COURSE CODE:	*FRM 504*
COURSE TITLE:	Wood Processing and Pulping Proceed
NUMBER OF UNITS:	*2 Units*
COURSE DURATION:	*Two hours per week*

COURSE DETAILS:

Course Coordinator: Dr. Adedokun Margaret Olufunsho *B.Sc; M.Sc; PhD*
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Office Location:
Other Lecturers:

COURSE CONTENT:

Evaluation of quality of standing trees, felling and logging techniques, wood conservation and processing, wood seasoning and preservation; machining, gluing preservation and finishing ; charcoal production, chemical processing of pulp and paper.

COURSE REQUIREMENTS:

This is a compulsory course for all Forestry Option students in the University. In view

of this, students are expected to participate in all the course activities and have

minimum of 75% attendance to be able to write the final examination.

READING LIST:

LECTURE NOTES

WOOD PROCESSING AND PULPING PROCESS
LOGGING

Logging industry is a fast-growing business regardless of the many risks involved.

The procedures used to harvest wood are tree-length, full-length and cut-to-length logging. Choosing one over the other is simply a matter of choice since there are advantages and disadvantages with each of the various methods. The removal of too many trees from the forest can cause environmental hazards as well as the possible loss of our wildlife. Regardless, this industry is a business that provides the consumer with many needed products. It is, therefore, important to know the impact of logging methods on the forest environment and make wise decisions regarding our natural. Even though it is very risky, it is still is considered as a profitable market today. It is the primary source for many industries, including the thriving paper industry, lumber and fodder for animal feed. It is also used for other purposes such as the construction of buildings, wood fuel and many other forestry-related products.

Loggers generally fell trees with gasoline-powered chain saws. However, the use of mechanized felling equipment has increased on harvesting operations. Mechanical fellers, consisting of large steel blades mounted on a vehicle, sever the tree at the stump much as a pair of scissors cuts paper. Whether using chain saws or mechanical fellers, responsible loggers plan their cuts carefully to avoid smashing and scarring trees that are to be left standing. Once a tree is down, the logger removes its limbs to make it easier to transport the stem, or trunk.

After the trees are felled and trimmed, the logs are skidded to landings where they can be put on trucks and hauled to the mill. Skidding involves raising one end of the log and dragging it across the ground. Early skidding relied on teams of horses, mules, or oxen. The term *skid row,* used for a district of cheap saloons and rooming houses, takes its name from early loggers, or skidders, who frivolously spent their low wages in cheap areas of nearby towns.

Animal skidding still occurs in some developing countries and on small woodlots, but wheeled or tracked vehicles have largely replaced animals on commercial operations in North America. Cable skidders are vehicles that pull logs behind them with steel ropes placed, or choked, around each log. A grapple skidder saves time by scooping up a bunch, or hitch, of logs by means of hydraulic arms mounted on its back.

In muddy conditions, wheeled, trucklike vehicles called forwarders may carry logs to landings without dragging them. On difficult terrain and in remote areas, other systems replace wheeled vehicles. For example, on steep slopes in the Pacific Northwest, logs are skidded to a landing by a system of cables and pulleys mounted onto standing trees and driven by a machine called a cable yarder. In remote areas, even hot-air balloons and helicopters may be used to transport logs to landings.

After the trees reach a landing, loggers cut, or buck, them into sawlogs—logs that are large enough to be sawed into lumber. At the landing, the logs are scaled and graded. Scaling estimates the number of board feet a sawlog contains. Grading describes the quality of the log, taking into account visible defects such as branch scars or rot. An experienced logger bucks trees in a manner that maximizes the scale and grade. The sawlogs are then loaded onto trucks by hydraulic booms and transported to a sawmill.

Technological advances have increased the speed and efficiency of harvesting through mechanization and reliable equipment that can perform under extreme conditions. Still, logging ranks as one of the most hazardous occupations, and many safety

precautions are necessary to avoid injury. Vehicles used as skidders are equipped with rollover cages and seat belts to protect the operator should the equipment turn over or a tree fall on it. Chain saws have safety features that allow quick shutoff in an emergency. Well-equipped loggers wear safety equipment, such as hard hats, ear protection, face screens, and steel-toed boots. Clothing made from the same material used in bullet-proof vests protects them from chain-saw cuts.

Logging is the felling, skidding, on-site processing, and loading of trees or logs onto trucks. In forestry, the term logging is sometimes used in a narrow sense concerning the logistics of moving wood from the stump to somewhere outside the forest, usually a sawmill or a lumber yard. However, in common usage, the term may be used to indicate a range of forestry or Silviculture activities. For example the practice of the removal of valuable trees from the forest has been called **Selective logging,** sometimes confused with selection cut.

Illegal logging refers to what in forestry might be called timber theft. In common usage what is sometimes called clear-cut logging is not necessarily considered a type of logging but a harvest or Silviculture method and is simply called clear-cutting or block cutting. In the forest products industry logging companies may be referred to as logging contractors.

Logging usually refers to above-ground forestry logging. Submerged forests exist on land that has been flooded by damming to create reservoirs. Such trees are logged using underwater logging or by the lowering of the reservoirs in question.

Clear-cutting

Clear-cutting, or clear-felling, is a harvest method that removes essentially all the standing trees in a selected area. Depending on management objectives, a clear-cut may or may not have reserve trees left to attain goals other than regeneration, including wildlife habitat management, mitigation of potential erosion or water quality concerns. Silviculture objectives for clear-cutting, (for example, healthy regeneration of new trees on the site) and a focus on forestry distinguish it from deforestation.

METHODS OF LOGGING

There are several procedures that have been utilized for the purpose of harvesting wood, including tree-length, full-length and cut-to-length logging.

- **Tree-length -** Using this type of technique, trees are felled manually or mechanically using a chainsaw to cut them. After being felled, the removal of the branches and crowns will follow at the same location before the logs are transported to sawmill or lumberyards. Forestry trucks, such as feller bunchers

or harvesters, often play an important role in de-limbing and bucking the wood. When this type of harvesting method is used, the entire tree is transported to the production plant. At the lumber yard, applicable parts are separated for other functional purposes. If the trunks are too long, they will be cut into three segments at the felling site for long distance transport.

- **Full-length Logging -** This technique involves cutting down the trees then transporting them to the roadside with branches and crowns intact. The transportation of the wood to the roadside is usually done by a grapple skidder. Full trees are then hauled to sawmills and/or lumberyards for further processing. Sometimes de-limbing and de-barking are done at the roadside before they are transported to the mills.
- **Cut-to-Length Logging -** This technique is otherwise known as short-wood. Trees are felled, bucked and de-limbed to several lengths. The trunks are measured and cut in the forest and are then piled up into the trucks which will transport them according to their functional use. They are cut into saw logs, lathe logs and pulpwood before they are ultimately transported to the processing plants. Forestry trucks such as harvesters and forwarders typically handle this method. Harvesters fell and de-limb the trunks while forwarders do the hauling to the roadside.

WOOD CONSERVATION

As an organic material, wood normally decays under combined biological and chemical degradation when buried in earth; it may, however, survive prolonged exposure to extreme dryness or wetness. In shipwreck sites, the wooden components of the hull and small artifacts (object made by man e.g. tool) of wood often survive in good condition, albeit thoroughly waterlogged. The mechanisms of the organic deterioration of wood are succinctly (brief to point) presented in Florian (1987).

Successful conservation of wooden artifacts is dependent upon knowledge of wood structure and types. Trees are divided into two broad categories: hardwoods and softwoods. Hardwoods are classified as angiosperms, which refers to broadleaf trees which are usually deciduous. Angiosperms are referred to as 'porous' woods because they have vessel pores. Oak and birch are typical examples of hardwoods. Softwoods, or gymnosperms, are needle-bearing trees or conifers. Gymnosperms are considered 'non-porous' because they lack vessel pores. Pines are typical examples of softwood. It is critical that conservators know the category of wood that they are treating; in many instances, it is equally important that a wooden object is identified to the species level in order to successfully conserve the waterlogged wood.

Through the loss of moisture, freshly cut, sound wood will generally experience a radial shrinkage of ca. 3-6 percent, a tangential shrinkage of 5-10 percent, and a longitudinal shrinkage of - 0.5 percent. Fresh oak shrinks 4 percent radially and 8 percent tangentially when air dried after cutting, while waterlogged oak can shrink 12 percent radially and ca. 24 percent tangentially. Proper conservation treatments can control the amount of shrinkage experienced by waterlogged wood during drying. In practice, a particular conservation technique is often selected because it is known that the treated wood will shrink a desired amount (Patton 1988:43).

The manner in which a plank of wood was originally sawn from a log will have an effect on how the plank, or an object manufactured from the plank, will shrink after undergoing any conservation treatment. Flat- or plain-sawn lumber has similar proportions of radial and tangential surfaces with arched grain patterns; these features predispose the wood to warping during drying. In order for lumber to exhibit true tangential and radial planes, it must be rift- or flitch-sawn. Because rift sawing is complex and inefficient, a modified pattern called quarter-sawing was developed. Quarter-sawing results in lumber with predominantly radial surfaces on the faces, a feature which makes the wood less likely to warp during the drying process. In some cases, the manner in which planks were extracted from a log will result in the cracking and warping of a treated wooden object, regardless of the conservation technique used.

In most environments the primary factors for the degradation of wood include:

 (1) Physical action (changes in temperature, fluctuations in relative humidity, etc.),

 (2) Insect attack, and

(3) Fungal decay.

Fungal decay can be eliminated as long as the wood is kept in an environment with a relative humidity of less than 65 percent. In anaerobic waterlogged environments, however, wood undergoes profound chemical changes and alterations that result in a significant loss of strength while retaining overall shape and form.

WATERLOGGED WOOD

In all wood, after long periods in wet soil, peat bogs, and marine sites, bacterial action causes a degradation of cell wall components. In general, water-soluble substances, such as starch and sugar, are the first to be leached from waterlogged wood, along with mineral salts, colouring agents, tanning matters, and other bonding materials. In time, through hydrolysis, cellulose in the cell walls disintegrates, leaving only a lignin network to support the wood. Even the lignin will break down over a long period of time. As a result of the disintegration of cellulose and lignin, spaces between the cells and molecules increase, and the wood becomes more porous and permeable to water. All of the deteriorated elements of the wood, including all cell cavities and intermolecular spaces, are filled with water. The remaining lignin structure of wood cells and the absorbed water preserves the shape of the wood. The loss of the finer cellulose tissue does not cause much alteration in the gross volume of wood, but the porosity is increased, and the wood absorbs water like a sponge. A waterlogged wooden object will retain its shape as long as it is kept wet. If the wood is exposed to air, the excess water evaporates, and the resulting surface tension forces of the evaporating water cause the weakened cell walls to collapse, creating considerable shrinkage and distortion. The amount of shrinkage is dependent upon the degree of disintegration and the amount of water present. The amount of water in waterlogged wood is determined by the following formula:

% water = <u>weight of wet wood - weight of oven-dried wood</u>   x 100

Weight of oven-dried wood

Wood containing more than 200 percent water is considered to be degraded; it is not uncommon to find wood that contains more than 500 percent or even 1000 percent water. Waterlogged wood is often classed according to the amount of water is contains.

Class I; over 400% water

Class I; over 185-400% water

Class I; less than 185% water

The Class III hardwoods are the most difficult to conserve.

WATERLOGGED WOOD CONSERVATION METHOD
The conservation of waterlogged wood is a two-fold process that involves (1) the incorporation of a material into the wood that will consolidate and confer mechanical strength to the wood while the water is being removed (e.g., PEG- or sugar-bulking treatments), and (2) the removal of the excess water by a method which will prevent any shrinkage or distortion of the wood (e.g., solvent- or freeze-drying). The most common techniques for treating waterlogged wood are discussed below. In any treatment involving wood recovered from a salt water environment, it is necessary that the bulk of the soluble salts be removed first. If the salts are not removed prior to treatment, they will cause a white bloom on the conserved wood and may adversely affect any remaining iron components in the wood and even other material in the same room or environment in which the treated wood is stored.

POLYETHYLENE GLYCOL (PEG) METHOD

Polyethylene glycol (PEG) is a synthetic material that has the generalized formula H_2OCH (CH_2OH_2) CH_2OH. The low molecular weight PEGs (300 - 600) are liquids, the intermediate members (1000-1500) are semi-liquids or have the consistency of Vaseline, and the higher molecular weight PEGs (3250-6000) are wax-like materials. The various PEGs are now designated by their average molecular weight. What was once called PEG 1500 is now called 540 Blend (it is equal parts PEG 300 and PEG 1500), PEG 1540 is now called PEG 1500, and PEG 4000 is now called PEG 3250. Although the PEGs have some of the physical properties of waxes, they are distinguished from true waxes by the fact that they are freely soluble in alcohol (ethanol, methanol, isopropanol), as well as water. PEG 4000, which has a melting point of 53-55°C, was once the most commonly used PEG because it is the least hygroscopic; its large molecules, however, prevent it from penetrating dense wood. Now PEG 1500 and the 540 Blend are more commonly used.

The PEG conservation process was the first reliable method for treating waterlogged wood that was also relatively simple to perform. This method removes excess water while simultaneously bulking the wood. After preliminary cleaning to remove all surface dirt, the waterlogged object is placed in a ventilated vat containing a solution

of PEG and solvent (water or alcohol). The vat temperature is gradually increased until, after a period of days or weeks, it has reached 60°C. During this time, the PEG percentage of the solution increases as additional increments of PEG are added while the solvent evaporates. During the conservation process, the wax slowly permeates the wood, displacing the water. At the end of the operation, the wooden object is covered with 70-100 percent molten PEG, depending upon the nature of the wood. The object is then removed, the excess wax wiped off, and the object is allowed to cool. After cooling, any excess wax on the surface of the object is removed with a hot-air gun or with hot water.

In most instances, the wood to be treated is placed in a vat of water containing a small increment of PEG (usually 1-5 percent. The vat is kept at a constant temperature of approximately 52°C. If the solution is not heated, it will solidify when the concentration of PEG in the solution reaches 20-30 percent. Over a period of months (or even years), the PEG percentage of the solution is increased in small increments until a minimum concentration of 70 percent is reached. If this minimum concentration is reached, the wood will remain stable. In some instances, if the percentage of PEG in solution exceeds 70 percent, water may be drawn out of the well-preserved heartwood without being replaced by PEG; this will cause the wood to collapse. The size of the PEG increments is dependent upon the condition, size, and specie of the wood being treated.

