

SOLVENT SEASONING OF REDWOOD

By Arthur B. Anderson and Charles B. Wilke

One of the problems associated with the manufacture of redwood lumber is the extremely long time required to dry it to a suitable moisture content. Current practice is to air-season heavy and medium segregation lumber for months to 30 to 50 per cent moisture content before kiln drying. The air-drying period may last 6 to 12 months, followed by 6 to 20 days of kiln-drying (8, 9, 11). If freshly cut 4/4 heavy segregation stock were put directly in the dry kiln, (a practice seldom followed), it would take about 30 to 35 days to dry -- or 26 to 27 days if using an accelerated dry kiln schedule (10). Resch and Ecklund have recently found that heavy 4/4 redwood stock could be dried in about 27 days, using 18 days of pre-drying and 9 days of kiln drying (13).

This long drying time, the longest for any commercial softwoods, requires storage of large quantities of redwood lumber in air-drying yards and thus necessitates a large capital investment (13). Among the major drying defects associated with heavy segregated redwood stock are end-checking, collapse, honeycomb, casehardening, and chemical seasoning stain (2, 3, 10).

The Solvent Drying Process

The California Redwood Association asked the University of California's Forest Products Laboratory to investigate drying of heavy segregated redwood lumber using the solvent-drying process (5). Objectives were to determine and compare the drying schedules of this special seasoning method and the presently used drying procedures. Degree of seasoning defects and commercial feasibility were also studied to a limited extent.

The solvent-drying process involves the use of certain water-miscible polar organic solvents to remove water from green lumber (16, 17). Green lumber is stacked vertically in a vapor-tight extraction chamber and a heated water-miscible solvent, such as acetone, is circulated over the lumber. As hot solvent passes over the lumber it extracts water and removes it in solution with the solvent. When sufficient water has been extracted the solvent in the lumber, which largely replaces the water, is removed by circulation of hot air or inert gases over the lumber, followed by a short steaming period. Since acetone has a much higher vapor pressure than water, the solvent removal and recovery period usually involves only a matter of hours. Solvent is recovered from the gases by condensation and absorption. The effluent of solvent and extracted water is distilled for solvent recovery and re-use. Extractive components removed from lumber during the extraction period remain in the aqueous fraction resulting from the distillation. The type and quantity of extract recovered as a by-product will depend upon the species of lumber being processed (1, 5, 17).

Ponderosa pine 4/4 green heartwood stock could be dried in about 18 hours when using acetone as the drying solvent (17), as compared to 72 to 104 hours in dry kilns (12). With 4/4 tanoak sapwood the dry-kiln schedule requires about 14 days, while solvent-drying involves only 30 hours (1).

It is apparent that the solvent-drying process is much faster than kiln-drying. Considerable up-grading results when the lumber is solvent dried, because the stock is relatively free of the seasoning defects encountered in normal dry-kiln practice (1, 5, 17). Additionally, solvent-drying process costs do not seem prohibitive (17).

Solvent Drying of Redwood using Acetone

Acetone was the first solvent investigated in the drying of redwood (5). The pilot unit used in this investigation has a capacity of about 200 board feet and handles boards up to 6 feet long (Figure 1).

Preliminary runs indicated that board position in the extraction chamber, whether vertical or horizontal, had no material effect on rate of water removal during the solvent-extraction cycle. These initial runs also indicated that it was more convenient to run the extraction cycle with boards placed horizontally and immersed in the solvent.

Before starting a run in which continuous counter-current conditions were to be simulated in the batch extractor, an operating line was plotted. This was prepared by calculating (by means of a material balance) the moisture content of solvent that would correspond to a given moisture content of the wood, i. e., equilibrium data (1, 5). Although, solvent concentration would, ideally be adjusted continuously to just below the operating line in order to maintain a driving force, in practice it was found that better control was obtained if this was done intermittently. Solvent additions were made at 2-hour intervals for the first day and subsequently at intervals of 4 hours. Conditions were controlled so that at the beginning of the fixed hour the concentration of the water in the solvent would be below that dictated by the operating line, and at the hour when conditions were to be changed the water content would approach, or be at, the operating line.

The general procedure was as follows: ten to twelve freshly-cut 4/4 heavy segregated redwood boards were selected and samples taken for moisture content. The boards were then cut into 6-foot lengths, a 1/4-inch hole drilled about 6 inches from each end of each board, and the boards were then weighed. An aluminum bolt was passed through each hold and 1/4-inch thick aluminum washers were placed between the boards to separate them in order to expose all their surfaces to solvent during the extraction cycle. Each of the two 5- to 6-board packaged units were lowered into the extractor in horizontal position, and the lid of the extractor was then secured.

