TIP 0404-07

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Paper machine drying rate

Scope

This TIP outlines procedures for calculating paper machine drying rates for coated and uncoated papers and provides drying rate curves. The objective of the TIP is to define rate of water removal on a common basis for mills to use to compare a particular machine to past performance and to other machines. The definition of drying rate and its calculation are simple to permit widespread use. These procedures cannot be used for machines with auxiliary drying equipment such as infrared dryers and impingement dryers unless these auxiliary dryers are shut off.

Data points on the curves represent observed performance of existing machines. Lines represent calculated average and two-sigma variation of plotted data.

The calculation does not identify or account for factors that affect drying rate. There are many variables that can affect calculated drying rate. These factors include:

• Sheet furnish	• Dryer configuration	• Type of pressing
• Siphon design	• Dryer felting	• Amount of pressing
• Use of dryer bars	• Dryer surface scale	• Breaker stack
• Pocket ventilation	• Hood humidity	• Sheet smoothness
• Dryer fabric application	• Reel moisture content	• Moisture content before drying
• Sheet grammage	• Breaker stack	• Dryer speed

Safety precautions

This TIP outlines a calculation procedure. No safety precautions are required.

Definition of drying rate

The drying rate (R_W) as applied to drying on the machine is defined as the amount of water evaporated per hour per unit area of drying surface. Drying surface is defined as the total circumference of all steam-heated dryers that are in contact with the sheet multiplied by the width of the sheet at the reel. Drying rate is expressed as pounds per hour per square foot in customary units and as kilograms per hour per square meter in SI units, and reported at the average steam temperature.

Drying rate for uncoated papers

Equations 1 and 2 are used to calculate the drying rate for uncoated papers:

$$M = \frac{L}{E} - 1 \tag{1}$$

$$R_W = 60 \frac{SBM}{NA\pi D} \tag{2}$$

where the factor 60 is minutes per hour and the variables are defined as:

R_W	=	drying rate, amount of water evaporated, kg/h•m^2 (lb/h•ft^2)
S	=	machine speed, m/min (ft/min)
B	=	basis weight of the sheet as it leaves the dryer section as dried (wet basis), kg/m^2 (lb/ream)
M	=	weight of water evaporated per unit weight of paper as dried (wet basis)
N	=	number of steam-heated dryers that contact the sheet
A	=	area of standard ream, 1.0 m^2 (ft^2)
π	=	3.1416
D	=	diameter of dryer cylinders, m (ft)
L	=	percent dryness (wet basis) of sheet leaving the last cylinder (the larger number)
E	=	percent dryness (wet basis) of sheet entering on the first dryer (the smaller number).

Dryers that do not contact the sheet include bottom unrun dryers, top dryers of inverted unrun sections, felt dryers, and Feeney dryers. Dryers that are not heated include cooling dryers, sweat dryers, and dryers that are valved off. None of these dryers should be counted in the number of dryers.

An accurate value for the dryness "E" of the web entering a dryer section must be available in order to calculate the drying rate. An error of 2% dryness (say 38% dry instead of 40% dry) can result in a 9% error in the calculated drying rate. The entering dryness often is not readily available, is difficult to determine accurately, and is a cause of inaccurate rate calculations. The dryness can be determined by carefully taking and testing samples of the wet web before the dryer section, according to TIP 0404-01 or measured by properly calibrated on-line systems.

Pulp air dryers do not have dryer cylinders. The drying surface area for pulp air dryers is the length of a dryer pass times the number of passes times the sheet width off the machine.

An example of these equations is given in both customary and SI units as follows:

Customary units

S	=	2000 ft/min
B	=	43 lb/ream
L	=	94% dry leaving
E	=	40% dry entering
A	=	3300 ft^2/ream
N	=	45 paper dryers
D	=	5.0 ft diameter

$$M = \frac{94}{40} - 1 = 1.35$$

$$R_W = 60 \frac{(2000)(43)(1.35)}{(45)(3300)\pi(5.0)}$$

$$R_W = 3.0 \text{ lb water/h/ft}^2$$

SI units

S	=	610 m/min
B	=	63.6 g/m^2 = (63.6/1000) kg/m^2
L	=	94% dry leaving
E	=	40% dry entering
A	=	1.0
N	=	45 paper dryers
D	=	1.52 m diameter

$$M = \frac{94}{40} - 1 = 1.35$$

$$R_W = \frac{60(610)(63.6/1000)(1.35)}{(45)(1.0)\pi(1.52)}$$

$$R_W \quad = \quad 14.6 \text{ kg water/h/m}^2$$

Drying rate comparison

Calculated drying rate can be compared to other paper machines by referring to the following Fig.s:

Fig. 1E Corrugating Medium (English units)
Fig. 1M Corrugating Medium (metric units)
Fig. 2E Woodfree printing and writing (English units)
Fig. 2M Woodfree printing and writing (metric units)
Fig. 3E Linerboard (English units)
Fig. 3M Linerboard (metric units)
Fig. 4E Bleached board (English units)
Fig. 4M Bleached board (metric units)
Fig. 5E Newsprint (English units)
Fig. 5M Newsprint (metric units)
Fig. 6E Kraft papers (English units)
Fig. 6M Kraft papers (metric units)
Fig. 7E Wood-containing paper (English units)
Fig. 7M Wood-containing paper (metric units)
Fig. 8E After-size press drying (English units)
Fig. 8M After-size press drying (metric units)
Fig. 9E Pulp (cylinder dryers) (English units)
Fig. 9M Pulp (cylinder dryers) (metric units)
Fig. 10E Pulp (air dryers) (English units)
Fig. 10M Pulp (air dryers) (metric units)
Fig. 11E Paperboard (English units)
Fig. 11M Paperboard (metric units)
Fig. 12E Gypsum wallboard (English units)
Fig. 12M (Gypsum wallboard (metric units)

