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A STUDY OF THE KILN DRYING OF LUMBER FROM COTTONWOOD (POPULUS DELTOIDES MARSHALL)

by

FRED EUGENE DICKINSON

#### A THESIS

Submitted to the Graduate School of Michigan State College of Agriculture and Applied Science in partial fulfilment of the requirements for the degree of

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THESIS

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#### INTRODUCTION

At the present time the kiln drying of lumber has reached a point of high efficiency due to the rapid advancement in dry kiln equipment and drying methods during the last several decades. Even so, the kiln operator often finds that the available information and equipment are inadequate to solve his many problems.

Little is known about the drying of some of the lower quality woods such as cottonwood. More information is needed about suitable schedules and some of the more harmful defects that are liable to appear during the seasoning process. The true drying conditions in the kiln are another problem that arises. Does the operator have the conditions in the kiln that he desires, and if not, what can he do to arrive at these conditions?

While little information is available concerning the kiln drying of cottonwood, several drying schedules have been developed, the latest of which is contributed by the Forest Products Laboratory (13).

Tiemann (10) has given considerable attention to seasoning defects in both hardwoods and conifers. He has been particularly interested in collapse, a defect very likely to occur when drying green cottonwood.

Circulation in the kiln has received attention, both in respect to rate of circulation and uniformity of circulation. Hermann and Rasmussen (4) in their work with western pine in 1938 discovered that the rate of drying was increased by increasing the rate of circulation. Greenhill (2) working with Australian timbers had previously arrived at the same general conclusions in 1936. The mathematical part of the work herein described is based on drying experiments with sitka spruce carried on by Tuttle (12) in 1925 and with poplar slabs by Sherwood (8) several years later. In both instances the Fourier heat conduction equations were used in the analysis of the drying. Additional work using the same principle was carried on by Nelson (7) in 1934 using Douglas fir lumber.

The objects of the problem were: (a) to find a suitable schedule for drying green cottonwood, (b) to study any defects liable to occur while drying green cottonwood, and (c) to obtain the best possible drying conditions in the dry kiln with the available equipment.

The experiment was performed at the Department of Forestry, Michigan State College, East Lansing, Michigan during the years 1940 and 1941.

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#### EQUIPMENT

The experimental dry kiln used is of the recirculating compartment type, located in the basement of the forestry building.

The compartment, constructed with double walls and ceiling to prevent escape of heat and moisture, is 10 feet wide, 17 feet long, and 8 feet high. Back of this is located a housing which incloses the blower, heating coils, and spray jets.

The kiln is equipped with a Toledo scale capable of weighing loads up to 10,500 pounds. Four corner posts resting on cement piers support the scale platform on which the lumber is piled in loading the kiln. By means of a series of levers, the platform is connected with the scale dial located outside the compartment. Weights can be estimated to a quarter of a pound, as the dial is graduated in two-pound divisions.

Provision is made for circulation of air in the kiln by the external blower system which consists of one large non-reversible fan powered by a 1 H.P. electric motor. Entering the compartment through a central duct running lengthwise along the floor of the kiln, the air passes through the load, and is returned to the blower by two exhaust ducts, one located on each side of the kiln.

Temperature and humidity in the kiln are automatically controlled and recorded by a Foxboro controller-recorder. Two bulbs, one dry and one kept wet by an enveloping wick, are connected by vapor filled tubes to the instrument located on the outside of the kiln. The two bulbs are placed in the center of the kiln directly above the entering air duct so that the condition of the air is measured immediately

before entering the load of lumber.

Any desired wet and dry bulb temperatures up to 200 degrees
Fahr. are obtained in the kiln by setting the instrument for those
temperatures. Using compressed air, valves on the steam and spray
lines are operated by the instrument to maintain the desired temperature and relative humidity conditions. Steam furnished by the College
power plant is used in operating the kiln.

Additional equipment consisted of a small band saw, triple beam balance, and an electric oven which were used in moisture content determination.

### CHECKING THE INSTRUMENT

To make sure the instrument was in perfect adjustment, it was calibrated on a rising temperature before the first and fourth runs.

## DETERMINATION OF THE RATE OF CIRCULATION

During Runs 1, 2, and 3 the velocity of the air in the kiln was measured by an anemometer on the leaving side of the load. As the movement of air was just sufficient to move the anemometer, a velocity of 15 feet per minute was assumed.

During Run 4 after a new method of piling the lumber was adopted, the rate of circulation was measured on the leaving side of the load using a velometer. Readings were taken in the air space between every board at both ends and in the middle of the load. The average velocity after adjusting for temperature, humidity, and atmospheric pressure was found to be 148 feet per minute at a temperature of 117.5 degrees Fahr. and 24 percent relative humidity.

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#### MATERIAL.

The lumber, cottonwood (Populus deltoides Marshall), used was sawed at the Forestry Department's sawmill from logs out on College property during 1940. It was flat grained stock of random widths, 12 feet long, 1 1/8 inches thick and contained both heartwood and sapwood. After sawing, the lumber was piled without stickers to prevent as little drying as possible before placing it in the kiln.

#### LOADING THE KILN

Three methods of piling were used in the experiment to determine the effect on air flow through the load and the slope of the drying curves. For each piling method, 1 by  $1\frac{1}{2}$ -inch basswood stickers placed at 3-foot intervals were used.

The lumber in Runs 1 and 2 was flat piled, leaving a central chimney 20 inches wide for the incoming air. Each load was 20 courses high and 12 inches wide on each side of the central chimney.

For Run 3, a modification of the first method was used. The lumber was flat piled with a chimney tapering from a width of 20 inches at the base to 14 inches at the top. The load was 16 courses high and 12 inches wide on each side of the central chimney. In all three loads, the chimney was roofed over so that the air had to pass through the load.

To combat recirculation of air through the bottom of the load during Run 3, a wooden grille was constructed and placed in the central chimney at the same level as the bottom boards of the pile. By breaking up the air stream, recirculation was stopped and even distribution of air throughout the load was produced.

To obtain faster circulation of air through the load during

the remaining four runs, baffles, 20 inches apart, were constructed on each side of the incoming air duct to a height of 14 inches above the wet and dry bulbs. Standards upon which the lumber was piled were built up from the scale platform to a height of 2 inches above the wet and dry bulbs. Each of the remaining four loads was edgepiled on the standards and was 10 boards wide. The height of the loads varied from 10 to 12 inches as determined by the width of the boards. Bindings which could be tightened with turnbuckles were placed at 3-foot intervals to hold the loads together. These bindings kept the stickers from falling out and prevented the lumber from cupping and warping badly.

Before loading the kiln, the stickers, and for Runs 4 to 7, inclusive, the standards and bindings, were weighed and their weight set off on the tare beam of the scale. Hence, the reading on the scale dial was that of the weight of the lumber and its moisture.

#### OPERATION OF THE KILN

Before each run was started, a new wick was placed on the wet bulb and a new chart on the instrument. The fan and motors were inspected, greased and oiled.

The drying operation was begun by starting the blower and opening the valves on the steam and spray lines. The instrument was set for the desired wet and dry bulb temperatures which were recorded continuously on the chart by two pens. Weight of the lumber was read at the time of starting and then at fifteen minute intervals until condensation within the kiln caused by the steam striking the cold lumber had stopped and the load had nearly regained its original weight through drying.

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During the rest of the run, readings of the weight of the lumber were taken at 2- to 8-hour intervals excepting at schedule changes when readings were taken at fifteen minute intervals for several hours.

During Runs 6 and 7, the wet and dry bulb temperatures on the leaving air side of the load were checked twice daily by a hygrometer to determine the drop in temperature across the load. These readings were taken directly above the location of the wet and dry bulbs of the instrument.

The schedules used for the runs were based on the equilibrium moisture content principle. Badger and McCabe (1) explain this as follows:

"In general, a given material, if brought into contact with air of definite temperature and humidity, will reach a definite moisture content that will be unchanged by further exposure to this same air. This is known as the equilibrium moisture content of the material under the specified conditions. If the material contains more moisture than the equilibrium value, it will dry until its moisture content reached the equilibrium value. On the other hand, if the material is drier than the equilibrium value and is brought into contact with air of the stated temperature and humidity, it will absorb water until it reaches this same equilibrium point."

Four different schedules were used and their effects on the rate of drying and seasoning defects observed. A constant dry bulb was used with all runs except the first.

## RECORDING THE DATA

Complete information for each run was recorded on a prepared

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form. This included such items as load weights, corresponding moisture contents, kiln schedule followed, drying time, kind of material, and condition of the lumber before and after drying.

