PROCEEDINGS

Sixty-Fifth Annual Meeting

of the

AMERICAN WOOD-PRESERVERS' ASSOCIATION

Denver Hilton Hotel, Denver, Colorado
April 28, 29 and 30, 1969

◆

VOLUME 65

◆

AMERICAN WOOD-PRESERVERS' ASSOCIATION
1012 FOURTEENTH STREET, N. W. • WASHINGTON, D. C. 20005

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Pilot Plant Evaluation of Shock-Wave Pressure Treatments

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Sharp faced, repetitive, hydrodynamic shock waves applied in a pilot pressure cylinder charged with commercial white stock to facilitate preservative treatment is reported as one of the first significant "in cylinder" modifications of the wood preserving process in about 50 years. Pressure cycles may be reduced to 1/6 or 1/20 of the time used in present commercial practice, depending on conditions. A transducer for generating shock waves of adequate energy level and wave-form is described.

Introduction

The porous structure of seasoned wood has long been accepted as fact, and on this concept methods of impregnating it with preservatives, and other liquids, as developed by Bethel (1), Lowry (2) and Reuping (3), have been practiced commercially in this country since about 1900. The common factor in all of these methods is the use of hydraulic pressure, and all are characterized by the need for slow up-pressure programming and of long pressure pumping cycles to obtain adequate retention and penetration of the preservative liquid.

Service records on pressure treated wood, as reported in the Proceedings of the American Wood-Preservers' Association in 1966 and prior years, show that the results from these conventional treatments are satisfactory. The need for shortening the treating cycle, however, is self-evident and has been the object of research by many investigators. One of the more recent methods was proposed by Hudson and Henriksson (4) and was based on pressure oscillations, basically of sine wave form.

Studies on the micro-structure and ultra structure of wood (5) using the Electron Microscope show that wood is not a simple porous material. Its behavior under treatment follows the presence of bordered pit pairs in some species, simple bordered pits in others, which act as check valves, blocking to some extent the flow of liquid into the structure. Occluded pressure may be locked also in the treated wood, even after exposure to high vacuum. Dr. M. S. Hudson has suggested that resistance to flow in wood involves a deferent mechanism, and his thesis may have merit (6).

In 1960 Robert Z. Page and Benjamin E. Reed observed a movie of a creosoted pile being driven by a sonic pile driver. It was an electrically activated sonic device, capable of being tuned to the fundamental resonance of the pile. As the pile resonated, it showered creosote over the area. They reasoned that if the pile could be made to eject preservative so effectively and dramatically, wood under similar exitation should absorb preservative, if under pressure, at an accelerated rate. They devised a series of tests in a very small pressure vessel and found that sharp faced, repetitive shock waves would accelerate absorption and determined the level of energy needed (7).

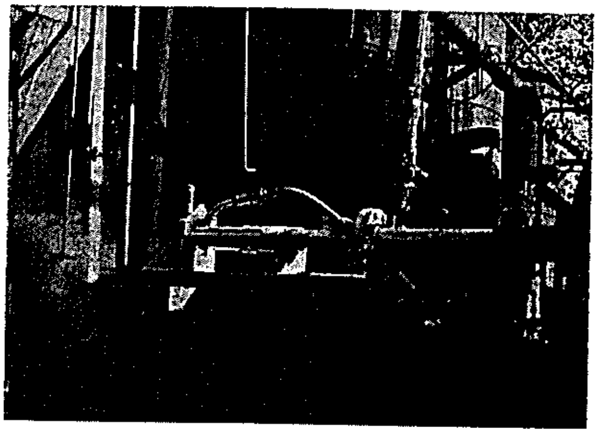

Figure 1.

The pilot equipment used here required a transducer through which a pavement breaker air-hammer could efficiently deliver its energy to the charge of wood in the form of a train of sharp faced shock waves, having longer trailing decay waves (8). (See Fig. 1)

Theory

Page and Reed theorized that the success of shock waves in wood treatment is due to acceleration of a column of liquid in the wood pore, causing it to penetrate much as a straw may be driven into a wood structure by the high velocity winds of a tornado.

Another theory envisioned that the shock wave travels by fluid connection into the channels of the wood, and compresses the whole wood structure by force on those parts of the wood surface where no pores exist.

The compression wave seemingly travels through the wood at a slower rate than the hydraulic shock wave travels through the wood pores.

The fast moving liquid in the wood pore, accelerated by shock wave energy, would force a fine spray of oil through the minute openings in the cell walls, over-riding surface tensions and other restraining forces. The spray droplets would first behave as an "oil in air" suspension, quickly coalesce and occlude the air into an "air in oil" emulsion, much as water behaves when it is drawn from a kitchen tap that is equipped with a very fine screen at its outlet. Such a device causes the drawn water to appear as a frothy, bubbly liquid.

If the compression wave, which travels slower, should squeeze the cell walls after the impact of the shock wave had passed, some of the frothy oil-air mixture would be forced back into the cell from which it originally came, or possibly the flow is reversed by pneumatic rebound.

The reversal of flow would be expected to open the pit membranes momentarily, and in the process slam them open and shut repeatedly, until margo filaments should either be over-stressed, or fatigued, to the point that the torus would be displaced, no longer capable of acting as a check valve.

While shock waves seemingly are active in depths well below the penetration requirement established by existing specifications, it is obvious that as a shock wave treatment progresses, the length of the capillary wood pore becomes greater. Finally, at some depth in the wood, the sharp crack of the shock-wave is dulled. It then would lack the "punch" adequately to condition the pit membrane check valves. Thus, shock-wave treatments can emerge with occluded pressure in the center of the piece of wood beyond the hydrodynamic depth of the shock waves. (However, we have observed that the occluded pressure may be relieved if the shock waves are continued after the pressure pumps are shut down, and the transducer permitted to run until the pressure falls to about 60 psi. This process is called "hammer down".)

This theory is supported by the absence of "bleeders" after treatment by shock wave method. While we have not found any bleeders in the pole charges we have treated, we are not ready to say that we have solved the bleeding pole problem, however.

All of this theory spells out a shock-wave induced "excited state" in the wood, causing it to act much as a standard porous material instead of a material where each cell is to some extent blocked by a check valve.

Fortunately, it is simpler to demonstrate the effectiveness of shock waves in pressure vessels than it is to elucidate a theory that adequately will explain the results of treatment under shock wave excitation.

Equipment and Materials

The pilot plant installation used in these treatments is located at the Southern Wood Preserving Company, East Point, Georgia. The cylinder is three feet diameter and 26 feet long, all welded steel. It served originally in the plant of the Western Union Telegraph Company, Chattanooga, Tennessee, later as a pilot unit at the Taylor–Colquit Company in Spartanburg, South Carolina.

The shock wave generating transducer was designed for this cylinder for operation optimally at 200 psi and is attached through a flanged nozzle located in the rear dished head on the horizontal axis. It is comprised of a free piston which travels in a cylinder maintained in fluid connection with the pressure vessel. The force of hydraulic pressure in the vessel pushes the piston against a striker pad, which in turn rests on a bias spring, compressing it until the opposing force from the spring balances the force from the liquid in the vessel. In the pilot transducer these opposing forces are estimated to be 1190 lbs. at 200 psi in the vessel. When the two forces are equal, the free piston is held immobile at "top dead center" ready to receive its blow from the pneumatic pavement breaker hammer, by way of a striker rod and the striker pad.

Since the free piston is held in balance between two opposing forces, the hammer blow never sees the 1190 lb. force resulting from the hydraulic pressure in the vessel, but sees only the inertia of the mass of the striker rod, striker pad and free piston, and a little friction.

The hammer blow thus accelerates the free piston instantaneously to a high velocity and the leading edge of the shock wave is quickly formed. As the energy from the hammer blow is transformed into shock wave energy, the force of the hammer blow plus the force of the bias spring is dissipated, and the "power train" of the transducer is snubbed to a halt; but not for long. Force from hydraulic pressure in the vessel quickly moves the transducer power chain back to top dead center, where it promptly

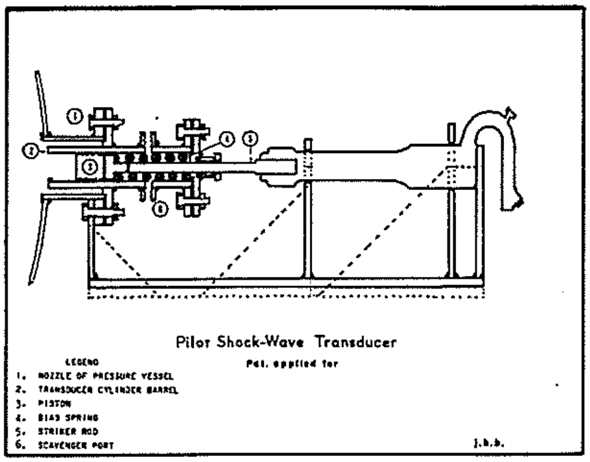

Figure 2.

receives another hammer blow. A sketch showing details of the transducer is shown on Figure 2.

