-6685.
12. Halvarsson S. Manufacture of straw mdf and fibreboards. Sundsvall : FSCN, 2010. ISBN 978-91-86073-86-2.
13. Herreras G.A. Maize cob board. Valencia : Department of rural engineering and food processing, 2010. Doctoral Thesis.

14. From crop to building material. Linex Pro-grass BV. [online][10.09.2015] Available at: http://www.linex-pg.nl.
15. TorZo Fabrication Guide: Orient, Durum, Hemp. TorZo surfaces. [online][10.09.2015] Available at: http://www.torzosurfaces.com.
16. Kancevica L., Putans H., Ziemelis Ivo. The tracking system for solar collectors with reflectors. Proceeding of the International Scientific Conference "Renewable Energy and Energy Efficiency". Jelgava, Latvia. 2012, pp. 190-195.
17. Lapiņš A., Kažotnieks J., Stašāns A. Skābbarības ražošana. Jelgava: Jelgavas tipogrāfija, 1998.
18. Idler C., u.c., Wet processing of hemp: an overview. Potsdam : Taylor& Francis, 2011. pp. 59-80. Vol. 8. ISSN 1544-0478.
19. Ivanovs, A. Rucins. Cutting of the biological mass of industrial hemp. Journal of Research and Applications in Agricultural Engineering, vol. 59 Nr. 3, 2014, pp. 87-90. [online][10.09.2015] Available at: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-8f9800cb-9e6b-40c2-b268-e4f1df7b731e
20. Semjons Ivanovs, Aleksandrs Adamovics, Adolfs Rucins, Volodimir Bulgakov. Investigation into losses of biological mass and quality during harvest of industrial hemp. / Engineering for Rural Development, Proceedings, vol. 13, 2014. pp.19-23.
21. Muehl J.H., u.c. CiteSeerX. CHAPTER 31 Performance of hardboards made from kenaf, 1999. [online][10.09.2015] Available at: http://citeseerx.ist.psu.edu/.