# WOOD, OIL, AND WATER

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*HTML version by Nicholas S. Lander*

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Imagine you have just acquired two recorders and the dealer has given you two oiling kits to maintain the bores. One contains Yamaha Bore Oil and the other Moeck Recorder Oil. Each is colorless, rather odorless and slightly viscous. Each can help protect the wood from water and slightly improve sound efficiency in rough bores. But, the oils are chemically quite different.

There have been many articles on the subject of recorder oiling. They are not always consistent, and most lack needed chemical and physical information. The best is by Simmons (1), and Naylor's report is provocative (2). This article provides an interlocking view of wood, oil, water and how they interact.

## BASIC CHEMISTRY

The chemical elements carbon (C), oxygen (O), and hydrogen (H) bond together like

Lego toys. The rules are simple; hydrogen bonds to one other thing, oxygen to two, and carbon to four. Carbon is one of the few elements to form chains, -C-C-C-.

# THE WOOD

CELLULOSE: The three major building blocks of wood are cellulose, hemicelluloses, and lignin. Cellulose is a polymer (many units) made up of repeating units of glucose. There may be 10,000 glucose units in the final polymer (Figure 1).

The cellulose polymer in wood forms long chains that bond with one another by a weak chemical linkage called a hydrogen bond. It is formed from the connection of the -OH of one chain with an O- of its neighbor, -OH...O-. These bound chains twist in space to make up ribbon-like sheets of material. These sheets are used as the basic construction material for a variety of tubular structures that run longitudinal to the trees axis. These serve as support columns and/or carry water in living wood from the roots to the growing tips and return newly synthesized carbohydrates downward for storage. The carbohydrates are made from atmospheric water ($H_2O$) and carbon dioxide ($CO_2$) in the leaves by the action of sunlight on a molecule called chlorophyll.

Hardwoods have longitudinal "vessels" that transport solutions, "fibers" that perform the mechanical support role, and "parenchyma" for storage. Hardwood vessels are 0.15-1.5 mm long, and 20-300 micron in diameter. Hardwood fibers average about 2 mm in length and 20 micron in diameter. Hardwood parenchyma are brick-shaped cells. These may be longitudinal and/or occur along radial lines (Figure 2).

At a macroscopic level we can think of vessels as closed tubes of cellulose having pores at each end that allow fluid to pass from one perforated tube to another. If many of these tubes are bundled together longitudinally in the tree trunk a pathway exists for fluid flow up and down. Imagine a bunch of soda straws glued together, all pinched off, but with small pin holes at each end. Some of the cellulose polymer areas are very ordered, and are termed crystalline. These segments are quite strong. Other areas are less ordered, and are called amorphous.

LIGNIN: As the tree grows between the bark and the sapwood each season, some of the carbohydrates are used to create another member of the composite, lignin. Lignins begin with a simple chemical substance derived from phenylpropane, phenylalanine. Phenylalanine can be converted to 4-hydroxyphenylalanine, tyrosine, by plants or man. Phenylalanine and tyrosine are important aminoacids in man.

In wood, as the process continues, a very complex polymer is produced made up of many phenylpropane units originally substituted at the 4 position with HO- and at the 3 and/or 5 positions with CH3O groups (Figure 1). Lignins with a majority of 3-methoxy substitution are found in softwoods, while hardwoods have a mixture of 3-methoxy and 3, 5-dimethoxy substitution. There may be 1,000 phenylpropane units of one kind or another in the final polymer network. The function of lignin in wood is to

provide another supporting structure, and to help the wood repel attacks from degrading organisms.

HEMICELLULOSES: The last major components in wood are called hemicelluloses. They are short polymer chains made up of a variety of carbohydrates. In hardwoods, the most common non-glucose carbohydrate found is called xylose. There might be 100-200 monomer units in the final polymer. Hemicelluloses play an important role at the interface between cellulose structures and the lignin portion of wood. Hemicelluloses are amorphous. Some theories suggest that small circular lignin polymer chains bonded periodically to the hemicelluloses encourage the surrounding cellulose chains to become more crystalline.

The normal cellulose/lignin/hemicellulose ratios vary from wood to wood. Typical ratios are 2.2:1:1.5 for hardwoods. Tropical hardwoods are usually more heavily ligninized. The three components together form a composite which provides strength and flexibility to the wood.

THE COMPOSITE: Cellulose occurs as long, threadlike fibers (microfibrils). These are imbedded in a matrix of hemicellulose and lignin. The assembly is just like fiber-glass imbedded in resins that are used to repair automobile body dents- a composite material. The microfibrils consist of the outer original primary wall (Figure 3), and three inner layers of secondary wall (S1, S2, and S3 (the innermost)). The three secondary walls have their microfibrils oriented at different biases with respect to the long axis, roughly like these lines; /, |, \. Biasing adds strength; e.g., the belting in tires, or your abdominal muscles.

