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Assessing a Byproduct of the CBD Ethanol Extraction Process for Potential as a Wood Finishing Product

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Upon initial observation of this material, CBD tar presented similarities to other plant tars such as creosote or bitumen—both of which had been historically used for waterproofing and sealing. Currently, however, natural sealants that are commonly used include boiled linseed oil and hempseed oil. If CBD tar could perform similarly to these materials and show an equal ability to reduce water absorption, potential use for this waste product could be determined.

To assess this, a saturated solution was created by dissolving CBD tar in Acetone in a ratio of 75g:150ml. The three treatments (CBD tar, boiled linseed oil, and hempseed oil) were applied to a variety of hardwood, softwood, and composite wood samples in a series of either one, two, or three coats. Southern yellow pine and white ash coated with the treatments were soaked in water for either a 1-hour or 3-hour period to gather data on water absorption of hardwood and softwoods. Composites such as HempWood®, oriented strand board, and particle board were soaked in water for three 24-hour periods to collect data on linear expansion and absorption.

Qualitative observations such as the material's ability to penetrate wood, as well as color change, were also included in this study.

The results showed high potential for further assessment of the material through a series of one tailed t-test comparisons that returned highly significant differences between applications of CBD-tar and no treatment in addition to CBD-tar against the manufactured treatments for solid wood. CBD-tar applied to composite wood OSB, and particle board also showed highly significant results against no treatment warranting further inspection of the materials ability to reduce linear expansion due to water absorption. Results from this experiment show that additional trials and analysis on alternative features of wood finish such as durability and ease of application would be worthwhile. Potentially, this waste byproduct could be transformed into a valuable resource that allows manufactures get more out of their processes by closing the loop on one waste stream.

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ASSESSING A BYPRODUCT OF THE CBD ETHANOL EXTRACTION PROCESS FOR POTENTIAL AS A WOOD FINISHING PRODUCT

BY

Avani M. Flanagan

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To assess this, a saturated solution was created by dissolving CBD tar in Acetone in a ratio of 75g:150ml. The three treatments (CBD tar, boiled linseed oil, and hempseed oil) were applied to a variety of hardwood, softwood, and composite wood samples in a series of either one, two, or three coats. Southern yellow pine and white ash coated with the treatments were soaked in water for either a 1-hour or 3-hour period to gather data on water absorption of hardwood and softwoods. Composites such as HempWood®, oriented strand board, and particle board were soaked in water for three 24-hour periods to collect data on linear expansion and absorption.

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Introduction

Contrary to the application of the 1937 Marihuana Tax Act, hemp and marijuana are two distinct variations of the same species, *Cannabis sativa* L. For millennia, it has been cultivated in Central Asia as a source of fiber for fabrics and twine as well as for oil and medicine, with its earliest record of use dating back to 2900 B.C. [1, 2]. It is believed to have been brought to the United States in 1606 for its medicinal properties [3]. Despite its long history tied closely to humanity, *Cannabis sativa* has faced a turbulent lifetime within the U.S. In the 1850's, marijuana was used as a mainstream medicine and was sold over the counter to treat a wide range of afflictions such as headaches, typhus, alcoholism, gout, and leprosy [4]. U.S. cultivation rates reached a record high during World War I when the imported supply had been cut off [3]. A little over a decade later, however, attitudes towards the plant shifted. Propaganda such as the 1936 film *Reefer Madness* spread fear as it depicted an association of cannabis with murder and insanity. As states began to pass their own anti-marijuana laws, the federal government passed the 1937 U.S. Marijuana Tax Act requiring all cultivators to receive permission from the USDA. World War II sparked a sudden surge within the hemp industry as it was urgently needed for the production of nautical ropes and parachutes [3]. Almost immediately after the war, production of hemp returned to being nearly obsolete. Several decades later, the Comprehensive Drug Abuse Prevention and Control Act of 1970 categorized both marijuana and hemp as controlled substances making both illegal to cultivate. It was not until 2018 when the Agriculture Improvement Act, better known as the Farm Bill, created distinct guidelines differentiating the two [5]. This legalized the growth and production of industrial hemp and CBD products that contained less than 0.3 percent THC in dry-weight resin.

THC, or tetrahydrocannabinol, is one of the two main cannabinoids found in *Cannabis sativa*—the other being CBD, or cannabidiol. THC, specifically the Δ9-tetrahydrocannabinol, is the main constituent of the psychoactive effects tied to marijuana. CBD, on the other hand, does not produce these effects. Typically, an inverse relationship exists between the two, meaning that *Cannabis* bred specifically for high THC content (marijuana), is vastly different from the varieties cultivated for high CBD content [6, 7]. It is for this reason that industrial hemp grown for its fiber content, and therefore containing less than 0.3% THC resin dry weight to comply with the Farm Act, has allowed the CBD industry to take off within recent years.

In the U.S. alone, *Cannabis* production totaled $824 million in 2021. Of this, $623 million was due to floral hemp production, $41.5 million from hemp seed production, and $41.4 million from fiber production [8]. In the same year, the global CBD market had grown to become a 5.13 billion (USD) industry. According to a report published by Grandview Research, an expected compound annual growth rate (CAGR) of 16.8% for the years leading up to 2030 will allow it to reach 13.4 billion (USD) [9]. As with any industry, this growth is dependent on the increased consumption and manufacturing of its products. This requires the optimization of all aspects of production, from cultivation to packaging. Developments within the industry have already shown a positive trend of waste reduction by finding purposeful uses for remaining biomass material. These advancements include bioethanol created from hemp stalks and the production of sugar by use of enzymatic hydrolysis [2]. Despite these advances, however, many waste streams within the industry still exist.

One known waste comes from the ethanol extraction process—the process used to separate CBD oil from unwanted impurities. This product, referred to as CBD-tar, is a collection of fats, waxes, and lipids that remain after distillation. It is currently discarded as waste with no current known uses. Not only does this cost resources to properly dispose of, but it also reduces a manufacturer's return on value (ROV). An initial inspection of the byproduct's physical features proved it to be thermoviscous. When heat was applied to the solid material, it melted into a liquified form. When the heat was removed, it solidified but did not re-take its previous shape. When water was introduced to the surface of the material, beads formed and rolled off. This raised the question of potential water resilience.

The initial observations of CBD-tar resembled similarities to other plant tars such as bitumen and pine tar. Evidence from the Neolithic age shows bitumen had been used to seal boats and waterproof baskets and jars [10]. Similarly, pine tar has been used historically by Swedish mariners to preserve their ships [11]. These treatments have since been replaced by more modern applications. Currently, oils from linseed, tung or hempseed are used to finish and seal wood products. If CBD-tar was found to provide similar water resilience in comparison to these finishes, it may have potential as a valuable material. This study aims to analyze CBD-tar's performance as a potential wood finishing product by examining its ability to prevent water absorption in solid wood and reduce spring-back or linear expansion in composite wood. Other properties of wood finish such as penetration and color change will also be observed.

If CBD-tar can provide results similar to or better than that of boiled linseed oil and hempseed oil, then potential use as a wood finishing treatment should be explored. This study could create the opportunity to transform a waste stream into valuable closed loop system.

Research Questions

Based upon initial observations, questions surrounding CBD-tar's water resistance and ability to perform as a wood finishing product arose. If this material contained these positive physical features, it could be further explored as a potentially valuable material. The following research questions were designed to guide the assessment of CBD-tar and its potential to perform competitively against currently used wood finishing product:

1. Is there a significant difference in water absorption of solid wood when CBD-tar is applied in various applications?
2. Is there a significant difference in linear expansion caused by water absorption of wood-based and hemp-based composites when CBD-tar is applied in various applications?
3. How does the penetration and color change of CBD-tar compare with linseed oil and hemp oil?

Literature Review

Ethanol Extraction Process

The CBD extraction process varies with each manufacturer's processing capabilities. Smaller yielding facilities often use different solvents and techniques than large facilities to cut down on processing costs. All, however, produce some form of waste. One of the most used extraction methods uses ethanol and a process called *winterization* (**Error! Reference source not found.**). First, dry hemp flowers and plant material are loaded into stainless steel tanks and soaked in ethyl alcohol until the cannabinoids have been dissolved into the liquid. From here, the extract is concentrated by evaporating the solvent, leaving behind a crude oily residue. The crude oil is chilled and filtered through a pressurized 'winterizing' system. By chilling the extract, the unwanted 'wax' coagulates and is removed (Figure 2). In this step alone, approximately 5-10% wt. of the input crude oil is collected for disposal. Next, the remaining crude CBD oil is heated to a maximum of 150°C and distilled through a vacuum [12]. The resulting material is a viscous, dark-colored distillate referred to by the industry as "terpenes." This is then re-distilled to recover any lost cannabinoids. The distillation process results in a 15% wt. loss of the input. Remaining inside the distillation vessel is a tar-like residue that represents 20-30% wt. waste from the initial crude oil. For the purpose of this study, this tar material is referred to as CBD-tar. Next, the crude oil is transferred to a wiped-film distillation apparatus, which increases the concentration of the product by removing a resin (RES) that represents 10-15% wt. waste from the input. Finally, the distilled concentrated CBD oil is crystalized from the organic solvent to produce a pure CBD isolate. The entire process generates a total of 58% wt. (of total crude extract) of by-product waste [12].

