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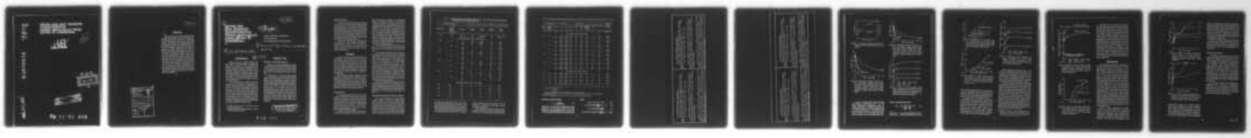

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Paper
FPL 338

1979

DRYING AND HEAT TRANSFER CHARACTERISTICS DURING BENCH-SCALE PRESS DRYING OF LINERBOARD

(A)

(lb/sq in.

Abstract

Drying rates and overall heat transfer (contact) coefficients were determined during laboratory press drying of linerboard-weight handsheets. Both drying rates and contact coefficients increased with external (Z-direction) pressure up to 60 lb/in.^{2} and leveled off thereafter. A family of curves was obtained for drying temperatures of 250° to 550° F with higher drying rates and contact coefficients obtained at higher drying temperatures. As expected, better thermal contact was obtained and higher drying rates resulted when webs at higher moisture content were dried. All drying rates and contact coefficients were higher than those reported for commercial linerboard production. Results of this study indicate that diffusion of the saturated water vapor (generated within the sheet during drying) may be the limiting factor which governs drying rate during press drying of linerboard.

(B)

(12) 12

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DRYING AND HEAT TRANSFER CHARACTERISTICS DURING BENCH-SCALE PRESS DRYING OF LINERBOARD.

By
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(9) Forest Service research paper,

(14) FS RP-FPL-338

(11) 1979

Introduction

Press drying is a process whereby the wet sheet is simultaneously pressed and dried. This process is unlike conventional drying where the sheet is pressed prior to drying on heated cylinders. Previous Forest Products Laboratory research (*2,3*)[2] shows that press drying is an effective way to maximize interfiber bonding, and thereby enable the usage of high-yield hardwood and softwood pulps for strong, stiff paper products such as linerboard.

The future utility of press drying depends on the practicality of obtaining sufficiently high drying rates for commercial production. This study was initiated to quantify the drying and heat transfer rates which are obtained on a bench scale with the static flat press currently used for press drying experiments. These drying and heat transfer rates are necessary to aid in the design of a continuous prototype press drying apparatus. This kind of apparatus will be the next step for further research in press drying.

Experimental

Materials and Sheetmaking

A 60 percent yield unbleached kraft pulp made from northern white oak (*Quercus alba* L.) was used for this study. The pulp received only a fiberizing treatment with the double disk refiner. No further refining was necessary.

Handsheets of 100 g/m^2 basis weight were prepared following TAPPI method T205 SU-58. For drying tests, two 100 g/m^2 handsheets were sandwiched together making the specimen basis weight 200 g/m^2 (approximately 42 $lb/1{,}000\ ft^2$). Since drying experiments were to be carried out with wet handsheets of two initial moisture levels (approximately 65 and 40 pct (wet basis)), one handsheet series was dried at the moisture level obtained by normal couching and wet pressing. Lower moisture level sheets were obtained by blotting the sheets against dry blotters until the desired moisture level was reached.

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

[2] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

141 700

Measurements

The drying experiments were carried out with a 9½- by 9½-inch electrically heated static flat press. For drying rate experiments, wet handsheets were weighed, sandwiched between 150-mesh stainless steel screens, then inserted between the heated press platens. After drying intervals varying from 1 to 120 seconds, the handsheets were removed and quickly weighed. Ovendry weights were obtained later on all handsheets.

Temperature profiles were obtained during drying for heat transfer calculations. Thermocouple probes were inserted between two wet (100 g/m²) sheets and the sheet temperature was recorded continuously during drying.

Results

Figure 1 shows a typical sheet dryness-temperature curve obtained in this study. The sheet temperature initially rises very rapidly to 212° F and remains constant until the free sheet moisture is evaporated. On the other hand, the sheet dryness rises almost linearly until the sheet is completely dry. After this dry point, the sheet temperature rises again and eventually levels off at an equilibrium temperature.