An additional method of treating waterlogged wood that is only appropriate for small objects and thus is seldom used in practice involves using a container in which the PEG concentration is increased solely by the evaporation of the solvent. When performing this procedure, it is important that the dimensions of the container be such that the amount of PEG in solution will be more than enough to cover the object at the end of the process.

It has already been noted that PEG is soluble in both water and various alcohols. Water is generally used in PEG solutions for large objects, as it is considerably cheaper than an equal volume of alcohol. When using PEG in water it is necessary to add a fungicide, such as Dowicide 1 (ortho phenylphenol), at .05 to .1 percent of the weight of the PEG used. During the conservation of the 17th-century warship *Wasa,* a fungicide consisting of seven parts boric acid and three parts sodium borate (1 percent of weight of PEG) was used (Barkman 1975:82). For smaller objects, it is often more convenient to use alcohol in the PEG solution. This considerably reduces the overall treatment time, and the finished product is lighter in both weight and color. To further reduce treatment time, the additional step of dehydrating the wood in at least three baths of ethanol before placing it in the first PEG/alcohol solution is recommended. However, it is not critical that all the water be removed from the wood prior to treatment, as PEG is soluble in both water and alcohol. Alcohol treatments save time but are less cost-effective and always pose the risks inherent in heating alcohol. Since all alcohols are fungicidal, no fungicide is required when using alcohol in PEG solutions. Before a decision is made to conserve wood with PEG, it is important to consider the fact that PEG is corrosive to all metals, especially iron. For this reason, PEG treatments should not be used on wood that will be in contact with any metal (e.g., gun stocks).

Treating small waterlogged wood artifacts with PEG in the laboratory is a simple and straightforward process. Small vats (stainless steel or glass) are readily available and they can be placed in a thermostatically controlled oven to maintain the correct temperature; furthermore, only a small amount of PEG is required. In contrast, when large pieces of wood are treated, there is a considerable investment in PEG (sometimes measured in the tons). A substantial vat must also be constructed with the capability to heat and circulate the solution. Laboratories that intend to conserve large pieces of waterlogged wood must be prepared to make major investments in both equipment and chemicals. Of all of the wood conservation methods discussed in this section, any of the various PEG treatments with water is the most utilized because of its reliability and low cost.

SUCROSE METHOD

The sucrose (sugar) method of conserving waterlogged wood was developed as an alternative to more expensive methods (Parrent 1983, 1985). The procedure is identical to that described for PEG, except that sucrose is used. Wood to be conserved should be carefully cleaned by rinsing in baths of fresh water to remove all ingrained dirt and to remove the bulk of any soluble salts that are present. Once the wood is cleaned, the following procedure is recommended:

1. Prepare a solution with a sufficiently low sucrose (1-5 percent) concentration to prevent the dehydration of well-preserved wood or regions of sound wood within an otherwise deteriorated piece. This necessitates the thorough examination of the wood to be treated in order to determine its state of preservation before treatment begins. With highly degraded wood, it is possible to start with a higher concentration of sucrose; however, if in doubt, start with a 1 percent weight/volume solution. Commence a program of weighing a representative sample of wood in treatment to determine when the wood has reached equilibrium with its solution. Once saturation with a given x percent solution is achieved, increase the sugar concentration by 1-10 percent.
2. Select an antimicrobial agent, such as Dowicide A, and add it to the first mixture of sucrose and water when it is initially prepared. This allows for the complete penetration and protection of the wood by the antimicrobial agent.
3. The incremental percentages of increase can be higher and more closely spaced if the wood is highly degraded. It is best to start with a low percentage increase, e.g., 1-5 percent, until a concentration of 50 percent is reached. Then the solution can be increased in 10-percent increments. Again, if in doubt, the same incremental increases used at the start of the treatment can be used throughout the treatment. The treatment continues until sucrose concentration reaches 70 percent, and the wood has equalized at this concentration.
4. If necessary, select an additive that will discourage insect and rodent attacks on the treated wood. There are many pesticides that will work, and selection depends on local availability. For thorough protection of wood, add the insecticide to the initial solution. If the wood is kept in a museum environment, problems with insects and rodents should be minimal and probably would be controlled by alternative means.
5. When the wood has reached equilibrium with the highest solution desired, air dries it slowly under conditions of controlled high humidity. Humidity can be lowered slowly as the wood dries. Submitting the wood too quickly to

conditions of low humidity will damage it. Slow, controlled drying and adjustment to the prevailing atmospheric conditions, as is the case in all the wood treatments described here, will maximize the success of the overall treatment.

6. Store the wood under conditions of less than 70 percent humidity if possible. The wood should not be subjected to humidity over 80 percent because of the possibility of condensation forming on the wood; this could leach out the sugar.

If sugar is selected as the treating medium, refined white sugar (pure sucrose) should be used. The brown- coloured, coarse-grained unrefined sugar (Type A sugar) should be avoided, as it is much more hygroscopic than the white. Each time the relative humidity rises, the surfaces of wood treated in unrefined sugar will become wet. This hygroscopicity is analogous to that encountered when using the medium molecular weight PEGs. The Type A sugar-treated wood, however, remains dimensionally stable. Maintaining artifacts treated by sugar in a controlled atmosphere will ensure the continued success of the conservation procedure. Artifacts conserved with this method require no more or no less care than those treated with other preservatives. This method constitutes an acceptable means of conserving waterlogged wood and is the least expensive of the methods currently available. Sucrose-treated wood, however, has a dull muted colour, and small hair line cracks will frequently form on the surfaces. The treatment will produce dimensionally stable wood and is a viable alternative when the overall cost is a major consideration. The required equipment is the same as discussed above for PEG treatments.

ACETONE-ROSIN METHOD

The treatment consists of replacing the water in wood with natural rosin, in this case, pine rosin (also called colophony). This treatment was developed to conserve well-preserved hardwoods that cannot be penetrated by the higher molecular weight PEGs (McKerrel and Varanyi 1972; Bryce et al. 1975).

The following procedure is recommended:

1. Wash object thoroughly, removing all dirt. It is usually necessary to store the wood in several rinses of fresh water.
2. Dehydrate the wood completely in three successive baths of acetone. Objects 5-10 cm thick require about four days in each acetone bath, while objects less than 5 cm thick require about two days in each acetone bath. It is important that all the water be removed, as water is incompatible with rosin.
3. Place the wood in a sealed container containing a saturated solution of rosin dissolved in acetone heated to 52°C. Only lump, technical-grade rosin should be used. Do not use powdered rosin, as it is difficult to handle and usually has a powdered substance added to it to keep it from sealing together.

   In a sealed container at a thermostatically controlled 52°C, a saturated solution of rosin in acetone is 67 percent rosin. To ensure a saturated solution, an excess amount of rosin should be placed in the container. This results in a thick, viscous layer of rosin that will settle to the bottom of the container. The object being treated should be suspended or supported above this undissolved

rosin. Objects 5-10 cm thick should be left in the solution for four weeks, while objects less than 5 cm thick should be left in the solution for two weeks. These treatment durations are only rough approximations; each piece of wood should be evaluated based upon its own characteristics.

4. Remove the object from the rosin solution, and wipe off excess rosin with acetone-moistened rags.

In some cases, when conserving very well-preserved hardwood, the conservator might consider submerging the wood in a 10 percent hydrochloric acid (HCl) bath after washing the object and before dehydrating the wood in Step 2 (above). Pre-treatment with hydrochloric acid improves the penetration of the rosin into the object by breaking down the organic acids in the wood. Caution must be exercised, however, as hydrochloric acid may result in a checked surface, which is more subject to cracking post-treatment. In addition, hydrochloric acid is supposed to bleach the wood to a more natural or original colour, but the bleaching is only temporary and rarely affects the final colour of the treated piece. (Hydrochloric acid pre-treatment can also be used to improve the penetration of PEG into wood, although the finished product may be more prone to checking and shrinkage.) To make the pre-treatment bath, mix one volume of HCl to nine volumes of water. The duration of pre-treatment is very variable, but objects 5-10 cm thick should be left in the acid for approximately four days, while objects less then 5 cm should be left in the acid for about two days. After pre-treatment, it is necessary to rinse the wood in running water for three to five days to thoroughly remove all traces of the acid before continuing to Step 2 (above). This pre-treatment is optional and is often eliminated because of the potential damage to the object.

In practice, ethanol is often used instead of accetone as a solvent for the rosin (especially when treatment is carried out in a PVC pipe). Room-temperature treatments, both in acetone and isopropanol, are also commonly employed. If room temperature treatments are used, the treatment time is increased considerably to ensure complete saturation of the object with the rosin solution.

The advantages of the acetone-rosin treatment include the fact that treated wood is light in weight, dry, strong, and can be glued and repaired easily. Because rosin does not react with any of the metals, the acetone-rosin treatment can be used on compound wood and metal objects. It is considered by many to be the treatment of choice for all composite wood/metal artifacts. Disadvantages include the flammability of acetone and the high cost of materials, which make this treatment practical only for small objects. In addition, the treatment would not be an ideal choice in cases where it is necessary to flex the treated wood (i.e., when reconstructing a composite object) because the wood will splinter and break if it is flexed too much.

In general, the only problems that have resulted from using acetone-rosin have occurred when an old solution was used in which the acetone had already absorbed a considerable amount of water from the atmosphere. It is important that dry acetone or alcohol be used. Despite the inherent dangers of the treatment and the relative expense, the acetone-rosin treatment should be used more frequently by conservators, particularly for small pieces. This treatment has one of the better success records in wood conservation and produces the most dimensionally stabilized wood after the

PEG 400 and 540 Blend treatments but without the hygroscopic problems of PEG (Grattan 1982b).

ALCOHOL-ETHER METHOD

This method is similar to the process used for drying out biological specimens. If necessary, the wood should be cleaned prior to treatment. The waterlogged object is first immersed in successive baths of alcohol until all the water has been replaced by the alcohol. Iso-propanol or ethanol is usually used. This is followed by successive baths of acetone. If necessary, the dehydration progress can be monitored by measuring the specific gravity of each bath. When all water has been replaced by acetone, the object is immersed in successive baths of di-methyl ether to replace all the acetone with ether. When this has been accomplished, the object is dried very quickly by placing it in vacuum to rapidly volatize the ether. Ether is used because it has a very low surface tension of 0.17 dyne/cm compared to 0.72 dyne/cm for water. This means that when the ether evaporates, the surface tension forces are so low that there is no appreciable collapse of the weakened cell wall. If desired, 10-20 percent dammar resin, colophony rosin, or a mixture of the two may be dissolved in the final bath of ether to consolidate the wood and to protect it from warping due to changes in relative humidity. PVA may be used in place of the resins on some pieces.

This method has proved to very successful, producing a very natural-looking wood that is light in both weight and colour. The dehydration process is very efficient, but the alcohols and ether must be water-free. For many objects, a dehydration of only alcohol and acetone is effective. Due to the high cost of the materials, this method is practical only for the treatment of small objects. The alcohols and especially the ether are highly flammable, and extreme caution should be taken when conserving wood with this method.

CAMPHOR-ALCOHOL METHOD

In essence, this treatment is analogous to the dehydration method described above but with a temporary bulking agent added. The water in the wood is completely displaced by a water-miscible alcohol, which is then displaced by camphor. The camphor fills the cavities and cell walls of the wood, and then slowly sublimates (goes directly from a solid state to a gas) without exerting any surface tension on the cell walls. Consequently, the wood does not collapse, shrink, or distort. The treatment results in a very aromatic, lightweight, and light-coloured wood. Camphor can be dissolved in any of the alcohols. The following procedure is recommended.

1. Wash object thoroughly and with care.
2. Dehydrate the specimen in a series of alcohol baths. Begin with a 50 percent alcohol/50 percent water bath (50/50 percent), then 75/25 percent, then 90/10 percent, and finally 100 percent alcohol. This is the most conservative procedure and, in practice, the exact strength of the alcohol baths can vary. The dehydration process is dependent upon the condition of the object to be treated.
3. Accurately weigh the object after it has been dehydrated. Leave the specimen in a 95 percent alcohol/5 percent camphor solution heated to 52°C until the object stops gaining weight. Check the progress by weighing daily. Each time

the weight levels off, add 5 percent camphor to the solution until a concentration of 75-80 percent camphor is achieved. This process may take several weeks or even months. Throughout the treatment the solution is kept heated to 52°C, and the level of the solution is kept constant by the addition of more alcohol. In practice, the treatment is carried out to completion with little monitoring.

4. After the object is removed from the bath, the alcohol will evaporate over a period of weeks, leaving behind crystallized camphor in the cell walls. Over a period of months, the camphor will vaporize by sublimation. Varnish, wax, polyurethane, dammar resin, colophony, and even PVA can be applied to the surface of the wood to reduce the evaporation of the camphor.

The camphor-alcohol method comes very highly recommended, but like the alcohol-ether method, it is economically impractical for the treatment of large objects and the solution is highly flammable.

FREEZE DRYING

Freeze drying is used with some regularity of small pieces of wood, but the only limitation is access to the properly sized freeze-drying container (Ambrose 1970, 1975; Rosenquist 1975; McCawley et al. 1982; Watson 1982). In the past, the main problem that presented itself was the tendency for the surface of the wood to check and crack. This is caused by the ice crystals expanding and damaging the cell walls. Ambrose (1970) found that if the wood is pre-treated by soaking it in a 10 percent solution of PEG 400 until it is saturated, the formation of ice crystals during the freeze-drying process is essentially eliminated. This pre-treatment has become a standard element of the freeze-drying method for wood, as well as for leather. In addition to inhibiting the formation of ice crystals during freeze drying, the PEG introduced into the object during pre-treatment will act as a humectant (absorbent substance) after treatment and prevents the wood from undergoing excessive shrinkage.

More recently, Watson (1987:274-275) observed that a 20 percent or higher PEG solution will dehydrate and kill any micro-organisms present in the solution through osmosis. He recommends using 20 percent PEG 400 for mildly degraded wood and 10 percent PEG 400 + 15 percent PEG 4000 for more degraded pieces. For severely degraded wood, the PEG 4000 may be increased to up to 25 percent, but treatment time is increased when PEG 4000 is used. If a PEG solution of less than 20 percent is used, a fungicide, such as 1 percent borax/boric acid or Dowicide 1, should be mixed with the PEG solution to stop any slime or mould from growing in the solution during pre-treatment.

