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Different Methods of Conserving Waterlogged Wood

Djeklil Taieb [1] , Hamira Mohamed [2]

[1] University of Ziane Achour Djelfa (algeria). Email : taiebdjeklil@gmail.com
[2] University of Ziane Achour Djelfa (Algeria). Email: moh.archeom82@gmail.cm

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Abstract

The challenge of preserving waterlogged wood, whether sourced from terrestrial finds or from freshwater and marine environments, can currently be regarded as adequately addressed for smaller artifacts. Provided that the storage conditions do not exhibit significant climatic variations, one can now select from a range of conservation techniques while also considering additional factors related to these methods, such as energy usage, financial implications, and aesthetic preferences. However, when dealing with larger wooden artifacts, such as ships or bridges, extreme climatic conditions significantly limit the available options. In such cases, even minimal dimensional alterations—resulting from fluctuations in moisture content—can accumulate, complicating the assembly of the various components of a large structure. L. Barkmann, in an unpublished report, has concluded from a series of experiments involving polyethylene glycols 1,500 and 4,000 applied to oak wood from the Wasa warship that the effectiveness of penetration and distribution is inadequate to prevent shrinkage satisfactorily.

Keywords: Waterlogged wood, Heritage, Conservation, , Alterations, Polyethylene.

Introduction

The challenge of preserving waterlogged wood recovered from archaeological sites or sourced from freshwater and saltwater environments can currently be regarded as effectively addressed for smaller artifacts. Provided that the subsequent environmental conditions during storage do not involve significant fluctuations, a variety of conservation techniques can be selected based on diverse criteria, including but not limited to energy efficiency, financial considerations, and aesthetic preferences. However, extreme environmental conditions significantly limit the range of options available as the size of the wooden artifacts increases. For larger structures, such as ships and bridges, even minimal dimensional alterations—such as shrinkage resulting from variations in moisture content—can accumulate, leading to issues where individual components of a sizable object may no longer align properly. L. Barkmann, in an unpublished report, suggests through a series of experiments utilizing polyethylene glycols 1500 and 4000 on oak wood from the Wasa warship that the degree of penetration and distribution achieved is insufficient to effectively prevent shrinkage. This conclusion is consistent across all conducted tests, and B. Brorson-Christensen has articulated that achieving the consolidation of waterlogged wood without any form of contraction is nearly unattainable.

1- Waterlogged Wood

Tannin present in wood serves as a protective agent against decay, enabling certain types of wood, particularly those rich in tannins, to remain in relatively good condition over time. However, when wood is subjected to prolonged exposure to wet environments, such as damp soil, peat bogs, or marine areas, bacterial activity leads to the breakdown of the cellulosic components found in the cell walls. Typically, the first substances to be lost from wood are water-soluble elements, including starch and sugars, along with mineral salts, colorants, tanning agents, and various binding materials. As time progresses, hydrolysis causes the cellulose within the cell walls to break down, resulting in a lignin framework that provides structural support. Eventually, even this lignin can degrade over extended periods. The degradation of cellulose and lignin leads to an increase in the spaces between cells and molecules, making the wood more porous and allowing it to absorb water more readily. As a consequence, all deteriorated regions, including cell cavities and intermolecular spaces, become filled with water. The remaining lignin structure, combined with the absorbed water, helps maintain the wood's shape. While the loss of finer cellulose tissue does not significantly alter the overall volume of the wood, it does enhance its porosity, causing the wood to soak up water like a sponge.[1]

When waterlogged wooden artifacts remain saturated, they maintain their original form. However, exposure to air leads to the evaporation of excess moisture, which generates surface tension forces that can compromise the integrity of the weakened cellular structure, resulting in significant shrinkage and deformation. It has been observed that freshly cut, intact timber experiences a loss of water that causes a radial shrinkage of approximately 3-6%, tangential shrinkage of 5-10%, and a minimal longitudinal shrinkage of roughly 0.5%. Specifically, oak exhibits radial shrinkage of 4% and tangential shrinkage of 8% when air-dried post-harvesting, in contrast to waterlogged oak, which can experience radial shrinkage of up to 12% and tangential shrinkage of around 24%. The extent of shrinkage is influenced by the wood's degree of degradation and its water content. The water content in waterlogged wood can be quantified using the following equation:

$\%H2O$ = (weight of wet wood - weight of oven-dried wood) / weight of oven-dried wood × 100.