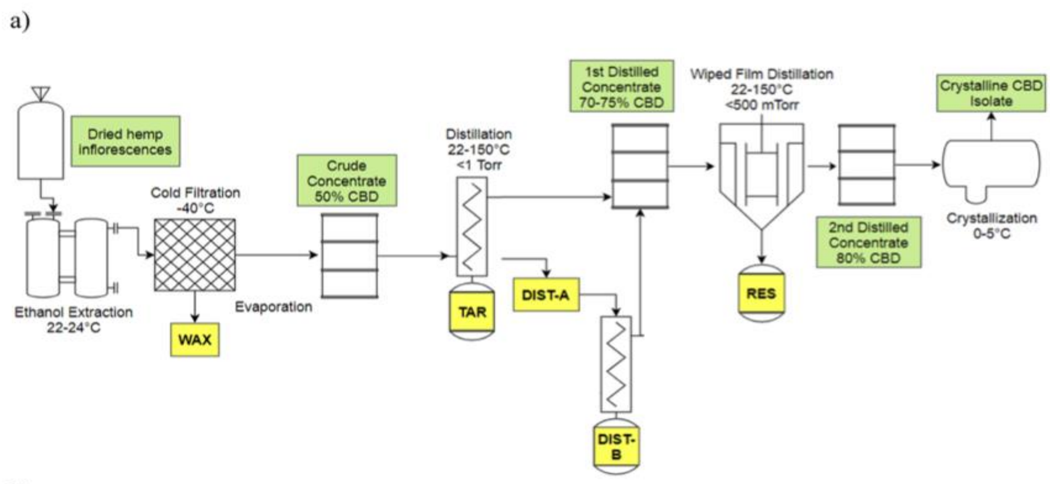

Figure 1: The CBD Extraction Process [12]

In this study, the waste stream of interest is CBD-tar from the second distillation. Leyva-Gutierrez et al. (year?) describes this material upon first appearance as resembling black coal. When heated above 150°C, however, his study mentions that it becomes "viscous, tacky, and odorous. On cooling to ambient conditions, it solidifies as a hard but malleable solid. If deformed and left unrestrained, it flows slowly into a puddle over the course of several days" [12]. Additional literature mentioning this material was limited. Numerous studies mention that waste is produced and removed throughout the extraction process. However, it appears rare to analyze this waste for positive properties.

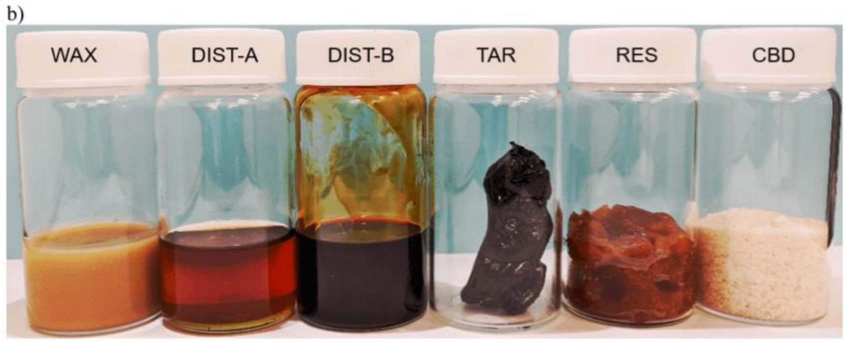

Figure 2: Byproducts of the CBD Extraction Process [12]

Plant Tars

As mentioned, additional properties of CBD-tar were observed supplementary to Leyva-Gutierrez et al. When heated, CBD tar melted into a flat puddle and showed signs of burning, yet it did not ignite. After cooling, the melted material returned to a solid state. When the material was subjected to water, beads formed and easily rolled off. CBD-Tar shares similarities with other plant tars such as bitumen, an organic, naturally occurring byproduct of decomposed plants. Bitumen is a dark, viscous form of petroleum that has been used by humans for a wide variety of tasks such as waterproofing for the past 40,000 years [13]. In ancient Mesopotamia, bitumen was used for caulking ships and as an adhesive for mosaics. Near Sacramento NM, Native Americans used bitumen as a waterproofing agent for their baskets and jars [14 ,10]. Similar to CBD TAR, Bitumen is ridged at lower temperatures and increases in flexibility as temperatures increase, making the two materials thermoviscous and potentially similar in physical attributions.

Wood-Composites

The term "wood composites" refers to a variety of wood products that are made by taking solid wood and creating wood pieces that are sized depending on the composite’s purpose. These pieces are coated in an adhesive or glue binder and re-combined to form a new desired product.

Each type of composite is determined by the shape or size of the pieces used and the type of binder. Common wood composites include cross laminated timber, plywood, medium density fiber board, particle board, and oriented strand lumber [15]. Similar products made from non-wood materials—typically fast growing plants like bamboo or hemp—can also be processed in a similar fashion to create alternative composite materials [16]. This includes products such as HempWood®.

Adhesives

The adhesives used to produce wood composites can be categorized as thermoplastic or thermoset. The term thermoset means that after curing, the adhesive cannot be re-melted. This includes cured resins, such as epoxies and phenolics like phenol-formaldehyde. In contrast, thermoplastic or thermoviscous refers to polymers that can be melted repeatedly. This includes polyethylene, polypropylene, and polyvinyl chloride (PVC) [17]. The two most commonly used adhesives (by volume) are urea-formaldehyde (UF) and phenol-formaldehyde (PF) [18]. Urea-formaldehyde is an inexpensive thermoset used for interior composites such as particleboard and medium density fiberboard (MDF). Phenol-formaldehyde is an exterior-grade thermoset adhesive that is water-resistant and used typically for OSB, marine plywood, and housing purposes. The cure-time for phenol-formaldehydes is typically longer than for other adhesives [18].

Alternative adhesives used in wood composites include bio-based adhesives such as tannins and soy protein. In some instances, these alternatives are still being developed and in other cases they have been used commercially for many years. The term "bio-based adhesive" is defined to include only a few specified materials that consist of only natural, non-mineral origin that need only slight modification in order to reproduce the behavior and performance of synthetic adhesives [18]. In most cases, bio-based adhesives are thermoplastics, which can provide the benefits of being able to re-heat and-therefore readjust bonds between wood. Tannins are extracted from the bark and wood of trees, and experiments have gained positive results from testing soy flour and soy protein adhesives [18].

Particleboard

Particle board is a cost-effective, multifaceted product that was developed by German inventor Max Himmelherber in 1932 [15]. It is produced by reducing solid alder, beech, birch, pine, or spruce into small chips and fibers. The wood particles are then mixed with thermosetting adhesive resins, urea–formaldehyde (UF), melamine–urea–formaldehyde (MUF), phenolic resins (PF and TF), or isocyanates (pMDI), and then heat pressed with high temperature and pressure. Most often, particleboard is composed of three distinct layers with the surface layers made up of finer particles than the center coarser layers [18]. Typically, particleboard is used for indoor purposes such as flooring, furniture, and kitchen cabinetry. Due to its absorbent nature, exterior uses are not appropriate. Moisture can easily cause expansion and warping [15].

Oriented Strand Board

Oriented strand board, (OSB), is a structural wood-based composite consisting of three layers of wood strands or wafers that have been hot-pressed together with small amounts of thermosetting adhesives[18]. The strands are purposefully positioned in altering directions so that each layer varies by 90°, providing the product with high mechanical strength [15]. OSB has been engineered to be equal to plywood in strength and stiffness [19]. Phenol formaldehyde (PF) and diphenylmethane diisocyanate (MDI) are two water-resistant binders that are most used in the manufacturing of OSB. Both are thermosetting plastics, meaning pressure and temperature are required to cure. Typically, this requires a temperature between 400 - 425°F and a pressure between 650 - 800 psi for approximately 4 to 6 minutes. Because it is a thermosetting plastic, the binding material will remain rigid even if exposed to high temperatures [18].

HempWood®

HempWood®, an alternative to wood composites trademarked by a company based in Murry Kentucky, uses a similar concept to OSB in its production. Instead of chipped wood, however, hemp stalks are used. After being harvested for its flower for use in CBD and THC products, retted hemp stalks are bailed for transport. At the production facility, the broken stalks are spread evenly into a layer and briefly submerged into an organic soy adhesive. Each layer is allowed time to dry before being compiled and pressed together into beams using 3000 tons of pressure (sic) [20]. The beams are placed in an oven so the thermoplastic soy adhesive can soften and 'glue' the fibers together when it eventually cools and rehardens. Finally, each beam is cut into several boards using a vertical rift cut or horizontal live cut. Because the organic binding material Is thermoplastic, high heat exposure could compromise the composure and strength of the composite [21], (Figure 3).

Although some composites such as OSB are produced to have higher strength, composites all provide their own advantages for specific applications. However, one major drawback is their inability to resist water absorption. Composites with low-density show higher rates of water absorption than those with higher densities [22].