# OILS AND WAXES

VEGETABLE OILS AND WAXES: Glucose polymers are one way nature stores energy, in you or the tree. Another storage form involves long chains of carbon that terminate in a -COOH group, R-COOH molecules. These are called carboxylic acids or fatty acids (Figure 1). Their biosynthesis favors even numbered fatty acids, from C12 to C22. These are weak acids, about the same strength as acetic acid or vinegar, which is CH3-COOH.
In plants and animals these free acids would make the environment too acidic, so nature found a way to make the molecules neutral. It does this by forming what is called an ester. This involves removing a molecule of water between the R-COOH and an HO-R' alcohol molecule to give R-CO-OR' (Figure 1). Esters with small R, R' groups are volatile liquids and usually have characteristic pleasant odors. The energy storage elements, however, need to be viscous or semi-solid materials at body temperature that can sustain body shape, yet not be too rigid. When the carbon chains are longer, and the ester product is a solid, it is called a vegetable wax. Vegetable oils have three ester groups in the same molecule, since the alcohol has three HO- groups react with three fatty acids (Figure 1, Figure 4). In porous recorder woods, like maple or some fruit species, the wood is often impregnated with waxes (either ester or paraffin

waxes) by the maker to make them resist moisture uptake from the breath during playing. Vegetable oils are often used to oil bores made from fine grain wood. But so are paraffin oils.

MINERAL WAXES, OILS: Paraffin (mineral) waxes and oils are long hydrocarbon chains (Figure 1, Figure 4). If they are solid at room temperature they are called paraffin waxes, and mineral oils if they are liquid. They are organic compounds, despite the names. Some players use the latter as bore oils.

# WOOD AND WATER

Water, HOH, is essential to the living tree and our own bodies. Newly hewn green tree wood can contain a great deal of water. How much? 40-200%! Where is it all located? Some is bound near the surfaces of hemicellulose and cellulose structures. The rest is free water in the open tubules. The internal surface area of wood is enormous. Internal surface areas viewable by visible microscopy in a one cubic centimeter piece of wood will be larger than the combined area of several pages of this magazine. Smaller tubules, from 1 micron to 4 nanometer, augment this surface area by factors of a hundred. Wood is a very porous material. How porous? Density is defined as a weight/volume relationship, grams/cubic centimeter (gm/cc). The density of "wood substance" (the collection of cellulose, lignin and hemicelluloses) is about 1.5 gm/cc. A dried wood sample of Scots pine with a density of 0.5 gm/cc would have a void volume of about 0.65 cc/cc (internal empty space/wood volume). Common recorder woods and their reported densities (3,4) are: maple 0.72, pear 0.76, rosewood 0.88, boxwood 1.00, and grenadilla 1.29 gm/cc. Their calculated void volumes range from 0.50 to 0.20 cc/cc.

Wood shrinks as water is lost (desorbed). Wood swells as water sorption occurs. The term sorption will be used to avoid the confusing adsorption and absorption terms. The addition of water to dried wood takes place in three successive steps. First, individual water molecules insinuate themselves between the elements making up the hydrogen bonds that hold the cellulose chains together. This swells the wood composite. This insertion occurs mainly in the hemicellulose and amorphous cellulose regions. The more ordered crystalline cellulose regions are much less affected. Large amounts of lignin will reduce the amount of water taken up.

The chemist, in plotting the amount of water uptake versus the relative humidity (RH), would say that the first step in water sorption by dry wood was obeying a principle called a Langmuir isotherm (Figure 5). This can be viewed as the formation of a single and then double layer of water molecules across the affected wood surfaces. The amount of water sorption first rises as the RH increases, and then levels off somewhat as the layering becomes complete (20-60% RH). As the RH increases (60-90% RH) a point is reached where the layering becomes so deep that hydrogen bonding of water with itself becomes the important factor. The equilibrium moisture content (EMC) now begins to rise rapidly with increasing RH. This sorption mechanism continues until the

wood fibers have taken on as much water as they can without the void volume becoming filled with bulk condensed water. This is called the fiber saturation point (FSP). This point is actually somewhat indefinite.

For Scots pine the FSP is 30% EMC; the void volume of the swelled structure is 0.55 cc/cc, and its density is about 0.45 gm/cc. If condensed water vapor then filled all the void volume, the third and final step, the maximum moisture content of the wood would be 190%!

RECORDERS AND WATER: Fortunately, the player is not often faced with a water logged instrument, nor a completely dry one. If you care for your recorder the room humidity or the instrument case should be near a relative humidity of 50%. This lies in an area where the plot of water sorption versus change in RH is the flattest. Humidity control can be important. If you store your recorder in the shower, the RH can be near 100%. The outdoor RH in Denver can drop to the high 30s, and in back-of-Bourke, Australia it can drop to the low 20s.

As the instrument is played, the water content of the air in the bore quickly reaches a high RH. Untreated wood would start water sorption and move toward the fiber saturation point. At some point, the smaller tubules would begin to fill with condensed water. Small tubes (under 20 micron) condense water at lower RH than large spaces. Fortunately, the rate of water sorption is not very rapid. Typical hardwood sections, 4 mm in thickness, take about 18 hours to reach the average moisture content as the RH is stepped from 60 to 90% on both sides. It takes over 36 hours to reach 90% EMC.