#### MOISTURE CONTENT DETERMINATION

The moisture content of the lumber can most accurately be determined by taking small samples of the wood which are weighed, dried, and then weighed again and the two weights used in determining the moisture content in percent based on the oven-dry weight of the wood.

The method used was to cross-cut a board about 2 feet from one end to get away from the effect of end drying. Then a section 2-inch wide was cut from the board using the band saw. Loose splinters were removed from the section and the section weighed immediately on the balance. It was then placed in the electric oven at a temperature of 212 degrees Fahr. until the sample reached a constant weight when it was removed from the oven, weighed, and the weight recorded as the oven-dry weight of the wood. The moisture content of the sample was calculated by the following formula:

Moisture Content in Percent = (Original weight Oven-dry weight -1)100

When loading the kiln, the moisture contents of samples from four or five boards were determined. The average moisture content of these samples was taken as the average moisture content of the load and was used in determining when the schedule should be changed during the run.

On completion of the run, one sample was cut from each board in Runs 4 to 7, inclusive, and from every other board in the first three runs. Alternate samples were taken from alternate ends of the load. The average moisture content of these samples was calculated and used as the true moisture content of the load at the time the samples were cut. Using this moisture content, the average original moisture content of the load and the intermediate moisture contents during the run were calculated.

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Run 1

	y Bulb				Bulb			Mod	ilibi	•	p-	Moisture Content of
	Temperature Temperature Degrees Fahr. Degrees Fahr.				in Percent					Stock		
4,555	135 140 145 155 165				127 130 126 129 127				13.4 12.1 8.3 6.4 4.6			105.3 43.8 33.4 23.2 18.0
Average	Origi	nal	Moist	ıre	Conte	ent	(0)					105.3%
Average	Final	Mo	isture	Co	ntent							9.1%
Collapse	э .										25%	of Load
Cupping						•						Slight
Warping												None

11.8 . 5 -		Current '			
Age	Weight	Moisture '		e)100 = E	
of	of	Content '	(	0-0)	
Run	Load	in Percent '			
Hours	Pounds	С	c-e	0-0	E
0.00	2453	105.3	91.9	91.9	100.0
.25	2488	108.2	94.8		103.2
.50	2517	110.5	97.1		105.7
•75	2526	111.5	98.1		106.7
1.00	2522	111.0	97.6		106.2
1.25	2518	110.8	97.4		106.0
1.50	2515	110.3	96.9		105.4
2.75	2498	109.0	95.6		104.0
3.00	2496	108.9	95.5		103.9
5.50	2475	107.0	93.6		101.8
6.00	2470	106.6	93.2		101.1
6.50	2465	106.2	92.8		101.0
17.00	2374	98.7	85.3		92.8
19.25	2356	97.0	83.6		91.0
23.00	2328	95.0	81.6		88.8
26.00	2308	93.4	80.0		87.1
29.25	2283	91.2	77.8		84.7

		Run 1 (Cont'	1)	-	
Aria	Weight	Current Moisture	;	(c-e)100 _ F	, 2
Age	of	Content	1	(0-e)	3
Run	Load	in Percent	,	(0-0)	
Hours	Pounds	C C	0-0	0-0	E
120 20					pic y
30.50	2276	90.5	77.1		83.9
41.00	2200	84.4	71.0		77.3
44.00	2182	82.5	69.1		75.2
49.75	5174	79.4	66.0		71.8
54.00	2118	77.1	63.7		69.3
65.00	2052	72.8	59.4		64.6
69.00	2031	70.3	56.9		61.9
72.50	2012	69.4	56.0		60.9
74.50	2002	67.7	54.3		59.1
76.75	1992	66.9	53.5		58.2
90.50	1925	61.1	47.7		51.9
94.00	1908	59.5	46.1		50.2
97.75	1891	58.5	45.1		49.1
101.25	1876	57.0	43.6		47.4
113.75	1821	52.5	39.1		42.5
116.50	1811	51.8	38.4		41.8
122.25	1792	50.0	36.6		39.8
126.50	1774	48.5	35.1		38.2
137.75	1734	45.1	31.7		34.5
140.00	1728	44.5	31.1		33.8
143.00	1718	43.8	30.4	91.9	33.1
*143.00	1718	43.8	31.7	93.2	34.0
143.25	1716	43.6	31.5		33.8
143.50	1714	43.4	31.3		33.6
143.75	1712	43.2	31.1		33.4
144.00	1711	43.1	31.0		33.3
14.25	1709	42.9	30.8		33.0
144.50	1708	42.8	30.7		32.9
14.75	1706	42.7	30.6		32.8
145.00	1704	42.5	30.4		32.6
146.00	1698	42.1	30.0		32.2
150.25	1672	40.0	27.9		29.0
161.00	1614	35.1	23.0		24.7
164.00	1598	33.7	21.6		23.2
165.00	1595	33.4	21.3	93.2	22.9
*165.00	1595	33.4	25.1	97.0	25.9
165.25	1592	33.2	24.9	7100	25.7
165.50	1589	33.0	24.7		25.5
165.75	1587	32.7	24.4		25.2
166.00	1584	32.5	24.2		24.9
166.25	1582	32.3	24.0		24.7
166.50	1579	32.1	23.8		24.5
167.00	1575	31.8	23.5		24.2
167.25	1572	31.5	23.2		23.9

		Current '			
Age	Weight	Moisture !		(c-e)100 - E	
of	of	Content '		(o-e)	
Run	Load	in Percent '		0.0	
Hours	Pounds	С	c-e	0-0	E
170.00	1553	30.0	21.7		22.3
174.25	1524	27.5	19.2		19.8
181.75	1482	24.0	15.7		16.2
183.50	1472	23.2	14.9	97.0	15.4
*183.50	1472	23.2	16.8	98.9	17.0
183.75	1470	23.1	16.7		16.9
184.00	1469	22.9	16.5		16.7
184.25	1466	22.7	16.3		16.5
184.50	1464	22.5	16.1		16.3
184.75	1462	22.3	15.9		16.1
185.00	1461	22.2	15.8		16.0
185.25	1460	22.2	15.8		16.0
185.75	1457	22.0	15.6		15.8
187.75	1445	20.9	14.5		14.7
190.25	1432	19.9	13.5		13.7
192.00	1422	19.0	12.6		12.7
194.25	1410	18.0	11.6	98.9	11.7
*194.25	1410	18.0	13.4	100.7	13.3
194.50	1408	17.8	13.2		13.1
194.75	1406	17.5	12.9		12.8
195.00	1404	17.3	12.7		12.6
195.25	1403	17.2	12.6		12.5
198.00	1386	15.9	11.3		11.2
210.25	1335	11.6	7.0		7.0
211.75	1330	11.2	6.6		6.6
215.00	1321	10.6	6.0		6.0
218.00	1312	9.8	5.2		5.2
221.75	1304	9.1	4.5	100.7	4.5

Run 1 (Cont'd)

\*Schedule change.

Run 2

Dry Bulb Temperature		Bulb erature	Moi Co	sturenten	e t		Moisture Content of Stock
Degrees Fahr	. Degre	es Fahr.		е			Percent
135 135 135 135		127 125 116 109	1	3.4 2.1 8.3 6.6			97.1 45.2 35.5 18.9
verage Origi	nal Moistu	re Content	(0) .				. 97.1%
205. 5				•		•	. 97.1%
verage Final				:		•	3.5
werage Crigitwerage Final							. 11.0%

45-1-		Current '			
Age	Weight	Moisture '		e)100 =	E
of	of	Content	(	o-e)	
Run	Load	in Percent '			
Hours	Pounds	С	с-е	о-е	E
0.00	2538	97.1	83.7	83.7	100.0
.25	2558	98.7	85.3		101.9
•50	2580	100.4	87.0		103.9
.75	2590	101.2	87.8		104.9
1.00	2592	101.3	87.9		105.0
1.25	2590	101.2	87.8		104.9
2.25	2579	100.3	86.9		103.8
3.75	2560	98.9	85.5		102.2
5.75	2537	97.1	83.7		100.0
7.25	2520	95.7	82.3		98.3
11.00	2482	92.8	79.4		94.9
22.25	2380	84.9	71.5		85.1
25.25	2355	82.9	69.5		83.0
26.25	2346	82.2	68.8		82.2
29.25	2321	80.3	66.9		79.9
31.25	2306	79.1	65.7		78.5
36.00	2269	76.2	62.8		75.0
46.50	2191	70.2	56.8		67.9
49.25	2174	68.9	55.5		66.3

