

Wool and Leather Waste Materials with Thermo-Insulating Properties

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Abstract: Seven new different thermo-insulating materials based on wool and /or skin wastes were obtained. To emphasize this capability, the effective thermal diffusivities were determined at a material moisture content of 10%, in a temperature range of 10 to 40° C. Depending on the material composition, the results showed that the effective thermal diffusivity varies between the limits of 6E-8 and 8.5E-8 m²/s. The smallest values were obtained for the untreated wool and for the material obtained from both untreated wool and finished leather powder. The obtained values underline the fact that the investigated materials can be used to obtain composites with good thermo-insulating properties.

Keywords: leather waste, wool, thermal diffusivity, water uptake, thermo-insulating

1.Introduction

Recycling organic waste from preliminary operations in wool processing industry, aims to use the resulting by-products in areas as diverse as agriculture, cosmetics, building materials, biomaterials, etc [1-3].

Also, the leather industry provides a large amount of nontanned and tanned collagenous solid waste. In 2004, 1.601204 tons of sheepskin were produced, amount of which 60% represented the quantity of waste containing fat and proteins, after processing [4-6]. This category includes the wastes produced during the process of polishing Chamois leather, used in the auto industry, and also, the wastes resulted in the leather goods industry, where 8-10 million leather pieces are processed every year [7]. Furthermore, nontanned and tanned leather wastes can be processed in order to obtain precursors for biofertilizers with protein additives, biofuels or other materials with thermo and phonoinsulating properties used in building materials industry [8, 9].

Sheep skin processed wool can be used both in processing and building materials industries, for some pollutants retention and as a thermo and phono-insulating material. Regarding its thermal insulation capacity, sheep wool has a unique quality, namely it is breathable. This feature refers to the ability to absorb and release moisture from/to the environmental air, without compromising the material thermal efficiency. With moisture absorption, wool fibers also generate small amounts of heat which prevent condensation, and subsequently the mold formation. Like skin, wool is a hygroscopic material which feels wet when touched. This property creates a naturally occurring dabbing effect that reduces the need to adjust the heating / cooling cycle. Thus, a wool insulated building remains cooler during the day and warmer, at night.

Owing to an up to 30-40% moisture retention of its own weight, both sheepskin and wool present also flame retardant properties, being resistant to fire and not maintaining the burning after removing the flame.

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Due to the similarity of some physical / chemical, thermal and hygienic properties of wool fibers and sheepskins with some other thermo-insulating materials, some laboratory experiments were developed to study the possibilities to recycle leather and wool wastes in order to obtain new insulating materials. Depending on the manufacturer of the insulating material, the thermal conductivity of insulation wool can range from $\lambda = 0.0356 \text{ W} / \text{m}^2 \text{ K}$ to $0.040 \text{ W} / \text{m}^2 \text{ K}$.

In this work, for the two types of materials used individually or in various combinations, the effective thermal diffusivity coefficients were determined experimentally, at temperatures close to the ambient temperature. Additionally, the apparent density and water uptake vs. relative humidity were measured in order to completely characterize the materials. To our knowledge, the literature does not provide experimental data concerning the effective thermal diffusivity in such materials.

2. Materials and methods

2.1. Materials and apparatus

In order to conduct the laboratory experiments, the following substances were used: NaOH, NaCl, Na₂CO₃, HCl, acetone, trichlorethylene, ethyl alcohol, surfactant, wool wastes, and Chamois powder wastes (from drying finishing operations). For wool wastes degreasing, a classic Soxhlet installation was used.

2.2. Working method

Wool samples treatment

The wool washing poses some technical problems and needs to be designed to minimize the fiber movement and maximize the liquid transfer so as to avoid felting. For the same reason detergents used in the scouring process need to be in a slightly alkaline range ($pH \sim 8.5$). Thus, in the first phase, wool samples were cleaned in distilled water at 50°C, and then washed with a solution of 2 g/L Na₂CO₃ and a surfactant solution of 0.5 g/L concentration, afterwards washed three times in distilled water and then, dried in a thermo-regulated oven at 60°C, for 24 h.

In the second stage of the experiments, the traditional method for wool fiber samples degreasing with solvent (trichloroethylene) during an extraction process in a Soxhlet equipment was used [10]. Thus, each wool sample was treated individually in the Soxhlet equipment with trichloroethylene for 4 h, with approximately three extractions performed per hour (12 times recirculated).