The transducer is designed to start delivering low energy shock waves when the cylinder pressure reaches about 60 psi and to produce full strong shock-waves and a displacement volume per cycle equal to about 10 parts per million of cylinder volume when operated at 200 psi in the treating cylinder. By its nature, it is most efficient when operated at the cylinder pressure for which it was designed. It is equipped with a scavenger port through which free piston "blow by" liquid is returned to the treating tank. It also has a vent at the top tangent of the bias spring housing, providing access to the atmosphere at all times.

The treating cylinder is equipped with a bleed line which connects through a valve body to a port flush with the gate. It is at the highest point in the cylinder. Air bubbles that are driven out of the wood during shock wave treatment rise and are continuously withdrawn through the bleeder line. Its outfall is placed in the treating tank, so that any preservative that is entrained with air is returned to the system.

Pressure pump capacity sufficient to raise the pressure vessel to operating pressure within 1.5 to 3 minutes is provided. The pumps in these tests were steam pumps, and at times they were unable to maintain maximum pressure due to lack of primary steam capacity.

Normally the pumps should deliver 70 percent or more of gross within five minutes, or less, of pressure pumping.

The treating tanks are equipped with float type gauges and are calibrated to read in 0.01 foot increments, equal to about 3.557 gallons, or about 0.51 pcf for the charge. Both the treating tank and the pressure vessel are equipped with probe type thermometers.

An Ingersoll–Rand stationary air compressor with receivers was available for Reuping air. The transducer actuator hammer was driven by a portable gasoline driven compressor capable of 125 cfm at 100 psi, but fed through a pressure reducing valve capable of maintaining uniform primary air pressure to the hammer.

The vacuum system is a steam ejector. It develops a vacuum of 26 in. of mercury.

All materials used in these tests were commercially produced by the Southern Wood Preserving Company. Pine poles, stump green, were shipped from the production area in bark, were peeled in plant. Oak crossties were from commercial and railroad production and were either air seasoned or shed seasoned, as indicated.

Shock-Wave Treatment Procedures

The shock-wave transducer equipped pressure treating cylinder is handled conventionally in its cycle up to the point when the pressure pump is started; then:

1. The bleeder line is cracked so that air escaping from the charge during shock-wave treatment may be continuously withdrawn.
2. The pressure pump is throttled wide open so that operating cylinder-pressure can be established within 1.5 to 3 minutes. (Under shock-wave excitation there apparently is no blockage of the wood by extremely short up-pressure programming.)
3. As the pressure passes 60 psi, the shock-wave transducer is activated.
4. Pressure pumping with shock-waves is continued until—
   A. In the case of a calculated gross, the gauge reading is reached, or
   B. In the case of a refusal charge, the gauge remains unmoved for one or two successive 3 to 5 minute periods.
5. After the desired gross, or refusal, has been reached, the pressure pump is stopped, but the shock-wave transducer is kept running until the pressure subsides to 60 psi. It is then shut off.

Conventional procedures are then resumed; i.e., transfer of the preservative, vacuum cycle, etc.

Data

Pertinent data observed on 18 charges treated in the pilot cylinder is tabulated below:

Table 1.—Shock-Wave Pilot Stump Green Southern Yellow Pine Poles

DATA

	Control	Shock-Wave	Shock-Wave	Shock-Wave	Commercial	Commercial
Date, 1968	1–22	1–24	1–25	8–27	8–2	8–3
Charge No.	62	63	64	83	654	657
Material	8 pc. 6/25′ syp—stump Green	8 pc. 6/25′ syp—stump Green	8 pc. 6/25′ syp—stump Green	7 pc. 5/25′ syp Green	CAS poles 35′ and 40′ Class 5	Green poles 30′–35′–45′ Class 5
Conditioning:	9.75 hrs. atm.	9.5 hrs. stm.	5.75 stm.	5 hrs. stm.	CAS+6 hrs. stm.	18 hrs. stm.
vac.:	--------	--------	--------	1:00 hrs.	1:00 hrs.	2:30 hrs.
Moisture:						
1 in.						
1 in.–2 in.						
Balance						
Average %	87.5	87.5	87.5	56.7	--------	--------
Cubic ft.	61.36	61.36	61.36	62.4	2444	1950
Preservative	CTC	CTC	CTC	CTC	CTC	CTC
Sp. Gr. 100° F	1.076	1.076	1.076	1.076	1.077	1.077
% Water: Start	0.4	0.7	0.3	--------	--------	--------
Finish	1.1	0.8	0.7	--------	--------	--------
Type Treatment	Std. Reuping	Shock-Wave–Lowry	Shock-Wave–Lowry	Shock-Wave–Lowry	Reuping	Reuping
Initial Pressure, vac. in.	60	Atmos.	Atmos.	Atmos.	55	70
Pressure pump—mins.	70	25	20	17	180	180
Hammer time—mins.	0	21	23	20	0	0
Gross pcf	15.44	14.89	14.87	20.06	18.84	20.18
Sdt, min.—% Gross	10– 23.4%	4– 46.6%	2– 32.2%	5– 68%	15– 12%	15– 16%
	25– 50.0	5– 53.2	5– 61.1	10– 83.0	30– 23	30– 29
	30– 61.7	10– 73.6	7– 70.9	15– 98.0	45– 41	45– 44
	40– 80.0	15– 86.7	10– 77.2	17–100.0	60– 58	60– 55
	60– 93.4	20– 96.6	13– 83.9		90– 78	90– 77
	70–100.0	25–100.0	15– 90.2		120– 92	120– 89
			17– 93.3		150– 98	150– 96
			20–100.0		180–100	180–100
Net pcf	9.35	11.50	11.58	14.07	12.55	8.82
Penetration	2.6/98%	2.2/100%	2.3/91%	6–100% 1–85%	Passed 3.5″ or 90%	Passed AWPA C4
Assay:						
0–½ in. pcf	14.16	24.63	23.10			
% Moisture	40.87	46.37	45.82			
Sp. Gr.	.5288	.5592	.5659			
½–2 in. pcf	7.64	9.18	6.39			
% Moisture	58.61	57.49	55.28			
Sp. Gr.	.5407	.5512	.5473			
Average						
0–2 in. pcf	9.27	13.05	10.57			
% Moisture	54.33	54.68	52.85			
Sp. Gr.	.5370	.5532	.5519			

Table 2.—Shock-Wave Pilot, Oak Crossties

DATA

Date, 1968	6–4	6–5	6–21
Charge No.	79 Sontek Full-Cell	80 Sontek Reuping–Lowry–Beth.	81 Control
Material	X-Ties Shed	X-Ties Shed	X-Ties
% Red Oak	43	43	52
% White Oak	57	57	48
% Moisture 1 in.	32.69	32.69	31.96
2 in.	50.09	50.09	58.88
Bal.	68.03	68.03	67.99
Avg.	53.81	53.81	53.07
Cu. ft.	75.5	77.1	75.6
Preservative (Rv)	CTC	CTC	CTC
SpGr @ 100° F	1.073	1.075	1.078
% Water: Start	0.5	0.0	0.1
End	0.6	0.1	0.3
Type Treatment	Full-Cell	R–L–F.C.	Reuping
Initial Pressure psi-Hg"	25.5"	60–0–22"	50
Pump time, hr.: min.	0:35	0:10, 0:15, 0:20	1:30
Hammer time, hr.: min.	0:30	0:15, 0:17, 0:20	0
Gross Absorb. pcf	5.38+	9.75	9.96
0–5 min. %	49.5%	R 4.96 (pcf)	------
0–10 min.	74.1	0.00	------
15	86.5	L 7.05	43.5
20	92.8	0.82	------
25	98.6	0.82	------
30	98.6	FC 3.30	68.0
35	100.0	0.82	------
40	------	0.45	------
45	------	0.45	77.0
1:00	------	------	84.9
1:15	------	------	93.5
1:30	------	------	100.0
2:00	------	------	------
3:00	------	------	------
4:00	------	------	------
5:00	------	------	------
6:00	------	------	------
Net Ret. pcf	11.58	6.63	7.40
Penetration			
Red O. %: Ring	73	82	70
Solid	1.41 in.	1.37 in.	1.0 in.
White O. %: Ring	25	27	19
Solid	.21 in.	.32 in.	.25 in.
Wt. Pick Up pcf			
Hammer End 1	8.4	6.0	3.3
2	8.4	4.9	4.9
Middle 3	5.2	3.4	5.4
4	4.0/4.7	3.5	5.6
Front End 5	------	3.3	5.3
6	------	3.9	5.3
Avg.	6.15	4.14	5.04