A water content exceeding 200% indicates degradation, and it is not unusual for wood to contain over 500% moisture, with instances of 1000% water content also reported. Waterlogged wood is typically categorized based on its moisture levels into three classes:

1- Class I encompasses wood with over 400% moisture content,

2- Class II includes wood with 185-400% moisture content, and

3- Class III is designated for wood with less than 185% moisture content.

The Class III hardwoods are the most difficult to conserve.[2]

2- Waterlogged Wood Conservation

The preservation of waterlogged wood presents a dual challenge. First, it requires the introduction of a substance that will strengthen the wood as moisture is extracted. Second, it calls for a method to eliminate excess water without causing any shrinkage or deformation. Techniques that utilize polyethylene glycol (PEG) or sugar serve as examples of the first approach, while methods such as solvent drying and freeze-drying illustrate the second. Below, we will explore the most prevalent techniques for treating waterlogged wood. It is essential to note that if the wood originates from a saltwater environment, the majority of soluble salts must be eliminated. Failure to do so may result in a white residue on the preserved wood and could negatively impact any remaining iron elements within the wood, as well as other materials located in the same area where the treated wood is kept. Here are some approaches for the restoration of antique wood:[3]

2-1 Méthode du Polyéthylène Glycol (PEG)

A key characteristic of polyethylene glycols lies in their ability to dissolve in water; in dilute aqueous solutions, the lower molecular weight variants can infiltrate wood through diffusion. At the hygroscopic regions of the cell wall material, sorption processes may also take place. The hydroxyl and ether functional groups present in the PEG molecule can facilitate swelling, although their effectiveness is limited in comparison to water. Achieving adequate impregnation of the submicroscopic cavity system is crucial for ensuring complete dimensional stabilization of the wood. For this technique, it is essential to allow ample time for PEG diffusion and to enhance this process through thorough initial washing to eliminate wood extractives and other contaminants. In our observations, many instances of failure can be attributed to inadequate treatment duration, rapid increases in solution temperature, excessively high initial concentrations of PEG, swift escalation of PEG solution concentration, or the selection of PEG with an excessively high average molecular weight.

The ability of polyethylene glycol (PEG) to penetrate increases as its mean molecular weight decreases. Nevertheless, this trend is accompanied by an increase in hygroscopicity, which means that PEG grades with molecular weights below 800 exhibit either the properties of a soft ointment or a liquid state. Consequently, the selection of suitable types of PEG is constrained to those with molecular weights ranging from 1,000 to 4,000. It is advisable to initiate treatment with a low solution concentration, typically between 10 and 15 percent, and to maintain the working temperature within the range of 35 to 45 degrees Celsius whenever feasible. Variations in conservation practices involving PEG across different laboratories can be attributed to differences in the type of PEG utilized, the initial concentration of the solution, the duration of treatment, and the operating temperature.[4]

2-2 Sucrose Method

The sucrose method for the preservation of waterlogged wood was introduced as a cost-effective alternative to pricier techniques. In essence, the process closely resembles that employed for polyethylene glycol (PEG), with the primary distinction being the use of sucrose. To initiate the conservation process, it is imperative to thoroughly cleanse the wood by immersing it in fresh water baths, thereby eliminating ingrained dirt and most of the soluble salts contained within. After achieving a satisfactory level of cleanliness, the subsequent steps are advised:

1- To formulate a solution with a sucrose concentration between 1% and 5%, it is essential to ensure that it is sufficiently low to avert dehydration of well-preserved wood or intact sections of wood within a generally deteriorated specimen. Prior to initiating treatment, a meticulous assessment of the wood's condition must be conducted to ascertain its preservation status. In instances where the wood exhibits significant degradation, it may be appropriate to commence with a higher sucrose concentration; nonetheless, in cases of uncertainty, it is advisable to begin with a 1% weight/volume solution.

Initiate a systematic approach by weighing a representative sample of the wood undergoing treatment to establish when it attains equilibrium with the solution. Upon achieving saturation with a specified x% solution, the sugar concentration should be incrementally elevated by 1% until it reaches a maximum of 10%.