After fat extraction, sample cartridges were washed with 50% alcohol solution, and then, dried at 50°C, for 24 h and conditioned at 20 °C and 65% humidity, for 24 h.

Chamois samples treatment

The second set of samples was based on the Chamois leather waste powder, obtained from dry finishing operations of sheepskins.

The material samples for which the thermal diffusivity coefficient was measured, contain both untreated and treated leather and/or wool waste. The treated leather was previously inflated and degreased with a solution of 2 g / L Na₂CO₃ and a surfactant solution of 0.5 g / L concentration, then washed for three times in distilled water and dried in the thermoregulated oven at 60°C, for 24 h.

The two categories of wool and skin (unskimmed and skimmed) were then mixed in equal proportions (1/1) and compacted with a hydraulic press in a 0.28 m length and 0.03 m diameter cylinder. Thus, seven different materials with characteristics shown in the Table 1 were obtained.

Exp.	Sample type	Mixing ratio	Compaction
nr.			pressure, MPa
1	Sample 1 (finished leather powder)	1	0.03
2	Sample 2(skimmed leather powder)	1	0.03
3	Sample 3(finished leather powder + untreated wool)	1/1	0.03
4	Sample 4(skimmed leather powder + untreated wool)	1/1	0.03

Tabel 1. Sample mixing ratio and compaction pressure



5	Sample 5(untreated wool)	1	0.03
6	Sample 6(skimmed wool)	1	0.03
7	Sample 7 (skimmed wool + finished leather powder)	1/1	0.03

The apparent densities of the material samples were calculated based on sample measured mass and volume. The obtained data are presented in Table 2.

Exp.nr.	Sample type	Sample mass,	Sample Volume	Apparent density
		kg	$X 10^5$, m ³	kg/m ³
1	Sample 1(Finished leather powder)	0.09489	2.9618	3203.79
2	Sample 2(Skimmed leather powder)	0.10228	3.5039	2919.03
3	Sample 3(Finished leather powder + untreated	0.0620	2.9455	2104.95
	wool)			
4	Sample 4(Skimmed leather powder +	0.07779	2.9455	2644.71
	untreated wool)			
5	Sample 5(Untreated wool)	0.04326	2.9455	1468.68
6	Sample 6(Skimmed wool)	0.04176	2.9455	1417.73
7	Sample 7(Skimmed wool + Finished leather	0.06084	2.9455	2065.49
	powder)			

Table 2. Apparent densities (compacted state)

The thermal diffusivity coefficient values were determined for all the above mentioned samples.

Thermal diffusivity coefficient measurements

The heat transfer in a porous bed is a complex phenomenon, which should be extensively studied. The knowledge of the transient heat transfer in a porous bed is fundamental to determine the insulation capacity of the porous material. In this context, the determination of some thermophysical properties such as density, specific heat, thermal conductivity and thermal diffusivity are important.

Thermal diffusivity is a significant transport property necessary in modeling and computations of transient heat transfer for basic processing operations, such as drying. The thermal diffusivity of a material is defined as the ratio of the heat transported by conduction to the heat capacity of a unit mass. The thermal diffusivity of a bed, consisting of the materials presented above, is more difficult to predict, due to its variable heterogeneous structure.

For an organic material, such as the investigated one, the thermal diffusivity is dependent on the temperature, moisture content, fat, pressure and density. In this case, the temperature and the moisture content are the most relevant parameters [13-16]. Generally, for an insulating material based on wool or leather, its moisture content ranges from 20 to 50 % (wet basis) and the relevant temperatures, from 0 to 50 °C. Based on these measurements, it is interesting to predict the effective thermal diffusivity of a porous bed. This work objective is to determine the effective thermal diffusivity (α_{ef}) of a porous bed containing the above-mentioned insulating materials, under different conditions.

2.3. Experimental measurements

The major aim of the study was the effective thermal diffusivity experimental measurement, as described below.

Determination of the effective thermal diffusivity

The equipment used to determine the effective thermal diffusivity is presented in Figure 1. The equipment consists of: two ultra thermostatic baths (Julabo, F12) with precision of 0.1° C, a digital thermometer with precision of 0.1° C, a copper – constantan (type T) thermocouple and a copper cylinder, with an internal diameter of 0.025 m and a height of 0.250 m and two Teflon end caps.