Acetone was pumped into the bottom of the extractor until the boards were immersed in solvent and the solvent was heated to near its boiling point (130-132°F) by means of immersed heating coil located at the base of the extractor. Solvent was circulated (40 gallons per minute per M bd. ft.) and the rate of water removal from the green stock was obtained by determining the specific gravity of the circulating solvent at various intervals. Periodically, a portion of the solvent mixture in the extractor was pumped as effluent to the recovery still, and an equal quantity of fresh solvent was immediately added to the extractor. By recording the amount of water removed the average moisture content of the lumber charge at any time could be readily determined. When the moisture content of the boards reached about 10 per cent (dry basis) circulation was stopped and all solvent in the extractor was pumped to the recovery still.

The next step was to remove solvent picked up by the boards during the extraction cycle. The solvent-removal cycle was carried out by applying heat to the unit heater and starting the blower, both of which were placed in the external duct, the inlet and outlet of which were connected to the top and base of the extractor (Figure 1). The circulation rate was 1,150 cubic feet per minute. The solvent vapors removed were condensed and recovered.

The maximum temperature reached during this period was about 190°F. When most of the solvent had been removed, saturated steam was blown into the extractor chamber to accelerate removal of residual acetone and to displace the solvent vapor remaining in the system. When the solvent-removal cycle was completed the boards were removed from the extractor and weighed, and their moisture and residual solvent contents were determined (5). The quantity of extract recovered in the various runs was also determined.

Runs were made using various quantities of fresh solvent. Here it is assumed that, in a commercial unit, wood and solvent would come in contact in a continuous counter-current or cascade counter-current operation. Final moisture content of the wood was chosen as 10 per cent (dry basis); the dry acetone feed concentration was 2 per cent of water (weight basis). By making a material balance the

concentration of water in the acetone corresponding to a given moisture content of the wood could be calculated. The ratio of dry acetone to dry wood has been termed the "solvent-operating ratio." An operating ratio of three (3) would then mean that conditions were simulated in which 3 pounds of dry acetone would come in contact with 1 pound of dry wood in a continuous counter-current manner.

Table 1 shows the results from a number of runs; Figure 2 shows three typical drying curves for 4/4 heavy segregated redwood.

Table 1

Solvent Drying of 4/4 Redwood with Acetone

Run	Green MC (%)	Solvent-operating ratio	Time of extraction (hrs)	Calc. Time to 10% MC (hrs)	Solvent recovery cycle (hrs)	Final* MC (%)	Acetone retention (%)	Extractive recovered (lb/MBF)
1	221	2:1	212	254	15	15.5	1.0	95
2	206	3:1	211	235	15-1/2	12.4	1.7	80
3	223	4:1	193	198	19-1/2	11.6	1.3	87
4	205	6:1	159	170	23	10.3	0.8	68
5	128	6:1	132	120	14	7.8	0.8	64

*Corrected for acetone content

These results show that drying time for a given green lumber moisture content is dependent on pounds of fresh solvent used per unit weight of redwood, i. e., solvent-operating ratio; the more solvent employed the faster water is removed from lumber (compare runs 2 and 4, Table 1). When 3 pounds of acetone per pound of redwood were used during the extraction cycle, 235 hours were required to bring the stock down to 10 per cent moisture content; when 6 pounds of acetone per pound of redwood were used, this was reduced to 170 hours.

As expected the time required for a given solvent-operating ratio and extraction temperature to bring the stock down to 10 per cent moisture content is determined by the moisture content of the green lumber charged into the extractor. Stock having 128 per cent moisture content required about 120 hours to dry to 10 per cent, while stock having 205 per cent moisture required 170 hours (runs 4 and 5, Table 1). A solvent operation ratio greater than 7 did not shorten the drying cycle.

The fundamental variables governing the rate of diffusion of water from the wood into the acetone are the water content of the acetone surrounding the board, the moisture content of the board, and the temperature of the system.

The most economical procedure will have to be determined, taking into account solvent-to-wood ratios or solvent-operating versus time.