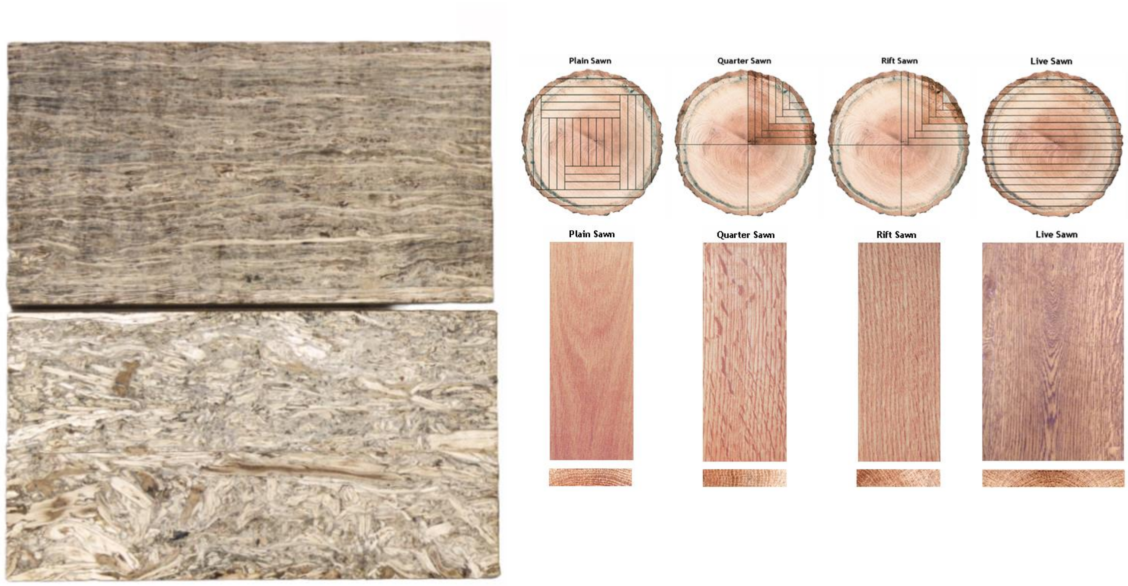

Figure 3: Rift vs. Live sawn HempWood® [21, 23]

Methodology

1. Is there a significant difference in water absorption of Solid Wood when CBD-Tar is applied in various applications?

This experiment aimed to test the absorption of water by solid wood as a direct effect of varying wood finishes. These finishes included *Klean Strip Boiled Linseed Oil*, in one and two coats (as specified by manufacturer); *Dr. Adorable Inc 100% Pure Unrefined Organic Hemp Seed oil*, in one and two coats (as specified by manufacturer); and CBD-tar solution as applied with one, two, and three coats. Both hardwood and softwood species were included in the design by using southern yellow pine and white ash. A soak time of 1 hour or 3 hours was incorporated into the design to test the treatments in short and long-term exposure to water.

For each of the two wood categories: southern yellow pine and white ash, 48 samples were cut to dimensions of 20 × 20 × 50 mm. (8" × 0.78" × 1.9"). Six were allocated to each of the following eight treatment groups:

Table 1: Treatment groups, Solid wood

Treatment and Coating Combinations		
No treatment		
Boiled linseed oil: 1 coat	Boiled linseed oil: 2 coats	
CBD TAR: 1 coat	CBD TAR: 2 coats	CBD TAR: 3 coats
Hempseed oil: 1 coat	Hempseed oil: 2 coats	

Each treatment group was then split into two subgroups: a 1-hour and 3-hour soak time with three samples allocated to each group. Samples were labeled with a wood punch with the following letters to represent each variable: 1 or 3= Soak time; P= southern yellow pine or A=white ash; 0=control group, B= boiled linseed oil, C=TAR, or D=hemp seed oil; 1,2, or 3= number of coats, Table 10, appendix.

Example:
3PD2 → (3, Three-hour soak) (P, southern yellow pine) (D, Hemp Seed oil) (2, two coats)

Boiled linseed oil was applied using a clean rag in accordance with the manufacturer's instructions for best results. The finish was generously applied, allotted 5 minutes to penetrate the wood, and then the excess was wiped off. Hemp seed oil was applied in the same manner. 24 hours was allotted to dry time for the samples requiring a second coat.

A saturated solution of CBD-tar was created by breaking 75 g of the material into a powder and dissolving it in 150 ml of acetone (Figure 4). Due to different viscosity in comparison to the finishing oils, CBD-tar solution had to be applied by a brief submersion rather than with a rag. This provided a more even coat. After each sample was individually dipped in the solution, they were placed on a drying rack with minimal contact to surrounding surfaces so that all sides could dry evenly. Due to the solution's quick dry time, an hour was allotted between each of the second and third coats for the samples that required it.

Figure 4: CBD-tar in original form (left), crushed powder (middle), and saturated solution (right)

After all wood finishing treatments were applied, all samples were left to settle in the same environmental conditions of ambient room temperature for one week to reach a practical equilibrium state [23].

Each sample's initial dry weight was recorded before being placed in a tub corresponding to its test group. Each sample was spread one inch from the other to ensure all sides were exposed. A piece of hardware cloth held down with weights and placed on top of the samples ensured each sample would remain in place and not float to the surface. Ambient temperature water was added to each tub so that all samples were submerged under at least one inch of water [23]. Samples in the 1-hour soak time groups were removed from the water after an hour, placed on a drying rack where they were given approximately 1 minute for excess water to drip off, and then immediately weighed. The same process repeated after 3 hours for the 3-hour soak groups.

The following formula was used to calculate the percent change in mass due to water absorbed by each sample:

$$\text{\% Change in Mass} = \frac{\text{B} - \text{A}}{\text{A}} * 100$$

Where:

A = Initial mass, g

B = Final mass, g

Finally, the average percent change in mass was calculated for each treatment group of each wood type (Table 11, appendix).

2. Is there a significant difference in linear expansion caused by water absorption of wood-based and hemp-based composites when CBD-tar is applied in various applications?

This experiment aimed to test the change in linear dimension, or spring-back, of wood composites caused by the absorption of water as a direct effect of the same varying applications of wood finishes as tested in section 1. Once again, *Klean Strip Boiled Linseed Oil*, *Dr. Adorable Inc 100% Pure Unrefined Organic Hemp Seed Oil*, and CBD-tar solution were tested as applied with one, two, and three coats. This time, however, they were tested on Hemp wood (rift and live-sawn), oriented strand board (OSB), and Fiber Board.

For each of the four wood composites, 38x50 mm (1.5 x 2 in) samples were cut and three were allocated to each of the following eight variable categories:

Table 2 Treatment Groups, Composite Wood

Treatment and Coating Combinations		
No treatment		
Boiled linseed oil: 1 coat	Boiled linseed oil: 2 coats	
CBD TAR: 1 coat	CBD TAR: 2 coats	CBD TAR: 3 coats
Hempseed oil: 1 coat	Hempseed oil: 2 coats	

Boiled linseed oil was applied using a clean rag in accordance with the manufacturer's instructions. The material was generously applied, allowed 5 minutes to penetrate the composite, and then the excess was wiped off. Hempseed oil was applied in the same manner. A time period of 24 hours was allotted to dry time for the samples requiring a second coat.

The same CBD-tar solution that was created using 75 g. of CBD-tar and 150 ml of acetone was applied using a quick submersion method. Due to the solution's quick dry time, an hour was allotted between each of the second and third coats for the samples requiring it.

Minor adjustments were made to the ASTM standard procedure in order to test the direct effects of each finishing treatment on the thickness swelling of the wood composites for this specific application. Samples did not adhere to the 12 × 12 in dimensions specified by the guidelines as it was determined that this was only necessary for testing total linear expansion whereas this study was interested only in thickness swelling. After all wood finishing treatments were applied, all samples were left to settle in the same environmental conditions for one week to reach a dry condition state [24].

The weight of each sample was measured to the nearest +/- 0.2 g. The length, width, and thickness were also measured and recorded. To account for uneven swelling, the thickness was measured at two points approximately 0.5 inches inwards from each of the shorter ends of the sample so that an average could later be found.

Samples of the same treatment were placed into separator baskets carefully marked so that each sample could be easily identified and taken for measurements again in the future. The baskets, topped with hardware cloth and weights to prevent floating, were submerged for 24 hours under 1 inch of water at ambient room temperature (Figure 5) [23]. After the 24-hour period, the samples were removed from the water and placed on a drying rack. For feasibility, this test was run on one type of wood composite at a time.

Figure 5 OSB in soak baskets held down by weights.

While standards specify oven drying the samples after submersion, the material composition of the wood composite required this to be adjusted. Oven drying HempWood®, which is made using a thermoplastic binder, could potentially impact composition of the material and compromise the experiment. Instead, samples were allotted one week to fully dry at ambient room temperature. Once dry, the weight and linear dimensions of length, width and thickness (in the same two placements 0.5 inches away from each short edge) were taken and recorded again. Each sample was placed back into the soak baskets and the process repeated twice more for a total of three 24-hour soak periods.

After all data were collected, the average thickness for each sample was calculated and then used to compute the linear change in thickness for each soak period by using the following equation:

$$\%\ \text{Change in Thickness} = \frac{\text{B} - \text{A}}{\text{A}} * 100$$

Where:

A = First Initial thickness, in.