The effects of several variables, including platen temperature (250° to 550° F), press pressure (2 to 400 lb/in.²), initial sheet moisture levels (65 and 40 pct), and one- versus two-sided drying (one or both platens heated during drying) were varied to determine their effects on sheet drying rates (table 1) and overall heat transfer coefficients (table 2).

Drying Rates

The average drying rates shown in table 1 were calculated by dividing the moisture difference (amount of water removed) by the drying time required. Figures 2 and 3 show the relation between total sheet basis weight and drying time. It is obvious that increasing drying temperature from 250° to 550° F at a given press pressure of 400 lb/in.² significantly increases the drying rate.

Figure 4 shows the effect of press pressure on drying rates (for two-sided drying at 550°, 450°, 350°, and 250° F) for linerboard-weight handsheets initially at 40 percent moisture content. The drying rate was increased by almost 70 percent when the press pressure was changed from 2 to 60 lb./in.². However, the rate was increased by only about 10 percent when the press pressure was increased from 60 to 400 lb/in.². It appears that drying rate levels off after 60 lb/in.² press pressure, and there is little to be gained by increasing press pressure above this level. Platen temperature, on the other hand, has a tremendous effect on drying rate at any given press pressure.

For one-sided drying at 60 lb/in.² and 550° F (fig. 5), the drying rate is only about one-third to one-half that for two-sided drying.

Conventional linerboard paper machine drying rates (*6*) (also shown in fig. 5) range from about 2 to 6 lb/hr-ft² (280° to 375° F). These drying rates are from one-third to one-half of the rates shown for one-sided press drying and one-eighth to one-fifth those shown for two-sided press drying. It is obvious, therefore, that the drying rates for laboratory press drying are far greater than in conventional drying. Since drying rates (at a given platen temperature) increase dramatically with increased press pressure up to 60 lb/in.², applying only 2 lb/in.² pressure during two-sided press drying results in a drying rate of almost three times that obtained with a conventional paper machine.

Figure 6 summarizes the effect of initial sheet moisture content on drying rate. The wetter sheet (65 pct moisture) dries two to three times faster than the drier sheet (40 pct moisture) at higher platen temperatures. No difference in drying rates was noted at 250° F.

Contact Resistance to Heat Transfer

The contact resistance to heat transfer (usually referred to as the contact coefficient) is a measure of the rate at which heat is transferred or the intimacy of contact between the paper web and the dryer surface. It provides an index of the efficiency of heat transfer from the dryer surface to the paper. Previous studies (*1,5*) indicate that thermal contact resistance varies with web moisture

Table 1.--Drying rates for linerboard-weight 60 pct. yield white oak kraft handsheets press dried in the static flat press

Drying conditions			65-40 pct. moisture range		40-20 pct. moisture range	
Temperature	Initial sheet moisture content	Pressure	Drying time	Drying rate	Drying time	Drying rate
°F	Pct	Lb/in.²	Sec	Lb/hr-ft²	Sec	Lb/hr-ft²
			TWO-SIDED DRYING--BOTH PLATENS HEATED			
550	65	2	4.0	40.7	3.0	18.9
		60	1.1	148.0	1.4	40.5
		400	1.0	162.8	1.2	47.3
	40	2	--	--	1.5	37.8
		60	--	--	.9	63.0
		400	--	--	.8	70.9
450	65	2	6.0	27.1	4.5	12.6
		60	1.4	116.3	1.6	35.4
		400	1.2	135.7	1.5	37.8
	40	2	--	--	1.8	31.5
		60	--	--	1.25	45.4
		400	--	--	1.2	47.3
350	65	2	7.5	21.7	7.5	7.6
		60	3.75	43.4	3.05	18.6
		400	3.3	49.3	2.4	23.6
	40	2	--	--	3.4	16.7
		60	--	--	2.1	27.0
		400	--	--	2.0	28.4
250	65	2	30	5.4	30	1.9
		60	14	11.6	12.5	4.5
		400	11.2	14.5	10.8	5.3
	40	2	--	--	11.2	5.0
		60	--	--	4.5	12.6
		400	--	--	4.3	13.2
			ONE-SIDED DRYING--ONE PLATEN HEATED			
550	65	60	2.0	81.4	3.5	16.2
	40	60	--	--	2.0	28.4
450	65	60	3.5	46.5	4.0	14.2
	40	60	--	--	2.5	22.7
350	65	60	7.5	21.7	8.5	6.7
	40	60	--	--	9.0	6.3
250	65	60	30.0	5.4	--	--
	40	60	--	--	15.0	3.8