Table 3.—Shock-Wave Pilot, Oak Crossties

DATA

Date, 1968	6–25	7–2	7–3
Charge No.	82 Sontek Lowry	543 Commercial	548 Commercial
Material	X-Ties	X-Ties AS Ga. RR 8.0 pcf	X-Ties Shed SCL 7 pcf
% Red Oak	43	--------	--------
% White Oak	57	--------	--------
% Moisture 1 in.	31.96	--------	--------
2 in.	58.88	--------	--------
Bal.	67.99	--------	--------
Avg.	53.07	Approx. 45 12 Months, Air	Approx. 52 8 Months, Shed
Cu. ft.	73.78	2721	2705
Preservative (Rv)	CTC	60/40	60/40
SpGr @ 100° F	1.078	1.105	1.105
% Water: Start	0.1	2.8	2.8
End	0.2	--------	--------
Type Treatment	Lowry	Reuping	Reuping
Initial Pressure psi-Hg"	0	60	45
Pump time, hr.: min.	0.45	1 hr. up to 225 psi + 5 hrs.	1½ hr. up to 225 psi + 5 hrs.
Hammer time, hr.: min.	0:55	0	0
Gross Absorb. pcf	8.25	11.36	7.93
0– 5 min. %	57.7	--------	--------
0–10 min.	75.4	--------	--------
15	75.4	19.6%	18.4%
20	75.4	--------	--------
25	83.7	--------	--------
30	89.0	39.2	33.4
35	94.4	--------	--------
40	100.0	--------	--------
45	-------	42.0	40.8
1:00	-------	53.0	48.1
1:15	-------	--------	52.8
1:30	-------	--------	58.9
2:00	-------	69.4	71.4
3:00	-------	77.8	79.0
4:00	-------	85.9	85.7
5:00	-------	91.4	96.0
6:00	-------	100.0	100.0
Net Ret. pcf	7.31	8.40	7.10
Penetration			
Red O. %: Ring	70	93	92
Solid	1.43 in.	1.20 in.	2.92 in.
White O. %: Ring	22	26	17
Solid	.35 in.	.38 in.	.41 in.
Wt. Pick Up pcf			
Hammer End 1	4.6	No Sample	No Sample
2	3.9	--------	--------
Middle 3	6.5	--------	--------
4	4.5	--------	--------
Front End 5	5.5	--------	--------
6	4.5	--------	--------
Avg.	4.90		

Table 4.—Shock-Wave Pilot Oak Crossties

DATA

Date, 1968	8–28	8–28	8–29	8–30
Charge No.	84	85	86	86 RT.
Material	Crossties Air-Seasoned 56% R.O. 44% W.O.	Crossties 100% W.O.	Crossties Shed dried 100% S. Ala. Swamp R.O.	
Moisture: 1 in.	28.58	--------	30.85	--------
1–2 in.	46.46	--------	56.16	--------
Balance	62.04	--------	70.81	
Average	46.68	44.58	55.65	
Cubic ft.	78.1	73.4	76.05	†72.3
Preservative	60/40	60/40	60/40	60/40
Sp. Gr. 100° F.	1.101	1.101	1.101	1.101
% Water: Start	Trace	0.15	--------	--------
End	0.2	0.05	--------	--------
Type Treatment	Shock-Wave–Lowry	Shock-Wave-Lowry	Shock-Wave–Full-Cell	Shock-Wave–Lowry
Initial Pressure—vac. in.	Atmos.	Atmos.	22 in.	Atmos.
Pump time, mins.	19	17	36	56
Hammer time, min.	30	22	38	72
Gross pcf	8.24	6.05	5.15	5.53
Sdt, % Gr.	3 min. 68% 6 min. 85 9 min. 90 12 min. 95 15 min. 100 19 min. 100	5 min. 68% 10 min. 83 15 min. 98 17 min. 100	3 min. 42% 6 min. 50 9 min. 58 12 min. 67 15 Hammer off 18 min. 75 21 min. 83 24 min. 92 27 min. 92 30 min. 92 33 min. 92 36 min. 100	3 min. 53% 6 min. 76 9 min. 76 12 min. 84 27 min. 92 42 min. 100 57 min. 100
Net pcf	5.21	3.14	4.55	0.98
Penetration	77% Rings R.O. 1.01" Solid 22% Ring W.O. 0.46 Solid	-------- -------- 20% 0.41" Solid	52% Rings 0.82" Solid -------- --------	54% Rings 0.93" Solid -------- --------
Weighed ties				
Hammer 1	12.0 lb.	9.0 lb.	4.50	8.00
2	13.25	10.0	19.25	2.00
Middle 3	17.50	*(33.75)	9.10	4.40
4	7.45	6.0	21.50	3.25
Front 5	21.0	7.0	25.00	†----
6	22.0	6.25	15.50	3.50
Average pcf	3.05	2.04	4.81	1.16

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*Atypical data—delete.

†1 tie cut up for wafers.

Table 5.—Shock-Wave Pilot Oak Crossties

DATA

Date, 1968	8-29		10-25		10-25	
Charge No.	737 Com.		89		90	
Material	Crossties Air-Seasoned 50% R.O. 50% W.O. (GaRR)		Crossties 45% R.O. 55% W.O. 46.40		Crossties 100% R.O. 46.40	
Cubic ft.	2484.		63.81		67.18	
Preservative	60/40		60/40		60/40	
Sp. Gr. 100° F.	1.103		1.101		1.101	
Type Treatment	Reuping		Boultonized Full-Cell		Sontek Lowry	
Initial Pressure—vac. in.	50		22.0 in.		Atmos.	
Pump time, min.	330		33		33	
Hammer time, min.	----		38		35	
Gross pcf	8.79		10.18		8.73	
Sdt, % Gr.	15 min.	22%	0	44.4%	3	59.8%
	30 min.	37	3	77.4	6	75.3
	45 min.	56	6	86.9	9	79.8
	60 min.	63	9	86.9	12	84.4
	90 min.	74	12	91.1	15	89.0
	120 min.	82	15	95.8	18	89.0
	150 min.	84	18	95.8	21	93.5
	180 min.	88	21	95.8	24	93.5
	210 min.	92	24	95.8	27	93.5
	240 min.	94	27	95.8	30	98.0
	270 min.	96	30	100	33	100.0
	300 min.	98	33	100		
	330 min.	100	36	100		
Net pcf	7.85		8.56		6.37	
Penetration	Satisfactory for customer AWPA C2		R.O. 79.9% Solid 1.42 in. W.O. 23.3% Solid 0.34		R.O. 57.9% Solid 0.88 in.	
Weighed ties						
Hammer 1	------		16.00 lb.		18.00 lb.	
2	------		11.17		12.50	
Middle 3	------		12.30		15.00	
4	------		12.20		18.25	
Front 5	------		21.31		20.25	
6	------		9.00		11.25	
Average pcf	------		4.50		4.83	