The gain or loss of water results in different dimensional changes in each type of wood. Each unique direction has two coefficients of change associated with it, a swelling and a shrinkage coefficient (Figure 5). There are three separate effects: one of change along the long axis of the tree (longitudinal), another in a direction perpendicular to this axis (radial), and a final one tangential to the growth rings. The tangential/radial coefficient ratio is often near 2:1. However, it is the percentage difference in the measured dimensional changes that determine if your recorder is in danger from water. Coefficient ratios over 2.2 and dimensional change differences greater than 3% indicate potential risk induced by too rapid a water sorption. The machined bore, tenons and holes are circular. Because of the different tangential/radial and longitudinal coefficient ratios, these structures oscillate between various elliptical shapes as the humidity changes. For palisander the differences between major and minor axes of the ellipses for EMC's of 50-80% RH is a few mils. The internal pressure changes in the wood are the biggest danger. These can exceed 2000 pounds/in2.

# OILS AND WATER

THE GOALS IN OILING: One goal in oiling bores is to reduce the rate and amount of

water vapor entering the wood so that it does not swell either to quickly or too much. The oil also prevents condensed water droplets from being imbibed into the wood structure. A third goal is to slow the loss of the water after playing, so that the wood is not suddenly stressed by rapid shrinkage. How can it play these three roles? Think of Gortex that is rain water resistant, yet permits water vapor from the body to escape.

CONTACT ANGLES: Vegetable oils and mineral oils have contact angles of less than 90 degrees with the wood surface. Drop one of these oils on a clean wood surface. The angle between the wood/oil interface and the exposed drop's surface will be less than a right angle. This indicates that the oil can "wet" the surface and can penetrate into the wood pores. Now, spread it out. The oil can provide the protection the instrument needs. Place a drop of water on the treated surface, and observe how it "beads up". The water drop cannot wet and penetrate the treated surface, but water vapor can slowly pass because of the thinness and/or nature of the surface oil film. How do typical wood finishes affect water vapor transport rates? Table I presents some data that may surprise you. Most films and paint allow the wood to breath, a requirement for wood stability.

## Table I: Film Water-Vapor Transportation Abilities [5]

| # Coats | Linseed Oil | Spar Varnish | Polyurethane Varnish | Two Part Epoxy | Paraffin Wax |
|---------|-------------|--------------|----------------------|----------------|--------------|
| 1 | -100%* | 100 | 89 | 47 | 31 |
| 2 | -100 | 85 | 64 | 18 | NA |

*Numbers represent uptake of water vapor by brush coated Ponderosa Pine samples compared to uncoated controls exposed in a high humidity chamber (90% RH @ 80 F) for a period of 14 days. Linseed Oil exposed for 1 day gave values of 88 and 78% for 1 & 2 coats respectively.

# OILS AND WOOD

VEGETABLE OILS: In fine grained woods, vegetable oils are often used by instrument players to prevent rapid water-induced wood swelling/shrinking. Nature uses Glycerin, an alcohol with three HO- groups, to make these. Each of the HO- groups is condensed with a fatty acid, R-COOH, to form a glyceryl triester (Figure 1). If this is liquid at room temperature it is called an oil. If solid, it would be a fat. A shorthand notation for the fatty acids will help in the following discussions. Their structure can be represented by (1) the number of carbon atoms, (2) how many C=C double bonds exist, and (3) where these bonds are located (indicating the carbon atom # at which they begin, counting from the -COOH); thus 18:2;9,12 represents CH3-(CH2)4-CH=CH-CH2-CH=CH-(CH2)7-COOH. (18 = the number of carbons, the 2 = the number of double

bonds, and the 9 and 12 = the # of the carbon atom where double bonds start.)

Some of the acids found in recorder oils are listed in Table II.

### Table II: Common Fatty (Carboxylic) Acids Found in Recorder Oils [9]

| Name | Structure |
|---|---|
| Lauric Acid | 12:0 |
| Myristic Acid | 14:0 |
| Palmitic Acid | 16:0 |
| Stearic Acid | 18:0 |
| Oleic Acid | 18:1;9 |
| Linoleic Acid | 18:2;9,12 |
| Linolenic Acid | 18:3;9,12,15 |
| Eleosteric Acid | 18:3;9,11,13 |
| Erucic Acid | 22:1;13 |

UNSATURATION: Compounds without C=C double bonds are saturated. Double bonds create unsaturation, since the carbons COULD bond to other atoms if they were available. For example, Oleic Acid can be converted to the saturated Stearic Acid by the addition of a molecule of H-H across the double bond. The degree of unsaturation in an oil determines its drying characteristics, and can be found by adding Iodine (I-I). The Iodine Number is the # of grams of iodine taken up by 100 grams of oil. Table III lists the approximate Iodine Numbers for four oils made up of the pure glyceryl triesters from Stearic, Oleic, Linoleic, and Linolenic Acids. The name Tristearin comes from TRI STEARic acid glycerIN, etc...

