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CHEMICAL RESEARCH AT U. S. FOREST PRODUCTS LABORATORY

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CHEMICAL RESEARCH AT U. S. FOREST PRODUCTS LABORATORY[1]

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The research and development personnel at the Forest Products Laboratory are in the fortunate position of having only one raw material. That raw material, of course, is wood.

But first, in order to convey to chemists and engineers the size of the forest products industries let me convert the usual production figures into tons and approach this using a material balance. The total timber input approaches 204,100,000 tons annually. This does not include bark but only wood substance. Bark would increase this figure by another 20,000,000 tons. These figures represent only timber cut and do not take into account the cull timber that needs to be removed from stands which are being logged.

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[2] Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

On the output side, the two main products, lumber and pulpwood, account for 52,000,000 tons and 39,000,000 tons, respectively. Fuelwood and mill residues used for fuel account for the major remaining amount of material--56,000,000 tons. The distribution of these products percentagewise, then, would be lumber 32 percent, pulpwood 24 percent, fuelwood 35 percent, and other products 9 percent. The unused logging and plant residues, which are of interest to the chemical industry as a raw material, amount to 51,000,000 tons. In addition to these unused residues, approximately 31,000,000 tons are used mostly at a low level so their value is that of the replacement cost of fuel.

Our research and development work starts back with the geneticist and the forester who are charged with the improvement and management of our timber stands. One of our important projects is the evaluation of the properties of the material being developed or being grown in the genetics and forest management program of the Forest Service. Wood structure and its relation to the end use of the material is under investigation. As a part of this program living trees are being treated with various chemicals for the possibility of inducing effects beneficial to wood quality.

The relation of wood properties to pulp properties is of extreme importance. The Forest Products Laboratory has established relations between southern pine growth characteristics, summerwood content, density, and sulfite pulp yield.

The old growth timber stands are being depleted and we are moving rapidly into a second-growth economy. As a result smaller sizes of lumber coupled with the need for more complete utilization have made the gluing of wood and wood-based materials extremely important. In 1956 gluing operations consumed 121,000,000 pounds of phenolic resins, 138,000,000 pounds of urea and melamine resins, and 42,000,000 pounds of vinyl resins. Not only are we able by gluing to obtain a higher utilization of the smaller pieces of wood, but we are able to combine pieces of different grades and species, resin modified woods, paper, particle boards, hardboards, plastic sheets and films, and metals. One of the major developments lying ahead is the engineering of these new composite wood products with superior properties.

Gluing is now essentially a secondary operation in the wood industry requiring rather extensive specialized equipment, careful technical control, and usually an involved batch process. We believe that in the near future the gluing of wood will become more of a primary operation in the mills producing the lumber. This will require more efficient gluing processes, lower cost glues, more versatile and durable but less critical glues, and preferably continuous gluing operations as are now used in corrugated fiberboard manufacture, book binding, and labeling. Examples are edge and end gluing of lumber into panels for easier installation, and laminating from 1-inch stock particularly the smaller more generally used sizes, such as 2 x 4's, 2 x 6's, and 2 x 8's.

The covering of lower grade but strong wood with veneers, paper, or plastic overlays to improve surface properties and appearances will continue to grow. Assembly of wood structures, such as glued trusses, prefabricated wall panels, and sandwich panels, require better and easier to use glues and gluing processes for wider use. For many of these applications of glued lumber as well as plywood, a single type of glued joint that is at least as strong and durable as wood itself would be desirable. Glued articles then could be used interchangeably with solid wood with complete confidence.

Some of the newer polymeric materials and adhesives being developed for entirely different uses such as hot melts for book binding or foil laminating may lead toward development of the new adhesives needed for broader utilization of wood through gluing.

In almost all uses, the moisture content of wood must be reduced to that level which it will attain when the wood is put in use. While our present methods are doing an excellent job the process is costly and time consuming. Such methods as solvent seasoning, vapor drying, and boiling in oil that involve removal of water by chemicals show some promise. A fundamental problem that warrants consideration is the treatment of green wood with chemicals that effectively increase its permeability. The "opened" structure would have a higher moisture-diffusion rate.

Associated with the problem of seasoning is the control of surface checking. Such hygroscopic chemicals as sodium chloride and urea are being used to a limited extent but not too satisfactorily. The hazards or difficulties caused by corrosion, condensation, and arcing in high-frequency heating for gluing are limiting a more general application of this technique. A low-cost chemical that does not cause discoloration or corrosion is needed. When green wood is treated with hygroscopic chemicals a vapor pressure difference can be created and yet keep the surface treated in a green or swollen condition. Drying then may occur without shrinking the surface layer with the result that the surface checking is minimized.