Table 6.—Uniformity of Treatment—Crossties

DATA

		Tram No. 1 At Transducer Port		Tram No. 2 Mid-Cylinder		Tram No. 3 At Cylinder Door
Ex. 79—June 4, 1968						
Tie	No. 1	18.60 lb. 5.20 pcf	No. 3	30.6 8.4		---------------
Tie	No. 2	30.88 lb. 8.40 pcf	No. 4	16.0 13.0 4.7 4.0		---------------
Mean		6.80 pcf		5.70 pcf		
Ex. 80—June 5, 1968						
Tie	No. 1	5.9 pcf	No. 3	3.4 pcf	No. 5	3.3 pcf
Tie	No. 2	4.8 pcf	No. 4	3.5 pcf	No. 6	3.9 pcf
Mean		5.35 pcf		3.45 pcf		3.60 pcf
Ex. 81—June 21, 1968						
Tie	No. 1	3.3 pcf	No. 3	5.4 pcf	No. 5	5.3 pcf
Tie	No. 2	4.9 pcf	No. 4	5.6 pcf	No. 6	5.3 pcf
Mean		4.10 pcf		5.50 pcf		5.30 pcf
Ex. 82—June 25, 1968						
Tie	No. 1	4.6 pcf	No. 3	6.5 pcf	No. 5	5.5 pcf
Tie	No. 2	3.9 pcf	No. 4	4.5 pcf	No. 6	4.5 pcf
Mean		4.25 pcf		5.50 pcf		5.00 pcf
Ex. 84—August 28, 1968						
Tie	No. 1	12.0 lb. 3.22 pcf	No. 3	17.5 lb. 4.71 pcf	No. 5	21.0 lb. 5.64 pcf
Tie	No. 2	13.25 lb. 3.56 pcf	No. 4	7.45 lb. 2.0 pcf	No. 6	22.0 lb. 5.92 pcf
Mean		12.63 lb. 3.40 pcf		12.48 lb. 3.36 pcf		21.50 lb. 5.78 pcf
Ex. 85—August 28, 1968						
Tie	No. 1	9.0 lb. 2.42 pcf	No. 3	(33.75 lb.) *(9.09 pcf)	No. 5	7.00 lb. 1.88 pcf
Tie	No. 2	10.0 lb. 2.69 pcf	No. 4	6.0 lb. 1.13 pcf	No. 6	6.25 lb. 1.68 pcf
Mean		9.5 lb. 2.55 pcf		6.0 lb. 1.61 pcf		6.63 lb. 1.78 pcf
Ex. 86—August 29, 1968						
Tie	No. 1	4.50 lb. 1.21 pcf	No. 3	9.1 lb. 2.45 pcf	No. 5	25.0 lb. 7.56 pcf
Tie	No. 2	19.25 lb. 5.17 pcf	No. 4	21.5 lb. 5.79 pcf	No. 6	15.5 lb. 4.16 pcf
Mean		11.88 lb. 3.19 pcf		15.30 lb. 4.12 pcf		20.25 lb. 5.86 pcf
Ex. 89—October 25, 1968						
Tie	No. 1	16.00 lb. 4.85 pcf	No. 3	12.30 lb. 3.31 pcf	No. 5	21.31 lb. 7.61 pcf
Tie	No. 2	11.17 lb. 3.98 pcf	No. 4	12.70 lb. 4.54 pcf	No. 6	9.00 lb. 3.22 pcf
Mean		13.59 lb. 4.42 pcf		12.50 lb. 3.93 pcf		15.16 lb. 5.42 pcf
Ex. 90—October 25, 1968						
Tie	No. 1	18.00 lb. 6.36 pcf	No. 3	15.00 lb. 4.53 pcf	No. 5	20.25 lb. 6.12 pcf
Tie	No. 2	12.50 lb. 4.42 pcf	No. 4	18.25 lb. 4.91 pcf	No. 6	11.25 lb. 3.03 pcf
Mean		15.25 lb. 5.39 pcf		16.76 lb. 4.72 pcf		15.75 lb. 4.58 pcf
Mean, all tests		Tram No. 1 At Transducer Port 4.38 pcf		Tram No. 2 Mid-Cylinder 4.21 pcf		Tram No. 3 At Cylinder Door 4.67 pcf

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*Atypical data, rejected.

Discussion

Our first attempts at treatments under shock-waves in the pilot cylinder were performed on April 6, 1967. The transducer design as originally conceived was defective and several changes to correct it were made during the period of April to August, 1967.

These early runs revealed strange behavior when the liquids were under high velocity shock-wave excitation. We found creosote oil acting as if it were a semi-solid in plug flow, causing shear turbulence and cavitation in gaskets. Modification of the transducer was made to remove the source of the turbulence.

After the transducer was modified, on August 1, 1967, we treated a charge of southern yellow pine poles at 42 percent moisture content to 12.24 pcf gross in 10 minutes, using cylinder pressure below 200 psi for a part of the run. On a subsequent run, poles were treated under shock-waves to 22.97 pcf refusal in 25 minutes pumping time, 23 minutes transducer time. This run confirmed that shock-waves, when in adequate dosage, would accelerate the rate of absorption of preservative.

Further changes were made in the transducer design in September, 1967. These changes brought improved results that caused previously observed data to be not comparable to the data that was subsequently observed. For that reason the data section of this paper covers charges treated between January 22, 1968 and October, 1968.

For the purpose of clarity, the data is arranged in sets of like material rather than in either numerical sequence or chronological order.

The first set of data (Table 1) covers a study on southern yellow pine poles and includes a control charge in the pilot cylinder, three shock-wave charges and two commercial charges. The pressure pumping cycle on fairly dry southern yellow pine poles was short under shock-wave conditions, but with commercial practice on pine, the pumping cycle does not take too many hours. It was felt that the shock wave treatment would not be of too great an economical importance in pine treatments. However, by comparison of the data on charges 63, stump green southern yellow pine poles, with charges 64 and 83, it will be seen that the steaming time on green southern yellow pine poles can be reduced by 40 percent to 50 percent, if subsequently shock-wave treated. The graph, Figure 3, shows a comparison of Ex. 83 shock-wave Lowry on green southern yellow pine poles steamed for six hours and held under vacuum for one hour, against a commercial run of class 5 poles 30 to 40 feet in length which required 13 hours steaming and 1.5 hours vacuum. The overall difference in time between these two runs was about 10 hours in favor of the shock-wave treatment. It may be true that the pilot cylinder data should not be compared to the commercial cylinder data, but it is intended that data almost similar to the pilot results should be obtained in commercial equipment. Fig. 4 is of a wafer cut from a pole treated in Ex. 83, showing that the sapwood was 100 percent penetrated.

Shock-wave treatments on mixed oak crossties comprise the balance of the data shown. Treatments that deserve special attention include Ex. 79 (Table 2) a full-cell treatment where in 35 minutes of shock-wave pumping a net 11.58 pcf was reported.

In treatment number Ex. 80 (Table 2) we undertook to treat by Reuping, Lowry and Bethal in sequence, all in 1/6 of the time that normally is required for treating ties. The results were somewhat confused, because we were changing methods of treatment so fast that we lost count of the gauge readings. Some modification of this sequence might be of commercial value.

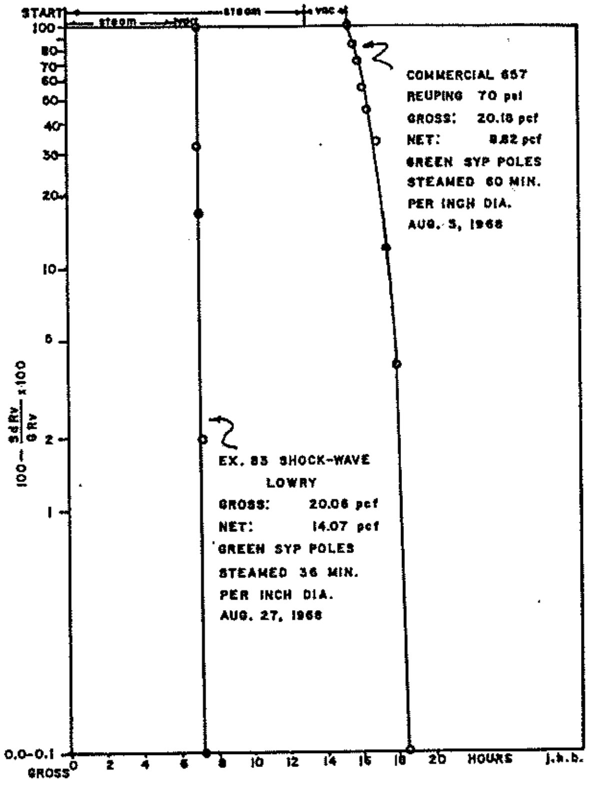

Figure 3.

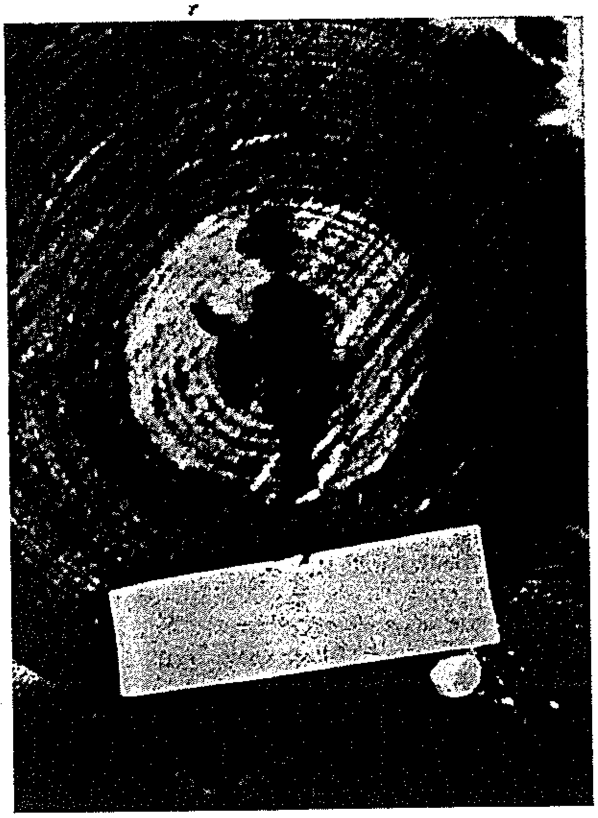

Figure 4.

