The behaviour of “liquid wood” when exposed to some physico-chemical factors

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Abstract. Because of an ever-increasing demand of non-toxic, biodegradable, naturally-sourced materials and products, the human society is always searching for new materials with specific applications, which are able to fulfil the above-mentioned requirements. Consequently, it is essential to identify the qualities of these materials and their behaviour when subjected to various external factors, in order to find their optimal solutions for application in various domains. Such a material, obtained from renewable resources, is known as “liquid wood”, a material which exhibits composite polymer-like properties, having a lignin matrix. “Liquid wood” can be found in three different forms: Arboform, Arbofill and Arboblend, depending on the natural substances (besides or associated with lignin), which are to be found in the material – resins, wax, vegetable fibres etc. As such, “liquid wood” has been subjected to various external factors, the aim being to determine the degradation of the material when acted upon by environmental factors. Thus, “liquid wood” has been immersed in distilled water and then in an alkaline environment and in an acid environment for 210 days. Measurements were periodically performed to determine the mass variation and the change of electrical properties when subjected to the specific environmental factors and to UV radiation. The changes were determined by comparison with standard samples. Following this study, it has been observed that the main degradation factor is water, which leads to cracking and then fracture in the material. Furthermore, significant changes have been observed in the electrical properties of the material and in the pH of the environments in which it has been immersed. These observations lead to the idea that the material is hydrophilic. The results obtained following the immersion of “liquid wood” in distilled water and then in an alkaline environment and in an acid environment point towards some of the possible application of this material in various fields of activity, which may have a significant positive impact upon the environment.

1. Introduction

“Liquid wood” is a biopolymeric composite, which has its basic matrix made of lignin. Lignin is an organic polymer mainly consisting of phenolic compounds. It makes up about 25 – 35\% of vegetal
biomass, [1]. Lignin has a macromolecular structure and, following recent determinations, an empirical chemical formula for this substance has been established: \(\text{C}_{42}\text{H}_{60}\text{O}_7\text{(OCH}_3)_n\text{(OH)}_4\). Lignin is of great importance to plants: it has an essential role in transporting water and nutrients, [2]. Being hydrophobic in nature, it lends rigidity to cellular walls and allows the linking of various parts of the vegetable mass, creating increased resistance to impact, compression and bending. Lignified weaves are very resilient to microorganism attack, denying the penetration of destructive enzymes into cellular walls. Starting from the premise that "liquid wood" is a biocomposite having its basic matrix made of lignin, it is intended to determine the manner and time under which "liquid wood" degrades when it is immersed in water in various conditions and when exposed to UV radiations.

"Liquid wood" comes in three presentation forms and in each one of them, lignin is found in various percentages. These are: ARBOFORM\(^\circ\) - lignin matrix (60%) enriched with vegetable flax or hemp fibres, ARBOBLEND\(^\circ\) - 99% lignin and 1% natural additives and ARBOFILL\(^\circ\) - biopolymeric composite with a lignin matrix (60%) and mixes of natural fibres, sawdust and petrochemical polymeric compounds like polyethylene and polypropylene (40%), [3]. The aim of this article is a comparative study regarding the degradation of "liquid wood" when subjected to the action of distilled water and UV radiation, as well as the degradation and biodegradation time, which can be approximately controlled by reinforcement with various other substances, and finally, how do the degradation factors influence the properties and the behaviour of "liquid wood", [4].

As such, it is important to determine the behaviour of "liquid wood" in various environments, in order to determine the variation of physico – chemical properties of the material in said environments. A series of conclusions may be drawn after the analysis of obtained results, which may lead to the best employment of "liquid wood" in accordance to Kyoto and Rio de Janeiro accords.

2. Technology and experimental plan
Taking into account the producers’ material presentation sheets, the materials that are generically named "liquid wood" has two important characteristics: they are obtained from renewable resources, they are degradable and biodegradable. The factors that generate the degradation of polymers are: physical factors – heat, radiation etc., chemical factors – oxygen, ozone and other chemical agents, biological factors – microorganisms from the environment, climatic factors – temperature variation, humidity variation, atmospheric variation. Through degradation, the macroscopic aspects (colour, texture, porosity) and especially the physical properties of polymers change, [5].

In this article, results obtained pertaining to the behavior of "liquid wood" in various environments by studying the variation of some physico – chemical properties are presented. The obtained results allowed for the formulation of several conclusions regarding the degradation of "liquid wood". A first study was carried out upon the variation of several “liquid wood” properties, when acted upon by distilled water at normal temperature (20\(^\circ\)C) and low temperature (4\(^\circ\)C). The same samples were then acted upon by an acidic environment and a base environment, [6].

Furthermore, the samples were exposed to UV radiations for one hour. The measurement of several physical properties has been performed at various time intervals, in order to document any modification which might occur in the created conditions, as well as to record at what time interval a modification did take place.