### Table III
### Iodine Numbers of Pure Glyceryl Triesters [9]

| Name | Iodine Number |
|---|---|
| Tristearin | 0 (saturated) |

| | |
|---|---|
| Triolein | 85 |
| Trilinolein | 170 |
| Trilinolenin | 255 (very unsaturated) |

Vegetable oils are mixtures of various saturated and unsaturated acids. With just Stearic Acid and Oleic Acid there are four (4) possible combinations. Using G to represent glycerin, and U and S to represent the unsaturated and saturated fatty acids attached to the glycerin, we have GS3, GUS2 ,GU2S, and GU3. Just imagine the number of combinations possible for 6 or more acids, as is common! Vegetable oils do not contain just one substance, but hundreds. Nature distributes the acids rather randomly among the many glycerin molecules, except that it usually avoids GS3 combinations which are solids. This is called a restricted random distribution. Why is this important? It determines the drying characteristics of the oil which is discussed later.

Table IV shows the fatty acid composition of typical oils that have been used for oiling recorder bores. These are nominal values, since genetics, growing conditions (soil and weather), storage, and processing can dramatically affect the ratios. The Table also gives an average Iodine Number for the oil, and divides the oils into non-drying (Iodine # <100), semi-drying (100-150), and drying (>150). The first remain quite fluid after application to a surface, semi-drying oils become somewhat more viscous over an extended time, and drying oils eventually form a tough film after 3-6 days.

DRYING OILS: For unfinished porous wood, rough surfaces, and occasional oiling the drying oils work best. When applied, the oily touch soon changes to a surface film described as "set-to-touch". The film is sticky, and if broken will transfer an oil residue to your finger. During film formation oxygen is rapidly absorbed by the surface of the oil, up to 10% by weight. After the set-to-touch point is reached, oxygen uptake is reduced by the polymerized surface. Eventually the film becomes hard and smooth. It helps repel bulk water but allows water vapor to slowly pass through. The oxidation process induces a complex polymerization process creating a three dimensional network that entraps smaller molecules, a gel.

## Table IV: Nominal Fatty Acid Composition Recorder Oils [9]

| Acid | Coconut | Olive | Peanut | Almond | Corn | Tung | Linseed |
|---|---|---|---|---|---|---|---|
| Lauric | 47 | | | | | | |
| Myristic | 18 | | | | | | |
| Palmitic | 9 | 9 | 11 | 5 | 10 | 3 | 6 |

| Stearic | 3 | 3 | 3 |  | 2 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| Oleic | 7 | 80 | 63 | 77 | 26 | 11 | 23 |
| Linoleic | 2 | 6 | 20 | 17 | 59 | 14 | 16 |
| Linolenic |  |  |  |  |  |  | 52 |
| Eleosteric |  |  |  |  |  | 70 |  |
| Iodine # | 9 | 85 | 91 | 100 | 120 | 167 | 190 |
|  | non-drying | | | semi-drying | | drying | |

What characterizes a drying oil? The ratio of the rate of oxidation of Oleic, Linoleic, and Linolenic Acids is 1:10:25. It is easier to polymerize carbon chains with two nearby C=C bonds (linoleic) than it is with just one double bond (oleic). Three such bonds in close proximity make it even better (linolenic). The presence of the three double bonds also promotes the 3-dimensional gel cross-linking, as does high GU3 content.

SEMI- and NON-DRYING OILS: These oils coat the wood surface, also preventing penetration by liquid water and reducing water vapor transport. The oils have a low vapor pressure and do not evaporate easily. However, periodic renewal is necessary. These may be of vegetable origin, a low viscosity mineral oil, or even a citrus oil.

# WHAT, WHICH, AND WHEN

WHAT KIND, WHEN? Experience suggests it is best not to randomly mix the two oiling approaches. Wax impregnated woods are already protected and occasional application of non-drying oils might help. Unfinished, rough bores will benefit from application of drying oils every 3-4 months for the first year, and then semi- or non-drying oils thereafter. Fine grain bores are possibly serviced best by semi- or non-drying oils from the outset. Always remove excess oil.

WHICH? But which oil to choose? Tung Oil, which has "conjugated" double bonds (C=C-C=C-C=C) drys very quickly, but may leave a frosted surface if you are not careful. Addition of iron ion or lead ion driers can help reduce this. The average player will use linseed oil. This should be the "raw" linseed oil. The nomenclature in the area is arcane and confusing. Raw linseed oil has actually been processed to remove undesirable materials. "Boiled" linseed oil has cobalt and manganese driers added to make the polymerization process faster. Its films can set up in hours, rather than days. Older boiled linseed oils had lead salts as the accelerator, but these have been abandoned because of toxicity. Unfortunately, cobalt driers can lead to frosting, since

"top drying" of the film is promoted. This leads to undesirable volume changes in the maturing film that may lead to cracking. Use raw linseed oil.

With semi- and non-drying oils, rancidity must be considered. This implies degradation of the oil to produce offensive or unusual odors. And this often makes the literature confusing. The reports are not necessarily wrong, but oils from different geographic sources, growing conditions, and processing steps respond differently. And rancidity can come from several sources. For example, liquid coconut oil would appear to be a perfect oil, since its low Iodine Number suggests stability. However, under certain conditions, hydrolysis of the esters back to free acids with unusual odors occurs.