Figure 1. Thermal diffusivity measurement device

The apparatus is similar to the one used by: Poulsen (1982) [13] and Dotto et al. (2015) [11]. Each sample was introduced in the cylindrical container illustrated in Figure 1. The effective thermal diffusivity was determined at a material moisture content of approximately 10 % and a temperature ranging from 10 to 40°C, as follows: at first, the cylinder was filled with the measuring material and a thermocouple was inserted into the bed center to measure the temperature. The filled bed (both top and bottom isolated) was completely immersed in an ultra thermostatic bath, until an initial uniform temperature of 10°C was attained. When the temperature became uniform, the bed was transferred to another ultra thermostatic bath with a temperature of 40°C. Starting from that moment, the temperature at the bed center was continuously registered, every 1 min, using the thermocouple connected to the data logger. All experiments were replicated (n = 2).

Thermal diffusivity was determined from the temperature variation recorded at the center of each cylindrical sample when a stepwise change of the surface temperature was given.

The effective thermal diffusivity (α_{ef}) was calculated from the experimental data using the method proposed Magge and Bransburg [12].

The method consists in a finite cylinder with initial uniform temperature, which is exposed to a different uniform temperature. Since the L/D ratio for the cylinder was not very high (L/D = 10), the system was considered two-dimensional.

For these conditions, in an isotropic case, the heat transfer conduction in the cylinder is given by [11, 17]:

$$\frac{\partial \mathbf{T}}{\partial \mathbf{t}} = \alpha_{ef} \left(\frac{\partial^2 \mathbf{T}}{\partial \mathbf{r}^2} + \frac{1}{\mathbf{r}} \frac{\partial \mathbf{T}}{\partial \mathbf{r}} + \frac{\partial^2 \mathbf{T}}{\partial \mathbf{z}^2} \right)$$
(1)

with the following conditions:

 $\begin{array}{l} \displaystyle \frac{\partial T}{\partial r} = 0 \ , \ \text{at } r = 0 \ \text{and } t \!\!>\!\! 0 \ (\text{radial symmetry condition}) \\ T = T_w \ \text{at } r = R \ \text{and } t \!\!>\!\! 0 \ (\text{radial boundary condition}) \\ \displaystyle \frac{\partial T}{\partial z} = 0 \ \text{at } z \!\!=\!\! 0 \ \text{and } t \!\!>\!\! 0 \ (\text{axial symmetry condition}) \\ T = T_w \ \text{at } z \!\!=\!\! L/2 \ \text{and } t \!\!>\!\! 0 \ (\text{axial symmetry condition}) \\ T(r,z) = T_0 \ \text{at } t \!\!>\!\! 0 \ (\text{initial condition}) \end{array}$

The solution is given as follows [11]:

$$\frac{T_{w} - T}{T_{w} - T_{0}} = \frac{8}{\pi} \sum_{n=1}^{\infty} \sum_{n=1}^{\infty} \left\{ \frac{2(-1)^{m+1}}{2m-1} \cos\left[\frac{(2m-1)\pi\pi}{L}\right] \cdot \frac{J_{0}(\alpha_{n})r/R}{\alpha_{n}J_{1}(\alpha_{n})} \exp\left\{-\left[\frac{\alpha_{n}^{2}}{R^{2}} + \frac{(2m-1)^{2}\pi^{2}}{L^{2}}\right]\alpha_{ef}t\right\} \right\}$$
(2)

where α_n are the roots of the zero order Bessel function

$$J_0(\alpha_n)=0.$$

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For a cylindrical bed exposed for long times, only the first term of the series in eq. 2 can be considered.

$$\label{eq:alpha1} \begin{split} \alpha_1 &= 2.405 \\ J_1(2.405) &= 0.5191 \\ For \ r &= 0 \ and \ z &= 0 \\ J_0(0) &= 1 \\ and; \end{split}$$

 $\frac{8}{\pi} \cdot \frac{2(-1)^{1+1}}{2 \cdot 1 - 1} \cos \left[\frac{(2 \cdot 1 - 1)\pi \cdot 0}{L} \right] \frac{J_0(0)}{\alpha_1 J_1(\alpha_1)} = 2.0397$