content, type and surface finish of the web, the paper and felt tension, the type of felt, and the dryer surface conditions. A good example of the web surface's influence on contact resistance is the fact that 26 lb/1,000 ft² corrugating medium (which has a relatively rough surface) dries more slowly than 42 lb/1,000 ft.² linerboard which has a much smoother surface (6).

The contact coefficient of heat transfer is determined from the amount of heat transferred and the temperature differential be-

Table 2.--Heat transfer values for linerboard-weight 60 pct. yield white oak kraft handsheets press dried in a static flat press

Drying conditions			Basis weights		Temperatures						
Temperature	Initial sheet moisture content	Pressure	Initial	Ovendry	Platen T_p	Initial sheet T_i	Final sheet T_f	Log mean[1] temperature difference ΔT_{1m}	Drying contact time	Total heat transferred[2]	Overall heat transfer (contact) coefficient
°F	Pct	Lb/in.^{2}	G/m^2	G/m^2	°F	°F	°F	°F	Sec	Btu	Btu/hr-ft^2-°F
TWO-SIDED DRYING--BOTH PLATENS HEATED[3]											
550	65	2	545.1	187.2	546	80	513	164	6	18.7	318.2
		60	545.5	188.7	546	81	517	157	4	18.6	496.2
		400	548.5	187.5	561	75	512	191	3.3	18.9	502.1
	40	2	316.1	192.5	553	81	530	149	3	7.3	275.8
		60	306.3	190.3	553	78	519	167	2	7.0	348.0
		400	300.0	175.0	561	69	507	198	1.5	7.3	411.6
450	65	2	554.9	192.2	450	78	421	134	15	18.7	155.3
		60	555.8	189.8	450	78	424	130	5	18.9	485.9
		400	533.5	189.5	452	75	408	155	3.9	17.8	493.0
	40	2	312.0	191.6	450	78	438	105	4	6.9	277.0
		60	313.0	190.7	450	75	427	126	3	7.0	310.5
		400	304.5	184.0	452	74	419	142	2.5	6.9	325.5
350	65	2	552.0	190.9	349	72	317	114	30	18.4	90.6
		60	536.1	190.1	349	72	319	111	10	19.0	286.5
		400	535.0	185.5	355	78	329	106	9.5	17.8	296.0
	40	2	323.3	195.1	349	72	330	96	10	7.1	122.8
		60	319.4	192.6	349	72	327	101	5	7.0	231.9
		400	297.5	188.0	355	75	329	107	4.0	6.1	238.6
250	65	2	540.0	189.4	251	75	234	68	120	17.6	36.1
		60	533.8	189.4	251	75	235	67	90	17.3	48.3
		400	544.9	185.8	253	75	222	84	70	18.0	51.3
	40	2	309.1	186.6	252	75	225	80	40	6.4	33.7
		60	323.1	184.5	250	75	225	77	20	7.2	78.3
		400	308.9	185.1	253	75	234	71	18	6.5	85.1
ONE-SIDED DRYING--ONE PLATEN HEATED[4]											
550	65	60	508.5	182.0	522	81	404	245	10	16.8	229.2
	40	60	309.9	182.4	522	78	432	222	5	7.2	217.6
450	65	60	518.8	183.9	444	81	404	147	12.5	17.2	314.3
	40	60	308.3	182.0	493	78	432	185	5	7.2	259.3
350	65	60	517.3	182.5	346	78	273	150	30	16.9	125.6
	40	60	317.0	181.4	332	78	280	127	30	7.2	62.8
250	65	60	516.6	182.0	228	75	205	69	120	16.7	68.0
	40	60	309.8	180.1	239	75	205	83	60	6.7	45.3

[1] $$\Delta T_{1m} = \frac{(T_p - T_i) - (T_p - T_f)}{\ln \frac{(T_p - T_i)}{(T_p - T_f)}}$$

[2] Total heat transferred is the sum of sensible, latent, and fiber heats.