Solvent Pick-up in Lumber during Solvent Extraction Cycle

The extraction of water from green lumber with acetone is accompanied by diffusion of acetone into wood. Solvent retained in the lumber after the extraction cycle is removed by passing hot air or

inert gases over the boards; this is followed by a short steaming period. Steaming accelerates removal of acetone during the last stages of solvent removal.

The volume of acetone in the boards at the end of the extraction cycle has been calculated for several runs (5). These values have been compared to calculated values of the water actually removed during the run, and results are shown in Table 2.

Table 2
Acetone Pick-up during Extraction Cycle

Run No.	Gallons of water removed per 100 lbs. of redwood	Gallons of acetone pick-up per 100 lbs. of redwood
51	21.2	21.1
59	16.7	17.7
63	24.0	23.2
64	23.3	23.2

As the volume of acetone recovered is comparable to volume of water removed during the extraction cycle, it appears that as water diffuses from wood it is replaced by about the same volume of acetone (5, 12). Therefore, extraction of water from green redwood by means of solvent appears to be an equi-volume counter-diffusion process.

Solvent Removal Cycle

The flow pattern of carrier gas, its rate of flow, and its temperature should affect the removal of solvent retained in boards at the finish of the solvent extraction cycle (5). Results indicated that the major resistance to acetone removal lies in the diffusion rate from within the lumber, so that as long as a sufficient excess of air, inert gas, or stream is supplied, the solvent removal rate depends only on the acetone content of the boards and the temperature of the system. Obviously, this relationship will no longer hold at sufficiently low air and steam rates.

At a maximum temperature of 190°F. results indicated that all of the solvent picked up by the boards could be removed from the lumber in about 14 to 15 hours, with solvent retentions in the lumber being around 1 per cent (dry basis). These results indicate the order of magnitude of the acetone removal cycle and are not necessarily optimum conditions.

Extractives Recovered as Silvichemical By-product

The solvent-drying process now makes available various silvichemicals as by-products, the amount and chemical nature of which are naturally dependent on the species of lumber processed. With redwood, the quantity of extract varied from 64 to 95 pounds per MBF, or 3.2 to 4.7 per cent yields based on dry weight of the wood. The amount of extractives recovered depends on the amount of extract present in the green lumber, and on the operating conditions used during the extraction cycle.

Recovered redwood extract contains mainly, tannins, phlobaphenes, and cyclitols, and these are being investigated and evaluated (3, 4). Should such products have commercial value additional quantities could readily be obtained by using effluent from the extractor to extract redwood residues in another extractor before the solvent is recovered for re-use.

Seasoning Defects

The solvent-dried stock was relatively free of honeycombing, collapse, case hardening, and end-checking. While freshly surfaced boards were lighter in color than kiln-dried stock, solvent-dried material approached the normal color of redwood after short exposure. Further, solvent-dried stock minimizes the chemical stain problem and tests indicated that solvent-dried redwood still retains its well-known durability properties (2, 6).

Solvent Drying of Redwood using Methanol

Solvent-drying runs using methanol were carried out in a smaller drying unit (14). The extraction chamber consisted of a stainless steel pipe 6 ft. long by 8" in diameter of 1/8" wall thickness placed in a vertical position. The schematic representation of the equipment is shown in Figure 3.

Two or three 4/4 heavy segregated redwood heartwood, 4 ft. long and 5 in. wide were used in each run. The boards were immersed in methanol, and the temperature maintained at 144-146°F. during the extraction cycle, with a solvent circulation rate of 2 gallons per minute. Runs were made at various solvent operating ratios as previously described. When the boards reached 10 per cent moisture content, solvent was pumped from the extractor and the solvent-recovery cycle started, with an air circulation rate of 100 cu. ft. per minute at a temperature of 200°F. The results are summarized in Table 3.

Table 3

Solvent Drying of 4/4 Redwood with Methanol

Run	Green M C (%)	Solvent operating ratio	Conc. of methanol (%)	Time of extraction (hrs)	Solvent recovery cycle (hrs)	Final MC*		Methanol retention (%)	Extractives recovered (lbs/MBF)
						Calc.	Found		
2	203	3:1	42-98	143	14 1/2	8.0	7.5	0.8	160
4	195	5:1	59-98	119	14	8.0	7.0	1.0	151
6	192	7:1	73-98	100	14	10.0	5.5	1.3	110

* Corrected for methanol content

As in the acetone runs, it is apparent that as the solvent-operating ratio increases, the time required to remove the water decreases. With a solvent-operating ratio of 3, an extraction cycle of 143 hours brought the boards down to 7.5 per cent moisture content, while a solvent-operating ratio of 7 brought the boards down to 5.5 per cent moisture content during a 100-hour extraction cycle (Figure 4).

