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The Thermal Insulation Capacity of Tree Bark

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Abstract – Nowadays increasing emphasis is placed on improving the quality of different insulation materials, and on developing such from materials of natural origin. The present research focuses on the thermal insulation capacity of the chipped bark of different broadleaved and coniferous wood species. We examined the bark of five tree species: black locust, a poplar clone, larch, spruce, and Scotch pine and compared their insulation characteristics to the traditionally used insulation materials. Results indicate that the thermal insulation capacity of chipped tree bark is comparable to that of generally used insulation materials, such as glass wool. Moisture content influences the thermal insulation capacity of chipped bark of the five examined species. Since energy requirement of producing chipped tree bark is very low, and it contributes also to storing carbon, therefore its CO_2 balance is more advantageous compared to that of traditional fibrous or foamy insulation materials.

tree bark / insulation capacity / moisture content / CO_2 footprint

Kivonat – A fakéreg hőszigetelési tulajdonságai Manapság egyre nagyobb hangsúlyt fektetnek a különböző szigetelőanyagok javítására. A tanulmány bemutatja a különböző lombos- és tűlevelű fafajok kérgének hőszigetelő képességét. Öt fafajt vizsgáltunk meg: az akácot, a Pannonia nyár klónt, az erdeifenyőt, a vörösfenyőt és a lucfenyőt. A tanulmány mind a kezdő nedvességtartalmú, mind a 12%-os nedvességtartalomra szárított kérgeket vizsgálja. A kutatás megmutatta, hogy a fakéreg hasonló hőszigetelési tulajdonságokkal rendelkezik, mint más, általánosan használt szigetelő anyagok. A fakéreg feldolgozása alacsony energiafelhasználással jár és CO_2 mérlege is lényegesen jobb, mint a hagyományos szigetelő anyagok.

fakéreg / hőszigetelő képesség / nedvességtartalom / CO_2 lábnyom

1 INTRODUCTION

Hungary produces about 500 thousand cubic meters per year of bark from forest harvests, spread evenly across the areas of primary wood processing. The proportion of bark of the harvested tree can be as much as 10–20%, depending on the species and diameter of the tree (Sopp – Kolozs 2000). The bark of processed wood is mostly used for generation of energy (Ragland et al. 1991), for mulching (Colorado Master Gardeners Program 2009), and for extracting of chemical compounds (Hoong et al. 2011), among other uses (Harkin – Rowe 1971, Pedieu et al. 2009). Since the bark does not possess a mechanical stability similar to wood, its use for insulation is mainly possible in the form of chips or particles. Skogsberg and

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Lundberg (2005) have shown that processed bark – applying proper treatment and technology – can be used as loose-fill insulation material.

The insulation capacity of tree bark plays an important role in case of forest fire also. The thick and well insulating bark protects the cambium layer of the tree and thus mitigates the damaging effects of fire (Bauer et al. 2010, Wang – Wangen 2011). Dimitri (1968) investigated the thermal conductivity of beech wood bark and found that the most significant and major factor is its moisture content. The effect of moisture content on thermal conductivity is well investigated as far as wood is concerned but much less for bark.

The CO_2 balance projected on the specific insulation effect is presumably better when using bark, compared to the use of other insulation materials (Buchanan – Levine 1999, Börjesson – Gustavson 2000, Gustavsson – Sathre 2006). Bark used for insulation purposes has obviously a higher economic value than lower value functions such as burning or as mulching. The bark insulation can be recycled at the end of its service life for energy or other purposes without polluting the environment. During its life as an insulation material, the carbon accumulated in the bark does not burden the atmosphere and helps reducing the emission of CO_2 which is an important greenhouse gas.

Finally, the bark contains protective materials (such as tannin, suberin) in higher amounts than wood, and thus the bark has natural protective elements against decay. Thus, bark used as insulation material will need less chemical protection compared to other materials used for insulation, contributing to possible lower costs.