Age of Run	Weight of Load	Current ' Moisture ' Content ' in Percent '	<u>(</u> c-	-e)100 = E	
Hours	Pounds	c c	с-е	0-0	E
54.00	2138	66.1	52.7		63.0
55.00	2132	65.6	52.2		62.4
59.75	2103	63.4	50.0		59.7
70.50	2039	58.4	45.0		53.8
74.50	2016	56.6	43.2		51.6
77.75	1996	55.0	41.6		49.7
83.75	1968	52.9	39.5		47.2
96.00	1910	48.4	35.0		41.8
100.75	1888	46.7	33.3		39.8
105.25	1869	45.2	31.8	83.7	38.0
105.25	1869	45.2	33.1	85.0	38.9
105.50	1867	45.0	32.9	09.0	38.7
105.75	1865	44.9	32.8		38.6
106.00	1863	44.7	32.6		38.4
106.25	1861	44.6	32.5		38.2
109.75	1844	43.2	32.1		37.8
118.50	1800	39.8	27.7		32.6
122.00	1782	38.4	26.3		30.9
123.50	1775	37.9	25.8		30.4
125.50	1769	37.4	25.3		29.8
127.50	1763	36.9	24.8		29.2
132.00	1745	35.5	23.4	85.0	27.5
132.00	1745	35.5	27.2	88.8	30.6
132.25	1742	35.3	27.0	00.0	30.4
132.50	1740	35.2	26.9		30.3
132.75	1738	35.0	26.7		30.1
133 - 00	1735	34.8	26.5		29.8
144.00	1664	29.3	21.0		23.6
146.25	1652	28.3	20.0		22.5
149.00	1636	27.1	18.8		21.2
152.25	1622	26.0	17.7		19.9
155.25	1610	25.1	16.8		18.9
156.00	160L	24.6	16.3		18.4
168.25	1549	20.3	12.0		13.5
173.25	1531	18.9	10.6	88.8	11.9
173.25	1531	18.9	12.3	90.5	13.6
173.50	1528	18.7	12.1	,,	13.4
173.75	1527	18.6	12.0		13.3
174.00	1524	18.4	11.8		12.0
174.25	1523	18.3	11.7		12.9
174.50	1520	18.1	11.5		12.7
177.00	1510	17.3	10.7		11.8
181.25	1493	16.0	9.4		10.4
192.75	1459	13.3	6.7		7.4
194.75	1553	12.9	6.3		7.0
199.50	1440	11.9	5.3		5.9
205.00	1429	11.0	4.4	90.5	4.9

Run 3

Dry Bulb Temperature		Wet Bulb Temperature Degrees Fahr.			Equilibrium Moisture Content in Percent				Moisture Content of Stock	
135 135 135 135 135 135 135	•	1 1 1 1 1	27 25 20 15 10	•		13	3.4 2.1 9.7 3.0 5.7			115.8 33.3 23.3 15.5 10.7 8.9
verage Origin	al Mois	ture	Conte	nt	(0)				•	115.8%
verage Final	Moistur	e Co	ntent							6.6%
Collapse .								•		None
Supping .										Slight
Warping .										None

Age	Weight	Current ' Moisture '		-e)100 - E	
of Run	of Load	Content ' in Percent '		(o-e)	
Hours	Pounds	C C	с-е	о-е	E
0.00	2117	115.8	102.4	102.4	100.0
0.25	2151	119.3	105.9		103.4
0.50	2169	121.1	107.7		105.2
0.75	2168	121.0	107.6		105.1
1.00	2164	120.6	107.2		104.7
1.25	2158	120.0	106.6		104.1
1.50	2153	119.5	106.1		103.6
1.75	2150	119.2	105.8		103.3
2.00	2146	118.8	105.4		102.9
2.50	2137	117.8	104.4		102.0
4.00	2114	115.5	102.1		99.7
5.00	2100	114.1	100.7		98.3
5.75	2090	113.0	99.6		97.3
7.00	2073	111.3	97.9		95.6
8.75	2055	109.5	96.1		93.8
14.75	1985	102.3	88.9		86.8

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		Run 3 (Cont'd) Current			
Age	Weight	Moisture '	(0	-e)100 - F	2
of	of	Content '		(o-e)	
Run	Load	in Percent '			
Hours	Pounds	С	.0-0	0-е	E
23.75	1905	94.2	80.8		78.9
26.00	1884	92.9	78.6		76.8
26.50	1880	91.6	78.2		76.4
29.00	1859	89.5	76.1		74.3
31.50	1837	87.2	73.8		72.1
36.75	1794	82.9	69.5		67.9
49.25	1703	73.6	60.2		58.8
54.00	1672	70.4	57.0		55.7
56.25	1657	68.9	55.5		54.2
70.75	1572	60.2	46.8		45.7
74.00	1554	58.4	45.0		43.9
76.00	1544	57.4	44.0		43.0
79.00	1528	55.8	42.4		41.4
83.75	1504	53.3	39.9		39.0
96.00	1450	47.8	34.4		33.6
98.50	1440	46.8	33.2		32.4
100.00	1434	46.2	32.8		32.0
103.25	1420	44.8	31.4		30.7
107.75	1407	43.4	30.0		29.3
119.50	1371	39.8	26.4		25.8
122.00	1364	39.0	25.6		25.0
124.00	1358	38.4	25.0		24.4
127.00	1350	37.6	24.2		23.6
132.00	1337	36.3	22.9		22.4
142.50	1314	33.9	20.5		20.0
145.00	1308	33.3	19.9	102.4	19.4
*145.00	1308	33.3	21.2	103.7	20.4
145.25	1306	33.1	21.0		20.3
145.50	1306	33.1	21.0		20.3
145.75	1305	33.0	20.9		20.2
146.00	1304	32.9	20.8		20.1
146.25	1304	32.9	20.8		20.1
146.50	1302	32.7	20.6		19.9
148.00	1298	32.3	20.2		19.5
151.00	1288	31.3	19.2		18.5
155.75	1276	30.1	18.0		17.4
168.00	1250	27.4	15.3		14.8
171.00	12/14	26.8	14.7		14.2
175.00	1237	26.1	14.0		13.5
180.25	1228	25.2	13.1		12.6
192.00	1211	23.4	11.3		10.9
192.50	1210	23.3	11.2	103.7	10.8
*192.50	1210	23.3	13.6	106.1	12.8
192.75	1209	23.2	13.5		12.7
193.00	1208	23.1	13.4		12.6
193.25	1207	23.0	13.3		12.5

	Rail ) (conc.d)			-
107-4-1-4			1200	
		10		
			(0-0)	
				E
Pounds	e	·C-6	0-0	E
1206	22.9	13.2		12.4
1205	22.8	13.1		12.3
				12.3
	22.6			12.2
				12.0
				11.5
				11.0
				10.0
	18.1			7.9
1150				7.1
11/18				6.9
	16.4			6.3
			106.1	5.5
				7.0
	15.4		10110	6.9
	15.3			6.8
	15.2			6.7
	15.2			6.7
				6.6
				6.6
				6.4
				6.2
				6.0
				5.7
				5.6
				5.0
	12.2			3.9
	11.0			3.6
				3.5
		3.6		3.3
				3.2
	10.7		107 9	
	10.7	1.0		2.5
		4.0	109.1	3.7
				3.7
				3.6
				3.5
	10.5			3.5
				3.5
1005				3.4
		2.1		3.4
				3.3
		2.4		3.1
		2.1		2.8
				2.5
	Weight of Load  Founds  1206 1205 1201 1203 1201 1196 1191 1180 1159 1159 1153 1133 1133 1133 1133 1131 1130 1129 1125 1122 1119 1118 1112 1100 1098 1097 1095 1086 1086 1086 1086 1086 1086 1086 1086	Weight   Current   Woisture   Content   Isoad   In Percent   Founds   Content   In Percent   Founds   Content   In Percent   In Percent   Founds   Content   In Percent   In Percent   In Percent   In Percent   In Percent   In Percent   In	Weight   Ourrent   Outrent   Outre	Weight   Current   Content   Conte

Run 3 (Cont'd)

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		Run 3 (Cont'd)			
		Current '			
Age	Weight	Moisture '	( e-	-e)100 🕳 E	
of	of	Content '		(o-e)	
Run	Load	in Percent '			
Hours	Pounds	C	с-е	0-6	E
312.75	1068	8.9	2.2	109.1	2.0
*312.75	1068	8.9	3.2	110.1	2.9
313.00	1068	8.9	3.2		2.9
313.25	1067	8.8	3.1		2.8
313.50	1067	8.8	3.1		2.8
313.75	1066	8.7	3.0		2.7
314.00	1066	8.7	3.0		2.7
315.50	1065	8.6	2.9		2.6
316.75	1064	8.5	2.8		2.5
317.75	1063	8.4	2.7		2.5
320.75	1061	8.2	2.5		2.3
334.00	1056	7.6	1.9		1.7
335 • <b>7</b> 5	1055	7.5	1.8		1.6
338.25	1054	7.4	1.7		1.5
340.75	1053	7.3	1.6		1.5
345.50	1052	7.2	1.5		1.4
357 • 75	1049	6.9	1.2		1.1
360.25	1048	6.8	1.1		1.0
365.75	1047	6.7	1.0		•9
370.50	1046	6.6	0.9	110.1	.8