Olive oil is a very promising candidate. Pure Triolein is rather resistant to oxidation, but Linoleic Acid appears to catalyze oxidative rancidity. Fortunately, high grade virgin olive oil has natural anti-oxidants present. These prevent the formation of oxidized Oleic Acid products that have unpleasant odors. Unfortunately, this same olive oil may also contain chlorophyll, trace metal ions, or other materials that serve as pro-oxidants, by activating oxygen in the presence of light. Which side wins?

IS AN OIL "THE" OIL?: To make life more complicated, plant growers and nature are altering the genetic make-up of many of the oil producing plants. Peanut Oil is in a transient state of natural genetic modification. Rape Seed Oil is an example where man has intervened. Many of the normal plant species produce an oil with high Erucic Acid content. Animals cannot use glycerides from this acid efficiently. Hybridizing and genetically altering the Rape Seed plant has produced Canbra and Canola Rape Seed Oil with low Erucic Acid and high Oleic Acid content. Is the oil you can get today the same as the oil in an old report or recommendation?

These problems can be avoided by using a commercial mineral oil bore protector that lacks the ester functions and double bonds which give vegetable oils their reactivity, potential rancidity, and tendency to revert back to odors typical of the unrefined oil.

# AN INFORMATIVE (?) SURVEY

Waldemar Meckes, of W. G. Smith Inc., an oil expert and music lover who provided technical input to this article, asked professional woodwind musicians with the Cleveland Symphony and Institute of Music what bore oil they preferred. Each had a different, strong opinion about what was "the good oil".

At the recent BEMF '95 the author took a survey of the woodwind makers present concerning their preferred bore oiling practice. This informative survey of six artisans revealed the following six different specific suggestions: (1) mineral oil, (2) olive, peanut, or corn oil with Vitamin E added for stability, (3) linseed oil, (4) linseed oil plus almond oil [2:1 or 1:1], (5) almond oil, and (6) boiled linseed oil. A Woodwind Quarterly E-Mail survey revealed that with some instrument makers another alternative found favor: (7) don't oil!

Despite this panorama of suggestions, there did seem to be general agreement that: (a) Drying oils often present considerable problems to instruments with pads and keys and bores when too generously used by owners. Excessive oiling without swabbing out before skin formation has led to instruments being returned for repair. A wooden dowel has often been needed to scrape out the hardened residues! (b) It is better to suggest an oil that owners commonly have around the house, since it encourages regular oiling practices. These suggest that an important variable is how players employ whatever oil they do choose.

When experts disagree, what does a player do? Decide yourself.

# COMMERCIAL PRODUCTS OR "DIY"

DO IT YOURSELF: Does that mean you have to purchase commercial bore-oils? Moeck Recorder Oil can be analyzed using C13 nuclear magnetic resonance (NMR) which clearly shows each type of carbon atom and allows you to count them. The Moeck Recorder Oil is a semi-drying triglyceride oil (Table 4), perhaps with some antioxidant added.

It is possible to add your own antioxidants to a semi- or non-drying high grade food oil you have selected. Find a friend who is taking Vitamin E capsules. Each contains 200 I.U. (200 mg) of alpha-tocopherol, enough to treat a pint of oil. Slit just one capsule open and stir the contents (not the capsule wall) into the oil. Then, keep the material in an amber bottle to prevent air and photo-oxidation. Moeck very carefully uses a brown PVC plastic bottle for their product to avoid light and oxygen diffusion through the container. Polyethylene containers are not safe, since they pass both light and oxygen.

What if you wanted to avoid vegetable oils? Yamaha Bore Oil, analyzed by NMR, is a low viscosity mineral oil (Figure 4). It is a mixture of long carbon chains with hydrogens attached at all points (hydrocarbons). A good grade of Baby Oil clearly labelled as Mineral Oil will suffice. The mineral oil used internally is more viscous.

For the connoisseur, Aerospace Lubricants, Inc. makes a series of lubricants of differing viscosities. NMR and infra-red analysis indicates that these are linear hydrocarbons. They are extremely pure, narrow molecular weight spread materials. This is of importance under high rates of shear, where traditional lubricants may exhibit thixotropic behavior and show a marked decrease in viscosity. They range (low to high viscosity) from Alisyn Valve and Slide Key, to Finger Board, and Bore Oil.

If you prefer pleasant odors, both lemon and (sweet) orange oils have been used. These are both about 90% limonene (Figure 1). This is a simple cyclic unsaturated hydrocarbon biosynthesized from two isoprene units in the plant. Your body uses isoprene units to build cholesterol and the sex hormones. The citrus oils differ in the small amounts of oxygenated materials present. The instability of these can rapidly

lead to a terebinthinate odor. Addition of about 5-10% of a non-drying vegetable oil will help prevent this because of their natural stabilizers, like tocopherol; or add your own Vit. E.

IS THERE A MAGIC OIL? Is there one magic formula that is better than anything else? Perhaps, but it is difficult to find controlled experimental evidence to substantiate such a claim. Players and makers have their own preferences based upon experience. All help smooth roughened, checked bores and provide a water barrier.