We investigated the bark of five tree species (black locust, a poplar clone ‘Pannonia’, larch, spruce, and Scotch pine) that are common across most of Europe. We aimed to investigate, determine and compare the specific thermal insulation capacity of the bark of these species, and to compare these capacities with other customary insulation materials. Developing new and more specific knowledge in this area will further expand the possibilities of using natural and recyclable resources as alternatives for thermal insulation. This also means potentially greater energy savings and reduction of the CO_2 footprint, through storing carbon and avoiding the release of CO_2 from burning. Possible use of bark for thermal insulation means new alternatives to other customarily used insulation materials that need more energy resources to produce and that also release CO_2 in the production process.

2 MATERIALS AND METHODS

The chosen broadleaved timber species are black locust (*Robinia pseudoacacia*) and the poplar clone ‘Pannonia’ (*Populus euramericana cv. Pannonia*). Both species have especially big bark-to-wood proportion of about 12–20 % based on the diameter of the trunk; however, their bark contains a lot of additional incrustation substances, and therefore are not suitable for mulching. Nevertheless, the high content of incrustation substances provides an advantage with respect to resistance to decay and therefore increases the durability.

The three coniferous species chosen are larch (*Larix decidua*), spruce (*Picea abies*), and Scotch pine (*Pinus silvestris*). Scotch pine and spruce have scaly outer bark which peels off in thin lamellas.

During timber processing, the bark that is removed usually comes off in different broken particles and has considerable moisture content. For comparability purposes, the bark samples from the five chosen species were chipped with the same chipping technology and device. Hence, the resulting particle size of the bark is almost the same for all five species, with little differences as summarized in *Table 1*. *Figure 1* shows the material prepared for testing.

Figure 1. Chipped bark of black locust is placed in the measurement box for testing.

Table 1. Particle size of chipped bark samples

Dimension	particle size (mm)
Thickness	1 – 26
Width	5 – 27
Length	10 – 48 (100)

The pine bark broke into flat, disc-like pieces because the bark layers are stronger compared to the other species. However, the bark of broadleaved species is structurally different, with ca. 100 mm long inner bark fibers appearing in black locust and poplar bark chips due to the higher proportion of inner bark in the material compared to the conifers. The inner bark content is different in amount and structure among wood species, with the difference being more pronounced between broadleaved and conifer species. There are differences in bark density also among species (MacFarlane – Luo 2009, Gryc et al. 2010).

According to Freire et al. (2002) and So et al. (2006), there are more significant differences between the outer bark and the inner bark in terms of structure and chemical components. The inner bark fibers play a cross-linking role in the chip; they also form further air layers between the bark elements reducing the connecting surfaces of bark pieces. Similar to the fibrous insulation materials, such as rock and glass wool, the wood bark fibers have air layers or space between them, so that they can improve the air-filling ratio of the system.

Another basic difference in the bark chips is density. The inner bark body of conifers has sieve cells whereas broadleaved trees have sieve tubes which develop from the fusion of more cells, so the bark of the latter has a more porous structure and consequently lower density. With respect to the firmness of the inner bark structure, Scotch pine has stalk fibers only while spruce and larch have sclereids, but the two broadleaved species examined have both sclereids and stalk fibers (Molnár 2004).

The heat flow through bark samples of the five tree species was measured. To help ensure that the heat fluxes in the test samples are parallel to each other and perpendicular to the surface, the width of the measuring surface should be greater compared to the thickness of the test sample. Moreover, the lateral heat fluxes were reduced by lateral insulation of the samples.

The bark measurement box had the dimensions 500 mm × 500 mm × 50 mm, with measurements on the middle 120 mm x 120 mm cross section as the transmitting area. No bonding materials were used, the chips were loosely scattered in the measuring box (*Figure 1)*. Density was not measured because the aim was to fill up the measurement box at 50 mm height similarly for all species. The coefficient of thermal conductivity λ was determined in steady state heat flow condition. The heat flow (or heat flux) Q in watts is given by the equation

$$Q = \frac{\lambda * A * \Delta T}{d}$$

where *d* is the thickness (50 mm) of the sample and ΔT is the temperature difference between warm and cold sides in Kelvin. Thus, the units of λ are *W/mK* which are obtained from the equation above when the heat flow values are measured. Steady state conditions were obtained by measuring heat flow to the cooler side every minute, defining “steady state” as the state when successive measurements per minute gave the same results to three decimals for a period of 30 minutes. The steady state thermal condition measurement was repeated 100 times. The λ values were determined as the average value of 100 data points.