B = Final average thickness (per period, after dry time), in.

Data can be found in Table 12 in the appendix.

3. How does the penetration and color change of CBD-tar compare with linseed oil and hemp oil?

This experiment aimed to collect information on alternative features of wood finish such as penetration and color change. Penetration is an important aspect to consider as it provides insight into a finish’s longevity. Film-forming finishes protect wood from weathering as that build a film or coat on the outside of the wood’s surface. These are more susceptible to cracking and deterioration. Oil-penetrating finishes, on the other hand, are absorbed into the surface and do not face the same failures as often [25]

An attempt to measure penetration used solid wood samples from Section 1. Cross sections of each sample were cut using a handsaw. These sections were placed under an Olympus dissecting microscope, cut side up. The depth of penetration into the wood surface would have been measured using ImageJ, however no visual indication of penetration was visible throughout any of the treatments or solid wood types.

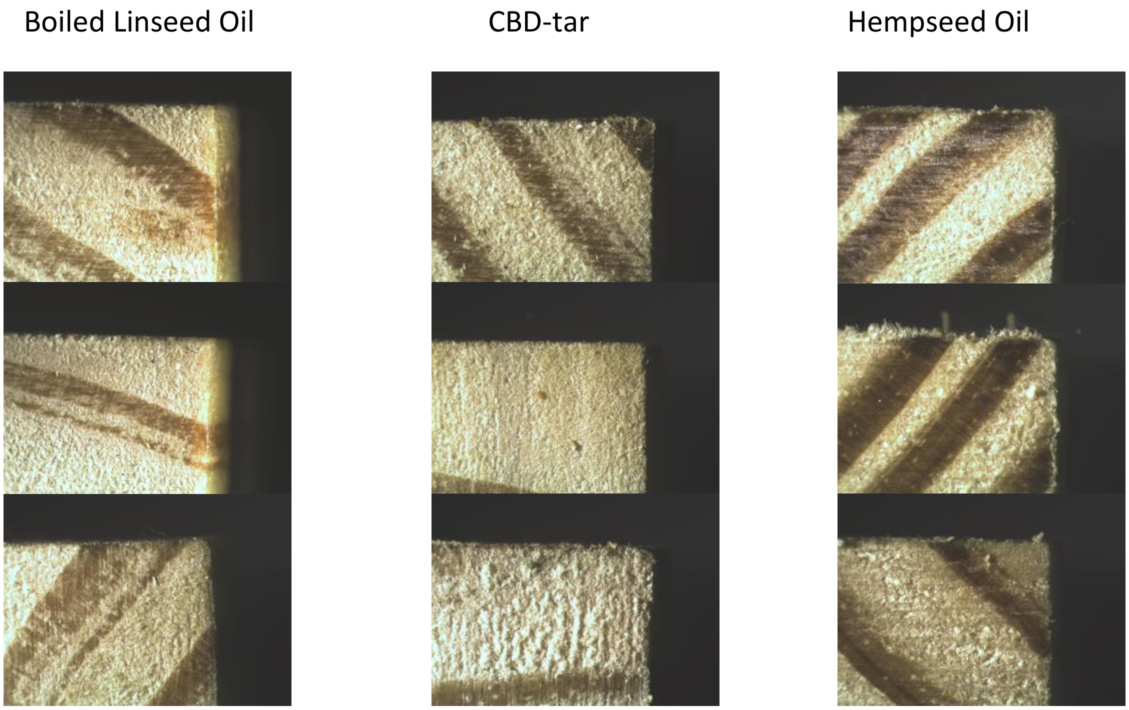

Figure 6 Cross sections of southern yellow pine under view of a dissecting scope.

Color Change:

The same solid wood samples from section 1 were used to analyze how CBD-tar impacted color change in comparison to boiled linseed oil and hempseed oil. A spectrophotometer was used to collect quantifiable data on the color of each sample from each treatment group. The spectrophotometer returned three values: L, a, and b. L represents the lightness on a scale of zero to 100. A and b represent hue or chromaticity with no scale endpoints.

The average of each aspect of color (L*a*B) was calculated from the three samples in each test group.

Results and Discussion

Solid Wood:

The lower the percent change in mass, the less water absorbed, and the better the water resilience a treatment may provide. All treatments appear to have had some result on the water absorbance when compared to the 'No Treatment' test group. By taking an average of the percent change in mass for each of the test groups, a loose trend seems to appear. Organized by finish type, it seems as though CBD-tar2 holds the lowest averages while CBD-tar3 and Hempseed Oil-2 look similar in comparison (Figure 7).

Table 3: Average Percent Change in Mass, Solid Wood

	No Treatment	Boiled Linseed Oil: 1 coat	Boiled Linseed Oil:2 coats	CBD TAR: 1 coat	CBD TAR: 2 coats	CBD TAR: 3 coats	Hemp Seed Oil: 1 coat	Hemp Seed Oil: 2 coats
SYP 1 Hour	33.931%	14.963%	11.025%	10.292%	8.137%	9.340%	13.111%	11.175%
SYP 3 Hour	31.674%	23.949%	17.636%	20.806%	13.353%	14.678%	22.528%	15.694%
WA 1 Hour	7.299%	4.802%	3.898%	4.286%	4.546%	4.514%	5.743%	5.159%
WA 3 Hour	12.732%	8.490%	6.719%	7.730%	7.658%	7.884%	8.843%	7.945%

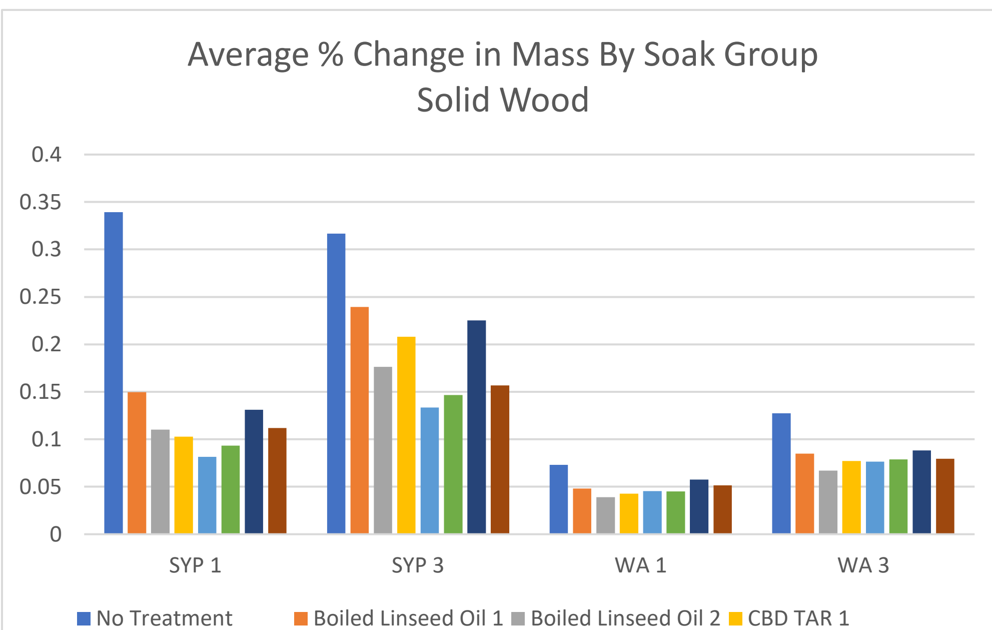

Figure 7: Average % Change in Mass of Solid Wood, SYP:southern yellow pine 1 and 3 hour soak; WA: white ash, 1 and 3 hour soak

When grouped based on wood type and soak time, an apparent trend seems to appear between treatments and wood types. For solid softwood (Southern Yellow pine), the data for CBD-tar treatments dip below the results of all other treatments. For solid hardwood (white ash), the results of CBD-tar appear to stay consistent with alternative treatments.

Interpreting the data for this section is a two-part process. First the values resulting from any number of applications of CBD-tar must be compared against 'No Treatment' to determine if any impact on water absorption was made at all. If a significant difference exists, the second aspect can be tested: Whether CBD-tar performs any differently from Boiled Linseed oil or Hempseed oil. CBD-tar must then be tested against both other treatments. If the difference was determined to be significant by a P-value of less than 0.05, then it can be determined that within *this* study, CBD-tar's ability to reduce water absorption produced significant results and therefore should be further researched.

To retrieve the calculated comparisons, an F test was first performed between 'no treatment' and each of the finished treatments. Then based on the results of the variance test, a t-test assuming equal or unequal variance was performed on the same comparative groups (Table 4).