Selected physical measurements to determine degradations were mass, electric conductivity and pH of the solution in which the samples were immersed. The mass was determined with an analytical scale, Partner XA 160. Determining the mass \(m_0\) meant that the hydration of the samples could be estimated, by the following method: hydration (water absorbed by the sample) \(= (m_f - m_i)\), where: \(m_i\) – initial mass of the sample (at moment 0), in grams, \(m_f\) – mass of the sample after hydration (after immersion in solution), in grams.

The determination of conductivity was carried out with an Accumet XL30, Fisher Scientific device. The determination of the solutions’ pH was carried out with a digital Ph – meter HQ11d pH by HACH, with a glass electrode. Sample surfaces (figure 9 – 20) have been studied with a Digital Microscope Motic stereomicroscope, with a magnification factor of 100X, [7].
The obtained results following the measurements concerning the behaviour of “liquid wood” when acted upon by distilled water in acidic and base environments at temperatures of 40°C and 20°C, and exposure to UV radiation can be consulted in the comparative tables. For each sample, microscope observations were carried out, in order to determine potential material fractures and the most interesting samples were photographed for the purpose of comparative observations. The obtained data was introduced in the Origin Lab Pro 9.0 software suite, thus time–dependent variation graphs of the quantities considered significant for the study of degradation were obtained, [8].

3. Results and discussions
In the following chapter, the time–dependent graphs of previously established quantities and conditions, pertaining to each material, are presented. In figures 1(a), (b), (c) the time – dependent variation of the samples’ mass, immersed in distilled water at 40°C, 20°C and 20°C with UV radiation exposure, can be observed.

![Figure 1](image1)

**Figure 1.** The time–dependent variation of the samples’ mass immersed in distilled water at 40°C, 20°C and 20°C with UV radiation exposure.

In figures 2(a), (b), (c) the time–dependent variation of the samples’ mass, immersed in a base environment, in the same temperature and radiation exposure conditions, can be observed.

![Figure 2](image2)

**Figure 2.** The time–dependent variation of the samples’ mass immersed in a base environment.

In figures 3(a), (b), (c) the time–dependent variation of the samples’ mass, immersed in an acidic environment, in the same established conditions, can be observed.
From the analysis of these time–dependent variation graphs, it can be observed that, irrespective of the conditions (temperature, acidic or base environment, UV radiation), all samples absorb water – depending on their composition – reaching a maximum mass of absorbed water after approximately 60 – 70 days. After this maximum is reached, it can be observed that, following this time period, the samples start to lose absorbed water (the quantity of absorbed water tends to reach the initial value after 210 days), [9].

In Figure 4 the time–dependent variation of the electrical conductivity for the three materials in the established environment conditions, in an environment with neutral pH – distilled water –, are presented.

In Figure 5 the time–dependent variation of conductivity of the samples, in an alkaline environment, in the same temperature and radiation exposure conditions, can be observed.
In figure 6 the time–dependent variation of conductivity of the samples, in a base environment, is described.

![Conductivity Graphs](image-url)

**Figure 6.** The time–dependent variation of conductivity of the samples, in a base environment.

From the analysis of these graphs, it can be observed that there is an increase of electrical conductivity for all the materials, in distilled water. In a base or acidic environment, an increase of electrical conductivity can be observed for some samples, up to a certain value, in an interval of 35 – 40 days; after that, the electrical conductivity decreases to a significantly lower value than the initial one, [10].

In figure 7 the time–dependent variation of the pH for samples of the three materials, immersed in distilled water, in the established temperature and UV radiation conditions, is presented.

![pH Graphs](image-url)

**Figure 7.** The time–dependent variation of the pH for samples of the three materials, immersed in distilled water, in the established temperature and UV radiation conditions.

In figure 8 the time–dependent variation of the pH for samples of the three materials, immersed in an alkaline solution, in the established temperature and UV radiation conditions, is presented.

![pH Graphs](image-url)

**Figure 8.** The time–dependent variation of the pH for samples of the three materials, immersed in an alkaline solution, in the established temperature and UV radiation conditions.
In figure 9 the time–dependent variation of the pH for samples of the three materials, immersed in an acidic solution, in the same temperature and UV radiation conditions, respectively 4°C, 20°C and 20°C with UV radiation exposure, is presented.

![Graphs of pH variation](image)

(a) Arboblend  
(b) Arboform  
(c) Arbofill

**Figure 9.** The time–dependent variation of the pH for samples of the three materials, immersed in an acidic solution, in the same temperature and UV radiation conditions, respectively 4°C, 20°C and 20°C with UV radiation exposure.

Furthermore, some significant images of the samples after they were immersed in the established temperature and UV radiation conditions, are presented. Modifications of the surface, taken place after the samples were immersed in established temperature and UV radiation conditions, when compared to the witness sample, may be observed, [11].