Table 7.—Typical Treatment of Data for Preparation of Graphs:

Ex. 89—Shock-wave—Boulton—Full-cell 60/40 soln.
Mixed Oak Crossties

Sdt Minutes	d-Gal.	Sd Gal.	$\frac{SdRv}{GRv} \times 100$	$100 - \frac{SdRv}{GRv} \times 100$	Injected Rv pcf
0	32.7	32.7	44.4%	55.6	4.50
3	24.3	57.0	77.4	22.6	7.85
6	6.9	63.9	86.9	13.1	8.8
9	0.0	63.9	86.9	13.1	8.8
12	3.2	67.1	91.1	8.9	9.24
15	3.4	70.5	95.8	4.2	9.7
18	0.0	70.5	95.8	4.2	9.7
21	0.0	70.5	95.8	4.2	9.7
24	0.0	70.5	95.8	4.2	9.7
27	0.0	70.5	95.8	4.2	9.7
30	3.1	73.6	100.0	0.0	10.12
33	0.0	73.6	100.0	0.0	10.12
36	0.0	73.6	100.0	0.0	10.12

The charge Ex. 84 (Table 4) was of interest as it was a dry air-seasoned charge of mixed oak ties, pumped to refusal under shock-waves in 15 minutes.

A charge of 100 percent white oak ties was reported on Ex. 85 (Table 4). This charge went to refusal under shock-wave pumping in 17 minutes with a gross of 6.05 pcf, net 3.14 pcf. The penetration was similar to what is normally obtained.

Charge Ex. 86 (Table 4) was undertaken as a 100 percent red oak charge, but it turned out to be red oak produced in south Alabama swamps. The material refused to treat adequately under shock-wave conditions, both in its initial treatment and its retreatment. These ties had most of their pores filled with tyloses.

Treatment Ex. 89 (Table 5 and 7) was undertaken in an attempt to establish the conditions in ties that result from a vapor drying cycle. The ties were Boultonized for about five hours, placed under vacuum for one hour and then treated full-cell. This charge appeared to have taken on 44.4 percent of its gross before the pressure pumps were started, pumped with shock-waves to about 10.18 pcf gross in 30 minutes for a net of 8.56 pcf. Pressure in the cylinder was not uniform during this treatment for the reason that the primary steam pressure available to the pressure pump varied over a wide range.

On Figure 5, Ex. 84, a shock-wave treatment is compared to a commercial treatment of mixed oak crossties. Both grossed in the 8-pound range. The time saving in the shock-wave treatment was about 5:25 hours. The performance of the shock-wave under the Boultonized treatment is shown in Ex. 89 (shown in Figure 6) where the instantaneous pressures in the cylinder are shown as the treatment progressed. Figure 7, shock-wave treatment Ex. 90 (Table 5 and 8) is drafted likewise to show variations in cylinder pressure.

The graphical presentation of these treatments, where the pressure cylinder is maintained in fairly constant pressure and the shock-wave excitation is adequate, shows the treatment line is straight on

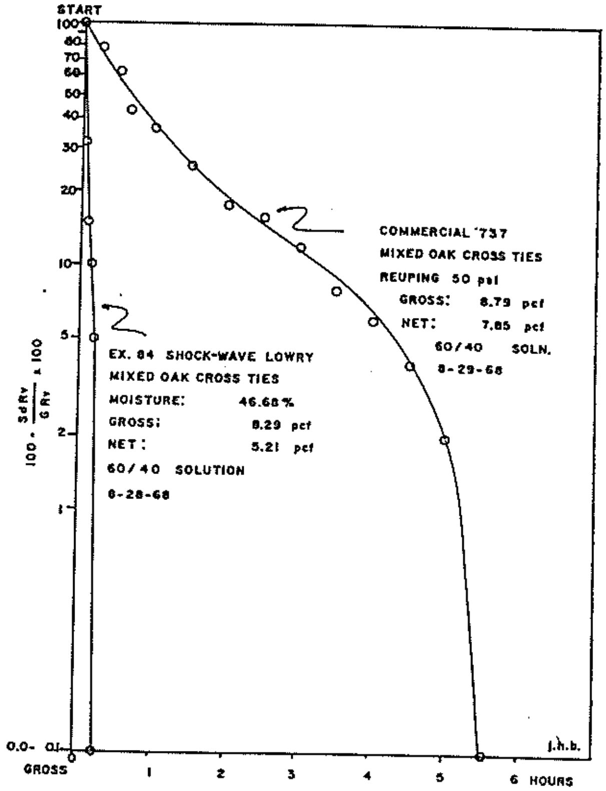

Figure 5.

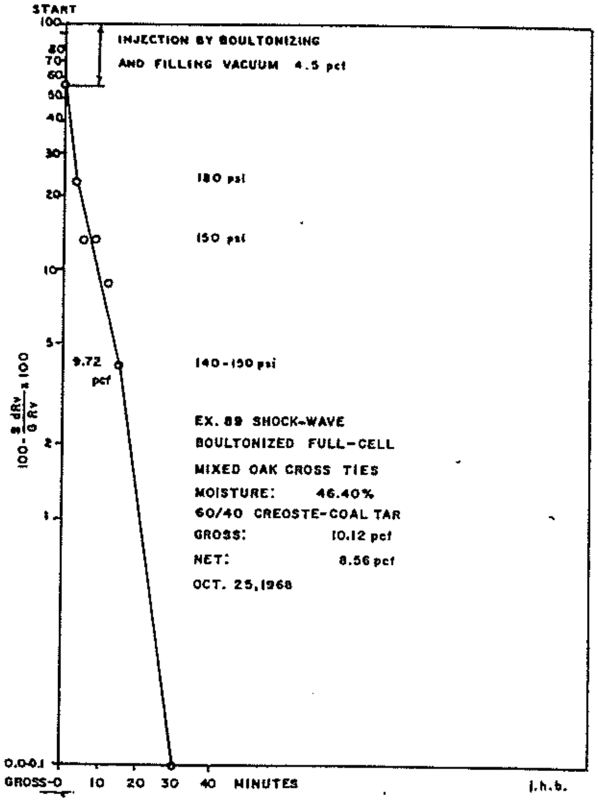

Figure 6.

Table 8

Ex. 90—100% Red Oak Crossties Shock-Wave—60/40 Solution—Lowry

Sdt Minutes	d-Gal.	Sd Gal.	$\frac{SdRv}{GRv} \times 100$	$100 - \frac{SdRv}{GRv} \times 100$
3	38.2	38.2	59.8	40.2
6	9.9	48.1	75.3	24.7
9	2.8	50.9	79.8	20.2
12	2.9	53.8	84.4	15.6
15	3.0	56.8	89.0	11.0
18	0.0	56.8	89.0	11.0
21	2.9	59.7	93.5	6.5
24	0.0	59.7	93.5	6.5
27	0.0	59.7	93.5	6.5
30	2.9	62.6	98.0	2.0
33	1.3	63.9	100.0	0.0

Sdt = Cumulative pumping time, minutes.
d-gal. = Injected preservative increment, gallons.
Sd gal. = Summation of preservative increments, gallons.
Rv = Preservative.
G = Gross.
pcf = Pounds per cubic foot.

semi-logarithm paper. Non shock-wave treatments are characterized by curved lines, as is also the shock-wave treatments that are undertaken at variable pressure, or low pressure. This convention of plotting shock-wave treatment data thus becomes a quality control method, showing at a glance whether the shock-wave generating transducer is properly operating.

In each of nine charges of crossties (Table 6) pieces were weighed before and after treatment to determine if there might be any peaking of the treatment in those pieces located nearest to the transducer port, where the shock-waves would be expected to carry the highest energy content. Data on these weighed ties is tabulated in Table 6. The mean weight gain for all tests:

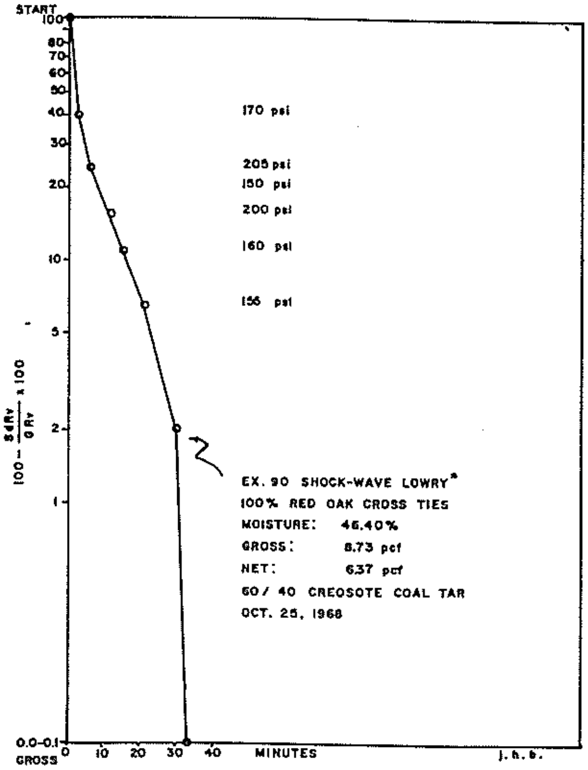

Figure 7.