<sup>\*</sup> Schedule Change

Run 4

Equilibrium

Dry Bulb Wet Bulb Temperature Temperature Degrees Fahr. Degrees Fahr.				Moisture Content in Percent			Content of Stock						
				e e e e e e e e e e e e e e e e e e e			_	Percent					
135						13					3.1		
135 135				12				12	•1 •7				6.4 4.0
135				11					• /				3.0
135				10					•7				7.0
Average Or	igi	nal l	Moist	ure	Cont	ent	(0)					133	.1%
Average Fi	nal	Moi	sture	Co	ntent		•					11	. 2%
Collapse											10%	of I	oad
Cupping.							•			•		Sli	ght
Warping.									•			N	lone
Age		We	ight	_	Curr		- T		(		)100		
of			of		Cont				7.		-e)	- E	
Run			oad		in Pe	_	nt '						
Hours		Po	unds		0				с-е		0.	-0	E
0.00		54	6.00		133	.1		1	19.7		119	9.7	100.0
0.25			0.00		139	.0		1:	25.6				104.9
0.50			2.00		139				26.5				105.7
0.75			9.50		138				25.4				104.8
1.00			7.00		137				24.3				103.8
1.25			4.50		136				23.3				103.0
1.50			2.50		135				22.4				102.3
1.75			0.00		134				21.4				101.4
2.00			9.00		134				21.0				101.1
2.25			7.00		133				20.1				100.3
13.00			0.00		113				00.00				83.5
16.00			0.50		109				96.0				80.2
18.50			3.00		106				92.8				77.5
19.00			2.00		105				92.4				77.2
20.50			8.00		104				90.6				75.7
21.50			4.00		102				88.9				74.3
26.00		46	2.00		97	•2			83.8				70.0

		Run 4 (Cont'd)			
		Current '			
Age	Weight	Moisture '	(c-	e)100 _ E	
of	of	Content	_	o-e)	
Run	Load	in Percent '			
Hours	Pounds	C	с-е	о-е	E
27.00	460.00	96.4	97.0		69.3
37.00	435.00		83.0		60.4
		85.7	72.3		
41.00 45.00	426.00	81.2 78.4	67.8		56.6
	418.00		65.0		54.3 50.6
50.00	407.50	74.0	60.6		
61.00	387.00	65.2	51.8		43.3
64.00	382.00	63.1	49.7		41.5
69.00	372.00	58.8	45.4		37.9
73.50	365.00	55.8	42.4		35.4
85.00	350.00	49.4	36.0		30.1
90.00	343.00	46.4	33.0	119.7	27.6
*90.00	343.00	46.4	34.3	121.0	28.3
90.25	342.50	46.2	34.1		28.2
90.50	342.00	46.0	33.9		28.0
90.75	341.50	45.8	33.7		27.9
91.00	341.25	45.7	33.6		27.8
91.25	341.00	45.6	33.5		27.7
91.50	340.00	45.1	33.0		27.3
93.25	338.50	44.5	32.4		26.8
97.00	333.00	42.1	30.0		24.8
109.75	318.00	35.7	23.6		19.5
112.50	315.50	34.7	22.6		18.7
114.00	314.00	34.0	21.9	121.0	18.1
*114.00	314.00	34.0	24.3	123.4	19.7
114.25	313.00	33.6	23.9		19.4
114.50	312.50	33.4	23.7		19.2
114.75	312.00	33.2	23.5		19.0
115.00	311.50	33.0	23.3		18.9
115.25	311.00	32.8	23.1		18.7
115.50	310.50	32.5	22.8		18.5
115.75	310.25	32.4	22.7		18.4
117.75	308.00	31.5	21.8		17.7
120.50	304.25	29.9	20.2		16.4
123.25	301.00	28.5	18.8		15.2
133.50	292.00	24.6	14.9	70.00.7	12.1
138.75	288.25	23.0	13.3	123.4	10.8
*138.75	288.25	23.0	15.0	125.1	12.0
139.00	288.00	22.9	14.9		11.9
139.25	287.50	22.7	14.7		11.8
139.50	287.00	22.5	14.5		11.6
139 <b>.7</b> 5	287.00	22.5	14.5		11.6
140.00	286.50	22.3	14.3		11.4
140.25	286.00	22.1	14.1		11.3
141.75	284.50	21.4	13.4		10.7
145.50	282.00	20.4	12.4		9.9

		Run 4 (Cont'd)			
	W-4 -1-4	Current '		-1100	
Age	Weight	Content '	(6-	-e)100 - E	
of Run	of	in Percent '		(o-e)	
	Load				Е
Hours	Pounds	c	с-е	о-е	ь.
148.75	280.50	19.7	11.7		9.4
156.75	275.00	17.4	9.4		7.5
159.50	274.00	17.0	9.0	125.1	7.2
·159.50	274.00	17.0	11.3	127.4	8.9
159.75	273.50	16.7	11.0		8.6
160.00	273.25	16.6	10.9		8.6
160.25	273.00	16.5	10.8		8.5
160.50	272.50	16.3	10.6		8.3
160.75	272.25	16.2	10.5		8.2
161.00	272.00	16.1	10.4		8.2
163.00	270.50	15.5	9.8		7.7
165.00	269.50	15.0	9.3		7.3
169.50	267.00	14.0	8.3		6.5
172.75	265.50	13.3	7.6		6.0
181.00	262.00	11.8	6.1		4.8
183.00	260.50	11.2	5.5	127.4	4.3

<sup>\*</sup> Schedule Change

Run 5

Dry Bulb Temperature		Wet Bulb		Equilibrium Moisture Content in Percent					Moisture Content of Stock		
Degrees Fahr	• Deg	rees F	ahr.		ө				Percent		
135 135		127 125			13.				116.3 26.8		
135		120			9.			17.9			
135		115		8.0			12.2				
135		105			5.	.7		9.9			
Average Origin Average Final				(0)	:	•	•		116.3% 7.7%		
Collapse .		•		•	•	•	•		None		
Cupping		•		•		•	•		Slight		
Warping						•	•	•	None		

Age of Run	Weight of Load	Current ' Moisture ' Content ' in Percent '		-e)100 (o-e) = E	
Hours	Pounds	c	с-е	0-е	Е
0.00	637.00	116.3	102.9	102.9	100.0
0.25	653.00	121.8	108.4		105.3
0.50	654.00	122.1	108.7		105.6
0.75	651.00	121.1	107.7		104.7
1.00	649.00	120.4	107.0		104.0
1.25	647.00	119.7	106.3		103.3
1.50	645.00	119.0	105.6		102.6
5.75	618.00	109.9	96.5		93.8
9.75	600.00	103.8	90.4		87.9
26.25	542.00	84.1	70.7		68.7
30.25	529.00	79.6	66.2		64.3
34.50	516.50	75.4	62.0		60.3
47.25	483.00	64.0	50.6		49.2
51.50	473.00	60.6	47.2		45.9
54.00	467.00	58.6	45.2		44.0
59.25	455.50	54.7	41.3		40.1
70.75	434.00	47.4	34.0		33.0