Following pre-treatment with PEG, the wood is frozen in a domestic freezer. After freezing, it is recommended that the wood be placed in a freeze-drying chamber at a temperature of -32 to -40°C, and a vacuum applied after the temperature of the wood reaches -25°C. During the process, the frozen ice crystals sublimate, and the water vapour is frozen onto the condenser coils. This continues until all the water is removed, which can be determined by weighing the piece being treated. The treatment is completed when the weight loss stabilizes. After treatment, the wood should be stored in a relative humidity of 45-60 percent. Freeze drying as described here and in

the chapter on leather is essentially the same when treating any waterlogged organic material

Although the freezing can be done in a chest freezer, like biological specimens, a quick freeze is best. This can be achieved by immersing the wood in a container with acetone and dry ice (frozen CO_2). Some acceptable results have been achieved using non-vacuum freeze drying in a domestic freezer (particularly frost-free freezers). When a domestic freezer is used, the pre-treated wood is placed in the freezer and left there until it is dried. In this non-vacuum process, treatment times are in terms of months, as opposed to weeks in a vacuum freeze drier (McCawley et al. 1982).

Of all of the treatments discussed in this section, freeze drying is the most expensive due to the high cost of freeze dryers. Because of the size limitations of most freeze dryers, and the substantially higher costs when investing in equipment capable of treating larger objects, freeze drying is restricted to small objects in most laboratories.

SILICONE OIL TREAMENT

Since 1993, Dr. C. Wayne Smith of the Conservation Research Laboratory and the Archaeological Preservation Research Laboratory at Texas A&M University has been conducting research in the use of polymer media for the stabilization and conservation of organic materials. Waterlogged wood, glass, leather, woven basketry, and cork have been successfully conserved with polymer media, as well as artifacts such as corn cobs, which have been nearly impossible to conserve while maintaining the diagnostic features of the samples. The conservation of animal hides, biological tissues, and archaeological and histological bone samples has also been successful. Electron microscopic and chemical analysis of organic samples, which have been stabilized by the displacement of free water and air with silicone polymers exhibit some unique qualities over water-stored and air-dried specimens. An informal survey of university laboratories and departments has indicated that there are numerous areas where silicone bulking and related technologies would have almost immediate beneficial impact. The same holds true for museum artifact conservation, archival work, and in industrial applications.

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

1. Place waterlogged wood directly into a bath of ethanol and hold under a vacuum (10 kg) for approximately one hour.
2. Place the dried wood into a bath of acetone and hold under a vacuum for approximately one hour.
3. Measure out a suitable amount of SFD-1 silicone oil and mix 4 percent iso-butyltrimethoxysilane by weight into the silicone oil. The iso-butyltrimethoxysilane is a cross linker that sets the silicone oil up for curing in the next steps. Keep wood submerged in this mixture under a low vacuum (5 kg) overnight. It is important during this stage not to draw too high of a vacuum; this will prevent the collapse of the wood cells.
4. Remove wood and pat dry with a dry rag to remove excess silicone oil on surface.

5. Place the wood in a closed container with a small dish containing a small volume of FASCAT Catalyst 4200 in it. Place everything in a furnace heated to 52°C. The heat of the furnace vaporizes the FASCAT and cures the silicone oil in the wood..

This silicone oil treatment results in a very naturally coloured wood that undergoes little to no dimensional changes. The wood is stable and does not require the close environmental controls like some other treated woods. The conservator must keep in mind that this treatment is not reversible; however, few of the other treatments outlined in this chapter are reversible.

WOOD PROCESSING

The trees used as raw material by the forest industry are often classified as either *softwoods* or *hardwoods*. Softwoods, or conifers, belong to the group of plants known as gymnosperms (flowerless seed-bearing plants). Conifers include pines, cedars, spruces, larches, and firs, and conifers are common in the world's temperate and boreal (northern) regions. Hardwoods belong to the group of plants called angiosperms (flowering plants). They include broad-leaved tree species such as oak, maple, beech, walnut, mahogany, teak, and balsa.

The name *softwood* does not imply that the wood of such a tree is softer than that from a hardwood. Indeed, the wood of some softwood trees is harder than that of some hardwood trees. All trees are formed mostly of cells whose length runs parallel to the stem. A smaller number of cells run perpendicular to the stem. Cells of both categories serve three functions in a tree: to transport water and nutrients, to provide mechanical strength and support, and to allow food storage. Hardwood trees have a greater variety of types of vertically aligned cells than do softwood trees. This greater variety often produces attractive grain patterns when wood is cut and finished along the length of these cells (the grain). Many hardwoods are desirable for making furniture, cabinets, and panelling.

Round wood products

The terms *roundwood* and *log* refer to the long section of the tree stem, or trunk. Roundwood products include fence posts, home-building logs, utility poles, and marine pilings. Roundwood products are manufactured by first removing the bark and then milling the resulting log to the desired shape and diameter. Some roundwood products are treated with chemical preservatives, such as creosote and chromated copper arsenate (CCA), to prevent damage from insects and rotting.

Lumber products

Lumber is a rectangular length of wood sawn parallel to the tree stem and cut to specific width, thickness, and length. To manufacture lumber, logs are received in a sawmill yard where they are sorted and graded to identify which logs are best suited for making specific products. Next, machines remove the bark from the logs, and then the logs are crosscut (cut perpendicular to the grain) to specific lumber lengths. Each crosscut log is conveyed into a saw that cuts through the log lengthwise at measured

intervals to produce boards of a given thickness. These boards are cut lengthwise to square the edges by removing the round outside surface of the log and to produce lumber of standardized widths. Then the ends of the boards are cut to square the ends and to produce lumber of standard lengths. Although this lumber may be sold in its "rough" condition, most lumber is dried in a kiln (drying oven) and then planed (levelled) to smooth the surfaces before being marketed.

Lumber is marketed in three major grades: structural grade, appearance grade, and factory grade. Structural grades are used as load-bearing (support) lumber in houses and other buildings. Structural lumber is typically covered by other materials in the finished building, so the appearance of structural lumber is often not a major consideration. Softwood species such as Douglas fir, western hemlock, and southern pines are the most common types of structural-grade lumber.

As its name suggests, appearance-grade lumber is valued for colour and texture. It is often used for flooring, panelling, shelving, and interior trimming. This grade of lumber is often stained or left in its natural state because of its quality appearance. Appearance-grade lumber of lower quality is used for crating and pallets, fence boards, and light general construction. Hardwood species used for appearance grade include oak, birch, maple, and cherry. Softwood species include Douglas fir, western hemlock, white pine, and ponderosa pine.

Factory-grade lumber is used to manufacture furniture, windows, doors, mouldings, stairs, cabinets, and many other products. While both structural-grade and appearance-grade lumbers typically are not tooled extensively for use, factory-grade lumber is usually tooled extensively to form furniture and other products. Lumber is limited by both tree size and the strength of the particular type of wood. These limitations can be overcome by finger-jointing, edge-gluing, and laminating boards together to create lumber of almost any size. Finger-jointing is a process of cutting grooves into board ends so that wood pieces can be fitted together end-to-end and glued into longer pieces. Edge-gluing is a process where the sides of narrow boards are glued together to make wider pieces. Laminating is a process where lumber is stacked and then glued together to make structural beams and other products. These processes are used to make products such as shelving, doors, and windows.

Techniques such as finger-jointing, edge-gluing, and laminating allow manufacturers to produce beams and other building components that are customized to meet specific size and strength requirements. The individual boards comprising a piece of laminated lumber can be kiln dried at precise temperatures, and knots and other defects are later removed as well. This type of quality control is not possible with large, single units of structural lumber; therefore, laminated lumber can be made stronger and with more uniform properties. Another advantage is that laminated beams can be shaped into curves and other configurations during the lamination process. For example, many arenas built for the 1994 Winter Olympic Games in Lillehammer, Norway, included laminated wood beams. In addition, large wood beams used in churches, gymnasiums, and office and shopping buildings are often composed of laminated lumber.

Veneer products

Veneer products are made by stacking wood sheets and then gluing these layers together. Once arranged, the sheets are glued together into a strong construction material that is used to make wall panels, highway signs, boats, cabinets, furniture, and numerous other wood products that are thin, strong, and can cover a large surface area. Two important types of veneer products are plywood and laminated veneer lumber.

Plywood

Plywood consists of several layers, or plies, of wood thoroughly bonded to one another by glue or synthetic resins. The layers are laid with the grain in different directions, generally perpendicular to one another, so that the resultant sheet of plywood is equally strong in all directions. The bonded joint is at least as strong as the wood itself, and moisture-resistant glues can be used if necessary, so that plywood is as durable as the wood of which it is made. So-called laminated wood is a similar product, made by bonding layers of wood with the grain all running in one direction. This procedure results in a product that, like ordinary lumber, is extremely strong in the direction of the grain and weak in other directions.

Only the layers on the outside of the plywood need have hardness and good appearance; the inner layers need only be strong. In some cases, only one side of the plywood is a high-grade layer; such plywoods are used, for example, in making cabinets of which the inside will not be visible. Fine and expensive woods, such as mahogany, satinwood, ebony, and zebrawood, are now commonly used in the form of plywood, with a thin layer of expensive wood covering several layers of strong but inexpensive ordinary wood such as Douglas fir. In this way, the expense of the wood is greatly reduced, the appearance is in no way changed, and the strength and resistance to warping is greatly increased. Plywoods made of less expensive wood have been used to substitute for metals.

Plywood may have first been used in the United States in 1830 as a construction material for pianos. Soon afterward, plywood was being used to make panelled doors, desktops, and many other furniture items. Early adhesives were not moisture-resistant, so plywood was confined mostly to interior use. When moisture-resistant synthetic resin adhesives were developed in the 1930s, plywood became a major construction and siding material.

Modern veneer mills make plywood by removing the bark from logs and cross-cutting each log into short sections about 2.5 m (8 ft) long. The log sections are softened with steam. They are then spun lengthwise on a rotary lathe against a long sharp knife to produce a long, wide ribbon of wood, similar to unrolling a length of paper. The rotary lathe cuts into the log until only a long, thin post (called a peeler core) remains. The long wood sheet is then cut to specific lengths, the sheets are dried, and knot holes in the sheets are patched. Next, the sheets are coated with an adhesive and arranged in layers of three to seven sheets, with the wood-grain direction of each layer running in alternate directions to strengthen the product. The sheets are then glued and mechanically pressed together. The plywood is then graded and packaged for shipping. Although plywood sheet thickness varies, standard thickness begins at 0.64 cm (0.25 in). The standard width and length of plywood are 1.22 by 2.44 m (4 by 8 ft).

Plywood is used widely as a construction material because it is light, strong, durable, and inexpensive (the cost of producing plywood is often reduced by using less-costly wood for the inner layers). Plywood resists warping and cracking, and is moderately flexible because the grain direction of each layer is alternated.

Plywood is used to underlay floors, roofs, and walls in homes and buildings. It is used for making boats, truck campers, trailers, highway signs, pallets, bins, and other crating. Plywood is used to make concrete forms for basements, bridges, and other foundations. Plywood is also used for decorative applications inside the home, including furniture, cabinets, and interior wall panels. While softwood plywood is typically used by the construction, transportation, and container industries, hardwood plywood is more commonly used for decorative applications. Most softwood plywood is made from Douglas fir and southern pine, while hardwood plywood is made from birch, oak, cottonwood, mahogany, and other tree species.

Laminated veneer lumber

Laminated veneer lumber is a product engineered to substitute for traditional structural lumber. Sheets of adhesive-covered veneer are stacked with the wood grains running in parallel directions. Typically, these layers are assembled into boards 1.22 m (4 ft) wide and 3.8 cm (1.5 in) thick. The boards are put through a press that applies heat and pressure to dry the adhesive. As each board exits the press, it is cut into specified lengths and widths. Laminated veneer lumber is becoming a popular substitute for standard lumber because it is strong, has uniform properties, does not warp easily, and can be produced in a range of dimensions. Laminated veneer lumber is often combined with plywood to produce beams that can replace steel and concrete.

Particleboard

Particleboard is usually manufactured from small, low-quality logs that are milled into wood particles. It may also be made from sawdust, shavings, and other wood waste generated by wood manufactures. These logs or wood scraps are milled to a specific particle size, and the particles are blended with an adhesive. This blend is then bonded in a hot press to form a panel. Particleboard is commonly used for making inexpensive furniture, cabinets, and shelving. It is also used to underlay floors, roofs, stairs, and countertops.

Wood flake and strand products

Like particleboard, wood flake and strand products differ from standard lumber and veneer products in that the log is first broken apart, and the products are then formed from these pieces. As their name implies, wood flake and strand (long thin strip of wood) products are made from large flakes and strands of wood that are arranged in layers and then pressed into panels. These panels can be as strong as plywood but are cheaper to make because flakes can be made from lower-quality logs.

Waferboard and oriented strand board

For waferboard, the bark is removed from the logs, which are then mechanically broken apart into square to rectangular flakes typically 5 to 8 cm (2 to 3 in) long.

These fragments are dried, coated with adhesive, distributed randomly, and pressed into a large panel, called waferboard, that is then cut into smaller panels—often with the same dimensions as plywood sheets.

Today, waferboard has been largely replaced by oriented strand board, which is stiffer and stronger than waferboard. Oriented strand board is made by the same method as waferboard but with longer wood flakes—about 8 to 10 cm (3 to 4 in) long. In addition to being longer than waferboard flakes, the flakes used to make oriented strand board are also narrower, allowing them to be more closely aligned. Three to five layers of flakes are stacked with the direction of the flakes in each layer running perpendicular to that of the flakes in the adjacent layers. These layers are then pressed into a panel.

The close alignment of the flakes and the perpendicular layering give oriented strand board nearly the same strength and stiffness as plywood. However, because small, crooked, and otherwise low-quality logs unsuitable for lumber or veneer can be used to make oriented strand board, it can be made less expensively than plywood. Being less expensive, it is replacing plywood in many applications, such as siding in building construction.

Laminated Strand Lumber and Oriented Strand Lumber

Laminated strand lumber and oriented strand lumber are made of wood flakes 30 cm (12 in) long. These flakes are much longer than the flakes used to make oriented strand board. They are dried, coated with adhesive, and pressed. Unlike oriented strand board, these types of engineered lumber are manufactured to dimensions that correspond to conventional lumber dimensions. Because of their strength, uniformity, straightness, and lower cost, laminated strand lumber and oriented strand lumber are increasingly replacing structural lumber as wall studs, rafters, and joists (floor- and ceiling-supporting beams).

Wood Fiber Products

Wood pulp (a mixture of ground up and moistened wood cells or "fibers") is the main source for paper and many other fiber products. While papermaking has been practiced for centuries, other wood fiber products, such as fiberboard, hardboard, and insulation board, have been developed in more recent years.