SWABBING: A convenient way to oil recorders takes advantage of the availability of gun cleaning patches of various sizes. They are tough, lint free, thin enough to discourage "soaking" the surface, and cheap enough to dispose after use. That is advisable for non-drying oils to prevent dirt accumulation, and necessary with drying oils because of the danger of heat build-up in improperly stored rags.

DECONGESTANT SOLUTION: It is also easy to make the decongestant solution sold by many vendors. It is a dilute solution of sodium lauryl sulfate. Reducing Lauric Acid produces Lauryl Alcohol. This forms an "inorganic" ester with sulfuric acid. Its sodium salt is a detergent. It is sold by DuPont under the trade-name Duponol, and you may be able to get small quantities as a sample. Since you only need 1 gm dissolved in 8 ounces of distilled water, a sample will take care of your consort's needs for years. Chemistry can be useful!

# WOOD, OIL AND WATER DO MIX

Wood is magic, and the various species all cast a different spell. With the above background it is now appropriate to examine the physical properties of some typical recorder woods (3,4). Table V shows why the dimensional instabilities of maple have been addressed by many vendors via wax impregnation. Pearwood is borderline, and some pear instruments are impregnated while others are not. The characteristics of Rosewood (Palisander) depend upon the species, so a "rose is not a rose, necessarily". Lignum vitae is included as a final reference point since the best literature source lacks data on the more popular heavily ligninized woods, such as grenadilla.

## Table V: Recorder Wood Properties [7]

| WOOD | FSP | DENSITY (gm/cc) oven-dry | DENSITY (gm/cc) ~50% RH (EMC) | tangential/radial |
|---|---|---|---|---|
| MAPLE | ~32% | 0.687 | 0.721 (12%) | 2.6 (3.9%) |
| PEAR | 28% | 0.665 | 0.695 ( 9%) | 2.5 (2.9%) |
| ROSEWOOD | 24% | 0.836 | 0.863 (10%) | 2.0 (2.6%) |

| L. VITAE | 20% | 1.215 | 1.301 (12%) | 1.5 (1.5%) |
|:---:|:---:|:---:|:---:|:---:|
| FSP=fiber sat. point, RH=rel. humidity, EMC=equil. moisture content |||||

BREAKING A RECORDER IN: The hysteresis shown in [Figure 5] for sorption/desorption of water indicates that the loss of water is slower than its uptake. As a new, or long unused recorder, is first played the water content in the wood increases. As it stands between sessions it loses water more slowly. If the playing sessions are spaced closely together the water content of the wood, on average, will slowly increase. That is why experts recommend a breaking in protocol of increasingly longer playing sessions spread over time. It allows the wood to adapt to the increasing water content, and avoids stress fractures. Water and water vapor barriers on the wood surface reduce the rates of sorption and desorption; but the build-up pattern remains. Softer woods pick up and lose the water more quickly. Thus, the wood, the oil, and the playing pattern interact in a complex way and each instrument/player combination is unique. Possibly this is why some players might prefer drying oils, others non-drying, and yet others mixtures of non- and semi-drying oils (2).

As the wood surface of the bore interior "weathers" due to repeated moisture sorption/desorption cycles it may grow rougher. Oils can reduce this type of roughness. Drying oils form a hard film, but users should recognize that it will follow the contours of the roughened surface to a great extent. Each treatment also reduces the bore diameter slightly. Semi- and non-drying oils reduce the roughness, but may locally deform due to flow/pressure. A dilemma! (But not a big one, since both will work to improve sound somewhat.)

# ALTERNATIVE IMPREGNATION STRATEGIES

Just when plastic recorders are making their products look like wood, there is interest in making wood/plastic composites. Sometimes the goal is cost, sometimes fashion, and sometimes it is the elusive immortal woodwind. The technique is not new. Amish farmers have impregnated maple wheel bearings for over a century with lard. The WWII Maytag ringer-washers used mineral wax impregnated maple. Most techniques today are aimed at the floor panel, knife handle, and designer pen body market. But woodwind makers may possibly realize shape stabilization, and water repellency. Only time will tell.

METHYL METHACRYLATE (MMA): Wood Stabilizing Specialists Inc. (Cedar Falls, IA), has produced a billet of cherry impregnated with polymerized methyl methacrylate. Scott Hirsch, a flute maker in Coleville, WA, has made instruments from the material. Wildwoods (Monclova, OH) has produced similar impregnated billets of maple and black-dyed birch for Powell Flutes (Waltham, MA). Tim Bernett of Powell Flute made an impregnated maple alto in the mid '80s. Bamboo has been treated for use in making Japanese flutes; Yamaha has worked with impregnated rosewood for clarinets. Roger

Rowell of the USDA Forest Product Laboratory has explored impregnating maple wood with MMA for recorder manufacture.