Two other possible approaches to the control of surface checking during the seasoning of refractory wood should be considered. One method would be to treat the green wood with an antishrink chemical so as to create a surface layer that has a decided reduction in shrinkage characteristics. A second method might be through the use of a coating. The surface areas of a green board might be roller coated with a fast-drying material that acts as a vapor barrier to control the steepness of the drying gradient in the hazardous area.

Two major problems stand out that tend to retard the use of wood as a construction material. The first of these is the shrinking and swelling of wood in use. We are all familiar with the sticking of doors, windows, and drawers. For special uses the wood structure can be impregnated with a water-soluble phenolic resin which for practical purposes will create dimensional stability. This is an expensive process because phenolic resin at 30 percent of the weight of the wood substance must be added, but last year 400,000 pounds of a 40 percent water solution of phenolic resin was used. The treatment of wood with 2 percent of formaldehyde produces an excellent stabilization but the catalyst needed for cross linking the cellulose chains reduces the abrasion resistance of the wood to the extent that the process is impractical. Such treatments as acetylation and cyanoethylation have been tried but again suitable catalysts, which do not impair the physical properties of the wood, are needed.

The second major problem is the protection of wood against fire. Wood in massive form has excellent fire resistance because of its strength and its self insulating qualities. The trend in wood construction, however, is toward thinner panels, sandwich construction, and light-weight trusses. All of these tend to decrease the overall resistance of the structure to rapid destruction by fire. There is, therefore, a need to find ways of giving wood products and wood structures greater protection from fire. Certain chemicals exert a strong influence on the combustion of wood. Information now available has been obtained empirically and some fire-retardant treatments have been developed. The known treatments, however, have limited use because of their cost, hygroscopicity, leachability, or poor paintability. Fundamental knowledge of the combustion of wood is needed so that this property can be modified by new inexpensive and effective fire-retardant treatments. More information is needed on the principle of intumescence; the formulation of more serviceable, weather-resistant fire-retardant paints; the development of non-leachable fire-retardant treatments for impregnating wood; vapor-phase flame retardants; relating existing action with chemical properties; and compounding superior flame retardants.

Much of the use of wood depends upon its painting and finishing. The painting characteristics of different species of wood, wood products, and modified and treated woods have been established as have the relations of design and occupancy of wood buildings to the performance of paints; and the bearing of paint composition, painting practices, and paint maintenance on paint service. The conditions essential for satisfactory use of paint on wood and many common causes of unsatisfactory experience, which have been revealed by the empirical methods of testing and observing paint performance, are becoming decreasingly productive despite much progress. Unsatisfactory forms of paint discoloration and premature paint failures continue to be widespread. Fundamental research on the chemistry and physics of paint aging and deterioration as well as the chemistry of wood weathering is in progress but much more is needed. Practically all exterior coatings on wood ultimately fail through loss of adhesion. One fruitful field for future research would be the development of chemical surface treatments of wood that would improve the adhesion to wood of exterior finishes both clear and pigmented.

Deterioration associated with fungus and insect attack of wood may arise during any stage in the manufacture of wood products as well as after the wood is placed in use. Control methods already developed have been notably successful in reducing losses that previously were tremendous. Even so the estimated annual loss in deterioration is still about one-half billion dollars, due in part to the lack of adequate preservative measures. Pentachlorophenol, the second most important preservative, is of relatively recent origin. Its initial commercial trials and later expanding use stem from the promise shown for such chemicals in early basic studies at the Forest Products Laboratory on chemical constitution in relation to toxicity of organic compounds to wood-destroying fungi.

There is great need for either new preservatives or types of chemical modification of wood substance that will immunize wood without imparting qualities that are hazardous or objectionable to humans. Promising results have been obtained by modifying the cellulose complex through cyanoethylation or by depleting minor nutritional elements in wood such as thiamin.

Present preservatives that are used for the protection of wood exposed to marine borer attack leave much to be desired. Various inorganic, metallic, and other preservatives have been tried but as yet none has proved preferable to the standard creosote or creosote-coal tar solutions. Of particular interest in improving present treatments are organometallic compounds that might be used alone or in combination with creosote solutions.