		Run 5 (Cont'd)			
Age	Weight	Current * Moisture *		(c-e)100 p	
of	of	Content '		(0-e) = E	
Run	Load	in Percent '		(0 0)	
Hours	Pounds	C	с-е	0-6	E
72.50	431.00	46.4	33.0		32.1
75.00	426.50	44.8	31.4		30.5
78.00	421.75	43.2	29.8		29.0
82.00	416.00	41.3	27.9		27.1
95.00	399.00	35.5	22.1		21.5
96.50	396.50	34.6	21.2		20.6
101.25	394.00	33.8	20.4		19.8
108.45	385.00	30.7	17.3		16.8
119.00	377.00	28.0	14.6		14.2
120.00	376.00	27.7	14.3		13.9
124.00	373.50	26.8	13.4	102.9	13.0
*124.00	373.50	26.8	14.7	104.2	14.1
124.25	373.00	26.7	14.6		14.0
124.50	372.50	26.5	14.4		13.8
124.75	372.00	26.3	14.2		13.6
125.00	372.00	26.3	14.2		13.6
125.25	371.75	26.2 26.2	14.1		13.5
125.50	371.50		14.1		13.5
130.25 142.25	368.00 360.00	25.0 22.3	12.9		12.4 9.8
144.00	358.50	21.7	9.6		9.2
146.00	357•75	21.5	9.4		9.0
149.00	356.00	20.9	8.8		8.4
154.00	353.50	20.0	7.9		7.6
167.00	348.25	18.3	6.2		6.0
168.00	348.00	18.2	6.1		5.9
171.25	347.25	17.9	5.8	104.2	5.6
*171.25	347.25	17.9	8.2	106.6	7.7
171.50	347.00	17.8	8.1		7.6
171.75	346.25	17.5	7.8		7.3
172.00	346.00	17.5	7.8		7.3
172.25	245.75	17.4	7.7		7.2
172.50	345.50	17.3	7.6		7.1
173.00	345.00	17.2	7.5		7.0
173.25	344.75	17.1	7.4		6.9
177.75	342.00	16.4	6.7		6.3
192.50	336.00	14.1	4.4		4.1
197 <b>.7</b> 5	334.25	13.5	3.8		3.6
202.50	333.50	13.3	3.6		3.4
215.50	331.25	12.5	2.8		2.6
217.50	330 <b>.7</b> 5	12.3	2.6	//	2.4
219.00	330.25	12.2	2.5	106.6	2.3
*219.00	330.25	12.2	4.2	108.3	3.9
219.25	330.00	12.1 12.1	4.1		3.8
219.50 219.75	330.00		4.1		3.8
C17 • ()	329 <b>.7</b> 5	12.0	4.0		3.7

Run	5	(Cont'd)

		Current			
Age	Weight	Moisture '	(	c-e)100 _ E	
of	of	Content	-	(o-e)	
Run	Load	in Percent			
Hours	Pounds	0	c-e	0-6	E
220.25	329.25	11.8	3.8		3.5
220.50	329.00	11.7	3.7		3.4
220.75	328.75	11.6	3.6		3.3
222.00	328.00	11.4	3.4		3.1
225.00	327.00	11.1	3.1		2.9
226.50	326.75	11.0	3.0		2.8
238.75	324.25	10.1	2.1		1.9
243.25	324.00	10.0	2.0		1.8
244.00	323.50	9.9	1.9	108.3	1.8
*2h/1.00	323.50	9.9	4.2	110.6	3.8
244.25	323.00	9.7	4.0		3.6
244.50	323.00	9.7	4.0		3.6
244.75	322 <b>.7</b> 5	9.6	3.9		3.5
245.00	322.50	9.5	3.8		3.1
245.25	322.25	9.4	3.7		3.3
245.50	322.00	9.3	3.6		3.3
246.25	321.75	9.3	3.6		3.3
251.00	320.00	8.7	3.0		2.7
262.50	317.75	7.9	2.2		2.0
265.00	317.25	7.7	2.0		1.8
267.25	317.00	7.7	2.0	110.6	1.8

<sup>\*</sup> Schedule Change.

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Run 6

Dry Bulb Temperature	Wet B		Equilibrium Moisture Content in Percent				Moisture Content of Stock		
Degrees Fahr.	Degrees	Fahr.		•				Percent	
135 135	12 12	5		12	3.4 2.1			111.0 29.6	
135 135 135	12 11 10	5	9•7 8•0 5•7				21.7 13.7 8.8		
Average Origina	1 Moisture	Content						111.0%	
Average Final N	oisture Con	tent .			•			6.0%	
Collapse .				•				None	
Cupping								Slight	
orbhrug									

Age of Run	Weight of Load	Current ' Moisture ' Content ' in Percent '	<u>)</u>	c-e)100 (o-e) = E	
Hours	Pounds	0	с-е	o-e	E
0.00	612.00	111.0	97.6	97.6	100.0
0.25	628.00	116.5	103.1		105.6
0.50	628.00	116.5	103.1		105.6
0.75	626.00	115.8	102.4		104.9
1.00	623.00	114.7	101.3		103.8
1.25	621.50	114.2	100.8		103.3
1.50	618.50	113.2	99.8		102.3
7.00	586.00	102.0	88.6		90.8
12.00	566.00	95.1	81.7		83.7
23.75	525.00	81.0	67.6		69.3
28.00	511.00	76.1	62.7		64.2
30.50	500.00	72.3	58.9		60.3
35.00	487.00	67.9	54.5		55.8
47.75	454.00	56.5	43.1		44.2
50.50	1478 · 00	54.4	41.0		42.0
54.50	439.00	51.3	37.9		38.8
59.50	429.50	48.1	34.7		35.6

		Run 6 (Cont'd	)		
Age	Weight	Current ' Moisture '		-e)100 = E	
of	of	Content '		o-e)	
Run	Load	in Percent '			
Hours	Pounds	c	c-e	0-0	E
72.00	408.50	40.8	27.4		28.1
78.50	398.50	37.4	24.0		24.6
80.00	397.00	36.8	23.4		24.0
84.00	391.00	34.8	21.4		21.9
94.75	379.00	30.6	17.2		17.6
97.00	376.00	29.6	16.2	97.6	16.6
*97.00	376.00	29.6	17.5	98.9	17.7
97.25	375 • 75	29.5	17.4		17.6
97.50	375.00	29.3	17.2		17.4
97.75	374.75	29.2	17.1		17.3
98.00	374.25	29.0	16.9		17.1
98.25	374.00	28.9	16.8		17.0
99.50	372.50	28.4	16.3		16.5
104.75	366.50	26.3	14.2		14.4
106.75	364.50	25.6	13.5		13.7
119.00	354.00	22.0	9.9		10.0
120.50	353.00	21.7	9.6	98.9	9.7
*120.50	353.00	21.7	12.0	101.3	11.8
120.75	352.50	21.5	11.8		11.6
121.00	352.00	21.3	11.6		11.5
121.25	351.50	21.2	11.5		11.4
121.75	351.00	21.0	11.3		11.2
122.00	350.75	20.9	11.2		11.1
124.75	348.00	20.0	10.3		10.2
127.75	344.50	18.7	9.0		8.9
131.75	341.50	17.7	8.0		7.9
143.25	334.00	15.1	5.4		5.3
145.50	333.25	14.9	5.2		5.1
150.50	331.00	14.1	4.4		4.3
154.25	329.75	13.7	4.0	101.3	3.9
*154.25	329.75	13.7	5.7	103.0	5.5
154.50	329.50	13.6	5.6		5.4
154.75	329.00	13.4	5.4		5.2
155.00	329.00	13.4	5.4		5.2
155.25	328.75	13.3	5.3		5.2
155.50	328.50	13.2	5.2		5.0
156.75	328.00	13.1	5.1		5.0
171.00	322.00	11.0	3.0		2.9
178.75	320.00	10.3	2.3		2.2
192.00	317.00	9.3	1.3		1.3
194.00	316.50	9.1	1.1		1.1
197.75	316.25	9.0	1.0		1.0
199.75	316.00	8.9	0.9		•9
203.00	315.50	8.8	0.8	103.0	.8
*203.00	315.50	8.8	3.1	105.3	2.9

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•5

Age of Run	Weight of Load	Current Moisture Content in Percent	'	(c-e)100 = E	
Hours	Pounds	0	с-е	0-е	E
203.25	315.00	8.6	2.9		2.8
203.50	315.00	8.6	2.9		2.8
203.75	314.75	8.5	2.8		2.7
204.00	314.50	8.4	2.7		2.6
214.75	312.00	7.5	1.8		1.7
217.00	311.00	7.2	1.5		1.1
219.50	310.50	7.0	1.3		1.2
224.75	310.00	6.9	1.2		1.1

6.3

6.2

6.0

0.6

0.5

0.3

105.3

Pun 6 (Contid)

308.25

308.00

307.50

238.75

244.25

249.00

<sup>\*</sup> Schedule Change.