	Weighed Ties on Tram Adjacent to Transducer Port	Weighed Ties in Mid-cylinder Tram	Weighed Ties on Tram at Cylinder Door
Mean Weight Gain........	4.38 pcf	4.21 pcf	4.67 pcf

The weight increments on the weighed ties might suggest that the shock-waves were more effective on pieces remote from the transducer port, but we doubt that such is the case. More likely, if a sufficient population of tests were made, the weight gain would average the same regardless of the position in the cylinder of the piece under treatment. The weight increment data was not corrected for loss of moisture during treatment, so the figures do not accurately reflect the total preservative retained.

Conclusions

From this pilot-plant study we can conclude that shock-waves, when applied under proper conditions in adequate dosage and wave form to conditioned charges of commercial white stock in a pressure treating cylinder, are effective as a means to accelerate injection of liquid preservatives.

In shock-wave treatments on stump green southern yellow pine poles, the steaming cycle may be reduced to 0.6 to 0.5 hour per inch of diameter. The over-all time saving per charge should be about nine to eleven hours.

Shock-wave treatments of oak crossties are effective and would appear from pilot data to shorten the time required per charge of about 5.5 hours.

None of the pieces of shock-wave treated wood were observed to "bleed" immediately after they were treated.

Occluded pressure inside pieces that had been shock-wave treated and hammered after the pressure pumps had been stopped appeared to be minimal.

It appears evident that shock-waves exert a scrubbing action both on the surface of the pieces, and in the wood pore channels. Pieces so treated appear to be "clean".

These pilot-plant studies indicate that extrapolations to commercial cylinders will be technically feasible.

Shock-waves in effective dosage and wave form do not appear to degrade the physical properties of the wood.

Examination of the pressure cylinder, while under shock-wave excitation at about 1,000 cycles per minute, did not reveal any vibrational behavior that would anticipate damage or over-stress to the pressure vessel, or its appurtenances. After some 31 runs, the pilot plant cylinder appeared to be in no way weakened; and no damage to pumps, valves, insulation, gaskets or piping could be found.

Such shock-wave treatments in commercial operations will be found to be both feasible and economically advantageous.

Acknowledgments

We acknowledge with sincere appreciation the use of pilot plant facilities, material and services of the Southern Wood Preserving Company, and the helpful cooperation of Mr. Harry Dunstan, President, and his staff including Mr. Walter Osterman, Wood Technologist, Mr. V. C. Nemeyer, and others; and for the mechanical services of Brock and Slevins Company, Rossville, Ga., W. G. McGlothlin, President, and Mr. Gene Smith.

We also express thanks to representatives of industry, including Mr. Lauress Collister and Mr. William Byers of the AT&SF Railway Company; Mr. George C. Eaton and Mr. Peter C. Gaskin of the Moss–American Company; Mr. Ralph Bescher and Mr. William St. Clair of The Koppers Company; Mr. M. A. Lane of The Southern Pacific Company; Mr. Lawrence J. Wildes of The Seaboard Coastline Railroad Company; and Mr. R. Z. Page, U. S. Navy Department, for their interest as observers and for their consultation during these pilot plant treatments.

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(6) Hudson, M. S., "Hudson Slurry Seal Method of Wood Preservation" before S. E. Section Forest Products Research Society, Montgomery, Alabama, December 6, 1968.

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(8) Barnett, J. H., Jr., Application U. S. Patent July 23, 1968.

Discussion

(The following comments by W. G. Lanterman were read by R. Z. Page.)

The U. S. Navy is a prime customer of the timber products and wood treating industries. The Navy has a vital concern for every factor tending to reduce initial costs of treated wood or tending to increase the effectiveness and extend the life of preservative treatments. The Navy's treated wood requirements include piling, planking, timber, poles and railroad ties.

Others more qualified than I will comment on the theory and development of the shock-wave process as presented in the Burdell/Barnett paper. As a Navy engineer concerned with Navy's use of treated wood, I am vitally interested, not in the theory and development of the process, but rather in the potential end products described above.

My comments may not seem closely related to the paper to which my comments are directed. However, this session of the convention presents an opportunity to communicate with all segments of industry represented in AWPA. My purpose is twofold: To emphasize current trends in the design and construction of facilities constructed of treated wood, and to solicit the assistance of the AWPA and all of its segments in the development and implementation of improved design and construction criteria required to reverse these trends.

Progress in wood preservation has been made but additional progress will be required to reverse current trends. Since World War II, the percentage of Navy's new construction starts for wood facilities, as opposed to steel and/or concrete facilities has decreased.

Treated wood piling, poles, and railroad ties and structural timber and planking provide a unique blend of strength and flexibility that, at comparable cost, can be provided by no other structural material. Premature failure of facilities constructed of treated wood usually is the result of premature biological deterioration originating where the treated shells of the wood have been damaged. Such damage is the result of careless handling, moving or dropping, use of sharp instruments or tools, drilling or dapping through the shells, or cutting or shaping treated wood to required dimensions. Increasing the thickness of the presently too thin treated shells would be a significant improvement for treated wood.

The Burdell/Barnett paper evaluates the reduced cylinder time for the shock-wave process compared to conventional processes. Reduced cycling time can be converted to reduced costs. The paper does not evaluate the potential for deeper penetration that might be realized.

Recent improvements such as more effective preservative treating materials, more effective treatment techniques and more effective quality controls significantly reduce prices and improve treated wood products. Many of the improvements have been the result of joint efforts of representatives of producers of timber and treatment material, treaters, suppliers, and users (including their contractors).

The same kind of joint effort, amplified and accelerated and, possibly, augmented by retaining professional engineering advice and assistance, is now required to develop and implement improved criteria for the design, construction, and maintenance of treated wood facilities. The Navy and other users of treated wood products (including their contractors) have been working to improve those criteria; regrettably their progress has been disappointing. AWPA members have a large investment at stake. Whether that investment appreciates or depreciates may depend on whether or not the necessary improvements in the design, construction and maintenance criteria can be developed.

The improved materials, techniques, and quality controls that have been developed will tend to minimize accidental damage to treated wood. However, improvements in design, construction and maintenance criteria must be developed and implemented to eliminate, or at least minimize treated shell damage during construction and subsequent maintenance of treated wood facilities.

Design and construction criteria must include the maximum of prefabrication of wood products prior to pressure treatment. Insofar as possible, construction details must be accurately predetermined. Holes must be drilled to receive all bolts, screws, spikes, and pins; necessary recesses, gaps and inserts must be predetermined and adzed, sawed or cut as appropriate; and the overall dimensions of members must be predetermined and each piece cut to the required dimensions. All such work must be completed accurately before the members can be considered ready for pressure treatment. The foregoing applies alike to railroad ties, utility poles and cross-arms, piling, timber and planking for all structures where effective pressure treatment is a requirement. Most importantly, effective and enforceable construction controls are needed to prevent on-the-job damage to the treated shells of such prefabricated material.

Other design and construction criteria improvements required include the development of new types of fasteners, connectors and positioners, the elimination wherever possible of diagonal braces whose dimensions are difficult to predetermine and whose raw ends cannot be protected from their environment. Improved field-applied preservatives and techniques are also essential.

Again, it is stressed that active AWPA support and assistance is solicited in developing and implementing improved design, construction and maintenance of treated wood facilities.

R. Z. PAGE: Following my reading of comments by Bill Lanterman, I now wish to present comments of my own and to pose questions to the authors.

Herman Barnett and his associates are to be highly commended on the commercial development of the equipment which so effectively reduces pressure-treating time. Results of their efforts, as presented in this paper, may be expected to quickly spread this new technique throughout the industry because of the financial savings to the treaters.

I wish to point out two minor errors in the paper. The first is on the first page of the preprint. It relates to the origin of the concept for shock-wave treatment. It was a film on pile driving rather than a demonstration which started the thought wheels turning. The second is a typographical error on page 11 under "acknowledgments" which incorrectly refers to be as Dr. Page.

Before any attempts to test our theory, Ben Reed and I hypothesized that if low energy levels per cross-sectional area were combined with the proper frequencies, the treating liquid contacting the tori and margos of the bordered pits of some woods would first wet the tori and margos and then vibrate them away from the overhanging pit borders thus preventing blockage by aspiration and permitting passage of the treating solution. Excessive forces would destroy the margos, and incorrect frequencies would fail to vibrate the margo–torus combination in the best locations. I note with interest two features of this paper. The first is that the authors are using frequencies and energy levels within the ranges first calculated by Ben Reed and me; and the second is the lack of bleeders in the material treated. If the margos were destroyed by shock wave treatment (as they would be with incorrect frequencies or energy levels) so that the tori could no longer effectively block the openings in the bordered pits, the bleeding would be expected to be greater than normally resulting from conventional treatment. If the majority of the margos sustain less damage from shock-wave treatment than from conventional treatment, the percentage of bleeders would be less than usual; and this is the end result observed by the authors.