Using the *z*-test, the thermal conductivity data were examined to determine if the sample size was representative of the whole population.

3 RESULTS AND DISCUSSIONS

Wet bark has a higher coefficient of thermal conductivity than bark with 12% moisture content, as shown in Table 2. The results also indicate that the thermal insulation qualities of the chipped bark of the five chosen species are comparable at 12% moisture content, with values ranging between 0.0613 *W/mK* and 0.0765 *W/mK*. In contrast, the initial moisture content of the bark samples varies significantly across the five species, with poplar having a higher value compared to the other four species. The lowest value (black locust) is almost three times that of poplar. *Figure 2* clearly shows the influence of moisture content on thermal conductivity across the five species.

Chipped wood and the air trapped within the bark pieces created a composite system. The heat is transmitted partly through the trapped air flow and through the linked thermal bridge system created by the contacting chip elements. The more the air flow and the size of contact surfaces decline, the more efficient the evolved thermal resistance is.

Static air of 0.025 *W/mK* value improves the thermal conductivity of the composite system. The basic thermal conductivity of broken bark also influences the thermal insulation capacity of the system. The thermal insulation values of chipped wood bark were comparable to the generally used insulation materials. The thermal insulation capacity of rock and glass wool is between 0.035–0.05 *W/mK*; for polystyrene this value is between 0.033–0.045 *W/mK* depending on density.

The flat disc-like shape of the bark of the spruce results in high contact surfaces and less blocked air ratio. In contrast, black locust has high inner bark content, and this causes more inner bark fibers to lower the contact surfaces of the bark elements and increase the proportion of blocked air. Results indicate that the thermal conductivity at 12% moisture content of chipped wood barks of broadleaved species are lower compared to the values for the coniferous species. Therefore the high inner bark content of the broadleaved wood species tends to positively affect the insulation capacity of the system.

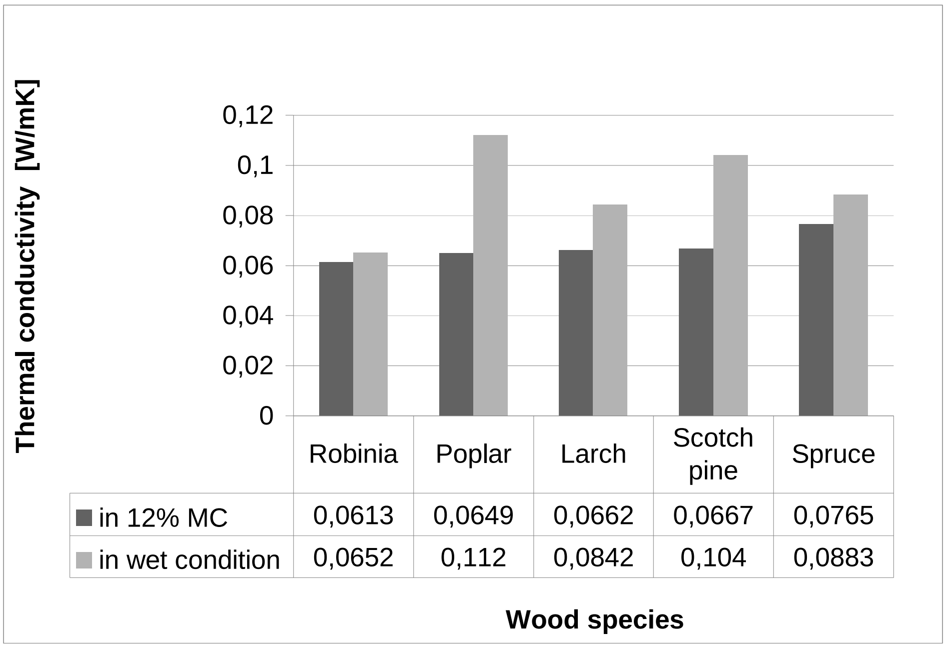

Figure 2. Thermal conductivity of different chipped wood barks in different moisture content

The results clearly support the effect of moisture content on the thermal insulation capacity of chipped bark (*Table 2.*). The high specific heat and good thermal conductivity of water influenced the thermal conductivity values unfavorably. Water fills cell lumen and provides better heat transfer in cell walls; on the other hand, the water vapor is able to transfer high amount of heat because of its high specific and latent heat. The heat difference can result also in vapor flow and, consequently, the heat transfer is increased by the specific heat amount of transferred vapor.