Medium Density Fiberboard

Density fiberboard is manufactured from mechanically pulped wood fibers that are blended with an adhesive and pressed into dense (517-834 kg/cu m; 31-50 lb/cu ft) panels. Medium density fiberboard is inexpensive because it is made from wood fibers generated from pulp chips, shavings, sawdust, and low-quality logs. Medium density fiberboard is replacing lumber and particleboard for use as door panels and other items because it possesses excellent surface qualities and is strong and durable.

Insulation Board

Insulation board is made by passing wet wood fibers over a screen to drain, and then pressing the remaining thick mat of fibers into a low-density (167-517 kg/cu m; 10-31 lb/cu ft) panel. This panel gets its strength from bonding between the fibers rather than from adhesives. Insulation board is used for acoustic tiles or combined with urethane foams, foils, and fiberglass for use as insulating panels.

Hardboard

Hardboard refers to panel products manufactured from fibers that are pressed between hot plates to densities exceeding 517 kg/cu m (31 lb/cu ft). Hardboard is fabricated either by a dry process similar to that used to make medium density fiberboard or by a wet process similar to that used to make insulation board. Dry-process hardboard is molded into door panels and other products. Wet-process hardboard is commonly used for siding, trim, and roofing tiles.

CHEMICAL PRODUCTS

Although most wood pulp is used for papermaking, some is refined to yield almost pure cellulose, an ingredient used to produce synthetic textile fibers, cellophane, food, paint, explosives, and pharmaceutical and cosmetic products.

Lignins, a natural chemical contained in wood, is being used to develop adhesives. These adhesives can substitute for adhesives that are often made from non-renewable resources, such as fossil fuels. Other chemicals extracted from wood are used to make various products, including insecticides, food flavourings, and fragrances (including lemon, spearmint, menthol, and peppermint).

Energy and fuel products

About 56 percent of the wood harvested worldwide each year is used directly as fuel for heating and cooking. For example, in Brazil wood is widely used as fuel because Brazil does not have extensive deposits of coal and oil. In addition, wood industries often burn by-products such as bark, sawdust, and scrap wood to produce energy for the manufacturing process. In the United States, sawmill, veneer, and pulp industries generate over 50 percent of their energy needs by burning wood by-products.

Methyl alcohol (CH_3OH), also called methanol and wood alcohol, can be made by the fermentation or hydrolysis of wood cellulose. Methanol, more commonly known as wood alcohol, is used for automobile fuel in countries such as Brazil and can also be combined with gasoline to form gasohol. Other less important mechanical properties may be critical for a particular use; for example, the elasticity and resonance of spruce render it the only material suitable for the sounding board of a fine piano.

Chemical wood products

Wood is an important raw material in the chemical industry. Each year an enormous quantity of wood is reduced to pulp and reconstituted mechanically to form paper. Some modern industries are based on extracting from wood its minor chemical

constituents, such as tannins, pigments (*see* Paint and Varnish), gums, resins, and oils, and further modifying these constituents.

In addition to water, the principal constituent of wood is cellulose. Much of the large quantity of cellulose used today in making rayon and nitrocellulose is obtained from such comparatively pure sources as cotton, but an increasing quantity is being obtained from wood. The chief difficulty in using cellulose from wood lies in separating it from its impurities, the most important of which is lignin, a carbohydrate. Formerly, the lignin was discarded, but it was found to be a raw material for the manufacture of plastics and a suitable medium for the cultivation of yeast, which is an important livestock and poultry feed.

Wood may be used as a chemical raw material, without separating the cellulose from the lignin, by several different processes. In the Bergius process, wood is treated with hydrochloric acid in order to produce sugars, which are either used as cattle feed or fermented to produce alcohol. Wood may be converted into liquid fuels by hydrogenation. Wood has long been used also as a source of chemicals by destructive distillation. Most of these chemicals, however, including acetic acid, methyl alcohol, and acetone, are now made synthetically.

Certain new products consist essentially of a mixture of wood with certain chemicals; such a mixture will have mechanical properties similar to those of wood, but will be stronger and more resistant chemically. The most important methods of making these mixtures consist of impregnating the wood with certain chemicals, such as a mixture of phenol and formaldehyde, and then heating the impregnated wood so that the chemicals react within the cells of the wood to form a plastic. Wood treated with such resins is known as impreg. It has great resistance to decay and to insect and borer attack; its specific gravity is increased, but its strength is increased only slightly, if at all. A different product, called compreg, is made by compressing the impregnated wood in a hydraulic press at pressures of about 70 kg/sq cm (about 1000 lb/sq in) while the chemical reaction which forms the plastic is progressing. Such compressed impregnated wood may have a specific gravity up to about 1.35. The hardness is many times as great as that of the original wood, and the strength is somewhat greater, although the toughness may be less.

In the mid-1980s the annual U.S. lumber production exceeded 85.6 million cu m (36.3 billion bd ft), of which about 71.5 million cu m (about 30.3 billion bd ft) were softwoods such as fir, pine, hemlock, and spruce, and about 14.1 million cu m (6 billion bd ft) were hardwoods such as oak, maple, poplar, beech, and elm.

Seasoning   (Drying)

Freshly cut wood contains considerable water, which amounts to from one-third to more than one-half of the total weight. The drying of wood before it is processed into lumber is called seasoning, and is done for a number of reasons. Seasoned wood is far more resistant to decay than fresh wood; it is much lighter and therefore less expensive to ship; it has much higher heating value, which is important if it is to be used as fuel; and, most important, wood changes in shape during drying, and this change in shape should be completed before the wood is sawed.

Wood may be seasoned either by air-drying or kiln-drying. Air-drying takes several months, whereas kiln-drying takes a few days. In both cases, the wood must be carefully stacked to prevent warping, and the rate of drying must be carefully controlled.

Methods of drying timber

Broadly, there are two methods by which timber can be dried: (i) natural drying or air drying and (ii) artificial drying.

Air drying

Air drying is the drying of timber by exposing it to the air. The technique of air drying consists mainly of making a stack of sawn timber (with the layers of boards separated by stickers) on raised foundations, in a clean, cool, dry and shady place. Rate of drying largely depends on climatic conditions, and on the air movement (exposure to the wind). For successful air drying, a continuous and uniform flow of air throughout the pile of the timber needs to be arranged (Desch and Dinwoodie, 1996). The rate of loss of moisture can be controlled by coating the planks with any substance that is relatively impermeable to moisture; ordinary mineral oil is usually quite effective. Coating the ends of logs with oil or thick paint, improves their quality upon drying. Wrapping planks or logs in materials which will allow some movement of moisture, generally works very well provided the wood is first treated against fungal infection by coating in petrol/gasoline or oil. Mineral oil will generally not soak in more than 1–2 mm below the surface and is easily removed by planning when the timber is suitably dry. Benefits- It can be less expensive to use this drying method (there are still costs associated with storing the wood, and with the slower process of getting the wood to market), and air drying often produces a higher quality, more easily workable wood than with kiln drying. Drawbacks- Depending on the climate, it takes several months to a number of years to air-dry the wood.

Kiln drying

The process of kiln drying consists basically of introducing heat. This may be directly, using natural gas and/or electricity or indirectly, through steam-heated heat exchangers, although solar energy is also possible. In the process, deliberate control of temperature, relative humidity and air circulation is provided to give conditions at various stages (moisture contents or times) of drying the timber to achieve effective drying. For this purpose, the timber is stacked in chambers, called wood drying kilns, which are fitted with equipment for manipulation and control of the temperature and the relative humidity of the drying air and its circulation rate through the timber stack (Walker *et al.*, 1993; Desch and Dinwoodie, 1996). Kiln drying provides a means of overcoming the limitations imposed by erratic weather conditions. In kiln drying as in air drying, unsaturated air is used as the drying medium. Almost all commercial timbers of the world are dried in industrial kilns. A comparison of air drying, conventional kiln and solar drying is given below:

1. Timber can be dried to any desired low moisture content by conventional or solar kiln drying, but in air drying, moisture contents of less than 18% are difficult to attain for most locations.

2. The drying times are considerably less in conventional kiln drying than in solar kiln drying, followed by air drying.
   1. This means that if capital outlay is involved, this capital is just sitting there for a longer time when air drying is used. On the other hand, installing an industrial kiln, to say nothing of maintenance and operation, is expensive.
   2. In addition, wood that is being air dried takes up space, which could also cost money.
3. In air drying, there is little control over the drying elements, so drying degrade cannot be controlled.
4. The temperatures employed in kiln drying typically kill all the fungi and insects in the wood if a maximum dry-bulb temperature of above 60 °C is used for the drying schedule. This is not guaranteed in air drying.
5. If air drying is done improperly (exposed to the sun), the rate of drying may be overly rapid in the dry summer months, causing cracking and splitting, and too slow during the cold winter months.

The significant advantages of conventional kiln drying include higher throughput and better control of the final moisture content. Conventional kiln and solar drying both enable wood to be dried to any moisture content regardless of weather conditions. For most large-scale drying operations solar and conventional kiln drying are more efficient than air drying.

Compartment-type kilns are most commonly used in timber companies. A compartment kiln is filled with a static batch of timber through which air is circulated. In these types of kiln, the timber remains stationary. The drying conditions are successively varied from time to time in such a way that the kilns provide control over the entire charge of timber being dried. This drying method is well suited to the needs of timber companies, which have to dry timbers of varied species and thickness, including refractory hardwoods that are more liable than other species to check and split.

The main elements of kiln drying are described below: a) Construction materials: The kiln chambers are generally built of brick masonry, or hollow cement-concrete slabs. Sheet metal or prefabricated aluminium in a double-walled construction with sandwiched thermal insulation, such as glass wool or polyurethane foams, are materials that are also used in some modern kilns. Some of the elements used in kiln construction. However, brick masonry chambers, with lime and (mortar) plaster on the inside and painted with impermeable coatings, are used widely and have been found to be satisfactory for many applications. b) Heating: Heating is usually carried out by steam heat exchangers and pipes of various configurations (e.g. plain or finned (transverse or longitudinal) tubes) or by large flue pipes through which hot gases from a wood burning furnace are passed. Only occasionally is electricity or gas employed for heating. c) Humidification: Humidification is commonly accomplished by introducing live steam into the kiln through a steam spray pipe. In order to limit and control the humidity of the air when large quantities of moisture are being rapidly evaporated from the timber, there is normally a provision for ventilation of the chamber in all types of kilns. d) Air circulation: Air circulation is the means for carrying the heat to and the moisture away from all parts of a load. Forced circulation kilns are most common, where the air is circulated by means of fans or blowers,

which may be installed outside the kiln chamber (external fan kiln) or inside it (internal fan kiln). Throughout the process, it is necessary to keep close control of the moisture content using a moisture meter system in order to reduce over-drying and allow operators to know when to pull the charge. Preferably, this in-kiln moisture meter will have an auto-shutoff feature.

Kiln drying schedules

Satisfactory kiln drying can usually be accomplished by regulating the temperature and humidity of the circulating air to suit the state of the timber at any given time. This condition is achieved by applying kiln-drying schedules. The desired objective of an appropriate schedule is to ensure drying timber at the fastest possible rate without causing objectionable degrade. The following factors have a considerable bearing on the schedules.

1. The species; because of the variations in physical, mechanical and transport properties between species.
2. The thickness of the timber; because the drying time is approximately inversely related to thickness and, to some extent, is also influenced by the width of the timber.
3. Whether the timber boards are quarter-sawn, back-sawn or mixed-sawn; because sawing pattern influences the distortion due to shrinkage anisotropy.
4. Permissible drying degrade; because aggressive drying schedules can cause timber to crack and distort.
5. Intended use of timber; because the required appearance of the timber surface and the target final moisture contents are different depending on the uses of timber.

Considering each of the factors, no one schedule is necessarily appropriate, even for similar loads of the same species. This is why there is so much timber drying research, including this work, focused on the development of effective drying schedules.

Wood-drying kiln

A variety of wood drying kiln technologies exist today: conventional, dehumidification, solar, vacuum and radio frequency.

Conventional wood dry kilns (Rasmussen, 1988) are either package-type (sideloader) or track-type (tram) construction. Most hardwood lumber kilns are sideloader kilns in which fork trucks are used to load lumber packages into the kiln. Most softwood lumber kilns are track types in which lumber packages are loaded on kiln/track cars for loading the kiln.

Modern high-temperature, high-air-velocity conventional kilns can typically dry 1-inch-thick (25 mm) green lumber in 10 hours down to a moisture content of 18%. However, 1-inch-thick green Red Oak requires about 28 days drying down to a moisture content of 8%.

Heat is typically introduced via steam running through fin/tube heat exchangers controlled by on/off pneumatic valves. Less common are proportional pneumatic valves or even various electrical actuators. Humidity is removed via a system of vents, the specific layout of which are usually particular to a given manufacturer. In general, cool dry air is introduced at one end of the kiln while warm moist air is expelled at the other. Hardwood conventional kilns also require the introduction of humidity via either steam spray or cold water misting systems to keep the relative humidity inside the kiln from dropping too low during the drying cycle. Fan directions are typically reversed periodically to ensure even drying of larger kiln charges.

Most softwood lumber kilns operate below 240 °F (116 °C) temperature. Hardwood lumber kiln drying schedules typically keep the dry bulb temperature below 180 °F (82 °C). Difficult-to-dry species might not exceed 140 degrees F.

Dehumidification kilns are very similar to conventional kilns in basic construction. Drying times are usually comparable. Heat is primarily supplied by an integral dehumidification unit which also serves to remove humidity. Auxiliary heat is often provided early in the schedule where the heat required may exceed the heat generated by the DH unit.

Solar kilns are conventional kilns, typically built by hobbyists to keep initial investment costs low. Heat is provided via solar radiation, while internal air circulation is typically passive.

In 1949 a Chicago company introduced a wood drying kiln that used infrared lamps that they claimed reduced the standard drying time from 14 days to 45 minutes.

Newer wood drying technologies have included the use of reduced atmospheric pressure to attempt to speed up the drying process. A variety of vacuum technologies exist, varying primarily in the method heat is introduced into the wood charge. Hot water platten vacuum kilns use aluminum heating plates with the water circulating within as the heat source, and typically operate at significantly reduced absolute pressure. Discontinuous and SSV (super-heated steam) use atmosphere to introduce heat into the kiln charge. Discontinuous technology allows the entire kiln charge to come up to full atmospheric pressure, the air in the chamber is then heated, and finally vacuum is pulled. SSV run at partial atmospheres (typically around 1/3 of full atmospheric pressure) in a hybrid of vacuum and conventional kiln technology (SSV kilns are significantly more popular in Europe where the locally harvested wood is easier to dry versus species found in North America). RF/V (radio frequency + vacuum) kilns use microwave radiation to heat the kiln charge, and typically have the highest operating cost due to the heat of vaporization being provided by electricity rather than local fossil fuel or waste wood sources.