As one of the two co-inventors named on the basic patent, now pending, I naturally have a personal interest in the expanding use of the techniques presented in this paper. However, I participate in AWPA activities not as a private citizen but as a Navy employee and civil servant. My primary reason for membership attendance and participation is the safeguarding of Navy interests. Ben Reed and I had calculated a range of energy levels which would do no damage to useful cell structures but which, we had hoped, would remove extraneous materials, particularly tyloses, to permit better treating results. While the authors are using energy levels within our originally calculated range, they say only that there appears to be no degradation of the physical properties of the wood. As a Navy representative, I am interested to know more about the effects of this treatment on strengths and on micro-structures of the wood as compared with wood treated by conventional methods.

MR. BURDELL: In regard to the last question, I believe there possibly may be further Navy research. The Navy has become interested in this and I don't know the exact position of it right now but further detailed research study has been applied for. Whether the grant comes through or not I have not been informed by the Sontek Corporation. Hopefully it will, where detail studies will be made on your question.

P. C. GASKIN: If we can process a dry mixed oak crosstie charge in one-sixth of the normal duration, production may be doubled—everything else being equal. Using the "Sontek" method in conjunction with a vapor dried charge may produce even more startling effects such as a pressure period of only a few minutes.

Dr. Monie Hudson and many others developed a successful method of decreasing the seasoning time of oak crossties (as an example) from 13 months to 13 hours, and now we have an idea proposed whereby the long, slow pressure period of about 5 hours can be decreased to 20 or 30 minutes; less for pine or mixed hardwood.

As indicated and described in the preprint, the high speed pressure fill pump, shocker and associated engineering are nominal in initial cost. Worthington, Allis–Chalmers and Ingersoll–Rand have quoted suitable pressure pumps. Ingersoll–Rand, Schramm and Chicago–Pneumatic also have an impact breaker which will produce the sharp faced hydrodynamic shock waves required. For one 7′ x 150′ cylinder, the necessary equipment and plant installation cost would be less than $10,000.00, not including cost of services by "Sontek."

I have read and partially understand the Jamin Effect—air bubbles block penetration of oil, the Page–Reed Effect—resonant shock waves eases injection of oil, and the opinion of Dr. Hossfeld—shock waves cause sharp reduction in permeability, and in the near future I would like to understand the effects, if any, shock waves may have on the material treated, the pressure cylinder and pump, and the shocker itself. Allis–Chalmers has offered to check any effect the shock waves may have on their pressure pump. This method of treatment appears as good as and better than the present method and I think it should be exploited for all it is worth.

As I have said before, your reports and "Sontek" details have been so well presented that as a layman I have had no difficulty in following and understanding the experiments. You, Walt Osterman and Mr. Barnett are certainly fortunate to have become involved in such an interesting and worthwhile project.

MR. BURDELL: Time, I guess will tell as to the ultimate outcome, but it does look promising and we're planning to do continued research at our plant.

MR. BRAMHALL: Do you have information on the peak pressure attained by the shock wave and of the treatments?

MR. BURDELL: I'll refer to my co-author on that.

MR. BARNETT: The instantaneous peak pressures are difficult to estimate. We have not had suitable crystal compression transistors to put on to the cylinder yet. We know that we're using instantaneous peak pressures adequate to do the job and that they are not capable of destroying the equipment.

MR. BRAMHALL: Do you have any information on the frequency of the shockwave?

MR. BARNETT: The actuator runs at about a thousand to 1500 blows per minute. There is a resonant frequency in the transducer. If we can operate the actuator at exactly the fundamental resonance frequency of the transducer, the transmission of energy through the transducer is maximum.

MR. BURDELL: Oscar Blew has some very interesting comments and pictures that I'm anxious to see myself.

(The following comments by E. A. Behr were presented by J. O. Blew.)

Having recently been engaged in a study[1] of the cellular location of preservatives in wood, I was interested in the statement of theory in this paper. The physical effect of a liquid-transmitted shock wave is also of considerable importance.

The authors provided me with a cross-section of a pole from each of charges 62, 63 and 64, the first being a conventional Rueping treatment and the latter two, shock wave—Lowry.

Thin sections for microscopic examination and photographs were made. Preparation technique was such that nearly no creosote was displaced from the wood.

[1] Michigan Agricultural Experiment Station Journal Article No. 4808.

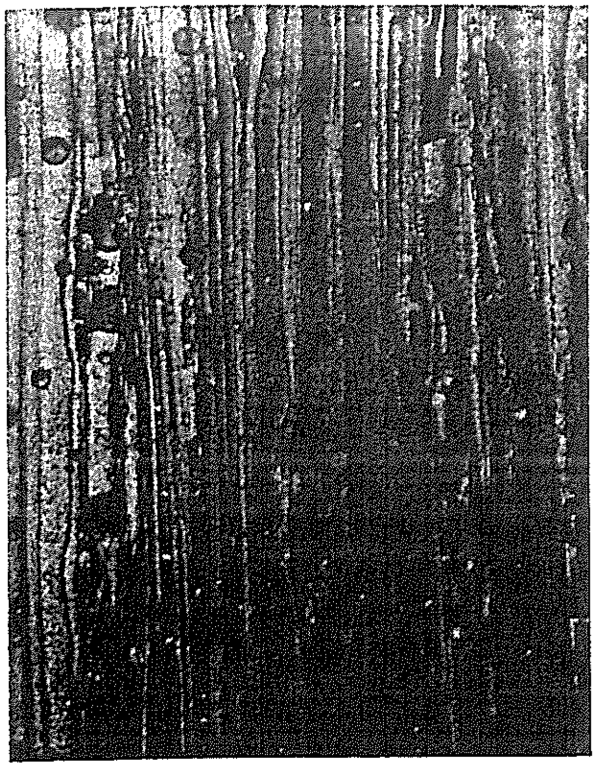

Figure 1.—Latewood tangential section from sapwood charge 63 Sontek. Note air bubbles distributed throughout the creosote in tracheids. 100 X.

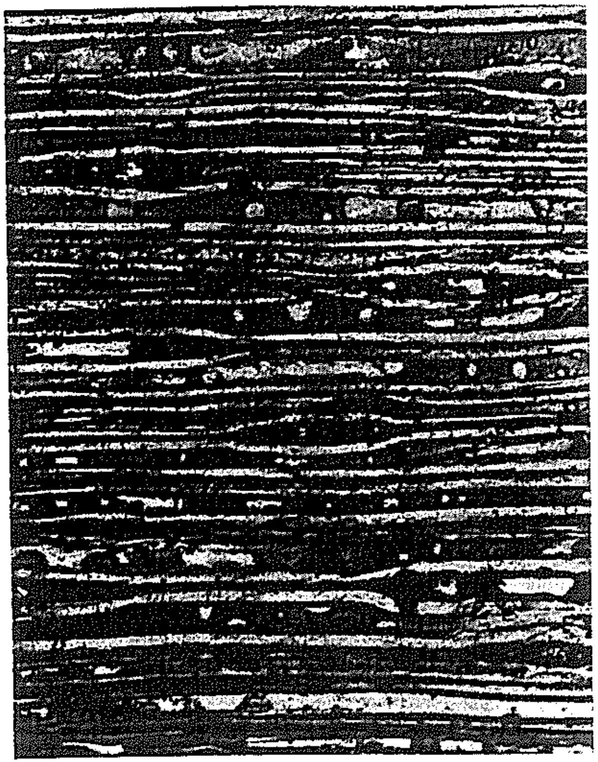

Figure 2.—Latewood tangential section from sapwood charge 62. Control 100 X.

Figure 3.—Earlywood tangential section from sapwood of charge 63 Sontek shows much of oil in larger tracheids is present as globules.

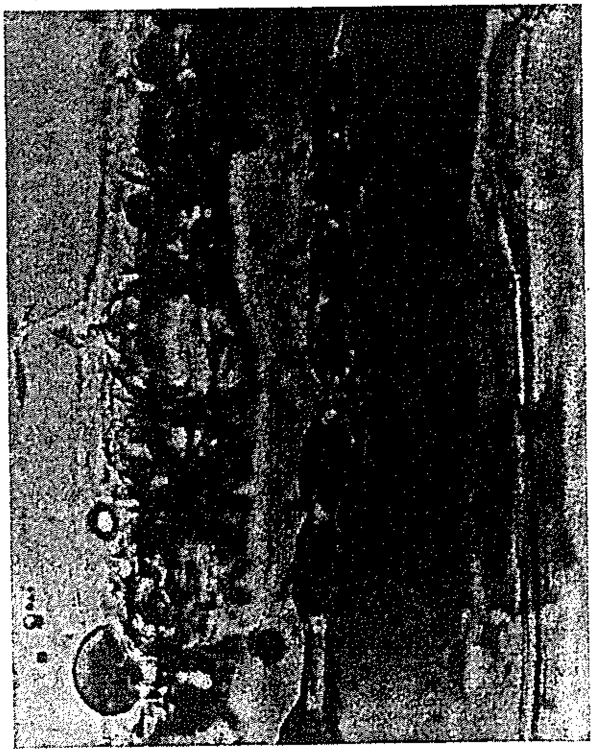

Figure 4.—Tangential section of earlywood area of heartwood from charge 62, control, illustrates aspirated pits with chambers full of creosote.