It is estimated that with a solvent-operating ratio of 5, the extraction cycle with acetone would be about 180 hours, while methanol would require only about 100 hours to bring the stock down to 10 per cent moisture content. It is apparent that methanol is substantially superior to acetone in rate of water removed from redwood.

The solvent-removal period required about 14 hours to recover the methanol from the lumber, which is about the same time noted for removing acetone, and the solvent retentions were around 1 per cent (dry wt. basis).

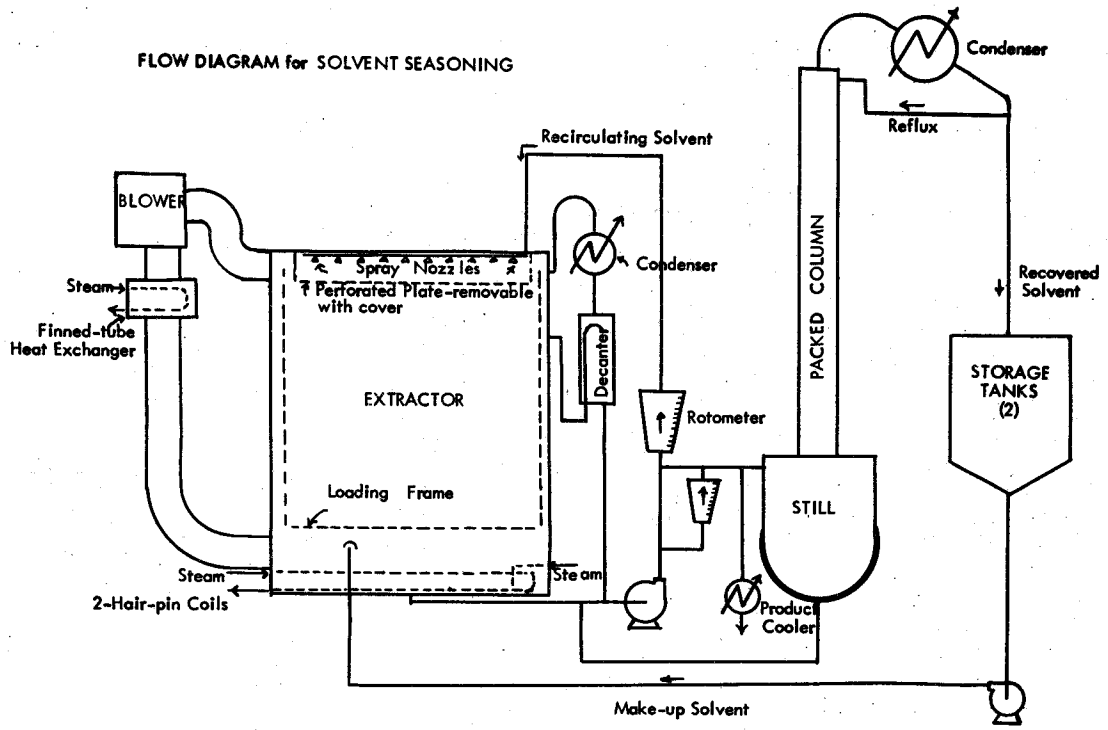


Figure 1

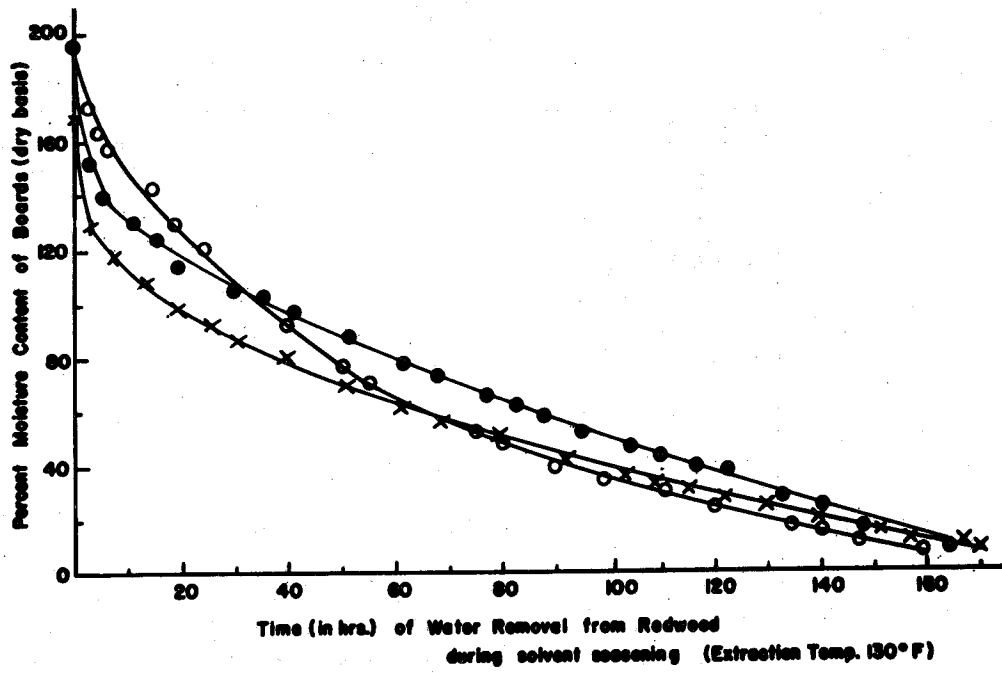


Figure 2

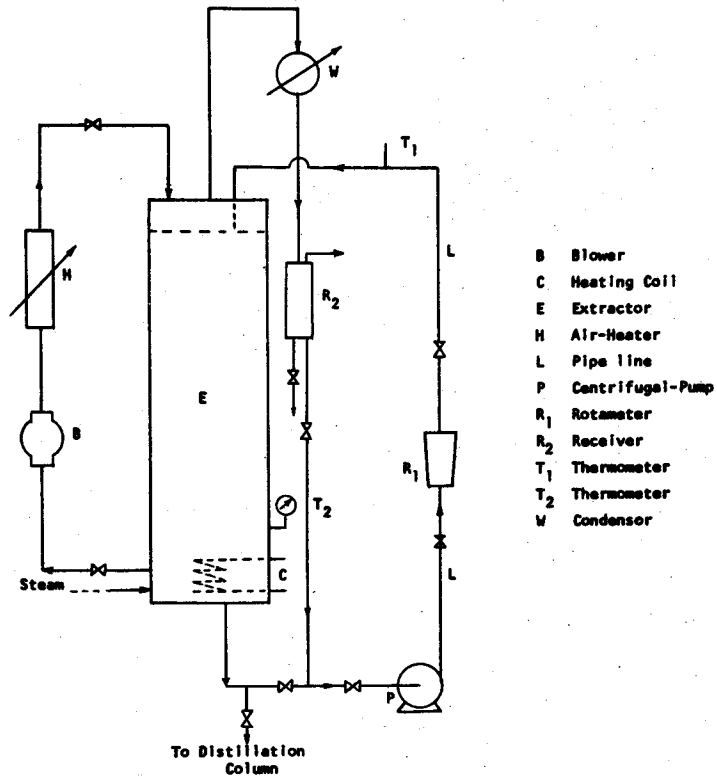


Figure 3. Schematic Diagram of Equipment

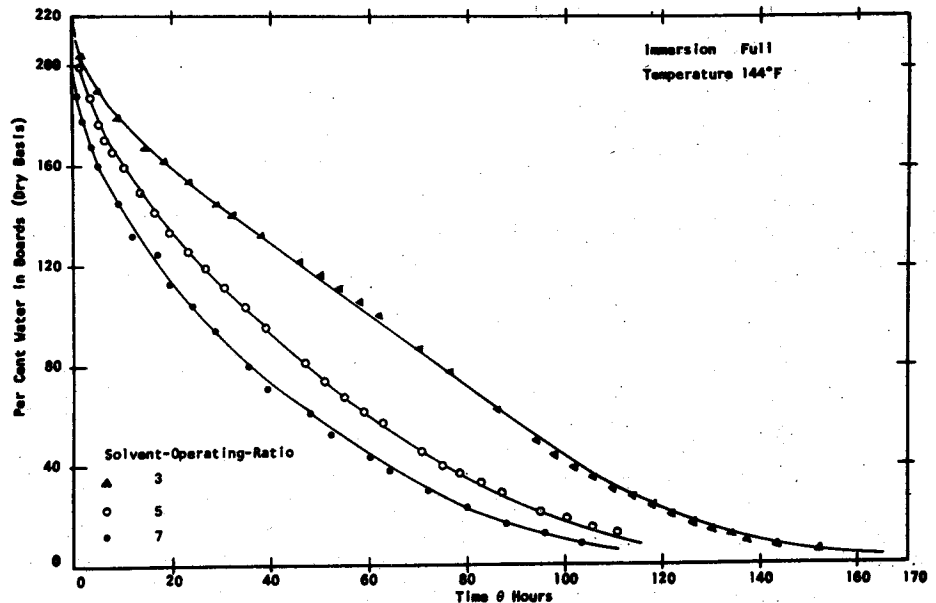


Figure 4. Extraction of Water from Redwood with Methanol. Effect of Varying Solvent Concentration

The quantity of extract recovered with methanol varied from 110 to 160 lbs per M B F -- somewhat more than when acetone was used as the drying solvent. The same freeness from seasoning defects was noted.

Summary

These investigations indicate that 4/4 heavy segregated redwood lumber of 200 per cent moisture content can be solvent-dried to an average of 10 per cent in about 195 hours using acetone as the drying solvent, and 115 hours using methanol, including extraction and solvent-removal cycles. These solvent-drying schedules are considerably shorter than the months required to dry redwood by conventional practice and the 25 to 27 days required by accelerated kiln-drying schedules.