Valid economic studies of different wood drying technologies are based on the total energy, capital, insurance/risk, environmental impacts, labor, maintenance, and product degrade costs for the task of removing water from the wood fiber. These costs (which can be a significant part of the entire plant costs) involve the differential impact of the presence of drying equipment in a specific plant. An example of this is that every piece of equipment (in a lumber manufacturing plant) from the green trimmer to the in feed system at the planer mill is the "drying system". Since

thousands of different types of wood products manufacturing plants exist around the globe, and may be integrated (lumber, plywood, paper, etc.) or stand alone (lumber only), the true costs of the drying system can only be determined when comparing the total plant costs and risks with and without drying.

The total (harmful) air emissions produced by wood kilns, including their heat source, can be significant. Typically, the higher the temperature the kiln operates at, the larger amount of emissions are produced (per pound of water removed). This is especially true in the drying of thin veneers and high-temperature drying of softwoods.

Wood Machining

Machine Tools

Machine Tools, stationary power-driven machines used to shape or form solid materials, especially metals. The shaping is accomplished by removing material from a workpiece or by pressing it into the desired shape. Machine tools form the basis of modern industry and are used either directly or indirectly in the manufacture of machine and tool parts.

Machine tools may be classified under three main categories: conventional chip-making machine tools, presses, and unconventional machine tools. Conventional chip-making tools shape the workpiece by cutting away the unwanted portion in the form of chips. Presses employ a number of different shaping processes, including shearing, pressing, or drawing (elongating). Unconventional machine tools employ light, electrical, chemical, and sonic energy; superheated gases; and high-energy particle beams to shape the exotic materials and alloys that have been developed to meet the needs of modern technology.

History

Modern machine tools date from about 1775, when the English inventor John Wilkinson constructed a horizontal boring machine for producing internal cylindrical surfaces. About 1794 Henry Maudslay developed the first engine lathe. Later, Joseph Whitworth speeded the wider use of Wilkinson's and Maudslay's machine tools by developing, in 1830, measuring instruments accurate to a millionth of an inch. His work was of great value because precise methods of measurement were necessary for the subsequent mass production of articles having interchangeable parts.

The earliest attempts to manufacture interchangeable parts occurred almost simultaneously in Europe and the United States. These efforts relied on the use of so-called filing jigs, with which parts could be hand-filed to substantially identical dimensions. The first true mass-production system was created by the American inventor Eli Whitney, who in 1798 obtained a contract with the U.S. government to produce 10,000 army muskets, all with interchangeable parts.

During the 19th century, such standard machine tools as lathes, shapers, planers, grinders, and saws and milling, drilling, and boring machines reached a fairly high degree of precision, and their use became widespread in the industrializing nations. During the early part of the 20th century, machine tools were enlarged and made even

more accurate. After 1920 they became more specialized in their applications. From about 1930 to 1950 more powerful and rigid machine tools were built to utilize effectively the greatly improved cutting materials that had become available. These specialized machine tools made it possible to manufacture standardized products very economically, using relatively unskilled labour. The machines lacked flexibility, however, and they were not adaptable to a variety of products or to variations in manufacturing standards. As a result, in the past three decades engineers have developed highly versatile and accurate machine tools that have been adapted to computer control, making possible the economical manufacture of products of complex design. Such tools are now widely used.

Conventional Machine Tools

Among the basic machine tools are the lathe, the shaper, the planer, and the milling machine. Auxiliary to these are drilling and boring machines, grinders, saws, and various metal-forming machines.

Lathe

A lathe, the oldest and most common type of turning machine, holds and rotates metal or wood while a cutting tool shapes the material. The tool may be moved parallel to or across the direction of rotation to form parts that have a cylindrical or conical shape or to cut threads. With special attachments, a lathe may also be used to produce flat surfaces, as a milling machine does, or it may drill or bore holes in the workpiece.

Shaper

The shaper is used primarily to produce flat surfaces. The tool slides against the stationary workpiece and cuts on one stroke, returns to its starting position, and then cuts on the next stroke after a slight lateral displacement. In general, the shaper can produce almost any surface composed of straight-line elements. It uses a single-point tool and is relatively slow, because it depends on reciprocating (alternating forward and return) strokes. For this reason, the shaper is seldom found on a production line. It is, however, valuable for tool and die rooms and for job shops where flexibility is essential and relative slowness is unimportant because few identical pieces are being made.

Planer

The planer is the largest of the reciprocating machine tools. Unlike the shaper, which moves a tool past a fixed workpiece, the planer moves the workpiece past a fixed tool. After each reciprocating cycle, the workpiece is advanced laterally to expose a new section to the tool. Like the shaper, the planer is intended to produce vertical, horizontal, or diagonal cuts. It is also possible to mount several tools at one time in any or all tool holders of a planer to execute multiple simultaneous cuts.

Milling machine

In a milling machine, a workpiece is fed against a circular device with a series of cutting edges on its circumference. The workpiece is held on a table that controls the feed against the cutter. The table conventionally has three possible movements: longitudinal, horizontal, and vertical; in some cases it can also rotate. Milling machines are the most versatile of all machine tools. Flat or contoured surfaces may be machined with excellent finish and accuracy. Angles, slots, gear teeth, and recess cuts can be made by using various cutters.

Drilling and Boring Machines

Hole-making machine tools are used to drill a hole where none previously existed; to alter a hole in accordance with some specification (by boring or reaming to enlarge it, or by tapping to cut threads for a screw); or to lap or hone a hole to create an accurate size or a smooth finish.

Drilling machines vary in size and function, ranging from portable drills to radial drilling machines, multi-spindle units, automatic production machines, and deep-hole-drilling machines.

Boring is a process that enlarges holes previously drilled, usually with a rotating single-point cutter held on a boring bar and fed against a stationary workpiece. Boring machines include jig borers and vertical and horizontal boring mills.

Grinders

Grinding is the removal of metal by a rotating abrasive wheel; the action is similar to that of a milling cutter. The wheel is composed of many small grains of abrasive, bonded together, with each grain acting as a miniature cutting tool. The process produces extremely smooth and accurate finishes. Because only a small amount of material is removed at each pass of the wheel, grinding machines require fine wheel regulation. The pressure of the wheel against the workpiece can be made very slight, so that grinding can be carried out on fragile materials that cannot be machined by other conventional devices.

Saws

Commonly used power-driven saws are classified into three general types, according to the kind of motion used in the cutting action: reciprocating, circular, and band-sawing machines. They generally consist of a bed or frame, a vise for clamping the workpiece, a feed mechanism, and the saw blade.

Cutting Tools and Fluids

Because cutting processes involve high local stresses, frictions, and considerable heat generation, cutting-tool material must combine strength, toughness, hardness, and wear resistance at elevated temperatures. These requirements are met in varying

degrees by such cutting-tool materials as carbon steels (steel containing 1 to 1.2 percent carbon), high-speed steels (iron alloys containing tungsten, chromium, vanadium, and carbon), tungsten carbide, and diamonds and by such recently developed materials as ceramic, carbide ceramic, and aluminum oxide.

In many cutting operations fluids are used to cool and lubricate. Cooling increases tool life and helps to stabilize the size of the finished part. Lubrication reduces friction, thus decreasing the heat generated and the power required for a given cut. Cutting fluids include water-based solutions, chemically inactive oils, and synthetic fluids.

Presses

Presses shape workpieces without cutting away material, that is, without making chips. A press consists of a frame supporting a stationary bed, a ram, a power source, and a mechanism that moves the ram in line with or at right angles to the bed. Presses are equipped with dies (*see* Die) and punches designed for such operations as forming, punching, and shearing. Presses are capable of rapid production because the operation time is that needed for only one stroke of the ram.

Unconventional machine tools

Unconventional machine tools include plasma-arc, laser-beam, electrodischarge, electrochemical, ultrasonic, and electron-beam machines. These machine tools were developed primarily to shape the ultrahard alloys used in heavy industry and in aerospace applications and to shape and etch the ultrathin materials used in such electronic devices as microprocessors.

Plasma Arc

Plasma-arc machining (PAM) employs a high-velocity jet of high-temperature gas (*see* Plasma) to melt and displace material in its path. The materials cut by PAM are generally those that are difficult to cut by any other means, such as stainless steels and aluminium alloys.

Laser

Laser-beam machining (LBM) is accomplished by precisely manipulating a beam of coherent light (*see* Laser) to vaporize unwanted material. LBM is particularly suited to making accurately placed holes. The LBM process can make holes in refractory metals and ceramics and in very thin materials without warping the workpiece. Extremely fine wires can also be welded using LBM equipment.

Electrodischarge

Electrodischarge machining (EDM), also known as spark erosion, employs electrical energy to remove metal from the workpiece without touching it. A pulsating high-frequency electric current is applied between the tool point and the workpiece, causing sparks to jump the gap and vaporize small areas of the workpiece. Because no cutting forces are involved, light, delicate operations can be performed on thin

workpieces. EDM can produce shapes unobtainable by any conventional machining process.

Electrochemical

Electrochemical machining (ECM) also uses electrical energy to remove material. An electrolytic cell is created in an electrolyte medium, with the tool as the cathode and the workpiece as the anode. A high-amperage, low-voltage current is used to dissolve the metal and to remove it from the workpiece, which must be electrically conductive. A wide variety of operations can be performed by ECM; these operations include etching, marking, hole making, and milling.

Ultrasonic

Ultrasonic machining (USM) employs high-frequency, low-amplitude vibrations to create holes and other cavities. A relatively soft tool is shaped as desired and vibrated against the workpiece while a mixture of fine abrasive and water flows between them. The friction of the abrasive particles gradually cuts the workpiece. Materials such as hardened steel, carbides, rubies, quartz, diamonds, and glass can easily be machined by USM.

Electron beam

In electron-beam machining (EBM), electrons are accelerated to a velocity nearly three-fourths that of light. The process is performed in a vacuum chamber to reduce the scattering of electrons by gas molecules in the atmosphere. The stream of electrons is directed against a precisely limited area of the workpiece; on impact, the kinetic energy of the electrons is converted into thermal energy that melts and vaporizes the material to be removed, forming holes or cuts. EBM equipment is commonly used by the electronics industry to aid in the etching of circuits in microprocessors. *See* Microprocessor.

Joinery and cabinet making

Joinery is the skill of fitting pieces of wood together precisely to form various articles. The word *joiner* was originally applied to workers in the late 16th century who practiced the craft of constructing and installing doors, windows, cabinets, and fittings for houses and ships. In England the term still applies to these activities, but in North America such workers are called carpenters, cabinetmakers, and millworkers. The term *joinery* now applies primarily to the skills of the cabinetmaker, the furniture maker, and the shipwright. Joint making is one of the highest skills of the woodworking craft. The most valued pieces of antique furniture were assembled by means of joinery in such a way that they have retained their beauty and utility down to the present.

Cabinetmakers are usually employed by manufacturers specializing in cabinets and furniture for storage and display. The skills of the cabinetmaker can be applied to the manufacture of pianos and harpsichords, household furnishings, ship's fittings, and

other wood objects in which precise joinery, knowledge of wood qualities and characteristics, and adherence to blueprint specifications are required.

Basic joints

Scores of joints can be used in wood assembly. The choice of joint depends on the quality of the wood used, the physical stresses expected in the finished product, and the preference of the artisan. Experienced woodworkers, however, usually choose the least elaborate joint that is suitable for a particular assembly. Most joints derive their strength from precise fit and glue; sometimes only wedging or pinning with brads or nails is needed.

The butt joint, used in box construction, is the simplest and most familiar joint. Two pieces of wood are simply placed end to end at a right angle and joined by nails, screws, or adhesives. The tongue and groove is best known as the joint used for installing hardwood floors. Today, tongue and groove joints are produced by mills, and wood so prepared is installed by carpenters.

A bevel joint is created by cutting the ends of wood obliquely, or with a bevel, so that the pieces to be joined meet at an angle in a continuous line. The term *miter* is applied to a bevel cut at 45°. The cuts for the miter joint are often handmade by sawing the wood along the precut grooves of a miter box.

The dado joint—frequently found in bookcases, shelves, and drawers—is made by cutting a channel in a piece of wood with a router. The edge of another piece of wood is then fitted, glued, and sometimes nailed into the channel.

The rabbet joint is similar to the dado, except that the channel, being at the end of one board, has an open side.

The lap joint is one of the most versatile and widely used joints. Variations on the lap joint are the cross lap, which is often used in building construction, and the half lap, end lap, and middle lap, which are used in cabinet and furniture making.

The dovetail joint and the notched joint are used in the manufacture of superior furniture. The dovetail joint is used to create a strong right angle from two flat pieces of wood. For the assembly of some wood items, woodworkers drill holes and insert wood dowels (round wood pegs) to create hidden joints.

The mortise and tenon joint is used to join two members perpendicularly. The tenon, a rectangular or square projection from the end of one member, fits snugly into the mortise cut in the second member. Variations on this joint have to do primarily with how far the tenon extends through the second member, and whether dowels or wedges are used to further strengthen the joint.

Finishing

The work of cabinetmakers and furniture builders is complete when the object being built is smoothed with sandpaper or steel wool to remove the marks left by the various cutting tools and, finally, when one or more finishes are applied to the object. Finishes

serve to protect and preserve the wood and to bring out the beauty of the grain—or, in some cases, to cover up the imperfections of lower quality wood. Common finishes include waxes, oils, bleaches, fillers, stains, shellac, varnish, lacquer, sealers, and paints, including enamels.

Recently developed polyurethane sealers impart a clear, highly durable finish that provides excellent waterproof protection and brings out the charm and beauty of the grain. The grain of more expensive wood is often simulated on lower quality sheets of plywood panelling by means of photographic techniques.

PAPER

Paper is a thin sheet of compressed vegetable cellulose fibers. Paper is used for writing and printing, for wrapping and packaging, and for a variety of special purposes ranging from the filtration of precipitates from solutions to the manufacture of certain types of building materials. Paper is a necessity in modern civilization, and the development of machinery for its high-speed production has been largely responsible for the increase in literacy and the raising of educational levels of people throughout the world.