Table 2. Relationship between moisture content and thermal conductivity

Wood species	Heat conductivity at 12% MC	Heat conductivity under wet condition		MC difference	Difference of heat conductivity [1]	Change of heat conductivity in percentage relation in 1% of MC change [2]
	(W/mK)	(W/mK)	MC (%)	(%)	(%)	((W/mK)/MC%)
Robinia	0.0613	0.0652	14.3	2.3	6.36	2.77
Poplar	0.0649	0.1120	40.2	28.2	72.57	2.57
Larch	0.0662	0.0842	24.2	12.2	27.19	2.23
Scots p	0.0667	0.1040	35.9	23.9	55.92	2.34
Spruce	0.0765	0.0883	22.8	10.8	15.42	1.43

[1] Difference of heat conductivity = (Heat conductivity under wet condition – Heat conductivity at 12%MC) / Heat conductivity at 12%MC *100%

[2] Change of heat conductivity in percentage relation in 1% of MC change = Difference of heat conductivity / MC difference

The coefficient of thermal conductivity measured at 12% moisture content indicates little difference between species except for spruce shows in the Table 2. Black locust had the highest value at 0.0613 *W/mK*, followed by poplar at 0.0649 *W/mK*, with only 5.5% difference between these two species. The larch has 7.4%, and Scotch pine has 8.1% higher coefficient of thermal conductivity than that of the black locust. The second column of *Table 2* shows that spruce has 19.8% higher thermal conductivity than black locust. The high thermal conductivity value of the chipped spruce bark seems to be influenced by the particle structure form. Note that the data in column 2 consider one degree Kelvin difference only, but at higher temperatures the value has to be multiplied by the temperature; thus, a smaller difference can mean a much higher thermal flux for higher temperatures.

The effect of moisture is shown the last column of Table 2. In the case of black locust, the 2.3% moisture content difference makes a 6.36% difference in the coefficient of thermal conductivity, which translates to a 2.77% change of heat conductivity per moisture percentage. For poplar, the 28.20% moisture content difference resulted in 72.57% change of heat conductivity which shows 2.57 change of coefficient of thermal conductivity for each moisture content percentage. The data for the larch and Scots pine also show similar values.

The value of spruce (last column last row in Table 2) is lower than for other wood species. The explanation is the disc-like shape of spruce bark and in its higher heat conductivity values under 12% moisture content conditions.

4 CONCLUSIONS

The results of the study have several significant implications:

- Compared to the coniferous species, the barks of the broadleaved species have lower thermal conductivity, possibly due to their high inner bark content, that positively affect their insulation quality. This suggests that bark of broadleaved species may be better thermal insulators than those of conifers.
- Thermal conductivity is better the lower the air flow and the smaller the contact surfaces of the bark. The longer fibers from the inner bark of broadleaved species affects their thermal conductivity positively compared to the conifer species.
- Our study also shows that the thermal insulation capacity of bark is comparable to generally used insulation materials such as glass wool and rock wool.
- The water content strongly influences the heat conductivity of wood bark chips. 1% change in MC influences the thermal conductivity 2.23% to 2.77% for all species except spruce. Of the five species examined, spruce has also the lowest value indicating it is not the best candidate for thermal insulation purposes.

The project results suggest that the use of wood bark for thermal insulation material has a significant potential. The use of bark for insulation needs further exploration of the connection between moisture content and thermal conductivity. Modification/preservation methods may lead to a product that will have a very good eco-balance. Further research is needed to etablish optimal size and form of chip elements in detail and to compare and determine optimal insulation capacity for bark from other species.

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