![Images of samples](image)

(a) 4°C  
(b) 20°C  
(c) 20°C + UV

**Figure 10.** Arboblend witness sample.

**Figure 11.** Images with the Arboblend samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

In figure 10, the surface of the witness sample is presented. By comparison, the changes that have occurred on the samples’ surface after 30 days from the beginning of the experiment can be observed.

Figure 11– images with the Arboblend samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).
Figure 12. Images with the Arboblend samples’ surface, after they were immersed in an acidic environment for 30 days, at temperatures of 40°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

Figure 13. Images with the Arboblend samples’ surface, after they were immersed in an alkaline environment for 30 days, at temperatures of 40°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

Figure 14. Arboform witness sample.

In figure 14, the surface of the witness sample is presented. By comparison, the changes that have occurred on the samples’ surface after 30 days from the beginning of the experiment can be observed.

Figure 15 – images with the Arboform samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 40°C (a), 20°C (b) and 20°C with UV radiation exposure (c).
Figure 15. Images with the Arboform samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 40°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

Figure 16 – images with the Arboform samples’ surface, after they were immersed in an acidic environment for 30 days, at temperatures of 40°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

Figure 17 – images with the Arboblend samples’ surface, after they were immersed in a base environment for 30 days, at temperatures of 40°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

In figure 18, the surface of the witness sample is presented. By comparison, the changes that have occurred on the samples’ surface after 30 days from the beginning of the experiment can be observed.
Figure 19 – images with the Arbofill samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

![Figure 18. Arbofill witness sample.](image)

Figure 19. Images with the Arbofill samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

Figure 20 – images with the Arbofill samples’ surface, after they were immersed in an acidic environment for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

![Figure 20. Images with the Arbofill samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).](image)

Figure 20. Images with the Arbofill samples’ surface, after they were immersed in distilled water for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

Figure 21 – images with the Arbofill samples’ surface, after they were immersed in a base environment for 30 days, at temperatures of 4°C (a), 20°C (b) and 20°C with UV radiation exposure (c).

The images of surfaces observed at 210 days, did not suffer any perceptible alterations compared to the surfaces observed at 30 days. Some fractures in the volume of the material, which lead to the idea that the samples’ mechanical properties have changed, can be noticed [12]. At the same time, a change
in the colour of the samples – especially for Arboform and Arbofill –, in certain conditions, indicate a possible structural change, [13].

Finally, the least affected samples in terms of aspect and colours are the Arboblend ones.

Figure 21. Images with the Arbofill samples’ surface, after they were immersed in a base environment for 30 days, at temperatures of 4° C (a), 20° C (b) and 20° C with UV radiation exposure (c).

4. Conclusions
Following the analysis of the time–dependent variation graphs, it can be concluded that, irrespective of the environment in which the samples have been immersed, the same algorithm is respected. A sudden rise exists for 35 – 40 days, after which saturation is achieved; after approximately 70 – 80 days, the samples’ mass begins to decrease, without reaching the value of the initial mass. Exceptions to this algorithm are the samples immersed at a temperature of 20° C, for which the mass remains relatively constant at the maximum achieved value, [14].

If the fact that the main substance found in these materials is lignin and lignin plays an essential role in the plants’ feeding process by transporting sap to the upper plants’ structure is considered, then it can be assumed that, in the case of the samples, the embedded lignin, even if it was structurally modified, it keeps its base functions. It is normal that the wettability of the studied materials is more pronounced at an increased temperature (20° C), taking into account that lignin is part of the principal matrix. Interesting is the fact that under UV radiation exposure, even if the temperature is 20° C, the mass of the samples drops, so the samples eliminate a greater quantity of absorbed liquid substance.

At the same time, it can be observed that the conductivity of the samples increases, which is normal, given the fact that liquid absorption implicitly increases the number of charge – carrying electrons. However, in an acid environment, a big decrease of conductivity can be observed, especially for Arboblend samples. This decrease, corroborated with the pH variation, leads to the idea that lignin acts as a pH regulator, seeking to reduce the samples’ pH value as much as possible to the normal value (pH= 7.0) - the value of distilled water. This tendency leads to the decrease of charge – carrying electrons.

From the analysis of the photographs, cracks on the surface of the samples can be observed, at an interval approximately equal to the interval of mass increase up to the maximum value [15]. Taking into account the hydrophilic character of lignin, and implicitly of the samples, the embedded liquid mass will lead to an increase of distance between internal particles, thus leading to a decreased mechanical resistance of the samples.

The final conclusion is that "liquid wood", irrespective of its presentation form, suffers a degradation of physical properties if it is immersed in a liquid environment, regardless of the latter’s pH. What is significant is the fact that, irrespective of its presentation form, "liquid wood" exhibits a tendency to modify the solution’s pH, in the sense that, in a certain period of time, its value would be neutral.

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