According to tradition, the Chinese were the first to make paper when they experimented with mixing fibers from cloth rags and old fishnets with the fibrous inner bark of the mulberry plant around AD 105. Later, fibers from the bamboo plant were used as well. The Chinese mixed these plant, rag, and old fishnet fibers with water and pounded them into a pulpy mass using mortar and pestle. The mass was then placed on a cloth screen held rigid by a bamboo frame. As the water drained through the screen, the damp, thin mat of fibers left behind dried into a sheet of paper. Papermaking was confined to China for about 500 years, until it was introduced to Japan about 610, and then to Central Asia about 750.

Paper was first made in Spain around 1150, and the craft quickly spread to other European countries. The first commercially successful papermaking machine was invented by French inventor Nicholas Louis Robert in 1798 and was later modified by British papermakers Henry and Sealy Fourdrinier (for whom the modern Fourdrinier machine is named). The Fourdrinier machine contains a wire-screen conveyor belt that drains water from the wet pulp, leaving a mat of wet fibers, which are air dried and pressed between rollers. Until the 19th century in Europe, rag fibers were pressed into sheets of paper. But as demand for paper increased, cloth rags became increasingly scarce. Frenchman René de Réamur devised the idea of using wood to make paper when he observed wasps making paperlike nests by softening wood fibers with their saliva. The first mechanical wood pulp-making process was introduced about 1840.

Today more than 95 percent of paper is made from wood, while the remainder consists of fibrous materials, such as rice chaff, flax, and rags. More than one-third of wood pulp is obtained from recycling paper and paperboard. About one-quarter is obtained from wood waste generated from sawmills, veneer mills, and other wood industries. About two-fifths is obtained directly from harvested trees that are small, crooked, or otherwise unsuitable for other uses. Other types of raw material used alone or in combination with wood fibers to make paper include cotton fibers, bamboo, wheat straw, and synthetic fibers.

The modern paper industry uses both mechanical and chemical processes to form wood pulp. In the mechanical processes, logs from which the bark has been removed are ground into pulp against a large revolving grindstone. Pulp is also made from wood chips by forcing the chips between revolving metal disks, which tear the chips into fibers. In the chemical processes, wood chips are treated with chemicals such as sodium sulfate or magnesium sulfate that dissolve lignin and other wood-binding materials, breaking the fibers into pulp. There are many variations of mechanical and chemical pulping methods, and some wood pulping plants combine both approaches. Commercial pulping processes cannot remove all the lignin from wood pulp. Because the residual lignin gives the pulp a brown color, the wood pulp is bleached with chemicals such as chlorine or sodium hydroxide to remove the residual lignin and whiten the pulp.

From the plant, the pulp is pumped to a Fourdrinier (papermaking) machine. This machine contains a wire-mesh conveyor belt that allows water to drain from the wet pulp, leaving a mat of wet fibers on the moving screen. Additional moisture is removed from the pulp by means of air suction pumps. The fibrous mat of pulp then passes through successive sets of felt and metal rollers, which press the mat into smooth paper. After being pressed, most paper is coated with substances such as clay, carbon, or calcium carbonate to increase its printing quality, as well as its colour, smoothness, and strength. The paper is then wound onto reels.

Paper products are classified as paper and paperboard with both bleached and unbleached grades. Paper includes newsprint, stationery, text paper, and computer printing paper. Paper products also include sanitary paper products such as paper towels and tissue papers, as well as coarse paper products used in grocery and shopping bags. Industrial papers are used to make filters, gaskets, and other heavy-duty items.

Paperboard is a thick type of paper often used in industrial and packaging applications. One class of paperboard, known as industrial papers, is used to make filters, gaskets, and other heavy-duty items. Another type of paperboard is cardboard, which is used to make cartons and boxes. Paperboard is made the same way paper is made. The major difference is that paperboard is at least 0.3 mm (0.012 in) thick. One type of cardboard, called *containerboard*, contains corrugated paper, which is two layers of cardboard encasing a layer of cardboard pressed into small ridges. Containerboard is used for packaging and shipping boxes. Other types of paperboard are used for milk and ice cream cartons, cereal boxes, paper plates, book bindings, and other items. Certain types of paperboard are coated with plastics or metal foils to create a moisture barrier and to provide packaging for food products.

Pulp and paper industry

These two kinds of industries are normally separated. The pulp (raw material for paper industry) and the paper industry, there is also a third related industry, the paper recycling industry, the three branches of industry are separated.

Production process, pulp industry

For paper production wood, bagasse (outer stalk sugar cane), hemp, straw, etc. are used. Five basic procedures are used to produce pulp in an industrial way. The conduction of case can be with or without a bleaching process.

If a bleaching process is also step of production, the Lignin will be destroyed. The effect is a whiter paper. The colour depends also on the different kinds of wood or other raw materials which are used for the production. This step has the disadvantage to load the environment more, because of the use of chemicals like chlorine or chlorine dioxide (which are restricted, because of the process). Chemical Processes

To produce pulp for fine and print paper, two chemical procedures are used.

The **Kraft process** is an alkaline process. The lignin is cracked by NaOH or Na_2S, which is very effective at different kind of woods especially the wood contains pollutions.

Disadvantage is the odour problem, based on thiols and sulfides. The pulp has also to be bleached more, compared to the suphite process.

Process water of this kind of process contains SO_2 and the pH is between 8 and 9. BOD and COD are depending on the kind of wood. Normally the BOD_5 is between 1-2 g/L, and the COD is 4- 7 g/L.

The **sulphite process** is a procedure based on acids. The effect is not the same compared to the alkaline process. The procedure is more sensitive, against pollution. Branches and bark disturb the chemical process and will not solute as well as the wood. Also resin disturbs the process.

Advantages of the "sulphite process" are more process variations and producing conditions without unwanted thiol and sulfide production.

Semichemical processes

The **NSSC (Neutral Sulphite Semichemical)** is most used. The yield of this process is approximately 75%,

The **TMP (Thermo-Mechanical Process)** is generally used for newsprint paper.

The new **CTMP (Chemi-Thermo-Mechanical Process)** is high efficient (approx. 95%) and the consumption of water is not as high as in other described processes. But it needs more energy to produce the pulp.

In modern pulp plants, this kind of waste water has to be treated generally:

- bleaching solutions
- washing and emptying
- evaporation condensates

The amount of water which has to be treated is very high

- Approx. 30m^3/t pulp with mechanical processes and up to 150 m^3/t pulp with chemical process. The waste water contains up to 10- 30% of fibres, fibrils and CaCO$_3$
- BOD$_5$ and COD load vary between different kind of wood (BOD$_5$- 100-1.000mg/L; COD- 300- 4.000mg/L)

Waste water is treated by anaerobic waste water treatment vaporizing, incineration and recovery. Paper waste water

Paper is produced from "new" or recycled pulp. Depending on the quality of pulp, it's used for different sorts of paper. During the process of paper producing, kaolin, CaCO$_3$, talc and/or TiO$_2$ are added to the pulp, to give the paper whiter colour.

Also chemicals like organic fillers (starch, latex), colours, aluminum sulfate, etc. are used to make paper of different properties or making the process simpler.

Paper can be decoloured, which can be done with two different processes. Washing the pulp with a high amount of water or washing with a low amount of water plus additions like sodium silicates, sodium carbonate, fatty acids or non ion detergents. Paper recycling

Pulp can be also made of recycled paper. But because of the colour on written, old papers the pulp has to be bleached. The following procedures can be used.

Depending of the agents to bleach the pulp, waste water has to be treated. Bleaching with peroxides, oxygen and ozone is not as efficient as using chlorine or chlorine dioxide, but the water has generally a very low or no amount of treatment chemicals. By using chloride or chloride dioxide, the water contains these agents which increase the AOX. On the other hand, chloride bleaching is the most efficient.

The waste water of paper recycling contains also particles which have to be filtrated. Rests of plastics, metal parts (paper clips, etc.) other waste have to be removed.

Hand paper making

The basic process of making paper has not changed in more than 2,000 years. It involves two stages: the breaking up of raw material in water to form a suspension of individual fibers and the formation of felted sheets by spreading this suspension on a suitable porous surface, through which excess water can drain.

In making paper by hand, the raw material—straw, leaves, bark, rags, or other fibrous material—is placed in a vat or trough and is pounded with a heavy pestle or hammer to separate the fibers. During the first portion of this operation, the material is washed with running water to remove impurities, but after the fibers have been sufficiently broken up, they are kept in suspension, and the water in the vat is not changed. At this stage the liquid material, called half stuff, is ready for the actual process of papermaking. The chief tool of the papermaker is the mould, a reinforced sheet of metal mesh having either a square mesh pattern, called a wove pattern, or a pattern of more widely spaced longitudinal wires held together with smaller transverse wires, called a laid pattern. The mould pattern imprints itself on the finished sheet of paper,

and thus handmade papers that are not given special finishes are identified as wove or laid papers, depending on the style of mould that is used in their making.

The mould is placed inside a removable wooden frame called a deckle, which forms a low rim around its edge. The papermaker dips the mould and deckle into a vat containing the half stuff; when the mould and deckle are removed from the vat, the surface of the mould is coated with a thin film of fiber-water mixture. The device is then shaken forward and backward and from side to side. This shaking has two effects; it distributes the mixture evenly on the surface of the mould and causes the individual fibers to interlock with the adjacent, giving strength to the sheet. While the device is being shaken, much of the water from the mixture drains out through the mould mesh. The device, with its formed sheet of wet paper, is then laid aside until the paper is sufficiently cohesive to permit the removal of the deckle.

After the deckle has been taken from the mould, the mould is turned over and the sheet of paper is laid smoothly on a sheet of woven woolen cloth, called a felt. Another felt is laid over the sheet of paper, and the process is repeated; the process of placing the paper between two felts is known as couching. When a number of sheets of paper have been interleaved with felts, the entire pile, called a post, is placed in a hydraulic press and subjected to a pressure of 100 or more tons, expelling most of the water remaining in the paper. The sheets of paper are then separated from the felts, stacked, and pressed. The process of pressing the stack of paper is repeated several times, and each time the stack is built up in a different order with the individual sheets in different positions relative to one another. This procedure is called exchanging, and its repetition improves the surface of the finished paper. The final stage in papermaking is drying. The paper is hung, in groups of four or five sheets, over ropes in a special drying room until its moisture has almost completely evaporated.

Papers that are to be used for writing or printing with ink require additional treatment following drying, because without such treatment the paper would absorb ink and yield fuzzy lines or impressions. The treatment consists of sizing the paper by dipping it into a solution of animal glue, drying the sized paper, and finally finishing the paper by pressing the sheets between sheets of metal or smooth cardboard. The amount of pressing determines the texture of the surface of the paper. Rough-textured papers are pressed lightly for a comparatively short period of time, and smooth-surfaced papers are pressed heavily for comparatively long periods.

Machine paper making

Although the essential procedures of papermaking by machine are identical with those of hand papermaking, machine papermaking is considerably more complex. The first step in machine papermaking is the preparation of the raw material. The materials chiefly used in modern papermaking are cotton or linen rags and wood pulp. Today more than 95 percent of paper is made from wood cellulose. For the cheapest grades of paper, such as newsprint, groundwood (mechanically processed) pulp alone is used; for better grades, chemical wood (pulp in which undesirable materials are chemically removed), pulp, or a mixture of pulp and rag fiber is employed; and for the finest papers, such as the highest grades of writing papers, rag fiber alone is used.

Rags used in papermaking are first cleaned mechanically to remove dust and foreign matter. Following this cleaning, the rags are cooked in a large rotary boiler. This process involves boiling the rags with lime under steam pressure for a period of several hours. The lime combines with greases and other impurities in the rags to form non-soluble soaps, which can be washed away in a later process, and at the same time reduces any coloured dyes present to colourless compounds. The rags are then transferred to a machine called a beater, or Hollander, which is a long tub divided longitudinally so as to form a continuous channel around the tub. In one half of the tub, a horizontal cylinder carrying a series of knives revolves rapidly close to a curved bedplate, which is also provided with knives. The mixture of rags and water passes between the cylinder and the bedplate, and the rags are reduced to fibers. In the other half of the tub, a hollow washing cylinder covered with fine mesh screening is arranged so that it scoops water from the tub, leaving the rags and fibers behind. As the mixture of rags and water flows around the beater, the dirt is removed and the rags are gradually softened until they are finally resolved into individual fibers. The half stuff is then passed through one or more secondary beaters to break up the fibers still further. At this point are added colouring matter, sizing material such as rosin or glue, and fillers such as sulfate of lime or kaolin, which give added weight and body to the finished paper. In many American paper mills the second beater is of the type known as a Jordan engine. This machine consists of a stationary cone fitted with knives mounted outside a revolving cone also equipped with knives. The fiber material flows between these two sets of knives, and the cones can be adjusted relative to each other with great accuracy to regulate the fineness of the fibers.

The preparation of wood for papermaking is accomplished in two different ways. In various chemical-solvent processes, wood chips are treated with solvents that remove resinous material and lignin from the wood, leaving pure fibers of cellulose. The oldest of the chemical-solvent processes, the soda process, introduced in 1851, employs a solution of caustic soda (sodium hydroxide) as a solvent. The wood is cooked or "digested" in this solution under steam pressure. The fibers produced by this process do not have great strength but are used in mixtures with other wood fibers. The process most generally employed in the United States is the sulfate process, which is named for the solvent used, either sodium sulfate or magnesium sulfate.

In the groundwood process, blocks of wood are held against a rapidly revolving grindstone that shreds off short wood fibers from the block. The fibers produced by this process are used only in the production of cheap newsprint and for admixture with other types of wood fiber in the making of high-quality paper. To produce white paper from this pulp, paper mills have historically bleached the pulp with chemicals such as chlorine. Chlorine removes lignin, which gives paper an often undesired brown colour. However, because bleaching paper with chlorine produces a carcinogen (cancer-causing compound) called dioxin, in 1998 the United States Environmental Protection Agency (EPA) published the pulp and paper industry Cluster Rule, which required U.S. paper companies to eliminate chlorine from the bleaching process by 2001. Instead, the mandate will require the companies to switch to safer compounds such as chlorine dioxide or sodium hydroxide.