The solvent-dried lumber is relatively free from the honeycombing, collapse, end-checking and case hardening associated with procedures now used in seasoning redwood lumber. While freshly-surfaced solvent-dried boards are lighter in color than kiln-dried stock, solvent-dried material approaches the normal color of redwood after short exposure. Further, the solvent-dried stock showed no chemical stain on subsequent storage and exposure.

The solvent-drying process makes available, for the first time, various silvichemicals as by-products from lumber. The yields of extract from solvent-dried redwood amounted to 64 to 160 lbs. per M B F and they are a potential source of income. Should these chemical extractives prove to be of value, considerable additional quantities could be produced by integrating an extractive unit to extract redwood plant residues with the solvent-drying plant. The extraction of redwood chips, for instance, would produce around 300 pounds or so of extract per ton of chips (14). Extracted chips would be more suitable for pulp and fiber products than unextracted chips. Also, redwood bark is very rich in extractives and a potential source of additional silvichemical products (4).

Drying Costs

The estimated costs in drying redwood lumber have been reviewed recently (13). These costs may be briefly summarized as follows:

<u>Method</u>	<u>Cost per M.bd. ft.</u>
Air-seasoning followed by kiln drying	\$14.58
Kiln drying (27 days)	21.65
Pre-drying (18 days) plus kiln drying (9 days)	17.67

The initial investment in kiln construction and equipment was estimated to be \$100,000 for a 100 M bd. ft. capacity kiln, which on a 27 day kiln schedule would produce 3.7 M bd. ft. per day.

It was estimated that a pre-drier would cost about \$65,000 for a 100 M bd. ft. capacity drier which, on an 18 day schedule, would produce 5.5 M bd. ft. of pre-dried lumber per day.