In recent years the deterioration of wood in industrial cooling towers has become increasingly important. Apparently a new type of fungus attack, which we call "soft rot", is largely involved, particularly in flooded parts of the tower. This rot, which we are studying at the Forest Products Laboratory, seems to be caused by fungi that heretofore were considered incapable of serious attack of wood. In efforts to maintain and extend the life of towers already in place more than 100 have been treated by the "double diffusion" process that was developed at the Forest Products Laboratory. The causal organisms are closely related to certain marine fungi that are gaining prominence in the deterioration of piling and other marine structures. It is conceivable that specific chemicals for the control of "soft rot" organisms may find further application in protecting marine structures.

Wood when in combination with other materials has been referred to as a composite product. Important developmental projects include those on honeycomb core material for sandwich construction, treated papers for laminating into plastics and for surfacing low-grade veneers, plywood, and lumber.

Sandwich construction combines high strength and stiffness with light weight, and promises to be an important structural material of the future. In house construction and the transportation industry the products that offer maximum economy coupled with desirable structural characteristics have facings of hardboard, plywood, cement asbestos board, or metals and cores of a resin-impregnated paper honeycomb. Research has led to the development of a mathematical design procedure for evaluation of sandwich constructions. The insulation value of the core might be improved by the addition of a synthetic foam that would fill the honeycomb cell.

The use of wood for the manufacture of insulating board, hardboard, and particle boards has expanded rapidly in the last 10 years. It has been estimated that 44 million pounds a year of thermosetting resins are used in particle board and hardboard manufacture. The cost of the binder in particle board now represents as much as half of the cost. The extent to which the board industry will develop is dependent upon more durable and more economical binder systems. In particle boards the binder for the particles is especially of great importance. Thermoplastics appear very promising.

About one-sixth of the lumber produced is now being used in packaging. A major weakness of the wood container is the fastening. Two new approaches to this problem are now being investigated. One involves the use of adhesives and the other plastic fastenings. The fact that a glue is excellent for bonding wood may not necessarily make it a good adhesive for containers. Very often a good adhesive produces an assembly that is very rigid. As a result it will fail under small impact loads because there is no elasticity to absorb shock. Plastic fasteners are an entirely new field but a thermoplastic nail has recently been developed. Plastic nails should produce a tough flexible fastening which might increase the rough handling absorbed by containers and wood structures.

Corrugated fiberboard is becoming of more and more importance in packaging. The component paperboard sheets are hygroscopic. Even though they may be bonded together with a water-resistant adhesive the boxes lose their rigidity with increases in moisture. This loss may be as much as 50 percent for a 10 percent increase in moisture content.

This adverse effect limits fiberboard containers in applications that involve humid wet conditions of prolonged storage.

While their use is restricted, pressure-sensitive tapes are being used in packaging. Improvement of the tapes should be approached from two standpoints--(1) the development of a pressure-sensitive adhesive that would reduce the creep or slippage under light constant pressures and have greater adherence of the tape to moist surfaces, and (2) the improvement of the backing material so that it might be used for outdoor structures. Polyvinyl backed tape shattered when it was used for such purposes at temperatures below freezing. A foil backing exhibited small pin holes or fractures at points of flexure.

Tests of materials that are used for shrouds or covers for outdoor storage have shown considerable room for improvement. The present materials, including polyethylene, do not stand up well under normal weather conditions or attack by rodents and insects. One large potential use might be in the shipment and storage of lumber. The handling of dry lumber could be greatly facilitated if it could be shipped in open cars.

Since World War II many cushioning materials have been developed. The characteristics of these materials are now being evaluated by dynamic and static tests instead of being chosen by arbitrary and empirical methods. The cushioning properties of any product should not change materially with temperatures between -60° and 160° F.

Up to this point we have been discussing the mechanical or structural uses of wood and modified woods. Of major importance in the program of the Forest Products Laboratory and to the forest industries is the chemical utilization of wood. The pulp and paper industry alone is now the fifth largest industry in the country and has been one of the most rapidly expanding ones.

One of the major objectives of the Forest Products Laboratory research program has been to improve the yield and quality of pulps from different wood species as well as the quality of the end products. Research includes basic investigations of pulping processes, bleaching processes, mechanical treatment processes such as beating, and the processes of paper and paperboard making. Much emphasis has been given to the development of new pulping processes suitable for the production of high-yield pulps from relatively small plant units having correspondingly low capital cost. The neutral sulfite semichemical process developed by the Laboratory about 1925, of special value for the pulping of hardwoods, returns some 65 to 85 percent of the wood as pulp. Originally this process was used only for corrugating pulp but subsequent research has shown that a good quality of bleached pulp for printing and bond papers may be produced.

More recently the Forest Products Laboratory developed the high-yield cold soda process for the pulping of hardwoods. Six mills in the

United States are now producing pulp by this process for use in printing papers and corrugating boards. A groundwood type of pulp can now be produced from wood residues by the cold soda process.