Eq. (2) can be simplified as:

$$\frac{T_{w} - T}{T_{w} - T_{0}} = 2.0397 \exp\left[-\left(\left(\frac{2.405}{R}\right)^{2} + \left(\frac{\pi}{L}\right)^{2}\right)\alpha_{of}t\right]$$
(3)

or:

$$\ln(T_{*} - T) = A - Bt \tag{4}$$

with: $A = ln(T_w - T_0)$ and:

$$\alpha_{\rm ef} = \mathbf{B} \left[\left(\frac{2.405}{R} \right)^2 + \left(\frac{\pi}{L} \right)^2 \right]^{-1}$$
(5)

The parameters A and B were estimated by linear regression of equation (3) using the experimental measured temperatures (T) along time (t) and α_{ef} was determined with equation (5).

3. Results and discussions

The experimental results are presented in Figures 2-4 (a) and (b). Figures 2-4 (a) reveal the temperature variation with time for three of the samples presented in Table 1. Figures 2-4 (b) show the linear variation of the natural logarithmic function $\ln [(T_W-T)/(T_W-T_0)]$ with time t, in accordance to equation (4). From the last graphs, slope values B were calculated and the thermal diffusivity, α_{ef} , was determined, according to equation (5).









Figure 2. Temperature variation with time, sample 1, $D_{ef} = 8.34 \times 10^{-8} \text{ m}^2/\text{s}$



(b) Figure 3. Temperature variation with time, sample 4, $D_{ef} = 7.66 \ x \ 10^{-8} \ m^2/s$





(b) Figure 4. Temperature variation with time, sample 7, $D_{ef} = 8.05 \text{ x } 10^{-8}, \text{ m}^2/\text{s}$

Similar trends were obtained for the other prepared samples, but the effective thermal diffusivities were different.

The obtained experimental thermal diffusivity values are presented in Table 3.

Table 3. Effective inermal diffusivities values					
Sample Nr.	Sample type	Humidity, kg water/ kg dried material	The regression equation	Effective thermal diffusivity, D _{eff} x 10 ⁸ , m ² /s	
1	Finished leather powder	0.1±0.01	$y = -0.00234x + 0.37713$ $R^2 = 0.999$	8.34	
2	Skimmed Leather powder	0.1±0.01	$y = -0.00208x + 0.14581$ $R^2 = 0.999$	7.38	
3	Finished leather powder + untreated wool	0.1±0.01	$y = -0.00194x + 0.22892$ $R^2 = 0.999$	6.94	
4	Skimmed leather powder + untreated wool	0.1±0.01	$y = -0.00215x + 0.25425$ $R^2 = 0.999$	7.66	
5	Untreated wool	0.1±0.01	$y = -0.00169x + 0.25338$ $R^2 = 0.999$	6.03	
6	Skimmed wool	0.1±0.01	$y = -0.00239x + 0.12778$ $R^2 = 0.991$	8.47	
7	Skimmed wool + finished leather powder	0.1±0.01	$y = -0.00227x + 0.21137$ $R^2 = 0.998$	8.05	

T 1.00 • . •



The samples used in the thermal diffusivity measurement experiments have humidity values close to 10g water/100g dried material. These values correspond to an air relative humidity (RH) value of approximately 35%. Water uptake experimental values were obtained using a previously constructed experimental setup, based on pressure decay, presented in [18]. These data are presented in Figure 5. For different analyzed samples, the water uptake does not significantly change at relative humidity less than 50%.



Figure 5. Water uptake dependence on relative humidity (RH) at 40°C

4. Conclusions

In this work, some new thermo-insulating materials base on wool and /or skin wastes were obtained. Accordingly, the effective thermal diffusivities of seven different materials containing wool and leather powders were determined under the following conditions: moisture content of 10%, temperature range $10^{\circ} - 40^{\circ}$ C. The results showed that the effective thermal diffusivity modifies in the limits of 6 x 10^{-8} and 8.5 x 10^{-8} , depending on the material composition. The smallest values were obtained for the untreated wool (sample 5) and for the material obtained from both untreated wool and finished leather powder (sample 3). The obtained values highlight the fact that the analyzed materials can be used to obtain composites with good thermo-insulating properties.

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Manuscript received: 20.05.2020