[3] Effective interfacial area (between 150-mesh wire screens, heated platens, and wet web) is assumed to be one-half of the total area.

[4] Effective interfacial area is one-fourth of total area (heated on only one surface).

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tween the contact surfaces:

$$h = \frac{Q_{total}}{(A)(t)(\Delta T_{lm})} \qquad (1)$$

where A is the effective interfacial contact area and t is the drying time. The total amount of heat transferred (Q_{total}) is the sum of the sensible (Q_s), latent (Q_l), and fiber (Q_F) heats:

$$Q_{total} = Q_s + Q_l + Q_F \qquad (2)$$

$$Q_s = (\text{lb H}_2\text{O})\left(\frac{1\ \text{Btu}}{\text{lb °F}}\right)(T_s - T_i) \qquad (3)$$

$$Q_l = (\text{lb H}_2\text{O})\left(973\ \frac{\text{Btu}}{\text{lb}}\right) \qquad (4)$$

$$Q_F = (\text{lb O.D. fiber})\left(0.35\ \frac{\text{Btu}}{\text{lb °F}}\right)(T_f - T_i) \qquad (5)$$

U.S. Forest Products Laboratory.

Drying and heat transfer characteristics during bench-scale press drying of linerboard, by Von L. Byrd. Madison, Wis., For. Prod. Lab., 1979.
9 p. (USDA For. Serv. Res. Pap. FPL 338).

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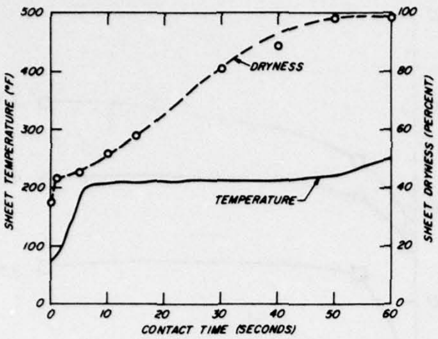

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Figure 1.—Typical sheet dryness and temperature profiles obtained during press drying.

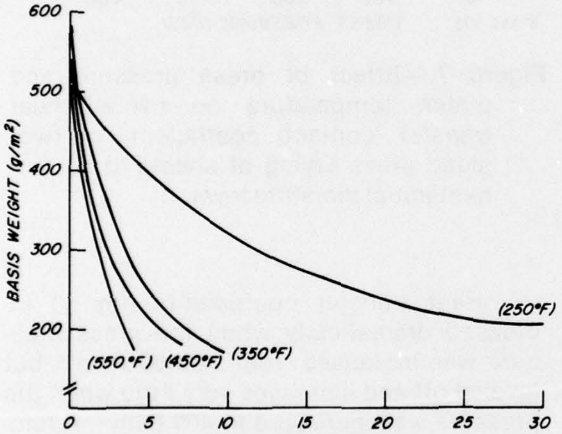

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Figure 2.—Changes in sheet moisture content (total basis weight) during press drying at platen temperatures varying from 250° to 550° F (400 lb/in.² press pressure). Sheets initially at 65 percent moisture content were dried in these tests.

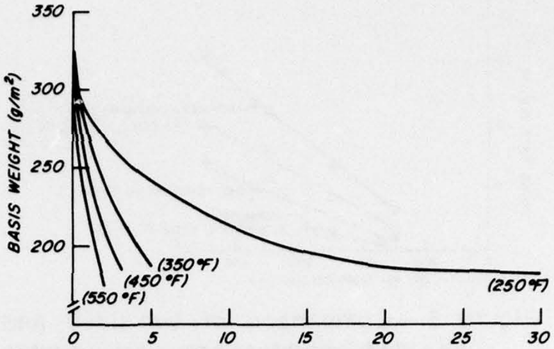

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Figure 3.—Changes in sheet moisture content (total basis weight) during press drying at platen temperatures varying from 250° to 550° F (400 lb/in.² press pressure). Sheets initially at 40 percent moisture content were dried in these tests.