Table 4: T-Test Results, Solid Wood

Test Group:	Comparison:			P value	Determination
southern yellow pine	No Treatment	:	Boiled Linseed Oil: 1 coat	0.0025	Highly Significant
1 Hour		:	Boiled Linseed Oil:2 coats	0.0003	Highly Significant
		:	CBD TAR: 1 coat	0.0000	Highly Significant
		:	CBD TAR: 2 coats	0.0003	Highly Significant
		:	CBD TAR: 3 coats	0.0000	Highly Significant
		:	Hemp Seed Oil: 1 coat	0.0000	Highly Significant
		:	Hemp Seed Oil: 2 coats	0.0000	Highly Significant
southern yellow pine	No Treatment	:	Boiled Linseed Oil: 1 coat	0.0412	Significant
3 Hour		:	Boiled Linseed Oil:2 coats	0.0205	Significant
		:	CBD TAR: 1 coat	0.0130	Significant
		:	CBD TAR: 2 coats	0.0120	Significant
		:	CBD TAR: 3 coats	0.0141	Significant
		:	Hemp Seed Oil: 1 coat	0.0927	Not Significant
		:	Hemp Seed Oil: 2 coats	0.0155	Significant
	CBD TAR: 2 coats	:	Boiled Linseed Oil:2 coats	0.0012	Highly Significant
		:	Hemp Seed Oil: 2 coats	0.0005	Highly Significant
					Highly Significant
white ash	No Treatment	:	Boiled Linseed Oil: 1 coat	0.0013	Highly Significant
1 Hour		:	Boiled Linseed Oil:2 coats	0.0046	Highly Significant
		:	CBD TAR: 1 coat	0.0004	Highly Significant
		:	CBD TAR: 2 coats	0.0006	Highly Significant
		:	CBD TAR: 3 coats	0.0014	Highly Significant
		:	Hemp Seed Oil: 1 coat	0.0205	Significant
		:	Hemp Seed Oil: 2 coats	0.0017	Highly Significant
white ash	No Treatment	:	Boiled Linseed Oil: 1 coat	0.0020	Highly Significant
3 Hour		:	Boiled Linseed Oil:2 coats	0.0009	Highly Significant
		:	CBD TAR: 1 coat	0.0002	Highly Significant
		:	CBD TAR: 2 coats	0.0000	Highly Significant
		:	CBD TAR: 3 coats	0.0001	Highly Significant
		:	Hemp Seed Oil: 1 coat	0.0001	Highly Significant
		:	Hemp Seed Oil: 2 coats	0.0001	Highly Significant
	CBD TAR: 2 coats	:	Boiled Linseed Oil:2 coats	0.0175	Significant
		:	Hemp Seed Oil: 2 coats	0.2216	Not Significant

As previously inferred from the graphs, all treatments were statistically significant when compared to the no treatment group except for Hempseed Oil: 2 coats from the southern yellow pine 3-hour soak group.

In all cases, all applications of CBD-tar were found to be significant against 'no treatment.' The significance tests all tested the same null hypothesis of $H_o: the\ difference\ in\ means = 0$, against the alternative $H_a: the\ difference\ in\ means \neq 0$ at the 95% confidence level. T-tests returning a P-value of 0.05 or less showed a 95% probability that the results were not random and therefore the difference in their means were significant. In these cases, there was statistical evidence to say the effect of CBD-tar on the reduction of water absorbance should be investigated more deeply with additional research.

Results from the three-hour groups were used to test CBD-tar:2 Coats against Boiled Linseed Oil: 2 Coats and Hempseed Oil: 2 Coats. This was to analyze the impact of CBD-tar against commonly used treatments in the worst of the two conditions. In three out of four of these instances, CBD-tar: 2 coats proved to have statistically significant results against the known finishes. This highlights a valuable and competitive feature of the material that is currently being wasted.

Composite Wood

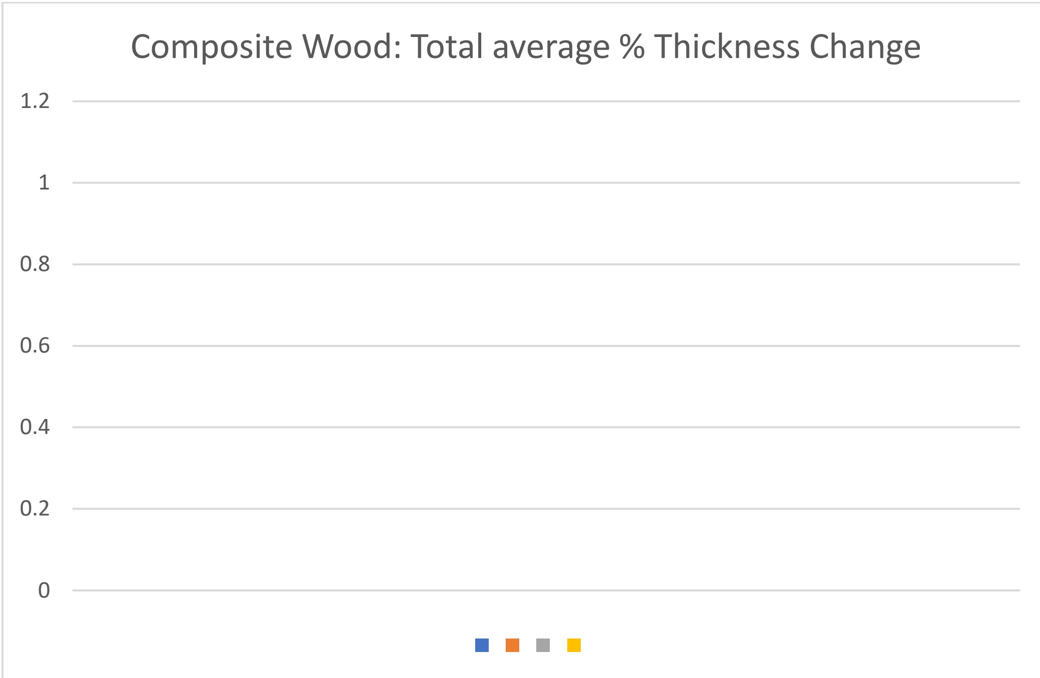

Figure 8: Total average % change in thickness of composite wood

Composite wood products are designed for specific applications. This means that even when placed under the same conditions, the resulting effects may vary greatly. As shown in Figure 8, live-sawn HempWood® gained a substantially larger change in thickness compared to other composites. This was due to the orientation of hemp layers within the sample, determined by the cut style. Live-sawn HempWood® has layers oriented flat, so expansion occurs vertically. Rift-sawn HempWood®, on the other hand, has layers oriented vertically, causing expansion to occur outwards rather than upwards (Figure 9, Figure 10).

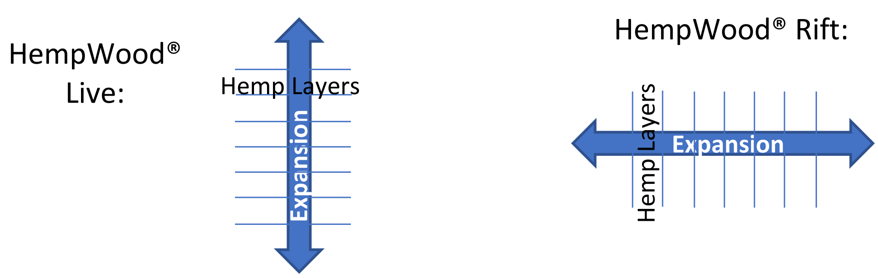

Figure 9: Visual of layer orientation of HempWood rift vs live cut

Figure 10 HempWood® Rift (left), HempWood® Live (right)

.

HempWood® (rift-sawn):

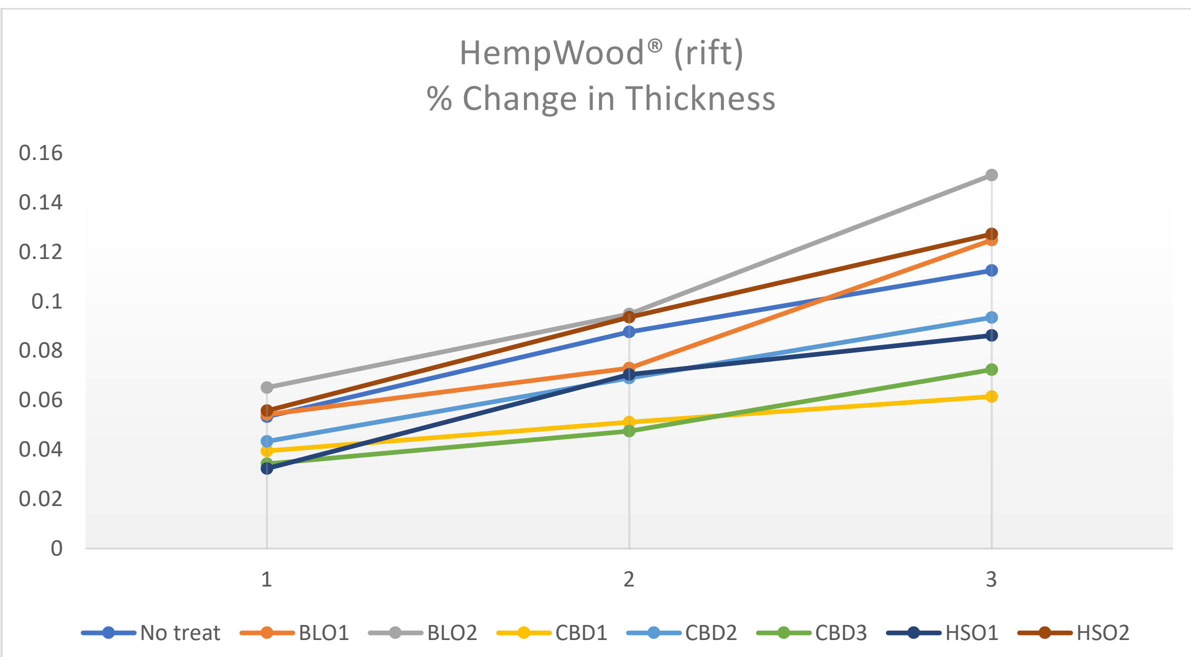

Figure 11: Percent change in thickness of Hempwood rift cut

Table 5: Percent change in thickness per soak in Hempwood rift cut

HempWood® (rift) % Change in Thickness	1	2	3
No treat	0.053329	0.087667	0.112432
BLO1	0.054172	0.072985	0.124769
BLO2	0.065121	0.094851	0.151033
CBD1	0.039486	0.051106	0.061473
CBD2	0.043345	0.068937	0.093454
CBD3	0.034249	0.047487	0.072349
HSO1	0.03238	0.070427	0.086188
HSO2	0.055743	0.093502	0.127161