The penetration and diffusion of pulping chemicals into wood chips is a continuing problem in pulp production. Experiments with surfactants in the cold soda pulping process show promise that the brightening of the pulp may be improved. Economically feasible pulping chemicals less destructive to the carbohydrate fraction of wood than those now used would be of great value. It is essential, however, that the chemicals be economically recoverable from the spent liquors and that pollution by the effluents be avoided. Chemicals that would minimize the volume of water required for the production of pulp as well as any that would result in a recoverable lignin with more potential uses than those now obtained would be a maximum contribution.

Fabrication studies under way include improvement of the specific product qualities by the addition of resins, starches, latexes, waxes, and synthetic fibers. Admixtures of glass fiber with wood pulps have been shown to improve the dimensional stability of paper. Likewise treatment of paper with formaldehyde shows great promise in its dimensional stabilization.

The pulp properties of strength, color, and opacity are of major importance in their influence on product properties. For example, the color of pulp is responsible for the huge capital investment in bleach plants and the continuing consumption of bleaching chemicals. Pulp bleaching techniques and procedures used commercially are chiefly an empirical development. Positive identification of the residues of the noncellulosic components of wood and their reaction products present in wood pulps should lead to more efficient and simpler processes for the bleaching of pulps. The production of high brightness, high yield pulps without loss in yield is now unavoidable under the present techniques. A greater understanding of the difference between pulp types and their response to bleaching is needed. The quality of opacity critical in printing papers is augmented when necessary by the addition of pigments, usually to pulp before the paper is formed. The pigment is entrained mechanically and may be a limitation to its effectiveness. Deposition of the pigment within the fiber wall seems worthy of study as a means to improve paper opacity.

Despite the large number of chemical additives and impregnants now available for paper making and composite pulp and paper products, there seems to be continuing interest among the users and makers of these chemicals for further improvement.

Means to effect the orientation of fibers during formation of the wet web of fiber on the machine and also the strength of this wet web are subject to research. In hardwood pulps the fibers are characteristically short and the strength of the wet web is often critical in their use. Especially is this so in respect to the speed which the paper machine can be run. For hardwood, the most readily available pulpwood and the least costly, this factor is extremely important.

Paper strength both in the dry and relatively wet conditions is often critical in product use. The same is true for repellency to water and mineral and vegetable oils as well as receptiveness to printing inks.

With 20 million tons of bark available for processing to some useful commodity instead of using it as a fuel, research on bark extractives takes on added importance. The phenolic derivatives have a possible use as a component of adhesives, while the waxes have been utilized in giving dimensional stability to hardboards. Work is under way now on the isolation and determination of the organic constituents present in the 10 to 30 percent of extractives present in bark.

The conversion of wood residues to chemicals holds great promise. Basic studies on the kinetics of the prehydrolysis of wood, the conversion of xylose to furfural, the conversion of glucose to hydroxymethylfurfural and levulinic acid, and the action of hydrotropic solvents on wood have laid the groundwork for the development of processes for the utilization of this material.

Hardwoods contain approximately 7 percent acetyl groups, 20 percent pentosans, 45 percent hexosans, and 28 percent lignin. Softwoods contain approximately the same percentages except that the acetyl groups are lower and the pentosans about half and mannans about 20 percent. With hardwood chips or sawdust as the raw material, the products of an integrated chemical plant might be acetic acid, furfural, and hydroxymethylfurfural, or in place of the hydroxymethylfurfural, levulinic acid.

Fermentation processes are also a means of utilizing the sugars that can be produced from wood. Work on a very intriguing glycerol process is about completed through the laboratory pilot-plant stage. This process is a bisulfite steered fermentation producing glycerol, ethyl alcohol, acetaldehyde and sodium sulfate from glucose, sulfuric acid, and soda ash.

Another type of fermentation, that using osmophilic yeasts with slight aeration, will produce the polyols, erythritol, arabitol, and glycerol in good yields in solutions from which the polyols should be capable of being recovered economically.

This takes care of the fiber or cellulose portion of wood. The lignin is still an unknown factor. Our present research is aimed at developing means of separating lignin in a form in which it can be utilized in adhesives and plastics or converted to economically salable chemicals.

Again let me point out that the total timber input to the forest products industries is now in excess of 200 million tons annually. It appears that in the year 2000 the total consumption of the timber resource will more than double. Pulpwood is expected to more than triple. Except in the most desirable grades for veneer and saw logs no shortage of this renewable resource appears on the horizon.