A preliminary economic evaluation was made for solvent-drying of redwood lumber using acetone as the solvent (15). It was based essentially on a preliminary design to season 16 M bd. ft. of heavy segregated 4/4 redwood from 200 per cent to 10 per cent moisture content per day. The design was based on a continuous counter-current extraction system using acetone at a solvent-operating ratio of 5 to 1, consisting of a 186 hour extraction cycle followed by a 14 hour solvent-recovery cycle, i. e., total 200 hour schedule. The total capital investment for such a unit was estimated to be about \$252,000. Production costs, including indirect costs, utilities, labor, and solvent, amounted to \$21.96 per M bd. ft.

Again, the design is subject to limitations of the data obtained to date and is subject to further optimization. If light, medium, and heavy segregated redwood were solvent dried further reduction in cost would result. The solvent-drying cost here is comparable to the estimated cost of drying heavy segregated redwood in dry kilns involving a 27 day drying schedule.

The seasoning loss due to end-checking encountered during air-seasoning has been estimated to range between \$3.90 and \$10.50 per M bd. ft. (13). The average seasoning loss has been estimated at 5 per cent or \$6.25 per M bd. ft. based on \$125/M bd. ft. rough green price (7).

While no detailed grading study was made on solvent-dried redwood, very little end-checking, collapse or honeycombing was observed during the many solvent-seasoning runs. This would indicate that solvent seasoning losses would be at a minimum, which is equivalent to a gain of \$6.25 per M bd. ft.