Over the course of the three 24-hour soaking periods, both CBD-tar 1 and CBD-tar 3 resulted in the lowest overall change in thickness for the HempWood® (rift-sawn) test group (Figure 11, Table 5). After the first soak, the only treatment that resulted in less dimensional change was hempseed oil 1. This quickly changed after the second soak, where the two CBD treatments resulted in substantially lower changes. A t-test of the final percent change after the third soak between the highest preforming CBD application (CBD1) and all other treatments was performed by testing the null hypothesis of $H_o: the\ difference\ in\ means = 0$, against the alternative $H_a: the\ difference\ in\ means \neq 0$ at the 95% confidence level . The results showed that thickness change when treated with CBD-tar 1 was significantly different when compared to no treatment and Hempseed Oil 2.

	t-Test Comparison			*p-Value*	*Determination*
HempWood® (rift)	*CBD TAR 1*	*vs.*	*No treat*	0.027694	Significant
	CBD TAR 1		*BLO1*	0.12386	Not Significant
	CBD TAR 1		*BLO2*	0.092367	Not Significant
	CBD TAR 1		*CBD2*	0.169714	Not Significant
	CBD TAR 1		*CBD3*	0.246504	Not Significant
	CBD TAR 1		*HSO1*	0.162693	Not Significant

CBD TAR 1	*HSO2*	0.032362	Significant

HempWood® (live -sawn):

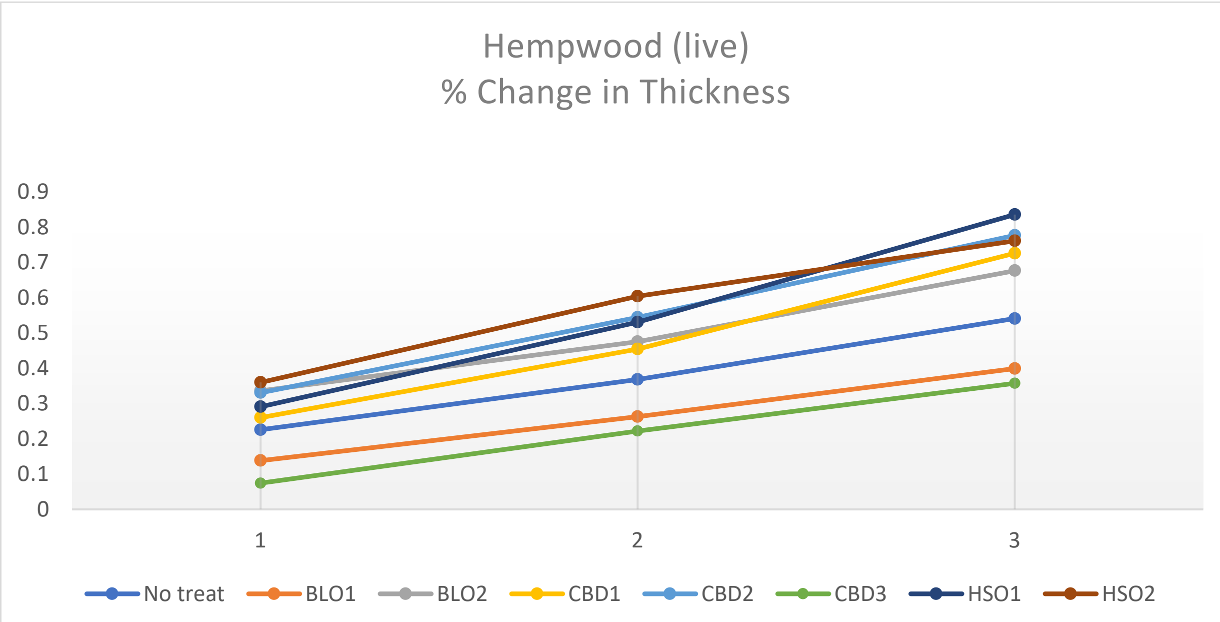

Figure 12: Percent change in thickness of HempWood live cut

Table 6: Percent change in thickness in HempWood live cut

HempWood® (live) % Change in Thickness			
Soak:	1	2	3
No treat	0.225949	0.368417	0.541316
BLO1	0.138242	0.263028	0.399318
BLO2	0.336256	0.475636	0.676861
CBD1	0.260208	0.455075	0.726451
CBD2	0.330746	0.544572	0.777096
CBD3	0.074484	0.222294	0.357572
HSO1	0.291021	0.530809	0.836133
HSO2	0.360005	0.604505	0.761538

All treatments applied to HempWood® (live sawn) showed consistent dimensional increase over the course of the three soak periods (Figure 12, Table 6). CBD-tar 3 resulted in the lowest change consistently, with boiled linseed oil 1 providing the second lowest results. An important aspect to note during this trial was that five treatments resulted in a higher percentage increase in thickness than the 'no treatment' group. One would expect samples with no treatment to have the largest increase because there was no additional water-resisting treatment. When CBD-tar 3 was compared with no treatment, the t-test resulted in no significant difference between the two. However, because boiled linseed oil 2 and hempseed oil 2 both had greater thickness change than no treatment, the t-test between these two and CBD 3 resulted in a significant difference. A comparison with even higher significance, however, was between CBD 3 and hempseed oil 1. With a P-value of 0.002, there was less than a .2% probability that the difference in means of the two treatments occurred by chance. This is a strong indicator that more trials and research need to be applied to the relationship between CBD-tar and the reduction in thickness swelling.

	t-Test Comparison			*p-Value*	*Determination*
HempWood® (live)	*CBD TAR 3*	*vs.*	*No treat*	0.078208	Not Significant
	CBD TAR 3		*BLO1*	0.330551	Not Significant
	CBD TAR 3		*BLO2*	0.006495	Significant
	CBD TAR 3		*CBD TAR 1*	0.072305	Not Significant
	CBD TAR 3		*CBD TAR 2*	0.011403	Significant
	CBD TAR 3		*HSO1*	0.002223	Highly Significant
	CBD TAR 3		*HSO2*	0.017476	Significant

Oriented Strand Board:

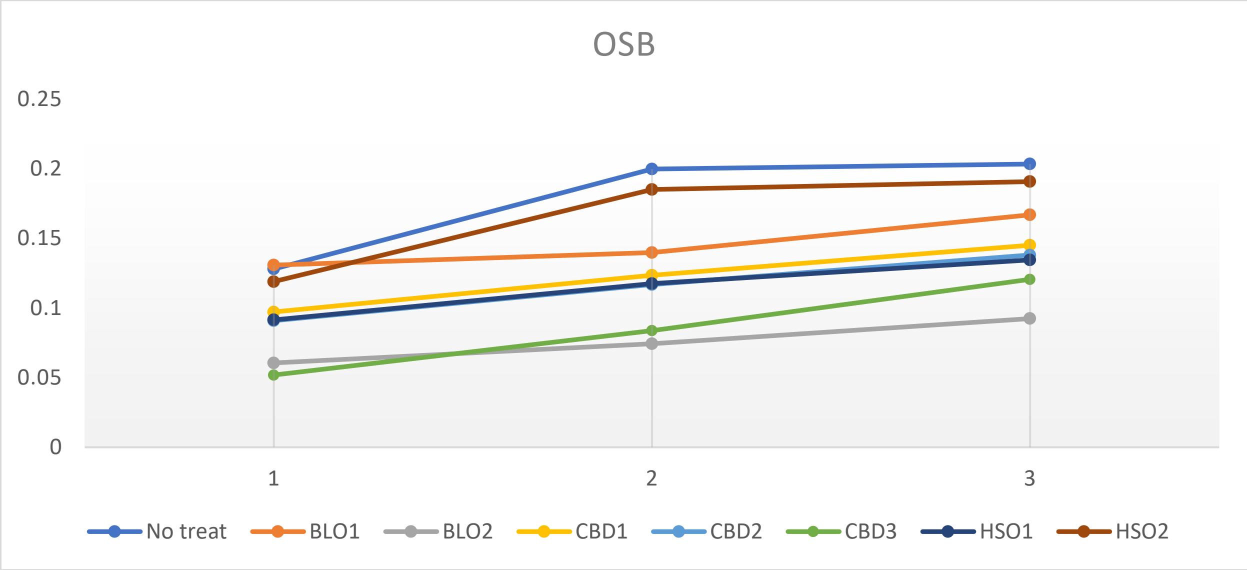

Figure 13: Percent change in thickness in OSB

Table 7: Percent change in thickness per soak, OSB

	OSB 1	2	3
No treat	0.127992	0.199636	0.203323
BLO1	0.130762	0.139842	0.166843
BLO2	0.060549	0.074329	0.092356
CBD1	0.097151	0.123556	0.14502
CBD2	0.090885	0.116764	0.138056
CBD3	0.051865	0.083751	0.12055
HSO1	0.091434	0.117575	0.134495
HSO2	0.118955	0.184923	0.190701