Temp	Temperature Tempe		Bulb eratu	re		Mod	libristur tent Perce	.6	Moisture Content of Stock		
Degre	es rai	nr.	1	egre	es ra	nr.	-		е		 Percent
	135 135 135 135 135				127 125 120 115 105				13.4 12.1 9.7 8.0 5.7		100.0 36.5 27.6 16.0 11.7
Average	Origin	nal	Moi	sture	Cont	ent	(0)				100.0%
Average	Final	Mo	istu	e Co	ntent						8.2%
Collapse											None
Cupping	60							•			Slight
Warping											None

-2104		Current	•		75.5	1000
Age	Weight	Moisture	•	1	(c-e)100 _	E
of	of	Content	•		(o-e)	
Run	Load	in Percent				1573
Hours	Pounds	С	_	с-е	о-е	E
0.00	605.0	100.0		86.6	86.6	100.0
0.25	620.5	105.1		91.7		105.9
0.50	622.0	105.6		92.2		106.5
0.75	621.5	105.5		92.1		106.4
1.00	619.0	104.6		91.2		105.3
1.25	617.5	104.2		90.8		104.8
1.50	616.0	103.7		90.3		104.3
1.75	614.0	103.0		89.6		103.5
4.25	598.0	97.7		84.3		97.3
7.75	583.5	92.9		79.5		91.8
12.25	567.0	87.5		74.1		85.6
24.50	530.5	75.4		62.0		71.6
27.00	524.0	73.2		59.8		69.1
29.50	518.0	71.3		57.9		66.9
32.25	511.5	69.1		55.7		64.3
36.50	501.5	65.8		52.4		60.5

			un 7 (Cont'd) Current		
	-e)100 _ E	10	Moisture '	Weight	Age
	(o-e)		Content '	of	of
	(0-0)		in Percent '	Load	Run
E	о-е	с-е	C C	Pounds	Hours
51.7		44.8	58.2	478.5	47.50
49.2		42.6	56.0	472.0	51.25
46.0		39.8	53.2	463.5	56.50
42.4		36.7	50.1	454.0	62.25
37.6		32.6	46.0	441.5	71.50
35.9		31.1	44.5	437.0	75.00
35.0		30.3	43.7	434.5	77.00
33.9		29.4	42.8	432.0	79.25
30.7		26.6	40.0	423.5	85.00
27.5		23.8	37.2	415.00	95.50
26.7	86.6	23.1	36.5	413.00	97.50
27.8	87.9	24.4	36.5	413.00	*97.50
27.5	010)	24.2	36.3	412.25	97.75
27.4		24.1	36.2	412.00	98.00
27.4		24.1	36.2	412.00	98.25
27.2		23.9	36.0	411.50	98.50
27.1		23.8	35.9	411.0	99.00
26.6		23.4	35.5	409.75	100.00
24.5		21.5	33.6	404.25	104.50
22.9			32.2	400.00	109.00
		20.1			119.50
19.3		17.0	29.1	390.50	121.00
18.5		16.3	28.4	388.25	
17.6	87.9	15.5	27.6	386.00	124.00
19.8	90.3	17.9	27.6	386.00	*124.00
19.6		17.7	27.4	385.25	124.25
19.4		17.5	27.2	384.75	124.50
19.2		17.3	27.0	384.25	124.75
19.2		17.3	27.0	384.00	125.00
18.8		17.0	26.7	383.25	125.75
18.1		16.3	26.0	381.00	127.75
16.6		15.0	24.7	377.25	130.75
12.5		11.3	21.0	366.00	142.75
11.7		10.6	20.3	364.00	146.25
11.1		10.0	19.7	362.00	149.00
9.3		8.4	18.1	357.25	156.75
7.0	90.3	6.3	16.0	351.00	170.25
8.7	92.0	8.0	16.0	351.00	*170.25
8.4	/	7.7	15.7	350.00	170.50
8.4		7.7	15.7	350.00	170.75
8.3		7.6	15.6	349.75	171.00
8.2		7.5	15.5	349.50	171.25
8.2		7.5	15.5	349.25	171.50
7.3		6.7	14.7	347.00	175.25
6.4		5.9	13.9	344.50	179.75
4.9		4.5	12.5	340.25	190.50
4.9		4.5	14.7	240.29	±50.50

Age of Run	Weight of Load	Current Moisture Content in Percent		$\frac{(c-e)100}{(o-e)} = E$	
Hours	Pounds	С	c-6	0-6	E
194.25	339.00	12.1	4.7		4.5
198.00	338.00	11.7	3.		4.0
*198.00	338.00	11.7	6.0	94.3	6.1
198.25	337.75	11.7	6.0	)	6.1
198.50	337.25	11.5	5.8	3	6.2
198.75	337.00	11.4	5.	7	6.0
199.00	336.75	11.3	5.0	5	5.9
199.25	336.50	11.3	5.6	5	5.9
203.50	334.00	10.4	4.	7	5.0
214.25	330.50	9.3	3.0	5	3.8
218.25	329.25	8.9	3.2	2	3.1
220.75	329.00	8.8	3.:	L	3.3
223.50	328.00	8.4	2.	7	2.9
227.50	327.25	8.2	2.		2.7

\*Schedule Change.

Run 7

Values of E Calculated on Basis of an
Original Moisture Content of 133.1 per cent.

		Current '	17.3		34
Age	Weight	Moisture '		-e)100 _ E	
of	of	Content '	33	(o-e)	
Run	Load	in Percent '	16.0		1.75
Hours	Pounds	0	0-0	0-0	E
0.00	605.00	100.0	86.6	119.7	72.3
.25	620.50	105.1	91.7		76.6
.50	622.00	105.6	92.2		77.0
.75	621.50	105.5	92.1		76.9
1.00	619.00	104.6	91.2		76.2
1.25	617.50	104.2	90.8		75 - 9
1.50	616.00	103.7	90.3		75.1
1.75	614.00	103.0	89.6		74.9
4.25	598.00	97.7	84.3		70.1
7.75	583.50	92.9	79.5		66.1
12.25	567.00	87.5	74.1		61.9
24.50	530.50	75.4	62.0		51.8
27.00	524.00	73.2	59.8		50.5
29.50	518.00	71.3	57.9		48.1
32.25	511.50	69.1	55.7		46.
36.50	501.50	65.8	52.4		43.8
47.50	478.50	58.2	44.8		37.1
51.25	472.00	56.0	42.6		35.6
56.50	463.50	53.2	39.8		33.8
62.25	454.00	50.1	36.7		30.
71.50	441.50	46.0	32.6		27.2
75.00	437.00	44.5	31.1		26.0
77.00	434.50	43.7	30.3		25.
79.25	432.00	42.8	29.4		24.6
85.00	423.50	40.0	26.6		22.2
95.50	415.00	37.2	23.8		19.9
97.50	413.00	36.5	23.1	119.7	19.
*97.50	413.00	36.5	24.4	121.0	20.2
97.75	412.25	36.3	24.2	121.0	20.0
98.00	412.00	36.2	24.1		19.9
98.25	412.00	36.2	24.1		
98.50	411.50	36.0	23.9		19.8
99.00	411.00	35.9	23.8		19.
100.00	409.75	35.5	23.4		19.
104.50	404.25	33.6	21.5		17.8
109.00	400.00	32.2	20.1		16.6
119.50	390.50	29.1	17.0		14.
121.00	388.25	28.4	16.3		13.5
124.00	386.00	27.6	15.5	121.0	12.8
124.00	386.00	27.6	17.9	123.4	14.5

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		Run 7 Cont'd			25
		Current '			
Age	Weight	Moisture '	(0	-e)100 _ E	
of	of	Content '		o-e)	
Run	Load	in Percent '			
Hours	Pounds	С	c-e	о-е	E
124.25	385.25	27.4	17.7		14.3
124.50	384.75	27.2	17.5		14.2
124.75	384.25	27.0	17.3		14.0
125.00	384.00	27.0	17.3		14.0
125.75	383.25	26.7	17.0		13.8
127.75	381.00	26.0	16.3		13.2
130.75	377.25	24.7	15.0		12.2
142.75	366.00	21.0	11.3		9.2
146.25	364.00	20.3	10.6		8.6
149.00	362.00	19.7	10.0		8.1
156.75	357.25	18.1	8.4		6.8
170.25	351.00	16.0	6.3	123.4	5.1
*170.25	351.00	16.0	8.0	125.1	6.1
170.50	350.00	15.7	7.7	19. 18 AND 1877	6.2
170.75	350.00	15.7	7.7		6.2
171.00	349.75	15.6	7.6		6.:
171.25	349.50	15.5	7.5		6.0
171.50	349.25	15.5	7.5		6.0
175.25	347.00	14.7	6.7		5.1
179.75	344.50	13.9	5.9		4.
190.50	340.25	12.5	4.5		3.0
194.25	339.00	12.1	4.1		3.3
198.00	338.00	11.7	3.7	125.1	3.0
*198.00	338.00	11.7	6.0	127.4	4.
198.25	337.75	11.7	6.0	20100	4.
198.50	337.25	11.5	5.8		4.0
198.75	337.00	11.4	5.7		4.
199.00	336.75	11.3	5.6		4.1
199.00	336.50	11.3	5.6		4.1
203.50	334.00	10.4			
			4.7		3.
214.25	330.50	9.3	3.6		2.8
218.25	329.25	8.9	3.2		2.
220.75	329.00	8.8	3.1		2.1
223.50	328.00	8.4	2.7	105	2.1
227.50	327.25	8.2	2.5	127.4	2.0

\*Schedule Change.