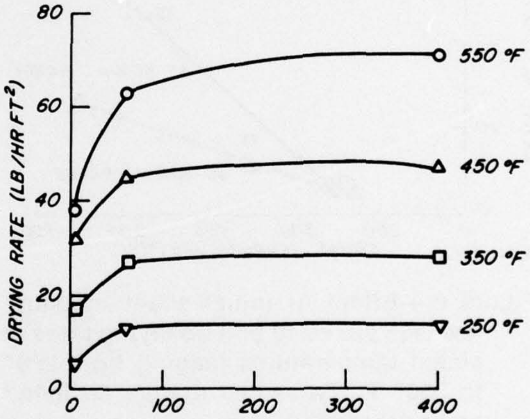

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Figure 4.—Effect of press pressure and platen temperature at 40 percent initial sheet moisture level on drying rates for two-sided press drying of sheets at 40 percent initial moisture content.

T_i and T_f are the initial and final sheet temperatures, respectively, and T_e is the water evaporation temperature since increased application of platen pressure tends to elevate it above 212° F. The specific heat of pulp fiber (0.35 Btu/lb °F) was taken from work by Stamm (4). The temperature differential required to accomplish the heat transferred is calculated as follows:

$$\Delta T_{lm} = \frac{(T_p - T_i) - (T_p - T_f)}{\ln \frac{(T_p - T_i)}{(T_p - T_f)}} \qquad (6)$$

where ΔT_{lm} = log mean temperature difference and T_p = platen temperature. Examina-

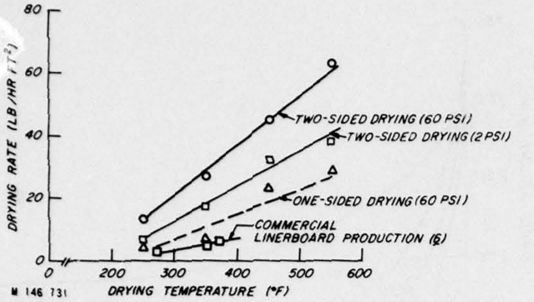

Figure 5.—Comparison of two-sided and one-sided laboratory press drying rates at 40 percent initial sheet moisture level with drying rates obtained during commercial linerboard production (6).

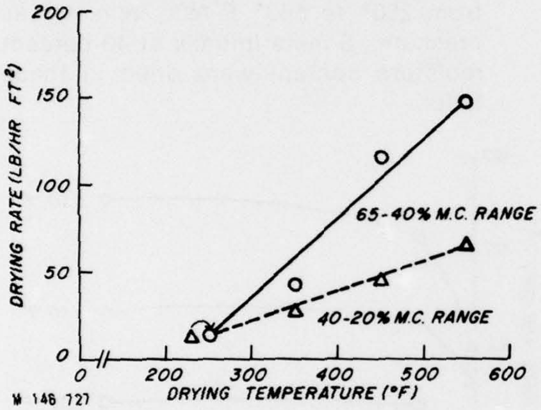

Figure 6.—Effect of initial sheet moisture level (65 pct vs 40 pct) on drying rates at platen temperatures ranging from 250° to 550° F. Two-sided drying, 60 lb/in.² press pressure.

tion of drying temperature-time curves (such as fig. 1) revealed that the log mean temperature difference provides a good approximation of the actual average temperature difference encountered during press drying.

Because the wet sheets were sandwiched between 150-mesh wire screens during drying, the effective interfacial contact area (A) was assumed to be approximately one-half of the total contact area. J. L. Chance (who made similar heat transfer measurements with wire screens at Beloit Corporation) also made the same assumptions regarding effective interfacial areas.

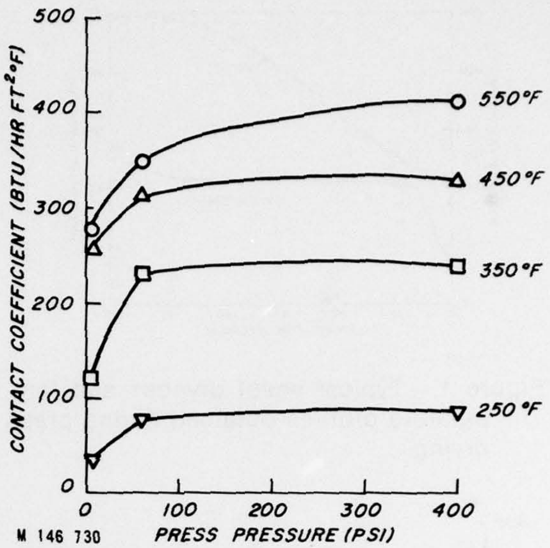

Figure 7.—Effect of press pressure and platen temperature on overall heat transfer (contact) coefficient for two-sided press drying of sheets at 40 percent initial moisture level.