2- Furthermore, select an antimicrobial agent such as Dowicide A and incorporate it into the initial preparation of the sucrose and water mixture. This ensures comprehensive penetration and protective measures against microbial activity within the wood.[5]

3- When dealing with highly degraded wood, the incremental increases in percentages may be greater and occur at closer intervals. It is advisable to initiate treatment with a modest percentage increase, ranging from 1% to 5%, until the concentration of sucrose reaches 50%. Following this threshold, the increments can be raised by 10%. If uncertainty arises during the process, one may revert to the initial incremental increases utilized at the commencement of treatment. The treatment persists until the sucrose concentration attains 70%, ensuring that the wood stabilizes at this level.

4- Should it be necessary, consider incorporating an additive that will deter insect and rodent infestations in the treated wood. Numerous pesticide options are available, with the choice largely influenced by local accessibility. For optimal protection, it is recommended to mix the insecticide into the initial solution. However, if the wood is stored in a museum-like environment, the risks of insect and rodent issues should be minimal, and alternative control measures may suffice.

5- Once the wood has achieved equilibrium with the desired maximum solution, it should be air-dried gradually under conditions of carefully regulated high humidity. As the drying process proceeds, the humidity can be systematically reduced.

Introducing wood to low humidity conditions too rapidly can lead to detrimental effects. A gradual and regulated drying process, alongside an adaptation to the existing atmospheric conditions—as outlined in the wood treatment methods discussed—will enhance the effectiveness of the treatment as a whole.

6- It is advisable to store the wood in environments where humidity levels do not exceed 70%. Exposure to humidity levels above 80% should be avoided, as such conditions can lead to condensation on the wood, which may result in the leaching of sugars.[6]

When sugar is chosen as the treating agent, it is essential to utilize refined white sugar, or pure sucrose. The use of unrefined sugar, characterized by its brownish hue and coarse granules (referred to as Type A sugar), is discouraged for wood treatment due to its significantly higher hygroscopic properties compared to wood treated with refined white sugar. In instances where relative humidity increases, the surfaces of wood treated with unrefined sugar tend to become damp. This hygroscopic behavior resembles that observed with medium molecular weight polyethylene glycols. Nevertheless, wood treated with Type A sugar exhibits dimensional stability, maintaining its form despite variations in moisture content.

2-3 Acetone-Rosin Method

The method is based on replacing the water in wood with a natural resin known as rosin or colophony as the impregnation substance. The rosin is insoluble in water, and is dissolved in organic solvents, the most frequently being used acetone or alcohol. For the method to be successful it is important to use only lump, technical-grade rosin and pure acetone or alcohol. Since rosin does not mix with water it is important to remove the water from the structure of the wood. The dehydration of waterlogged wood is achieved by submerging

the wood in three successive acetone baths.[7]

The process of dehydration in each of the baths lasts from two to four days until all of the water is replaced by acetone. For objects of 5 to 10 centimetre thickness the dehydration process last four days, while for objects thinner than 5 cm the process lasts for two days in each of the acetone baths. The dehydrated wood is then placed in closed containers with a saturated solution of rosin in

acetone. The solution contains 67% rosin, with a 52°C process temperature. The process of impregnation lasts from two to four weeks, depending on the thickness of the object, upon which the wood is taken out of the solution

and the excess rosin removed with rags moistened with acetone. The advantages of the method are the stability and low weight of the treated wood, and the ability to use the method when wood is present in combination with metal, as rosin does not react with metals. The drawbacks are the flammability of acetone and the high cost of the process. This method is recommended for the conservation of smaller waterlogged wood artefacts of considerable significance. [8]

2-4 Alcohol-Ether Method

This experimental method involves immediately immersing the excavated object in alcohol, which is then replaced with ether containing a mixture of dammar varnish, beeswax, carnauba wax, paraffin, and rosin. High temperatures aid penetration. Like PEG, this approach stabilizes the wood and reduces surface tension via alcohol or ether, preventing collapse. Several modified versions of this technique have since been developed.[9]

This technique bears resemblance to the methodology employed in the desiccation of biological specimens. Prior to initiation, it is essential to cleanse the wood if deemed necessary. The water-saturated object undergoes immersion in a series of alcohol baths, where the objective is to gradually substitute all water content with alcohol.