### THE DRYING OF WOOD

Tiemann (10) states, "That the moisture in wood may move in two distinct ways, namely, by flow as capillary free-water, like oil in a wick, and by diffusion through the cell walls as hygroscopic moisture." Both of these movements may occur in green wood. In sapwood, most of the free water will move by capillary flow, but the water in the heartwood may be bound up in the cells and have to pass through such small openings as to make capillary action impossible.

The rate of drying may be controlled by temperature and steepness of the moisture gradient, the moisture gradient being the difference in moisture concentrations between the center and surface of
the wood. Temperature influences the rate of drying, because heat
lowers the viscosity of water, making diffusion more rapid. The
steeper the moisture gradient, the greater will be the difference in
the concentrations of moisture at the center and at the surface of the
wood. The greater this difference, the more rapid the drying. The
steepness of the moisture gradient is controlled by the relative humidity and temperature in the kiln.

## PLOTTING OF DRYING CURVES

For purposes of comparison, drying curves for the several runs were made by plotting the percentage (on the oven-dry basis) of evaporable water in the lumber at various times against the age of the run in hours. The percentage of evaporable water in the lumber was determined by the following formula:

$$E = \frac{(c-e)100}{(o-e)}$$

#### Nomemclature:

- E the percentage of evaporable water.
- c the current moisture content of the wood in percent.
- e the equilibrium moisture content of the wood in percent.
- o the original moisture content of the wood in percent.

For example, in Run 7 when the original moisture content was 100 percent, the current moisture content was 40 percent, and the equilibrium moisture content was 13.4 percent, Z equaled (40.0 - 13.4) 100 or 30.7 percent.

The equilibrium moisture content must be subtracted from the current and original moisture contents in arriving at the percentage of evaporable water, because wood, as previously mentioned, will dry until its moisture content reaches the equilibrium value, and continued exposure to conditions of temperature and humidity giving the same equilibrium value will result in no further loss of moisture.

For each run, the values of E for various moisture contents were determined and plotted against age of run on semi-logarithmic paper (see charts 1 to 7, inclusive). In calculating the points for each change of a run, the original moisture content of the wood for that run was used in every instance. This gave the origin of each new curve a higher value than that of the final point of the preceding curve. The points for each schedule change fell in approximately a straight line (that is, the relationship between E and time was linear when plotted on semi-logarithmic paper) in every case except for the E values of the first few hours at the beginning of

each schedule change. These first slope values showed variable and more steep slopes on semi-logarithmic paper in every instance than did the values for the rest of the change which had a constant and more moderate slope. This rapid drying at the beginning of each change may be accounted for by the readjustment of the moisture gradient in the wood. Whereas, the concentration of moisture at the center of the wood remains approximately the same, the concentration of moisture on the wood's surface is lowered by changing the drying conditions so that the wood assumes a lower equilibrium moisture content. Consequently, evaporation from the surface of the wood is more rapid for a short time until the concentration of moisture on the surface of the wood is in equilibrium with the kiln's conditions.

Some differences in the original moisture contents of the runs due to air seasoning of the lumber before kiln drying were found, even though the lumber was piled without stickers. Also, the logs from which the lumber for Runs 1 and 2 was sawed were cut several months prior to sawing which allowed time for some air seasoning of the logs. To determine the effect of these differences in original moisture content on the character of the drying curves, two sets of E values were calculated for Run 7 using, first, 100 percent as the original moisture content and then 133.1 percent, the highest original moisture content found in any of the runs. Chart 7 shows the two sets of curves resulting from plotting the E values. Examination of the two sets of curves shows that using a different original moisture content has no effect on the slope of the curves as corresponding curves have identical slopes. The only effect pro-

duced by using the higher original moisture content is that it results in lower E values, thus lowering the position of the curves on the chart.

Table I

Slopes of the Linear Portions of the Drying Curves
for each Schedule Change of Runs 2 to 7, inclusive.

quilibrium Moisture Content	Slopes of Drying Curves						
Percent	2	3	1 4	5	6	1 7	
13.4	00423	00509	00632	00725	00823	00622	
12.1	00557	00522	00797	00839	01093	00775	
9.7		00759	00995	01028	01385	00957	
8.3	00938	, 2123	1		-000		
8.0		00922	00981	01170	01689	01135	
6.7	1	00822	The Control		16.5	MCT CO	
6.6	01341					-	
5.7	1	00882	01210	01192	01851	01105	

Table I gives the slope values of the linear portions of the drying curves for each schedule change for Runs 2 to 7, inclusive. Slope values for Run 1 are not included in this table because a constant dry bulb temperature was not used in drying. With the exception of the slope values for the equilibrium moisture contents of 6.7 percent and 5.7 percent in Run 3, of 8.0 percent in Run 4, and 5.7 percent in Run 7, there is an increase in the slope of the curves for each successive schedule change for each run. Nelson (7) in his work with Douglas fir lumber found that the curves resulting from plotting E against time were all of approximately the same slope when a constant dry bulb temperature was used. He used only Douglas fir heartwood lumber, a relatively impervious wood, and had a circulation

of 550 feet per minute in his kiln.

The slopes of the curves for Runs 5 and 6 are consistently steeper than those of the other runs for each equilibrium moisture content with one exception. For the equilibrium moisture content of 5.7 percent, the slope of the curve for Run 4 is .00018 steeper than the corresponding slope of the curve for Run 5. Several reasons exist for the steeper curves in Runs 5 and 6. Lumber of L- and 6-inch widths were used in building up the loads 10 inches high and 10 boards wide for these runs; whereas, for Runs 4 and 6, boards of 10- and 12inch widths were used. (Runs 2 and 3 are not taken into consideration because of the low rate of circulation used in drying them.) A higher percentage of sapwood was contained in the boards of L- and 6inch widths than in the wider boards as they were cut from the smaller logs and from the sapwood portion of the larger logs. The 10- and 12inch boards were cut from the center portion of the larger logs and contained no, or only a small strip of, sapwood on each side of the heartwood. As the sapwood of cottonwood is much more pervious and ordinarily contains a higher percentage of free water than heartwood, the rate of drying of sapwood is considerable faster than the rate of drying of heartwood. Also, using twice the number of boards in a load 10 or 12 inches high and 10 boards wide gives 40 board edges from which drying can take place in Runs 5 and 6 as compared with 20 edges in Runs 4 and 7. This increased drying surface area results in a greater amount of moisture being evaporated which increases the rate of drying.

Hermann and Rasmussen (4) working with sap ponderosa pine

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found that the rate of drying increased rapidly with an increase of circulation up to 365 feet per minute using one-way circulation. Sap ponderosa pine and sap cottonwood are woods which give up their free moisture with relative ease.

That the rate of circulation. 148 feet per minute, used in the last four runs of this experiment was too slow for maximum rate of drying is indicated by the temperature drop across the load as determined by measuring the conditions of the air on the leaving side of the load in Runs 6 and 7. A drop across the load of 4 degrees Fahr. with the corresponding increase in relative humidity existed for 128 hours during Run 6 and 36.5 hours during Run 7. Thus, the first part of the run is most affected by the slow rate of circulation; for, after wood dries to the fiber saturation point, water moves to the surface of the wood by diffusion rather than by capillary action. Therefore, the water arrives at the surface at a slower rate. It is then possible for the lower rate of circulation to remove the moisture from the surface as rapidly as it appears. Hermann and Rasmussen (4) found that below 25 percent moisture content, the rate of circulation could be reduced to 50 percent or less of that needed before the wood dried to that point. Consequently, the slopes of the drying curves for the last schedule changes probably more nearly represent what the slopes of the curves at the beginning of the runs would have been, providing the rate of circulation had been adequate.

#### EFFECT OF CIRCULATION ON THE DRYING CURVES

That the slopes of the drying curves are affected by changes in rate of circulation is shown by examination of table II. In every instance, for similar equilibrium moisture contents, the drying curves for Runs 4 to 7, inclusive, are steeper than the curves for Runs 2 and 3. A comparison of the average drying curve slopes of Runs 4 to 7, inclusive, with those of Runs 2 and 3 is made in table II. The greatest difference in slopes is found in the last schedule change while the least difference is in the first schedule change. The small sample makes impossible any conclusion other than an increase in the rate of circulation increases the steepness of the drying curves.

Table II

Effect of Increased Rate of Circulation on the Slopes of the Linear Portions of the Drying Curves for Runs 2 to 7, inclusive.