Heat transfer coefficients (fig. 7) increased dramatically when the press pressure was increased from 2 to 60 lb/in.², but leveled off and increased very little when the pressure was increased to 400 lb/in.². A family of curves was obtained when the platen temperature was varied from 250° to 500° F.

Figure 8 shows that contacting the dryer with a sheet at higher moisture content (65 pct) results in better heat transfer than drying a sheet at 40 percent moisture content. This same trend was reported earlier (5), and it helps to explain why the initial drying rates are faster for ingoing sheets at 65 percent moisture than for ingoing sheets at 40 percent moisture (fig. 6). Typical heat transfer coefficients for 42 lb/1,000 ft² linerboard production range from 50 to 100 Btu/hr-ft² °F.[3] Therefore, laboratory bench-scale press drying, even at 2 lb/in.² press pressure results in three times as efficient heat transfer from the dryer surface to the wet sheet.

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[3] Pantaleo, P. F., and S. P. Garvin. 1976. Measurements and Evaluation of Dryer Section Performance. Preprinted in Proceedings of the TAPPI Engineering Conference, Houston, Texas, Oct. 4-7.

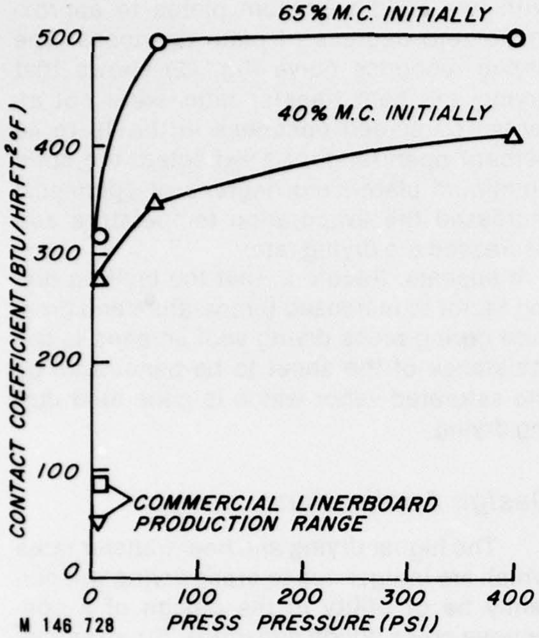

Figure 8.—Effect of initial sheet moisture level (65 pct vs 40 pct) on overall heat transfer (contact) coefficient for two-sided press drying of sheets at 550° F platen temperature.

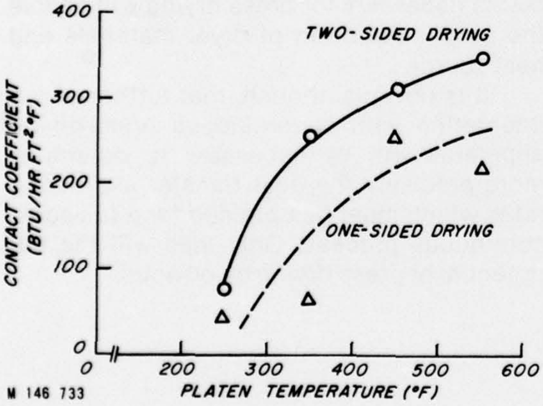

Figure 9.—Effect of two-sided versus one-sided press drying of sheets at 40 percent initial moisture content at 60 lb/in.² press pressure on overall heat transfer (contact) coefficient.

Because contact coefficient measures only the intimacy of contact and heat transfer efficiency between the heated surface and the wet sheet, this quantity should not be affected if the sheet undergoes two-sided or one-sided drying. However, figure 9 reveals that one-sided drying is less efficient (with regard to heat transfer) at all drying temperatures than two-sided drying. This is perhaps caused by the fact that, during one-sided drying, the unheated platen acts as a heat sink, lowering the temperature of the unheated sheet surface. In addition, it was more difficult to maintain a constant platen temperature during one-sided drying. This kind of problem probably would not be encountered during continuous operation, since the system would have ample time to reach equilibrium.