Typically, isopropanol or ethanol serves as the alcohol of choice. This initial phase is succeeded by multiple acetone baths. If required, the progress of dehydration may be assessed through the measurement of the specific gravity of each bath. Once all water has been effectively replaced with acetone, the object is then subjected to a series of dimethyl ether baths, facilitating the complete substitution of acetone with ether. Upon the successful completion of this phase, rapid drying of the object is achieved by placing it under vacuum conditions, allowing for the swift volatilization of the ether. The selection of ether is justified by its exceptionally low surface tension of 0.17 dyne/cm, in stark contrast to water's surface tension of 0.72 dyne/cm.

This indicates that upon the evaporation of ether, the forces associated with surface tension are sufficiently minimal, allowing the compromised cell wall to maintain its structure without significant collapse. If required, one can incorporate 10-20% of dammar resin, colophony rosin, or a combination of both into the final ether bath, facilitating the deposition of resin within the wood's pores to serve as a consolidating agent. In certain instances, polyvinyl acetate (PVA) may also be employed. While these resins effectively reinforce the wood, their primary role is to provide a seal that mitigates the risk of warping due to fluctuations in relative humidity.[10]

2-5 Camphor-Alcohol Method

The camphor-alcohol method is similar to the previous method, where water is replaced by alcohol using camphor, which slowly transitions from a solid to a gaseous state without damaging the wood. Camphor dissolves in any type of alcohol. Water removal is carried out according to the following procedures:

Thoroughly and carefully cleanse the object.

Subject the specimen to a dehydration process utilizing a sequence of alcohol baths. Begin with a mixture comprising 50% alcohol and 50% water, followed by baths of 75% alcohol to 25% water, then 90% alcohol to 10% water, and ultimately a bath of pure 100% alcohol. This approach represents a conservative method, and in practical application, the precise concentrations of the alcohol baths may fluctuate. The effectiveness of the dehydration process is contingent upon the initial state of the object being treated. In its initial formulation, the wood was dehydrated using methanol, which is a cumulative toxic agent; thus, either ethanol or isopropanol may be employed as alternatives.

Submerge the object in a solution consisting of 95% alcohol and 5% camphor. After the object has undergone dehydration, carefully measure its weight. Maintain the specimen in the 5% camphor solution until the weight stabilizes. Evaluate the progress through daily weigh-ins. Whenever the weight reaches a plateau, incrementally introduce an additional 5% camphor into the solution. Continue this process until the concentration of camphor reaches between 75% and 80%. This procedure may extend over several weeks or potentially months. Throughout the duration of treatment, it is essential to maintain the solution temperature at 52 degrees Celsius, ensuring that the solution level remains consistent by adding more alcohol as necessary. In practice, the treatment is typically completed with minimal oversight.

Once the object has been extracted from the bath, the alcohol will gradually evaporate over several weeks, resulting in the crystallization of camphor within the cell walls. Subsequently, over the course of months, the camphor will transition into vapor through the process of sublimation, thereby imposing no surface tension on the cell walls. To mitigate the evaporation of camphor, various substances such as varnish, wax, polyurethane, dammar resin, colophony, and even polyvinyl acetate (PVA) can be applied to the wood's surface. Although this technique is strongly endorsed, it shares a limitation with the alcohol-ether method, as it remains economically viable primarily for small specimens. Additionally, it poses a significant fire hazard.

2-6 Silicone Oil Treatment

A simplified version of the silicone bulking process that is applicable for the treatment of small wood artifacts and other organic material is as follows:

1. Take waterlogged wood and place directly in a bath of ethanol and hold under a vacuum for approximately one hour.
2. Place the dried wood into a bath of acetone and hold under vacuum for approximately one hour.
3. Remove wood and place it in SFD-1 silicone oil that has had 4% Isobutyltrimethoxysilane added to it. The isobutyltrimethoxysilane is a crosslinker that sets the silicone oil up for curing in the nest steps. Keep wood submerged in this mixture under vacuum over night.
4. Remove wood, and pat dry with a dry rag to remove excess silicone oil on surface
5. Place the wood in a closed container over a small dish containing a small volume of FASCAT Catalyst 4200 in it. Place everything in a furnace heated to 52^0 C. The heat of the furnace vaporizes the FASCAST and the vapors causes the silicone oil to cure in the wood, stabilizing it.