The pure polymer is the well known Lucite or Plexiglass. Such impregnated woods do pose challenges to the craftsman because of brittleness, the need to use low turning speeds and coolant because of the low melting point of the plastic, and a tendency to clog sanding materials. Finished instruments play well and seem to have good dimensional stability. Some results are reported in Woodwind Quarterly, #2, August 1993. Such impregnations for many commercial purposes began in the 1960's. Ken Caines of WSSI reports load factors of about 50% are normal with common woods. Exotics, such as ebony, accept much less polymer (<10%) and are prone to bleed displaced "wood oils" for many months after treatment. This can be removed by wiping with acetone. Odors from the monomer are often prominent, and are due to excessive water in the impregnated wood (>10%), or improper curing. Drying (40 C) can remove such odors.

OTHER ACRYLATES: Many other efforts in wood impregnation exist. Daniel Deitch, a Baroque woodwind maker in San Francisco, has utilized cyanoacrylate impregnation for wood stabilization. MMA has the structure $H_2C=C(CH_3)COOCH_3$, while a typical cyanoacrylate has a structure $H_2C=C(CN)COOCH_3$. They differ by the substitution of a -CN group for a -CH3. This substitution makes it easier for the material to polymerize into long carbon chains, much like a zipper closes. The cyanoacrylates are used as rapid setting "glues". Deitch swabs out the finished bores with the cyanoacrylates, lets the material polymerize, and then finishes the interior surface. Deitch also reports that he has been pleased with a technique for finishing the exterior learned from Rod Cameron, a flutemaker from Mendocino, CA. A few drops of the cyanoacrylate are added to linseed oil, and the mixture applied as a hardening finish to the exterior. The cyanoacrylate accelerates the hardening of the mixture. Do not be concerned about the presence of the -CN group in the molecule. It is an organic nitrile or cyanide, not an inorganic cyanide. The latter are toxic, but the organic -CN is not. Some artisans find the cyanoacrylic bore finish beads water excessively.

OTHER FORMS OF POLYMERIZATION: The polymerization of both the cyanoacrylates and methacrylates depend upon chemical induced free radical formation to begin the polymerization. A free radical is a carbon with only three groups around it, and one lone electron. This poses some interesting problems in getting complete penetration into all the void space of the porous wood. The cyanoacrylates react with air and polymerize quite rapidly, providing good near surface penetration. Free radical initiators added to the methacrylates allow somewhat deeper penetration before blockage occurs. Firms such as Applied Radiant Energy (Lynchburg, VA) have developed an alternate strategy for achieving an even more complete penetration. The methyl methacrylate is forced into the wood by first applying a vacuum, then flooding the chamber with the liquid acrylate, and finally bringing the head space up to atmospheric pressure. They can achieve loadings of 10-100% in this way, filling a great deal of the void space. The polymerization of the material is then induced by

exposure to gamma radiation. This ionizing radiation penetrates the wood completely and evenly, allowing uniform polymer hardening throughout. The degree of polymerization can be carefully controlled by the amount of irradiation. This permits careful adjustment of the working properties of the resulting composite. Don't be concerned about the radiation initiator. Gamma radiation is just like an X-Ray beam. Once the beam is turned off, its gone. The route has been used to sterilize food for long term preservation. Gamma radiation DOES NOT consist of radioactive particles which have long half-lives, and which slowly emit hazardous particles and radiation.

Billets up to 8"x8" have been treated. Ash, oak, pine and poplar are common. More exotic woods include cherry, ebony, and jatoba (Brazilian cherry). Best results come from using the heart wood. Robert Turner, a Charlottesville, VA recorder maker, is experimenting with some of the materials.

PHYSICAL AND PSYCHEDELIC PROPERTIES: It should be noted that these treatments do not prevent the penetration of water vapor into the wood. It is merely slowed down, as described earlier. The composites have increased tensile strength and lower impact resistance due to their brittleness. They are harder. Little objective acoustic data on composite woodwinds are available, although strong opinions exist.

Most composite manufacturers are focusing on dyed impregnated woods, often with multicolored, swirling patterns for designer products. Imagine a recorder playing cool jazz or hot Blues with a color scheme to match! Avant-garde players could have complete sets. On the other hand, although the Pacific Rim produces the greater part of ABS plastic instruments, most players there seem to prefer buying perfect, natural material woodwinds. But good grenadilla and rosewood are becoming scarce. Interesting marketing problems.

Wood, composite or plastic? Some subjective panels claim they can tell the difference; others claim no distinction. A paradox.

# ACOUSTICS AND WOODWIND MATERIALS

Buffet has announced its Green-Line series of commercial clarinets. These are made from grenadilla wood powder, polycarbonate fibers, and a bonding polymer. But, will recorders made from such synthetic and impregnated woods sound the same? Wait and hear.

The recorder player sees and feels wonderful instruments made from different bulk woods and hears differences. The artisan sees and feels different bore surfaces and hole edges and hears differences. The acoustician sees and feels (in the mind) the boundary air layers of the played instrument and conceives possible differences. But they use different languages in expressing cause/effect. Leibniz, in discussing a metaphysical approach to language, suggested the need for a Universal Language. We must try top hear these different views. Most players feel they detect tonal differences

in what appear to be identical instruments made from different materials; but, are they really identical. Experimental and theoretical evaluations (10) suggest that the bore wall construction material does not noticeably influence the timbre of sound produced from a thick-wall cylindrical "wood"-wind.