Looking at the final results of the third soak, CBD-tar 1, 2, and 3 are centered within the range of data (Figure 13, Table 7). The rate of change for all three appears to increase consistently throughout each of the three soak periods, rather than steeply increasing at first and tapering off as no treatment and hempseed oil 2 had. The t-test results showed that the difference in means between CBD-tar 3 and no treatment was highly significant with a p-value of 0.003. This demonstrates that the probability of the results occurring randomly is below 0.3%. There is strong evidence that suggests the relationship between CBD-tar and reduction in thickness swelling due to water absorption should be further explored.

	t-Test Comparison			p-Value	Determination
OSB	*CBD TAR 3*	*vs.*	*No treat*	0.003517	Highly Significant
	CBD TAR 3		*BLO1*	0.225974	Not Significant
	CBD TAR 3		*BLO2*	0.107085	Not Significant
	CBD TAR 3		*CBD TAR 1*	0.110531	Not Significant
	CBD TAR 3		*CBD TAR 2*	0.181208	Not Significant
	CBD TAR 3		*HSO1*	0.250434	Not Significant
	CBD TAR 3		*HSO2*	0.023098	Significant

Particle Board:

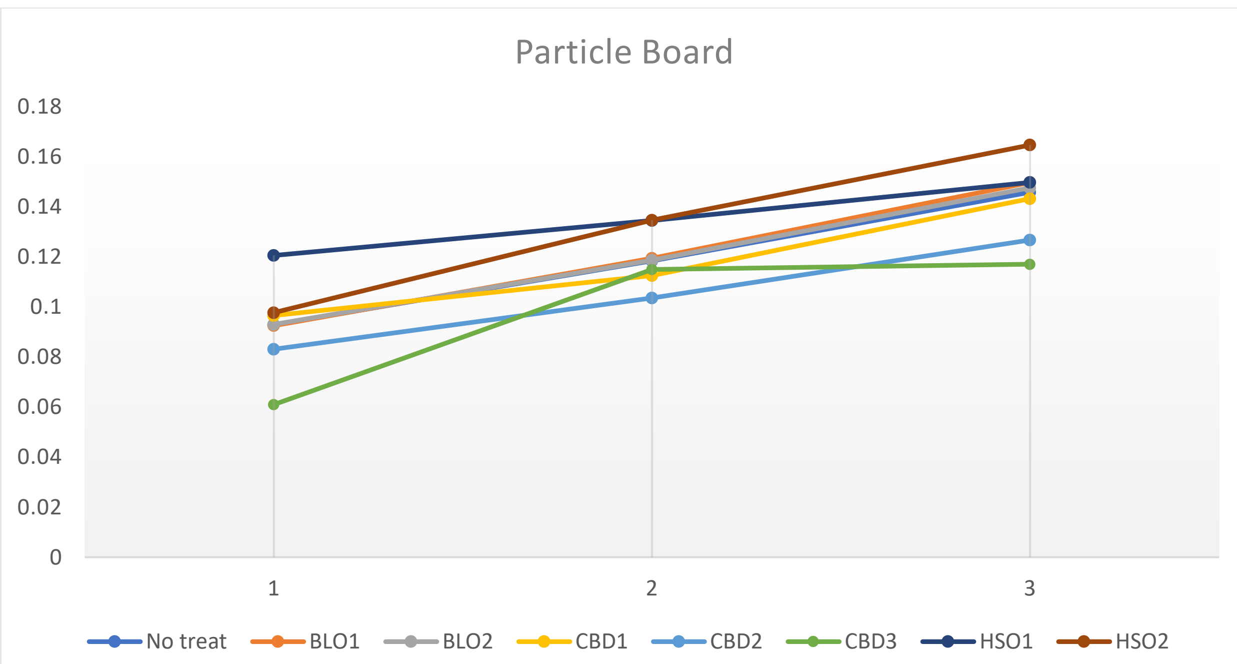

Figure 14: Percent change in thickness of particle board

Table 8: Percent change in thickness of particle board

Particle Board			
Soak	1	2	3
No treat	0.09285	0.11841	0.145801
BLO1	0.092499	0.119419	0.14973
BLO2	0.093	0.118601	0.147597
CBD1	0.120074	0.11248	0.14327
CBD2	0.083095	0.10361	0.126724
CBD3	0.060974	0.11495	0.117057
HSO1	0.204599	0.240904	0.279858
HSO2	0.09771	0.134712	0.164669

When applied to particle board, CBD-tar 3 appeared to reduce thickness swelling very well compared to all other treatments (Figure 14, Table 8). After the second soak, however, it swelled to such a high percentage that its thickness caught back up to be in centered within the data. After this point, CBD-tar 3 only swelled a slight percentage more while all others continued to thicken at their steady rate. T-test results showed that CBD-tar 3 performed significantly against all results, with high significance against no treatment, CBD-tar 1, and Hempseed oil 1 and 3.

	t-Test Comparison			*p-Value*	*Determination*
Particle Board	*CBD TAR 3*	vs.	No treat	0.00081	Highly Significant
	CBD TAR 3		BLO1	0.019783	Significant
	CBD TAR 3		BLO2	0.034274	Significant
	CBD TAR 3		*CBD TAR 1*	0.001081	Highly Significant
	CBD TAR 3		*CBD TAR 2*	0.012304	Significant
	CBD TAR 3		HSO1	0.006149	Highly Significant
	CBD TAR 3		HSO2	1.76E-05	Highly Significant

Table 9: T-test results, Composites

	t-Test Comparison			p-Value	Determination
HempWood® (rift)	*CBD TAR 1*	*vs.*	*No treat*	0.027694	Significant
	CBD TAR 1		*BLO1*	0.12386	Not Significant
	CBD TAR 1		*BLO2*	0.092367	Not Significant
	CBD TAR 1		*CBD2*	0.169714	Not Significant
	CBD TAR 1		*CBD3*	0.246504	Not Significant
	CBD TAR 1		*HSO1*	0.162693	Not Significant
	CBD TAR 1		*HSO2*	0.032362	Significant
HempWood® (live)	*CBD3*	*vs.*	*No treat*	0.078208	Not Significant
	CBD3		*BLO1*	0.330551	Not Significant
	CBD3		*BLO2*	0.006495	Significant
	CBD3		*CBD1*	0.072305	Not Significant
	CBD3		*CBD2*	0.011403	Significant
	CBD3		*HSO1*	0.002223	Highly Significant
	CBD3		*HSO2*	0.017476	Significant
OSB	*CBD3*	*vs.*	*No treat*	0.003517	Highly Significant
	CBD3		*BLO1*	0.225974	Not Significant
	CBD3		*BLO2*	0.107085	Not Significant
	CBD3		*CBD1*	0.110531	Not Significant
	CBD3		*CBD2*	0.181208	Not Significant
	CBD3		*HSO1*	0.250434	Not Significant
	CBD3		*HSO2*	0.023098	Significant
Particle Board	CBD3	vs.	No treat	0.00081	Highly Significant
	CBD3		BLO1	0.019783	Significant
	CBD3		BLO2	0.034274	Significant
	CBD3		CBD1	0.001081	Highly Significant
	CBD3		CBD2	0.012304	Significant
	CBD3		HSO1	0.006149	Significant
	CBD3		HSO2	1.76E-05	Highly Significant

Color Change:

The following graphic (Figure 15). was created to visualize the value returned from the spectrophotometer.