If this saving were applied to solvent-dried lumber, the production cost would be \$21.96 - 6.25, or \$15.71 per M bd. ft. This cost approaches the minimum drying cost of \$14.88.

Since acetone drying removes 75 to 90 lbs. of extract per M bd. ft. the reduction in weight could make a difference of up to \$1.47 per M bd. ft. on lumber going to the east coast (7). This is another benefit derived from solvent-dried stock.

Several uses have been proposed for recovered extract, and its value has been estimated at from 6 to 20 cents per pound, depending on end-use. At minimum value, the 75 to 90 pounds of extract recovered per M bd. ft. would amount to \$4.50 to \$5.40.

To summarize, the value gained per M bd. ft. of acetone-seasoned redwood stock is estimated to be:

	<u>Value/M bd. ft.</u>
Seasoning upgrading	\$6.25
Freight saving	1.47
Extract	<u>4.50</u>
Total	\$12.22

If such values are valid in appraising the over-all economics of the solvent-seasoning process, it is necessary to find the exact amounts of values accruing to the process, and not the rough estimates given here.

The production cost given is based on acetone as the solvent on drying 16 M bd. ft. of redwood per day. As plant capacity increases, capital investment generally decrease per unit of daily capacity. As shown in this report, methanol is superior to acetone in reducing extraction time from 186 to 100 hours -- a 46 per cent reduction which should lower production cost. Methanol, less costly than acetone, removes more extractives -- from 110 to 160 pounds of extract per M bd. ft.

The economics of solvent drying of redwood with methanol are presently being investigated. It is also planned to carry out solvent drying with methanol at higher temperatures (pressure), to determine any further reduction in over-all drying schedules. The use of other solvents is also planned.

Acknowledgments

The authors are grateful to the California Redwood Association for sponsorship in the form of grants-in-aid, and to the Oronite Chemical Company and the Hercules Powder Company for supplying the acetone and methanol, respectively.

Literature Cited

1. Anderson, A.B. and W.B. Fearing. 1960. Solvent seasoning of tanoak. For. Prod. Jour. 10:234-238.
2. Anderson, A.B., E.L. Ellwood, E. Zavarin and R.A. Erickson. 1960. Influence of extractives on seasoning stain of redwood lumber. For. Prod. Jour. 10:212-218.
3. Anderson, A.B. and W.B. Fearing. 1961. Distribution of extractives in solvent seasoned redwood lumber. For. Prod. Jour. 11:240-242.
4. Anderson, A.B. 1961. The influence of extractives on tree properties. 1. California redwood (Sequoia sempervirens). Jour. Inst. Wood Sci. 8, 14-34.
5. Anderson, A.B., W.B. Fearing and C.R. Wilke. 1962. Solvent drying of California redwood. For. Prod. Jour. 12:493-496.
6. Anderson, A.B., C.G. Duncan and T.C. Scheffer. 1962. Effect of drying conditions on durability of California redwood. For. Prod. Jour. 12:311-312.
7. California Redwood Association, communication.
8. Clausen, C.H. 1953. Air seasoning of California redwood. J. For. Prod. Res. Soc. 3:283-288.
9. Dost, W.N. 1956. Air drying of California redwood. California Redwood Association Resp. Report 3.21411 H.
10. Ellwood, E.C. and R.A. Erickson. 1962. Effect of presteaming on seasoning stain and drying rate of redwood. For. Prod. Jour. 12:328-332.
11. Johnson, P. 1958. Time schedules for kiln drying heavy segregation redwood lumber. California Redwood Association Res. Rept. 3.22120A.
12. Rasmussen, E.F. 1961. Dry kiln operators manual. U. S. D. A. Agric. Handbook 188.
13. Resch, H. and B.A. Ecklund. 1964. Accelerating the drying of redwood lumber. Calif. Agric. Expt. Sta. Bul. 830, University of California.
14. Seth, K.K. 1964. Solvent seasoning of redwood. M.S. Thesis, University of California, Berkeley.
15. University of California, Forest Products Laboratory, unpublished report.
16. U.S. For. Ser. 1961. Special methods of seasoning wood. Solvent seasoning. U. S. For. Prod. Lab. Rept. No. R-1685-2 (Rev.)
17. Western Pine Association. 1960. Solvent seasoning. Res. Rept. No. 4.312 (Rev.) Portland, Oregon.