Most paper today is made on Fourdrinier machines, which are patterned after the first successful papermaking machine, developed in 1803 by the British brothers Henry

Fourdrinier and Sealy Fourdrinier. The heart of the Fourdrinier machine is an endless belt of wire mesh that moves horizontally. A flow of watery pulp is spread on the level belt, which passes over a number of rolls. A shallow wooden box beneath the belt catches much of the water that drains off during this stage. This water is remixed with the pulp to salvage the fiber contained in it. Spreading of the sheet of wet pulp on the wire belt is limited by rubber deckle straps moving at the sides of the belt. Air suction pumps beneath the belt hasten drying of the paper, and the belt itself is moved from side to side to aid the felting of the fibers. As the paper travels along the belt it passes under a turning cylinder called a dandy roll. The surface of this cylinder is covered with wire mesh or single wires to impart a wove or laid surface to the paper. In addition, the surface carries words or patterns worked in wire; these are impressed on the paper and appear as watermarks that identify the grade of paper and the maker. In handmade papers, the watermark patterns are fixed to the surface of the mould.

Near the far end of the machine, the belt passes through two felt-covered couching rolls. These rolls press still more water out of the web of paper and consolidate the fiber, giving the paper enough strength to continue through the machine without the support of the belt. The function of these rolls is the same as that of the felts used in couching handmade paper. From the couching rolls, the paper is carried on a belt of cloth through two sets of smooth metal press rolls. These rolls impart a smooth finish to the upper and lower surfaces of the paper.

After pressing, the paper is fully formed. It is then carried through a series of heated rolls, which complete the drying. The next step is calendering, pressing between smooth chilled rolls to produce the smooth finish known as machine finish. At the end of the Fourdrinier machine, the paper is slit by revolving cutters and wound on reels. The manufacture of the paper is completed by cutting into sheets, unless the paper is to be used on a continuous press that employs rolls of paper. Special papers are given additional treatment. Supercalendered paper is subjected to a further calendering process under great pressure between metal and paper-covered rolls. Coated paper, such as is used for fine halftone reproduction, is sized with clay or glue and calendered. Paper is also made on cylinder machines. Much of the tissue paper manufactured is made on Yankee machines, which have a single steam-heated cylinder for drying. Equipment used in pulp making and papermaking is constantly being improved and modernized. For example, the Inverform machine, which was invented in England in the 1940s, is a high-speed machine that produces a range of box board used by the food packaging industry.

Synthetic-fiber paper

In 1955 papers were prepared from nylon, Dacron, and Orlon fibers, and from blends of these fibers with wood pulp. Such papers are produced on conventional papermaking machinery and can be made with a wide range of appearances and characteristics, from crisp stock resembling ordinary paper to drapable, fabriclike materials. Because of their unique properties, synthetic-fiber papers have many applications for which ordinary paper is unsuitable, notably as electrical insulation, filtration material in air-conditioning equipment, electrical tapes for sound recording, shoe fabrics, and interlining in clothing.

CHARCOAL

Charcoal is the dark grey residue consisting of impure carbon obtained by removing water and other volatile constituents from animal and vegetation substances. Charcoal is usually produced by slow pyrolysis, the heating of wood or other substances in the absence of oxygen. The resulting soft, brittle, lightweight, black, porous material resembles coal.[1] Note that the current trade nomenclature for charcoal is "lump charcoal" and that products sold as "charcoal briquettes" are not actually charcoal, but are made from coal or coke. Historically, production of wood charcoal in districts where there is an abundance of wood dates back to a very ancient period, and generally consists of piling billets of wood on their ends so as to form a conical pile, openings being left at the bottom to admit air, with a central shaft to serve as a flue. The whole pile is covered with turf or moistened clay. The firing is begun at the bottom of the flue, and gradually spreads outwards and upwards. The success of the operation depends upon the rate of the combustion. Under average conditions, 100 parts of wood yield about 60 parts by volume, or 25 parts by weight, of charcoal; small scale production on the spot often yields only about 50%, large scale was efficient to about 90% even by the seventeenth century. The operation is so delicate that it was generally left to colliers (professional charcoal burners).

The massive production of charcoal (at its height employing hundreds of thousands, mainly in Alpine and neighbouring forests) was a major cause of deforestation, especially in Central Europe. In England, many woods were managed as coppices, which were cut and regrew cyclically, so that a steady supply of charcoal would be available (in principle) forever; complaints (as early as the Stuart period) about shortages may relate to the results of temporary over-exploitation or the impossibility of increasing production to match growing demand. The increasing scarcity of easily harvested wood was a major factor for the switch to the fossil fuel equivalents, mainly coal and brown coal for industrial use.

The use of charcoal as a smelting fuel has been experiencing a resurgence in South America following Brazilian law changes in 2010 to reduce carbon emissions as part of President Lula da Silva's commitment to make "green steel".

The modern process of carbonizing wood, either in small pieces or as sawdust in cast iron retorts, is extensively practiced where wood is scarce, and also for the recovery of valuable byproducts (wood spirit, pyroligneous acid, wood tar), which the process permits. The question of the temperature of the carbonization is important; according to J. Percy, wood becomes brown at 220 °C (428 °F), a deep brown-black after some time at 280 °C (536 °F), and an easily powdered mass at 310 °C (590 °F).[citation needed] Charcoal made at 300°C (572 °F) is brown, soft and friable, and readily inflames at 380 °C (716 °F); made at higher temperatures it is hard and brittle, and does not fire until heated to about 700 °C (1,292 °F).

In Finland and Scandinavia, the charcoal was considered the by-product of wood tar production. The best tar came from pine, thus pinewoods were cut down for tar pyrolysis. The residual charcoal was widely used as substitute for metallurgical coke in blast furnaces for smelting. Tar production led to rapid deforestation: it has been estimated all Finnish forests are younger than 300 years. The end of tar production in the end of the 19th century meant also rapid re-forestation.

The charcoal briquette was first invented and patented by Ellsworth B. A. Zwoyer of Pennsylvania in 1897[2] and was produced by the Zwoyer Fuel Company. The process was further popularized by Henry Ford, who used wood and sawdust byproducts from automobile fabrication as a feedstock. Ford Charcoal went on to become the Kingsford Company.

Production methods

Charcoal has been made by various methods. The traditional method in Britain used a clamp. This is essentially a pile of wooden logs (e.g. seasoned oak) leaning against a chimney (logs are placed in a circle). The chimney consists of 4 wooden stakes held up by some rope. The logs are completely covered with soil & straw allowing no air to enter. It has to be lit by introducing some burning fuel into the chimney; the logs burn very slowly (cold fire) and transform into charcoal in a period of 5 days burning. If the soil covering gets torn (cracked) due to the fire, additional soil is placed on the cracks. Once the burn is complete, the chimney is plugged to prevent air to enter.

Modern methods use a sealed metal container, as this does not have to be watched lest fire break through the covering.

Types

- **Lump charcoal** is made directly from hardwood material and usually produces far less ash than briquettes.
- **Briquettes** are made by compressing charcoal, typically made from sawdust and other wood by-products, with a binder and other additives. The binder is usually starch. Some briquettes may also include brown coal (heat source), mineral carbon (heat source), borax, sodium nitrate (ignition aid), limestone (ash-whitening agent), raw sawdust (ignition aid), and other additives like paraffin or petroleum solvents to aid in ignition.[4]
- **Extruded charcoal** is made by extruding either raw ground wood or carbonized wood into logs without the use of a binder. The heat and pressure of the extruding process hold the charcoal together. If the extrusion is made from raw wood material, the extruded logs are then subsequently carbonized.[citation needed]

The characteristics of charcoal products (lump, briquette, or extruded forms) vary widely from product to product. Thus it is a common misconception to stereotype any kind of charcoal, saying which burns hotter, etc.

- Bamboo charcoal
- Activated carbon

Uses

Charcoal has been used since the earliest times for a range of purposes including art and medicine, but by far its most important use has been as a metallurgical fuel. Charcoal is the traditional fuel of a blacksmith's forge and other applications where an

intense heat is wanted. Charcoal was also used historically as a source of carbon black by grinding it up. In this form charcoal was important to early chemists and was a constituent of formulas for mixtures such as gunpowder. Due to its high surface area charcoal can be used as a filter, as a catalyst or as an absorbent.

Metallurgical fuel

Charcoal burns at intense temperatures, up to 2700 degrees Celsius. By comparison the melting point of iron is approximately 1200 to 1550 degrees Celsius. Due to its porosity it is sensitive to the flow of air and the heat generated can be moderated by controlling the air flow to the fire. For this reason charcoal is an ideal fuel for a forge and is still widely used by blacksmiths. Charcoal is also an excellent reducing fuel for the production of iron and has been used that way since Roman times. In the 16th century England had to pass laws to prevent the country from becoming completely denuded of trees due to production of iron. In the 19th century charcoal was largely replaced by coke, baked coal, in steel making due to cost. Charcoal is far superior fuel to coke, however, because it burns hotter and has no sulfur. Until World War II charcoal was still being used in Sweden to make ultra high-quality steel.

Cooking fuel

Prior to the industrial revolution charcoal was occasionally used as a cooking fuel. Modern "charcoal briquettes", widely used for outdoor grilling and barbecues in backyards and on camping trips, imitate this use, but are not actually charcoal. They are usually compacted mixtures of coal or coke and various binders.

Industrial fuel

Historically, charcoal was used in great quantities for smelting iron in bloomeries and later blast furnaces and finery forges. This use was replaced by coke during the Industrial Revolution. For this purpose, charcoal in England was measured in dozens (or loads) consisting of 12 sacks or shems or seams, each of 8 bushels

Automotive fuel

In times of scarce petroleum, automobiles and even buses have been converted to burn wood gas (gas mixture containing primarily carbon monoxide) released by burning charcoal or wood in a wood gas generator. In 1931 Tang Zhongming developed an automobile powered by charcoal, and these cars were popular in China until the 1950s. In occupied France during World War II, wood and wood charcoal production for such vehicles (called *gazogènes*) increased from pre-war figures of approximately fifty thousand tons a year to almost half a million tons in 1943.[5]

Purification and filtration

Activated carbon

Charcoal may be *activated* to increase its effectiveness as a filter. Activated charcoal readily adsorbs a wide range of organic compounds dissolved or suspended in gases and liquids. In certain industrial processes, such as the purification of sucrose from

cane sugar, impurities cause an undesirable color, which can be removed with activated charcoal. It is also used to absorb odors and toxins in gases, such as air. Charcoal filters are also used in some types of gas masks. The medical use of activated charcoal is mainly the adsorption of poisons, especially in the case of suicide attempts in which the patient has ingested a large amount of a drug. Activated charcoal is available without a prescription, so it is used for a variety of health-related applications. For example, it is often used to reduce discomfort (and embarrassment) due to excessive gas in the digestive tract. Animal charcoal or bone black is the carbonaceous residue obtained by the dry distillation of bones. It contains only about 10% carbon, the remainder being calcium and magnesium phosphates (80%) and other inorganic material originally present in the bones. It is generally manufactured from the residues obtained in the glue and gelatin industries. Its decolorizing power was applied in 1812 by Derosne to the clarification of the syrups obtained in sugar refining; but its use in this direction has now greatly diminished, owing to the introduction of more active and easily managed reagents. It is still used to some extent in laboratory practice. The decolorizing power is not permanent, becoming lost after using for some time; it may be revived, however, by washing and reheating. Wood charcoal also to some extent removes coloring material from solutions, but animal charcoal is generally more effective.

Art
Two charcoal pencils in paper sheaths designed to be unwrapped as the pencil is used and two charcoal pencils in wooden sheaths

Charcoal is used in art for drawing, making rough sketches in painting and is one of the possible media for making a parsemage. It must usually be preserved by the application of a fixative. Artists generally utilize charcoal in three forms:

- **Vine charcoal** is created by burning sticks of wood (usually willow or linden/Tilia) into soft, medium, and hard consistencies
- **Compressed charcoal** charcoal powder mixed with gum binder compressed into round or square sticks. The amount of binder determines the hardness of the stick. Compressed charcoal is used in charcoal pencils.
- **Powdered charcoal** is often used to "tone" or cover large sections of a drawing surface. Drawing over the toned areas will darken it further, but the artist can also lighten (or completely erase) within the toned area to create lighter tones.

Horticulture

One additional use of charcoal rediscovered recently is in horticulture. Although American gardeners have been using charcoal for a short while, research on Terra preta soils in the Amazon has found the widespread use of biochar by pre-Columbian natives to turn otherwise unproductive soil into very rich soil. The technique may find modern application, both to improve soils and as a means of carbon sequestration.

Medicine

Charcoal was consumed in the past as dietary supplement for gastric problems in the form of charcoal biscuits. Now it can be consumed in tablet, capsule or powder form, for digestive effects.[citation needed]

Red colobus monkeys in Africa have been observed eating charcoal for the purposes of self-medication. Their leafy diets contain high levels of cyanide, which may lead to indigestion. So they learned to consume charcoal, which absorbs the cyanide and relieves indigestion. This knowledge about supplementing their diet is transmitted from mother to infant.

Environmental implications

Charcoal production at a sub-industrial level is one of the primary causes of deforestation in the Developing World. Charcoal production is usually illegal and nearly always unregulated. Massive forest destruction has been documented in areas such as Virunga National Park in the Democratic Republic of Congo, where it is considered to be a primary threat to the survival of the mountain gorillas.

GLUE AND GLUING

There are many varieties of glue, ranging in price from twelve cents to fifty cents per pound. For general use, a good quality of glue can be purchased for twenty or twenty-five cents per pound. Previous to cooking, glue should be soaked in cold water till it becomes quite soft and pliable; the length of time required depends on the kind and quality of the glue: poor, cheap glue will nearly, and sometimes completely, dissolve in cold water; while good glue will require several hours' soaking; some kinds require to be soaked twenty-four hours or more, but such glue is not commonly used. When the glue has been soaked sufficiently, drain off what water remains, and set the dish holding the glue into a dish containing water, and set it over the fire to cook. The object of setting the glue-dish into water is to prevent the glue from getting scorched. The water cannot get hotter than 212°, which is not hot enough to injure the glue. To secure the best possible results, the following conditions must be complied with: namely, the glue must be of good quality and newly made; it must be of the proper consistency, neither too thick - or the two surfaces will not come together - nor yet too thin; the glue must be as hot as boiling water can heat it; the work must be properly fitted, and should be as warm as can be borne against the cheek: the room should be very warm, especially in gluing large surfaces, and veneering: the glue should be plentifully applied to both surfaces, and then the work should be clamped together firmly; and the clamps should not be taken off until the glue is hard, clear into the middle of the joints. Very large jobs of gluing should set two or three days before the clamps are removed. The consistency of the glue will depend somewhat on the kind of work to be done. For large surfaces, the glue may be quite thin, and plentifully used. For small work, the glue may be of thicker consistency; but it must be applied hot. For gluing wood endways, the ends should first be sized with a very thin coat of glue; when the sizing gets thoroughly dry. smooth the raised grain with a piece of fine sand-paper used over a straight stick; then coat each end with hot glue, and clamp firmly together; let it set over night, sure. In gluing boards together edgeways, many workmen do not bother to joint them both true, but depend on the clamps to force

them to a joint. If the glue is good, the work may hold together some time; but there is always a strain on the glue. Some spell of damp weather may soften the glue a very little, and open goes the joint. Of course, the glue gets the blame, instead of the workman, who deserves to be blamed. While many workmen make rubbed joints six feet or more in length, it is a bad practice: no joint longer than two feet ought ever to be merely rubbed together, and it is safer to apply clamps in every case. In veneering, put a thickness of newspaper between the veneer and the caul. This prevents the glue, which strikes through the veneer, from sticking the veneer to the caul. Some accomplish the same purpose by using sheets of zinc, which they rub with a piece of hard soap or wax. This is better than using paper, as it saves the labour of cleaning the paper off from the veneer.