Equilibrium Moisture Content	Average Drying Curve Slopes for Runs 2 and 3*	Average Drying Curve Slopes for Runs L to 7, inclusive	Difference
13.4%	00466	00701	.00235
12.1%	00540	00876	•00336
9.7%	00759	01091	.00332
8.0%	00922	01243	.00321
5.7%	00822	01340	.00518

<sup>\*</sup>Slope values for equilibrium moisture contents of 9.7%, 8.0%, and 5.7% are for Run 3 only.

#### EFFECT OF CIRCULATION ON DRYING TIME

Table III shows the total drying time in hours from a moisture content of 95 to 48 percent for each run except Run 1.

The ages of the runs at 95 and 48 percent were determined by calculating the E values for these moisture contents for each run and locating these values on the respective charts. The two moisture contents of 95 percent and 48 percent were chosen, as they fell within the limits of the first part of the schedule for the six runs.

Table III

Effect of Increased Rate of Circulation on Rate of Drying from a Moisture Content of 95% to 48%.

Run	Time	Rate of Circulation	Average Time for Runs 2 and 3	Average Time for Runs 4 to 7 inclusive
	Hours	Feet/Minute	Hours	Hours
2	88.25	15		
3	73.50	15	80.90	
4	59.50	148		
5	51.75	148		
6	45.00	148		
7	59 • <b>7</b> 5	148		57.40

Difference between average time of Runs 2 and 3 and Runs 4 to 7, inclusive . . . . . . . . . . . . . 23.50 hours.

The effect on the rate of drying of increasing the rate of circulation from 15 feet per minute in Runs 2 and 3 to 148 feet per minute in Runs 4 to 7, inclusive, is shown by the shortening of the average drying time 23.5 hours between the two above moisture contents in the latter runs.

#### SEASONING DEFECTS

While cottonwood has a tendency to warp badly, this was prevented by tightly binding the load. Cupping for the most part was prevented; but where it did occur, it was due to the difference in tangential and radial shrinkage in pieces cut near the pith of the log.

The most serious defect encountered was collapse which occurred in 25 percent of the load in Run 1 and 10 percent of the load in Run L. Tiemann (10) explains collapse as follows:

"When water is drawn out from completely filled cells
whose walls are relatively impermeable, that is when the surrounding cell membrane has openings so small that the water films over
their surfaces are capable of exerting a sufficient pull, the walls
of the cells may be drawn together or "collapsed" so that certain
areas, or even the entire cross-section of the wood may appear
greatly shrunken."

 $\label{eq:Amore detailed explanation of collapse is given by Koehler \\ \mbox{and Thelen (5) as follows:}$ 

"In very wet wood, some of the cells at least are entirely filled with water. As this water leaves the cell cavities, air
should take its place, but it is very difficult for air to pass
through the wet cell walls, so in the absence of air the cells flatten out as the water leaves. This is similar to what happens if
water is drawn out of a rubber tube without admitting air. It is not
the air pressure on the outside of the wood which is responsible for
this collapse, as that at the most could be only 15 pounds per

square inch, but rather the force of the water pulling the wet cells together as it leaves. This force is much greater than that due to atmospheric pressure. (The cohesive strength of water, when it can be effectually applied, has been variously estimated as being from 150 to 4,500 pounds per square inch.)"

Collapse occurs before the lumber dries to the fiber saturation point which is from 25 to 30 percent for most woods. The collapse found in this experiment occurred in every instance at the junction of the heartwood and sapwood. In this area, the surface of the boards assumed a greatly sunken appearence.

Table IV

Occurrence of Collapse in Cottonwood as Related to Temperature,
Equilibrium Moisture Content, and Rate of Circulation.

Run	Original Temper- ature	Original Equi- librium Moisture Content1/	Temperature immediately prior to 30%2/ Moisture Content	Equilibrium  Moisture  Content1/ immediately  prior to  30%2/ Moisture  Content	Rate of Circu- lation	Amount of Collapse
	Degrees Fahr.	Percent	Degrees Fahr.	Percent	Ft. per Minute	Percent
1 2 3 4 5 6 7	135 135 135 135 135 135 135	13.4 13.4 13.4 13.4 13.4 13.4	145 135 135 135 135 135 135	7.9 8.3 12.1 9.7 13.4 13.4	15 15 15 148 148 148 148	25.0 0.0 0.0 10.0 0.0 0.0

<sup>1/</sup> The equilibrium moisture contents indicated applied to entering air conditions.

<sup>2/</sup> Moisture content of 30 percent used as the fiber saturation point of wood.

The relation of temperature, equilibrium moisture content, and circulation to collapse in cottonwood is shown in table IV. In the first three runs, due to the slow rate of circulation, the equilibrium moisture content of the lumber actually was higher than indicated in the table. The values in the table indicate the condition of the air entering the load; but, because of the indisputable drop in temperature across the load, the equilibrium moisture content of the lumber on the leaving side would be considerably higher. This condition would not be as true for the last four runs because the increased rate of circulation caused the conditions throughout the load to be more uniform.

Tiemann (10) states that high temperatures are the cause of collapse rather than low humidities. The high temperatures make the cell walls plastic, and they are unable to withstand the terrific pull exerted on them. That even a moderate temperature of 135 degrees Fahr. may make the cell walls sufficiently plastic to permit collapse when subjected to rather severe drying conditions is shown in table IV.

In Runs 4 to 7, inclusive, where drying was more rapid because of increased circulation, collapse was found only in Run 4. In this run, changing the entering air conditions caused the equilibrium moisture content to drop from 13.4 percent to 9.7 percent before the lumber reached the fiber saturation point as contrasted to Runs 5, 6, and 7 where the next lowest equilibrium moisture content was 12.1 percent with no collapse resulting. The collapse in Run 4 was directly due to the lowered equilibrium moisture content which set up a steep moisture gradient causing rapid removal of the water; and the cell walls, too weak to withstand the cohesive force of the water, were

drawn together.

While an equilibrium moisture content higher than 9.7 percent undoubtedly existed in Run 1 when the load reached the fiber saturation point, increasing the temperature from 135 degrees Fahr. to 145 degrees Fahr. made the cell walls sufficiently plastic to collapse even with a lesser cohesive force exerted by the water on the cells.

As collapse weakens lumber and may be the cause of severe honeycombing, extreme care should be exercised in choosing a schedule for kiln drying green cottonwood. From the information gathered, as a result of these seven runs, a safe schedule using a temperature of 135 degrees Fahr. should use an equilibrium moisture content of 13.4 percent until the wood reaches a moisture content of 35 percent and then change to an equilibrium moisture content not lower than 12.1 percent until the lumber has dried to the fiber saturation point. This would preclude any possibility of collapse when the rate of circulation in the kiln is 148 feet per minute or less.

# LIMITATIONS OF RESULTS

Inadequate circulation in the dry kiln and lack of material precluded a more exhaustive study. Consequently, the results obtained are based on a limited sample and a limited range of conditions.

## SUMMARY

The study consisted of kiln drying 1 1/8-inch cottonwood lumber with original moisture contents ranging from 97.1 percent to 133.1 percent. With the exception of one run, the lumber was dried at a constant dry bulb temperature of 135 degrees Fahr., and the severity

of the drying conditions increased by lowering the wet bulb temperature. The results of the study are summarized as follows:

- In general, the slopes of the linear portions of the drying curves for cottonwood lumber dried at a constant dry bulb temperature became steeper at each schedule change as the severity of the drying conditions increased.
- 2. At every schedule change, very rapid drying took place for several hours until the moisture gradient in the lumber had adjusted itself to the new moisture equilibrium conditions in the dry kiln.
- 3. An increase in the rate of circulation from 15 feet per minute to 148 feet per minute increased the steepness of the slopes of the drying curves and, therefore, the rate of drying of cottonwood.
- 4. Degrade in cottonwood due to warping and cupping was reduced to a minimum by securely binding the load.
- Collapse in green cottonwood was found to occur when the following conditions existed in the kiln before the lumber reached the fiber saturation point.
  - A. An increase in the dry bulb temperature from 135 degrees Fahr.

    to 145 degrees Fahr. together with a change in the entering air

    conditions which caused a reduction in the equilibrium moisture

    content from 13.4 percent to 7.9 percent while using a rate of

    circulation of 15 feet per minute.
  - B. A constant dry bulb temperature of 135 degrees Fahr. together with a change in the entering air conditions which caused a reduction in the equilibrium moisture content from 13.4 percent to 9.7 percent while using a rate of circulation of 148 feet per minute.
- 6. In dry kilns with circulation rate of 148 feet per minute or less,

a safe schedule for the drying of green cottonwood using a temperature of 135 degrees Fahr. should use an equilibrium moisture content of 13.4 percent until the stock dries to a moisture content of 35 percent and then change to and maintain an equilibrium moisture content of not lower than 12.1 percent until the lumber reaches the fiber saturation point.

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