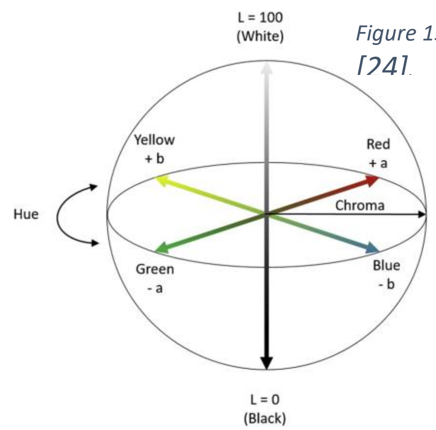

*Figure 15 Diagram of L*a*b spectrum [24].*

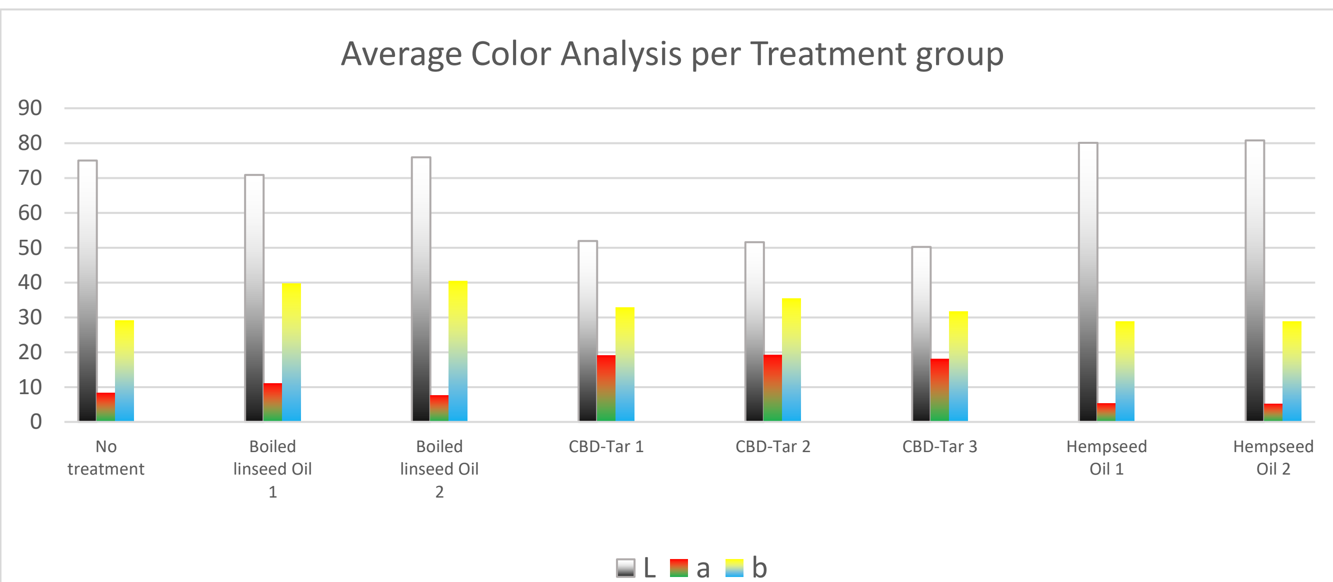

Figure 16: Analysis of average color per treatment

CBD-tar very clearly differs in color from Boiled Linseed and Hempseed oil. The L (lightness) factor differs majorly in that CBD -Tar is much darker (Figure 16). CBD-tar has a higher hue of red, and less yellow. In total CBD-tar changes wood color dramatically, turning it a very deep brown. If CBD-tar were to be used as a wood finish, this could be a potential benefit for those interested in a stain or a potential draw back for those who prefer to keep the natural color of wood.

Conclusion

This study aimed to analyze the potential of a CBD byproduct for possible use as wood finishing product. The material was evaluated against boiled linseed oil and hempseed oil, commonly used natural finishes. To expand the area of results, both solid hardwood, softwood, and composite wood types were included within the experimental design. Solid southern yellow pine and white ash were treated with each of the treatments applied in one, two, or three coat applications. T-tests assessing significant differences in means resulted in highly significant results between all three applications of CBD-tar against no treatment on both wood species. This strongly suggests a relationship between the application of CBD-tar and a reduction in water absorption that should be explored with further research as there was less than a 0.03% chance the results of this experiment were random. There was also a significance found between CBD-tar and the common wood finishes, indicating the potential for CBD-tar to reduce water absorption with an effectiveness similar to, or potentially better, than finishes currently on the market. This potential should be explored with additional testing that further explores the features of wood finishes that reach beyond water absorption such as durability, ease of application, and protection.

HempWood®, oriented strand board, and particle board were used to test the thickness swelling and linear dimensional change of composite woods. While CBD-tar did not perform significantly better than most of the treatments on HempWood®, it performed much better against no treatment on OSB and particle board. This again shows the potential of CBD-tar as a treatment for composites and should be further explored with future research.

Future research should also include testing different solvents when creating the CBD-tar solution as this study only used acetone. Additionally, other wood varnishes and lacquers should be explored for comparison. Physical features such as the finishes' longevity and how it performs with handling and daily use would also be important to fully assess its potential as a finish.

The results of this study point toward potential valuable features of CBD-tar that could open the door to the creation of products made from the repurposed waste of the ethanol extraction process. Creating closed-loop systems will become increasingly more popular as the industry continues to grow at a predicted rate of 16.8% each year [9]. This study not only intends to contribute to the reduction of waste streams, but to create additional value for CBD manufactures to gain the most return from their processes.

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Appendix

Table 10: Design Matrix, Solid Wood

Wood Type:	southern yellow pine		white ash	
Soak Time:	1 hour	3 Hours	1 Hour	3 Hour
Control	1P0	3P0	1A0	3A0
	1P0	3P0	1A0	3A0
	1P0	3P0	1A0	3A0
Boiled Linseed Oil: 1 coat	1PB1	3PB1	1AB1	3AB1
	1PB1	3PB1	1AB1	3AB1
	1PB1	3PB1	1AB1	3AB1
Boiled Linseed Oil: 2 coats	1PB2	3PB2	1AB2	3AB2
	1PB2	3PB2	1AB2	3AB2
	1PB2	3PB2	1AB2	3AB2
CBD TAR: 1 coat	1PC1	3PC1	1AC1	3AC1
	1PC1	3PC1	1AC1	3AC1
	1PC1	3PC1	1AC1	3AC1
CBD TAR: 2 coats	1PC2	3PC2	1AC2	3AC2
	1PC2	3PC2	1AC2	3AC2
	1PC2	3PC2	1AC2	3AC2
CBD TAR: 3 coats	1PC3	3PC3	1AC3	3AC3
	1PC3	3PC3	1AC3	3AC3
	1PC3	3PC3	1AC3	3AC3
Hemp Seed Oil 1 coats	1PD1	3PD1	1AD1	3AD1
	1PD1	3PD1	1AD1	3AD1
	1PD1	3PD1	1AD1	3AD1
Hemp Seed Oil 2 coats	1PD2	3PD2	1AD2	3AD2
	1PD2	3PD2	1AD2	3AD2
	1PD2	3PD2	1AD2	3AD2

Table 11: DATA Percent Change in Mass, Solid Wood

		1 coat	2 coats	1 coat	2 coats	3 coats	1 coat	2 coats
1 hour soak	Control	Boil Linseed Oil		CBDDB			Hemp Seed Oil	
southern yellow pine	33.93%	14.96%	11.02%	10.29%	8.14%	9.34%	13.11%	11.17%
white ash	7.30%	4.80%	3.90%	4.29%	4.55%	4.51%	5.74%	5.16%
3 Hour soak								
southern yellow pine	31.67%	23.95%	17.64%	20.81%	13.35%	14.68%	22.53%	15.69%
white ash	12.73%	8.49%	6.72%	7.73%	7.66%	7.88%	8.84%	7.95%

Table 12: DATA Percent Change in Thickness, Composite Wood

Initial	*HempWood® (rift)*	*HempWood® (live)*	*OSB*	*Particle Board*
No treat	1.1	1.012	0.436167	0.639
BLO1	1.1075	1.017667	0.42	0.637833
BLO2	1.104333	1.028167	0.4355	0.638
CBD1	1.098	1.018667	0.435333	0.638667
CBD2	1.116333	1.044667	0.438333	0.641833
CBD3	1.135667	1.033	0.443833	0.647833
HSO1	1.108167	1.014833	0.433833	0.593167
HSO2	1.099167	1.028833	0.4345	0.639667
After 1				
No treat	0.053329	0.225949	0.127992	0.09285
BLO1	0.054172	0.138242	0.130762	0.092499
BLO2	0.065121	0.336256	0.060549	0.093
CBD1	0.039486	0.260208	0.097151	0.120074
CBD2	0.043345	0.330746	0.090885	0.083095
CBD3	0.034249	0.074484	0.051865	0.060974
HSO1	0.03238	0.291021	0.091434	0.204599
HSO2	0.055743	0.360005	0.118955	0.09771
After 2				
No treat	0.087667	0.368417	0.199636	0.11841
BLO1	0.072985	0.263028	0.139842	0.119419
BLO2	0.094851	0.475636	0.074329	0.118601
CBD1	0.051106	0.455075	0.123556	0.11248
CBD2	0.068937	0.544572	0.116764	0.10361
CBD3	0.047487	0.222294	0.083751	0.11495

HSO1	0.070427	0.530809	0.117575	0.240904
HSO2	0.093502	0.604505	0.184923	0.134712
After 3				
No treat	0.112432	0.541316	0.203323	0.145801
BLO1	0.124769	0.399318	0.166843	0.14973
BLO2	0.151033	0.676861	0.092356	0.147597
CBD1	0.061473	0.726451	0.14502	0.14327
CBD2	0.093454	0.777096	0.138056	0.126724
CBD3	0.072349	0.357572	0.12055	0.117057
HSO1	0.086188	0.836133	0.134495	0.279858
HSO2	0.127161	0.761538	0.190701	0.164669