To keep glue from smelling, take the dish holding the glue out of the dish containing the water, when done using, so as to let the glue get cold as soon as possible. Also do not keep the glue boiling all day long, but heat it only when it is needed. It is a good plan to make up only enough at a time to last two or three days, especially in the summer-time, so as to have it fresh and good. A piece of sheet-zinc, as large as will lay in the bottom of the glue-pot, will also greatly aid in keeping the glue from smelling. Some put in a little alcohol, but it is doubtful whether it does any good: it probably very quickly evaporates. Oil of cloves would be better.

TYPES OF GLUE

Animal glue

These are the oldest known glues and date back to at least Egyptian times and probably even earlier. They are produced by immersing the hides of animals (usually cattle) in hot water to extract the parent substance of hide glue -- collagen. This product is processed further to yield glue. One interesting note is that the same process with cleaner, stainless steel equipment is used to make gelatine, the ingredient in Jelly.

Hide glues are available in different gram strengths, with the best furniture glues being 135-250g. Gram strength does not imply bond strength, rather, the higher the gram strength, the more viscous the glue is when mixed with equal amounts of water. Lower gram strengths have longer open times. Hide glues must be mixed with water to form a jelly-like mass and then must be heated to be applied as a glue. Glue pots are available for this purpose, but a double boiler will work just as well. 140 - 160 degrees F is the optimum temperature. At temperatures less than 140 degrees the glue will start to gel.

Hide glue is the only glue that possesses the unique property of re-adhering to its self. This is important when repairing pre World War II furniture. Use hide glue and it will re-melt the old glue a form a new permanent bond. The most unique property of hide glue is that since it is a protein, it will absorb stains and dyes in a similar manner as wood. Consequently, any errant splotches of glue won't show up under the finish.

The downside of hide glue is that it is not particularly moisture and heat resistant. This disadvantage to one woodworker however can be viewed as an advantage to another. Violin makers use hide glue because these instruments need to be taken apart

periodically to be "tuned" and conservators and restorers of antiques prefer it for its reversibility. Another downside for most woodworkers is that it gels very quickly or, has a very short open assembly time. Cold dry weather accelerates this feature. The open assembly time can be extended by adding table salt or urea to the hot glue. Approximately 1/2 - 1 tablespoon can be added to each cup of dry glue prepared.

Polyvinyl acetate adhesive (PVA Glues)

These are the most common woodworking glues which can be divided further into two types - white and yellow glues. They are an emulsion of polyvinyl acetate resin in water and are inexpensive, nontoxic and easy to use.

White PVA Glues - White glues like Elmer's are often dismissed as poor glues for wood but they are just as strong as their yellow counterparts. On the positive side, they have a slightly longer open time which makes them good for complex assemblies like chairs and large panels. On the negative side, they are rather runny and do not sand well because they soften easily under heat. Yellow PVA Glues - Yellow PVA's were originally formulated to overcome the negative aspects of white PVA's and are as close to all-purpose woodworking glue as you can get. Some companies market a version of yellow glue that is coloured brown to be less noticeable on dark woods.

Yellow glues are really white glues that have been modified to have better woodworking properties. They are less runny because they are thicker and have higher solids content (the ratio of resin to solvent.) They sand better because the resin is harder and consequently doesn't gum up and clog sandpaper.

While yellow glues have a number of advantages, there are several disadvantages you need to take into consideration. They have a short open time of around five minutes so you have to work quickly. They also have a high initial tack which makes re-positioning very difficult. Also, these type of glues and the white varieties have poor creep resistance. Their elastic nature allows them to slowly stretch under sustained loads. This is a problem in bent lamination and load bearing assemblies like structural beams. What happens is that the glue is so elastic it will move, which results in eventual joint failure.

Cross-linking PVA's - These are the newest PVA's on the market and were formulated to overcome the biggest objection to normal PVA's which is their poor moisture resistance. Cross-linking glues pass industrial standards for water resistance and can be used on outdoor furniture and projects that come into contact with a lot of water vapour - like kitchen cabinets. They handle very much like the normal yellow PVA's with the only difference being that they are slightly thicker and a different colour.

Urea formaldehyde adhesive and Resorcinol Glues

These glues are unequalled in all around performance. They have excellent water resistance, good gap-filling properties, sand extremely well, clean up with water and have the longest open time of most glues, approximately 20 to 30 minutes. They are creep-resistant and are used extensively in structural assemblies, veneering and production furniture shops. The downside is that they require longer clamping time - usually up to 12 hours. They also are sensitive to temperature and do not cure at

temperatures below 21C or 70F degrees (18C or 65F degrees for Unibond, discussed below). They need to be carefully mixed in the proper ratio of resin to catalyst. The curing process releases small amounts of formaldehyde but this is a negligible amount.

Some woodworkers may find the fumes irritating so it's a good idea to use these glues in well- ventilated areas and wear gloves when using. My favourite Urea-formaldehyde glue is Unibond 800 and I use it exclusively in my veneering work. This glue is sold as a modified Urea -formaldehyde and comes packaged as a liquid resin which is mixed with a powdered catalyst. The distinct advantage of this glue is that it contains no water, which is beneficial in veneering large and complicated assemblies. The powder comes in several colours, white, tan and brown so that the hard glue will match the wood being glued. Another manufacturer, Weldwood, sells a UF glue called Weldwood Plastic Resin and the powder is mixed with water to activate it. This is an easy glue to use and is similar to glues used to bond plywood and structural beams. Don't use this glue for veneering - water makes the veneer curl. The glue can be coloured by the addition of water-soluble dyes.

Resorcinol formaldehyde glues like Weldwood, have exceptional water resistance and are used in marine applications. I don't usually use them on furniture, as the glue mixes to a dark, reddish glue line, but on hidden joints like mortise and tenons this would not be a problem.

Epoxies

Epoxy is the best choice for prolonged immersion or contact wit water, such as boats. They are solvent resistant, have low creep, do not shrink, have excellent gap filling ability and parts can be assembled without using clamps. They are generally available in 5 minute and slow-set versions, but the final cure can take anywhere from 24 hours up to a week. Uncured and gelled epoxies can be cleaned up with alcohol but I know of no chemical that will remove cured epoxy. The glue can only be removed by burning. For this reason epoxy should never be used on wooden pieces that may need to be dismantled at a later date. This includes repairs to antiques as well as musical instruments.

The major advantage of epoxies is that they do not lose bonding power when they are used for gap-filling. Other glues fail in this regard. Consequently epoxy is a good choice when you have to glue parts that cannot be made to fit precisely. Another application for epoxies is in gluing oily woods like teak, rosewood and cocobolo. I like epoxy for repair work -- the clear resin and hardener can be mixed with anything from sawdust to powdered pigments to blend the dried glue with the surrounding surface. Another aspect I like is that you can deliberately adjust the mixing ratio to achieve different cured resin properties. More resin will increase the hardness and tensile strength, while more hardener will increase the elasticity or the cured glue. Many manufacturers sell additives for epoxies. Anti- sag additives could be purchased to keep the epoxy from running before it is cured.

There are also fillers which will make the epoxy act like putty.

One note of caution -- most epoxies do not need clamps, but if it will be used, just enough pressure to bring the parts together should be used. The minimum thickness for an epoxy joint should be at least 5 thousandths of an inch thick, about double that required for other glues. The down side of Epoxy is that it is expensive, with some of the optical grades even more so. It is also toxic, and gloves must be worn when using. However, the cured bond is non-toxic.

Cyanocrylate Adhesives

Cyanocrylate or "super-glues" are relatively new glue for woodworkers. They cure instantly, form waterproof bonds and do not need clamping. They are widely used by wood turners and are invaluable for quick repairs to annoying problems like small cracks and slivers. The downside is that they can be expensive and the fact that they cure to an extremely brittle bond. This is bad where joints are placed under stress such as chair rungs and mortise and tenon joints. The joint will break apart easily with a sharp rap or knock. They are invaluable for repairs to small pieces of inlay and the thin varieties of these glues will actually wick into small cracks by capillary action. I use these glues every day. I find them invaluable for quick assembly of jigs and fixtures, and for repair work they are extremely versatile. One technique I find invaluable are small imperfections in the wood that I find during sanding of new furniture. I place a few drops of glue on the defect and then immediately begin sanding. The glue mixes with the sawdust to form an almost imperceptible repair. Don't do this on furniture that will be subsequently stained. You will never remove all of the glue and this will show up as an unsightly splotch under the stain. On furniture that will be unstained, this technique is fine.

Miscellaneous Glues

There are other glues that eventually crop up in discussion of woodworking glues, but I don't consider them capable of forming a permanent bond on wood. These include hot-melt glues which will temporarily attach pieces together for jigs and fixtures. Contact cements are sometimes recommended for veneering, but I would discourage their use since any of the glues above is better for this purpose. Contact cements are used for attaching plastic laminates like Formica to particle board, but do not find any other use for them in woodworking techniques.

It should be clear that matching the right glue to the job is one of the most important factors in choosing glue. There isn't one all-purpose glue for all woodworking jobs, so most shops keep several for different tasks. Because my shop does a lot of repair work, both on modern and antique furniture, I use almost all of the glues mentioned in the article. I use white and yellow PVA's and hide glue the most -- but invariably find uses for cyanoacrylates, urea-formaldehyde and epoxies. I prefer the slow-set epoxies because they form a more water-resistant, harder bond, and the parts can be repositioned before the glue sets. The five minute epoxies are handy for repair work where you need good gap-filling properties. If all you're doing is new furniture construction you can get by with the yellow PVA's. However, don't be led into the false assumption that some glues will make up for poor joints. Good glue joints are the result of a number of factors, beginning with good joint preparation.

NATURAL ADHESIVES

Animal Glue

These adhesives (often called "hot glue") are made from hides, bones, and other parts of cattle. These are applied hot to the pieces to be glued and, as the adhesives cool and lose their moisture, they become quite hard. The glue is supplied in flakes, which are soaked in water and then heated with additional water in the old-time glue pot. In addition, the wood must also be warm: cold wood can cool the adhesive too rapidly to permit a strong joint. The major drawback to these adhesives is their low moisture resistance. In the presence of moisture, the strength of the joint deteriorates.

Starch (vegetable) Glues

This is made from cassava starch in water, these adhesives can be available that can eliminate these disadvantages.

Other natural: Soybean and Blood Glue

These adhesives are similar to vegetable and casein and are used primarily for veneer gluing. Blood glues are quite moisture resistant due to natural phenolics.

Synthetic Adhesives

These adhesives are of two basic chemical types: (1) thermosetting, which require heat to cure, and thermoplastic, which undergo irreversible chemical curing reactions to produce the glue joint; and (2) those that do not chemically cure and, therefore, may soften with heat. The thermosetting adhesives often contain formaldehyde as a major ingredient (but the name may not include the word "formaldehyde"). Most thermosetting adhesives have catalysts added to control the speed of the curing reaction. Fillers can be added to control glue properties - for example, to make the adhesive thicker. Extenders can be added to reduce the amount of glue used (and therefore costs). Two other subgroups are emulsion, which is dispersed through a water system, and elastomeric, which remains elastic.

THERMOSETTING ADHESIVES

Urea, urea-formaldehyde. - This is one of the most popular woodworking adhesives, as it will provide moderate moisture resistance, colourless gluelines, and a wide variety of properties through multiple formations. Its chief disadvantage is that it is not good gap filler. In gaps, it will crystallize and crumble in time, so the joints must fit well. Although often cured in minutes at high temperature, it can be formulated to cure at room temperature.

Phenol - This dark red adhesive is usually cured above 250 degrees F and provides the most moisture-durable joint. Although expensive, it contains no moisture, and can be provided in a thin, dry film for gluing thin, fragile veneers.

Resorcinol and phenol-resorcinol - The resorcinol adhesives are similar to the phenols, but cure at low temperatures. As they are expensive, a formulation of phenol-resorcinol provides a lower cost adhesive that still has exceptional and desirable properties. They are used in exterior exposure conditions, including boat building.

Melamine - These adhesives, providing intermediate cost and performance could be applied hot or cold. They cure by loss of moisture. Prepared from powder mixed with water, they are usually very thick. Their chief advantage is the very slow curing rate although there is plenty of assembly time. Disadvantages include slight staining of the wood and poor moisture resistance.

Casein
A popular adhesive, casein is formulated from protein (curds) obtained from milk. It is usually supplied in powder form and mixed with water. It cures by evaporation of the water, so temperature is important. Its low cost, ease of use, good gap-filling properties, and moderate moisture resistance contribute to its popularity. Disadvantages include the tendency to stain wood, short working life, and dulling effects on knives when glued pieces are machined. Also, high density species often glue less well. However, recent improved formulations between urea and phenols, are seldom used alone, but rather are combined with urea adhesives to increase urea's moisture durability. Melamine-urea is suitable for radio-frequency curing.

Epoxy, cyanoacrylate. - These adhesives are usually too expensive for production woodworking - other adhesives (above) will provide the same performance.

Thermoplastic Hot Melts

These popular adhesives, using polyamides and polyesters (polyethylene and polypropylene, for example), cure by cooling, so care must be taken to assure that the joint is assembled before the glue cools. The fast cure rate, but easy handling, is their main advantage. They can be used to tack a joint together before the main adhesive has cured.

Thermoplastic Emulsion (PVA)

These adhesives come ready to use and set to a colourless glue line at room temperature by losing water. PVA (polyvinyl-acetate) is often called "white glue." Elmer's is one brand. The aliphatic resin glues (Titebond brand, for example) are yellowish, but still PVA. They have a high degree of tack (instant stickiness) with a wide range of application temperatures. These are suitable adhesives for furniture manufacturing and the home workshop alike.