A WOOD IS A WOOD IS A WOOD? Considering mechanical distortion, differing construction materials can affect sound quality in thin square or rectangular tubes (organ pipes), or where the material is essential to sound production (like string instruments), or in very thin wall wind instruments with very large side holes. Thick walled circular bore instruments are quite different. Compare the relative compliance associated with expansion of the bore under pressure, and the compression of the air in the tube. The ratio is about .001 for even thin walled cylinders. Direct sound radiation from wall vibration is insignificant. This is not surprising, since it would require local changes in the radius of the bore, coupled to air column vibrations. The walls are just too stiff. Such vibration levels are estimated to be some 60 dB below that of the air column. It is like hearing a cat purr next to a subway train.

Only a few percent of the energy of the air stream makes it way out of the tone holes as perceived sound (0.5-1%). Where does the rest go? Tube walls can influence vibrations of the contained air column because of viscous air and thermal losses across the air/wood boundary layer. This is where free movement of the air is affected by the proximity of the wall and viscous and thermal losses occur. Wall materials all have thermal conductivities much greater than air so this cannot be a differentiating factor. Surface roughness only becomes a factor when it develops to a scale relevant to the thickness of the boundary layer. The viscous and thermal boundary layers are frequency dependent, but range from about 0.1-0.05 mm (100-50 micron). Machining practices yield a surface roughness average of 10-1 micron. Wood grain and smoothness can affect the damping coefficient or drag, but in a filled, fine-finished and oiled bore such differences are small compared to those caused by the edges of chamfers, the blade, finger holes, key pads or even finger tips, which are sources of turbulence. These variables are determined by the working nature of the material, the skill of the artisan, and how much time can be afforded by player and maker.

CHEMICAL CHANGES: Sorbed water, or chemical modification of the wood material, can change the visco-elastic properties of the wood composite. Here, the word viscous refers to a material that absorbs sound energy and converts it to heat. Elastic refers to a material that can give back such energy, like stretching and releasing a rubber band. Wood is inbetween, and is called visco-elastic. Sorbed water makes it a little more viscous. Benders of wood "knew" this, since steaming wood (heat + water) allows you to form the complex shaped ribs of a violin. The water acts as a plasticizer, lowering the glass-transition temperature of the composite. This is the temperature where longer segments of associated molecules in the composite can begin to slip past one another, but basic form is retained (rubbery). The heat raised the rib material above this temperature. In the finished violin there is a major air resonance from the box, as well as a top-plate wood resonance. The latter can certainly be affected by wood

composition and treatment. In recorders the cylindrical bore is used below its glass-transition temperature and any affects are less than most musicians can detect.

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# REFERENCES, SUGGESTED READING, AND SOURCE BOOKS

1. "The Good Oil", T. Simmons, *The Recorder*. #17, 15, 1993.
2. "Grenadilla Wood and the Environment", L. Naylor, *Woodwind Quarterly*, #6, August 1994.

3. "Woods Used for Woodwind Instruments Since the 16th Century", M. Zadro, *Early Music* 3, #2 134; and 3, #3 249, 1975.
4. "Which Wood Should I Use?", P. Levine, *American Recorder*, May 1986, 60.
5. "The Moisture Excluding Effectiveness of Finishes on Wood Surfaces", W. Feist, J. Little, J. Wennesheimer, *USDA Forest Products Laboratory, Research Paper* FPL 462, 1985.
6. Wood Structure and Composition, edited by M. Lewis and I. Goldstein, Marcel Dekker, New York, 1991.
7. Physical and Related Properties of 145 Timbers, J. Rijsdijk and P. Laming, Kluwer Publishers, Dordrecht, 1994.
8. The Chemistry of Wood, B. Browning, R. Krieger, Huntington, NY, 1975.
9. Bailey's Industrial Oil and Fat Products, edited by D. Swern, Wiley-Interscience, New York, 1979. The Physics of Musical Instruments, N. Fletcher and T. Rossing, Springer-Verlag, New York, 1991.

# FIGURE CAPTIONS

## 1. Simplified Chemical Structures In Wood And Oils

a. Glucose
b. Lignin Precursors
c. A Carboxylic, or Fatty Acid
d. An Alcohol
e. An Ester
f. A Glyceryl Triester
g. Limonene

## 2. Microscopic View of the Cross-Section of a Typical Hardwood

V=Vessels, F=Fibers, R=radial parenchyma
Micrometer bar in lower right is 10 micrometer (micron)
(from Ref. 6 with permission)

## 3. Idealized Microfibril Cellulose Wall Construction

(from Ref. 6 with permission)

## 4. Space-Filling Models of

A. Triolein (Vegetable Oil)
B. Mineral Oil (typical chain)

## 5. Water/Wood Interactions

a. A Plot of Equilibrium Moisture Content (EMC) versus Relative Humidity (RH) for Brazilian Rosewood (Dalbergia nigra). The separation of sorption and desorption curves is common and is called hysteresis.

b. A Plot of Radial and Tangential Shrinkage and Swellage of D. nigra at various EMCs. (r=radial, tg=tangential) (from Ref. 7 with permission)

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