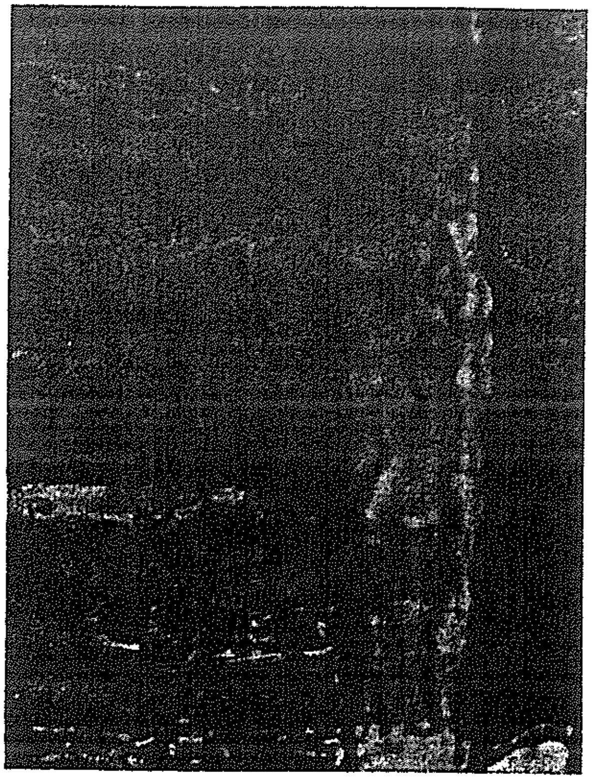

Figure 5.—Radial section from sapwood charge 64, Sontek. Bordered pits are unaspirated.

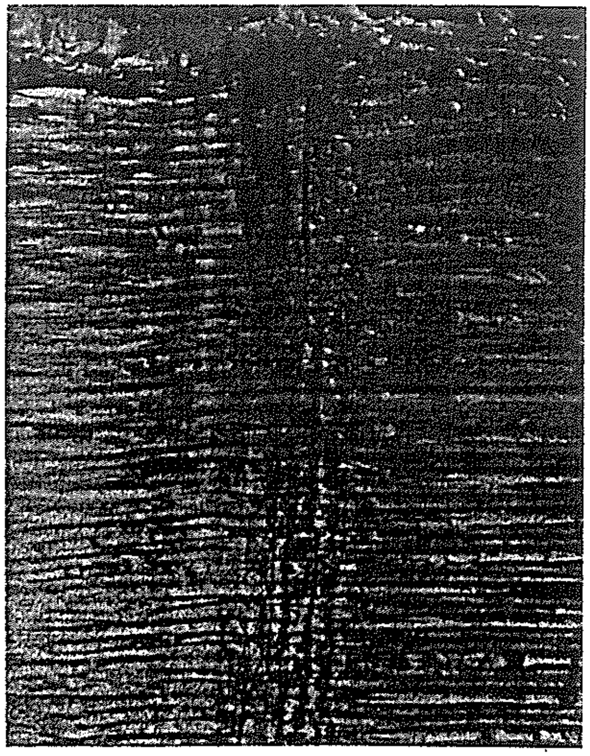

Figure 7.— Ray cells in heartwood from charge 62 control: Note this conventionally treated sample has little oil.

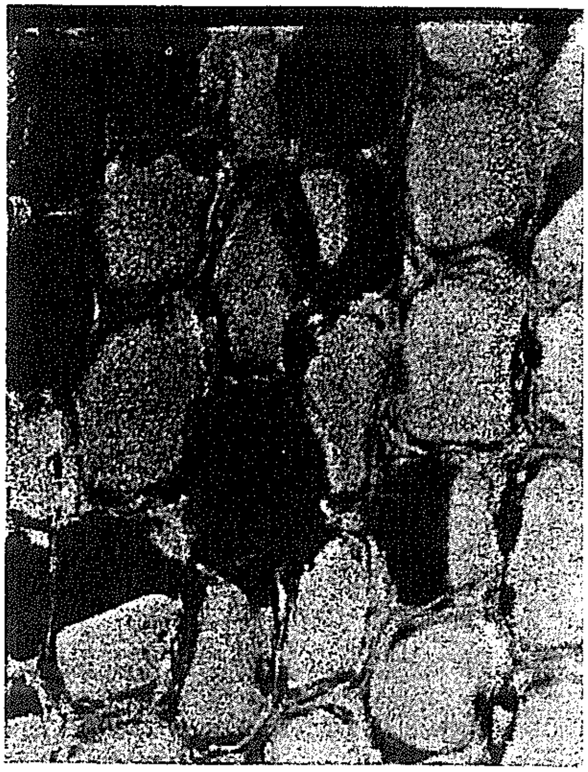

Figure 6.—Transverse section from sapwood charge 64 Sontek shows the bordered pits to be unaspirated.

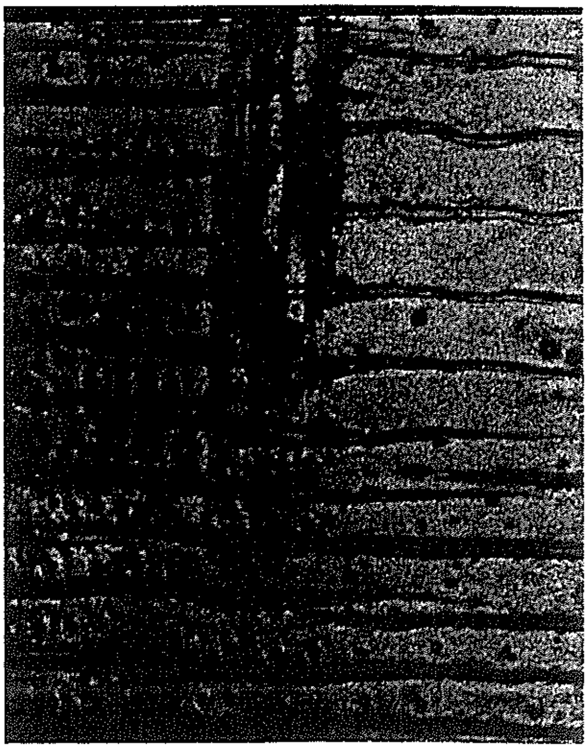

Figure 8.—Radial section from heartwood charge 64 Sontek. This shock-wave treated section shows the ray cells to be well filled with creosote.

The authors may have come close to describing the mechanism of penetration when they theorize that spray droplets of creosote form an air in oil emulsion. Figure 1, a latewood tangential section from the sapwood, charge 63, clearly shows air bubbles distributed throughout the creosote in tracheids. Figure 2, a latewood tangential section from the sapwood of charge 62, on the other hand, shows fewer, irregular air inclusions in the oil. Figure 3, an earlywood tangential section from the sapwood of charge 63 indicated much of the oil in the larger tracheids is present as globules. Just why the difference between early and latewood form of the oil I am not prepared to say.

No evidence could be found for a valve-like operation of the torus in pits, although this doesn't mean that it isn't possible. Figure 4, a tangential section from the earlywood area of the heartwood, illustrates aspirated pits with the chambers full of creosote. Unfortunately, I have no exactly comparable picture of pits from charges 63 or 64 but it is interesting to note Figures 5 and 6. These are radial and transverse section from the sapwood of charge 64. In both of these the bordered pits are unaspirated.

Comparing oil content in the rays in charge 62 and 64, both taken from the heartwood, I note the conventionally treated sample has little oil but the shock treated wood shows a well filled ray. (Figures 7 and 8, charge 62 and charge 64 respectively.)

Thus, there appear to be differences in the location and form of creosote deposits in the wood treated by the two methods. More extensive examination might uncover others or confirm present findings.

No difference could be seen in the structure of the wood after treatment by the two methods. In other words, no changes were seen in cell wall integrity or relationship of one cell to another using the light microscope.

Session Chairman Miller: Thank you, Charlie and Herman, for a very interesting paper and new idea. I am sure we will be hearing more of it.

The next item on our program is the Reports of the Treatments Committees. I will call on Dan Davies, General Chairman of these Committees to come forward and introduce the Chairmen of the various Committees.