Discussion

It is of particular interest to understand the limiting factors which influence the drying rates and contact resistance of linerboard-weight sheets during press drying. At 250° F platen temperature, the sheet temperature rises initially and levels off at about 212° F. The sheet temperature increases slightly after the moisture is evaporated. At platen temperatures of 350°, 450°, and 550° F, the evaporation temperature increases significantly above 212° F (fig. 10), indicating that the temperature of the free water within the sheet has risen above the saturation vapor temperature of water. A similar effect was noted (fig. 11) when platen pressure was increased from 2 to 400 lb/in.² at a constant (550° F) platen temperature. These results suggest that increasing either platen temperature or pressure during drying increases the sheet flow resistance to the saturated vapor generated within the sheet during drying and implies that the limiting drying factor may be the resistance to the saturated vapor flow through the sheet.

Further drying experiments utilizing screens with varying degrees of openness tended to further confirm the preceding statement. Drying tests were conducted with microetched stainless steel screens with degrees of openness varying from 16 to 40 percent. Two 100 g/m² handsheets were

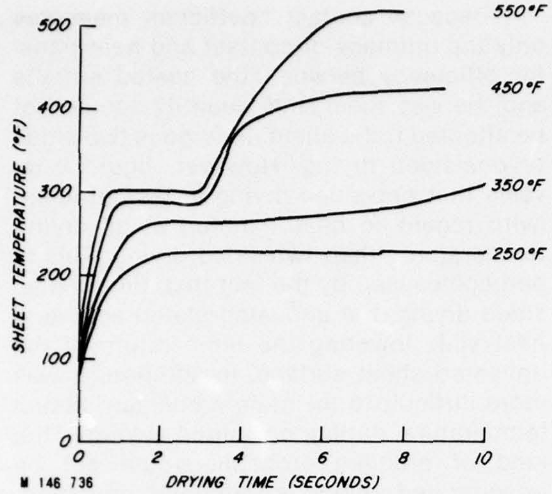

Figure 10.—Effect of platen temperature (250° to 550° F) on press drying response of sheets at 65 percent initial moisture content and 60 lb/in.² press pressure.

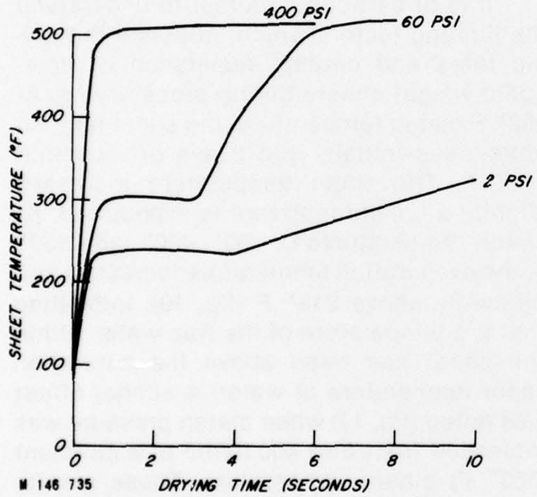

Figure 11.—Effect of platen pressure (2 to 400 lb/in.²) on press drying response of sheets at 65 percent initial moisture content and 550° F platen temperature.

sandwiched together and dried between each screen backed by a solid aluminum plate. Press conditions were 550° F and 60 lb/in.² pressure. A thermocouple probe was inserted between the two sheets enabling a continuous temperature profile during drying. Control experiments were conducted with two solid aluminum plates to approximate zero degrees of plate openness. The drying response curve (fig. 12) shows that drying and heat transfer rates were not affected by screen openness in the 16 to 40 percent open range. As expected, the solid aluminum plate (zero degrees of openness) increased the evaporation temperature and decreased the drying rate.

It appears, therefore, that the limiting drying factor to increased temperature and pressure during press drying with screens is the resistance of the sheet to be penetrated by the saturated vapor which is generated during drying.