This chemical material has been suggested to replace PEG, as the experts from the A&M University of Texas claim that “this silicone oil treatment results in a very naturally colored wood that undergoes little to no dimensional changes. The wood is stable and does not require the close environmental controls that some other treated woods do. Still, it must be kept in mind that this treatment is not reversible, but for that matter most of the other treatments are not either.”[11]

2-7 Radiation-Induced Polymerization

Developed in the United States, this method uses gamma radiation to polymerize monomer-impregnated wood. Initially, methanol replaces all water. Different labs use various monomers (styrene, methyl acrylate, methyl methacrylate, or 2-

hydroxyethyl methacrylate). After impregnation, the object is irradiated with cobalt-60.

Results show excellent dimensional stabilization (shrinkage < 1%, and sometimes even slight expansion up to 3% without damage), although these results were obtained under controlled lab conditions. .[12]

2-8 Freeze Drying of Waterlogged Wood

Procedure:

1- field treatment : where the recovered wood is sufficiently sound it is washed extraneous material, drained dry and coated with 50% solution of polyethylene glycol 400. This is then parcelled in polyethylene sheet or , for a smaller item, in a plastic bag.

2- soaking : when the wood is received for treatment it is placed in polyethylene-lined tanks for soaking in a 10% aqueous solution of polyethyelen glycol 400. A smal amount of water – soluable fungicide (sodium salicylanilide tetrahydrate)[2] is added. The wood is soaked for at least one month, though larger items may be left for up to six months, before being treated.[13]

3- Freezing : the wood is imbedded in a trough of crushed co_2 for 30 minutes to tow hours. When the item is solidly frozen it is wrapped tightly in aluminium foil while a few holes (1-2 cms) are torn in the surrounding metal to assist the removal of vapour from the package. A small hole be drilled to the centre of the frozen wood to accommodate the trip of a thermocouple.

4- vacuum drying : The item wrapped in foil is placed on the heating coil within the vacuum chamber, the thermocouple is inserted and Embedded with'a few drops of water which quickly freezein place; a second thermocouple is taped on to the surface,the chamber is closed and pumping commences.The progress and speed of the subsequent drying depends on the load within the chamber,the woods'percent-age of water as ice,and the surface area of the various items.Several small items together will be processed in a shorter time than one single items of equivalent weight.

Conservation method based on vacuum drying process in low temperature is the most often recommended one, particularly for materials having badly destroyed structure. According to this method, material frozen earlier is subsequently dried in sublimation process, i.e. without passing ice through liquid phase (melting). Water sublimates from solid state (ice) to gaseous one (water vapor), when molecules have sufficient energy to release, but they are in conditions making creation of liquid state impossible. For determining in what state of matter (solid, liquid or gaseous) a molecule is, knowing two cardinal parameters: the temperature and the ambient pressure is indispensable. They both should be in adequate interval, in order to obtain required state of substance's aggregation.[14]

3- Conservation Examples

Chinese archaeologists have successfully elevated an entire wooden shipwreck from the ocean floor utilizing a specifically engineered support system, facilitating thorough examination on dry land. During the 2017 International Symposium on the Discovery and Research of the Nanhai I Shipwreck, Sun Jian, the Chief Technology Officer of the Underwater Archaeology Unit at the National Center for Underwater Cultural Heritage, along with Cui Yong, the Deputy Director of the Guangdong Provincial Institute of Archaeology, presented the paper titled "The Discovery and Research of the Nanhai I Shipwreck."

They conveyed that even within meticulously regulated environmental parameters—where the temperature was consistently held at 18 °C and relative humidity fluctuated between 70 and 80%, complemented by automated misting of the entire area seven times each day—considerable alterations were nevertheless observed. Additionally, a comprehensive 3D scan of the entire workspace was conducted on a daily basis. Notwithstanding these extensive preservation efforts, the wooden structure exhibited an average volumetric and dimensional deformation reaching as high as 25%.

Conclusion

Numerous alternative methods exist for the preservation of waterlogged wood, including the use of paraffin in a hexane solution for bulking, although these techniques are not widely implemented. It is essential to recognize that various treatments can effectively address the challenges associated with conserving waterlogged wood. The choice of treatment may often hinge on aesthetic factors; for instance, some methods yield a specific wood coloration, enhance the natural wood grain, and may impart properties such as glueability, flexibility, or rigidity. Additionally, certain treatments accommodate the integration of wood within composite wood-metal artifacts, exhibit resilience to humidity fluctuations, and prove suitable for storage under challenging conditions. Each of these aspects must be taken into account, and there are treatment strategies available that cater to all of these criteria. Each method is applicable in particular contexts and serves as a viable alternative.

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