Design Application

The higher drying and heat transfer rates which are indigenous to press drying will certainly be of utility in the design of a continuous press drying apparatus. For example, it is possible to calculate the appropriate dryer diameter which will be needed for paper machine speeds ranging from 50 to 2,000 ft/min as shown in figure 13. It is obvious that increasing press pressure or drying temperature (or both) can significantly reduce the dryer size needed to properly dry the sheet. Use of the heat transfer coefficients necessary for press drying will enable the proper selection of dryer materials and heat source.

It is obvious, though, that further experimentation with a continuous press-drying apparatus will be necessary to determine more precisely the heat transfer and drying rates which must be obtained for a full-scale continuous process. Only then will the full potential of press drying be obvious.

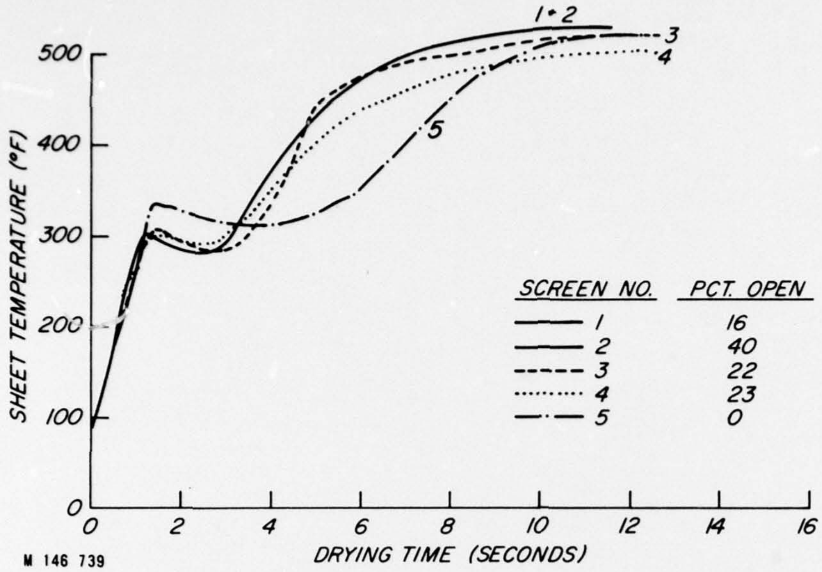

Figure 12.—Effect of screen openness (varying from 16 to 40 pct) on the drying response of sheets at 65 percent initial moisture content, 550° F platen temperature, and 60 lb/in.^{2} press pressure.

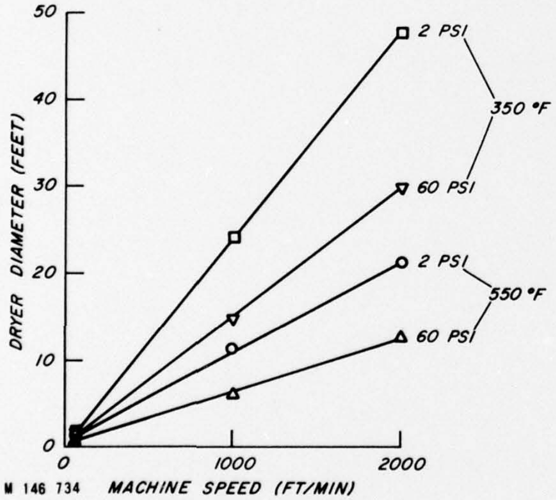

Figure 13.—Dryer diameter size required for press drying at paper machine speeds ranging from 50 to 2,000 ft/min at the following press drying conditions: 40 percent initial sheet moisture content, 350° and 550° F platen temperature, and 2 and 60 lb/in.^{2} press pressure.

Literature Cited

1. Dreshfield, A. C., and S. T. Han.
   1956. Tappi 39(7):449.
2. Setterholm, V. C., R. E. Benson, J. F. Wichmann, and R. J. Auchter.
   1975. USDA For. Serv. Res. Pap. FPL 256. For. Prod. Lab., Madison, Wis.
3. Setterholm, V. C., and R. E. Benson.
   1977. USDA For. Serv. Res. Pap. FPL 295. For. Prod. Lab., Madison, Wis.
4. Stamm, A. J.
   1964. *Wood and Cellulose Science,* Ronald Press, p. 284.
5. Sundberg, T., and L. Osterberg.
   1966. Svensk Papperstidn. 69(24):854.
6. TAPPI Standard Method TIS 014-42.
   1974. March.

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