Fig.s 13E (English units) and Fig. 13M (metric units) show average curves for all machines listed above.
Saturated steam temperatures are shown in Table 1 (English units) and Table 2 (metric units).
Calculated drying rate and average steam temperature establish a point on the appropriate drying rate curve.
The average steam temperature used for these drying rate curves is the average saturation steam temperature, weighted for the number of dryers operating at the respective temperatures, as follows:

$$T_{avg} = \frac{1}{N}\sum_{i=1}^{N}(T_i)$$ (3)

where:

T_{avg}	=	average saturation steam temperature, °C (°F)
T_i	=	saturation steam temperature of dryer (i), °C (°F)
N	=	number of steam-heated dryers that contact the sheet

Saturation steam temperatures can be determined from measured dryer steam pressures using common steam tables (*1, 2*). Abbreviated excerpts from these references are included in Tables 1 and 2.

Note that a weighted average steam pressure does not correspond directly to the weighted average steam temperature. This is because steam pressure and steam temperature are not linearly related. Also note that the temperature of the saturated steam in the dryer is higher than the temperature of the condensate leaving the dryer. This is because the pressure inside the dryer is higher than the discharge pressure.

Drying rate for coated papers

Equations 1 and 2 can also be used to compute the drying rate for coated papers. However, entering dryness E must generally be calculated from information on coating weight and moisture, while reel basis weight B can be either used directly or computed from the raw stock basis weight. The equations for these calculations are as follows:

$$B = \frac{B_c(P/100)+W}{(L/100)}$$ (4)

$$E = 100 - 100\left[\frac{B_c(1-\frac{P}{100})+W(\frac{100}{C}-1)}{B_c+\frac{(100W)}{C}}\right]$$ (5)

in which the variables are defined as:

B_c	=	basis weight of the sheet entering the coater (wet basis), kg/m^2 (lb/ream)
W	=	dry coating weight applied, kg/m^2 (lb/ream)
P	=	percent dryness of sheet entering the coater
C	=	percent coating solids in coating solution as applied to the sheet (wet basis).

Equations 4 and 5 can also be used to calculate the drying rate after a size press, where W is the dry weight per ream of the starch picked up and C is the percent starch solids in the size solution.

An example of these equations follows in both customary and SI units:

Customary units

S	=	2000 ft/min
B_c	=	43 lb/ream into coater (includes moisture)
L	=	96% dryness (fiber and coating) leaving the dryer section
P	=	94% dry (wet basis) entering the coater
A	=	3300 ft^2/ream
D	=	5.0 ft diameter
N	=	6 coater dryers
W	=	8 lb of dry coating applied per ream
C	=	60% coating solids

$$E = 100 - 100 \left[\frac{43(1 - \frac{94}{100}) + 8(\frac{100}{60} - 1)}{43 + \frac{(100(8)}{60}} \right]$$

E $=$ 86% solids (fiber and coating) entering the dryer section

$$B = \frac{43 \, (94/100) + 8}{(96/100)}$$

B $=$ 50.4 lb/ream out of dryer section as dried

M $=$ (96/86) – 1
M $=$ 0.116 lb water evaporated per lb coated paper (wet basis)

$$R_W = 60 \frac{(2000)(50.4)(0.116)}{(6)(3300)\pi(5.0)}$$

R_w $=$ 2.26 lb water evaporated/h/ft^2

SI units

S $=$ 610 m/min
B_c $=$ 63.6 g/m^2 = 63.6/1000 kg/m^2 into coater (includes moisture)
L $=$ 96% solids (fiber and coating) leaving the dryer section
P $=$ 94% solids (fiber and coating) entering the coater
A $=$ 1.0
D $=$ 1.52 m diameter
N $=$ 6 coater dryers
W $=$ 11.8/1000 kg/m^2 of dry coating applied
C $=$ 60% coating solids

$$E = 100 - 100 \left[\frac{63.6(1 - \frac{94}{100}) + 11.8(\frac{100}{60} - 1)}{63.6 + \frac{(100(11.8)}{60}} \right]$$

E $=$ 86% solids (fiber and coating) entering the dryer section

$$B = \frac{(63.6/1000)(94/100) + (11.8/1000)}{(96/100)}$$

B	=	$(74.6/1000)$ kg/m^2 out of dryer section as dried
M	=	$(96/86) - 1$
M	=	0.116 kg water evaporated per kg coated paper (wet basis)

$$R_W = 60 \frac{(610)(74.6/1000)(0.116)}{(6)(1.0)\pi(1.52)}$$

R_w	=	11.1 kg water evaporated/h/m^2

Keywords

Dryers, Drying, Computation, Water removal, Corrugating medium, Linerboard, Wood free papers, Free sheet, Printing papers, Writing papers, Fine papers, Bleached board, Newsprint, Kraft papers, Bags, Mechanical papers, After dryers, Pulps

Additional information

This revision of TIP 0404-07 incorporates the drying rate curves from the following former TIPs (now withdrawn): TIP 0404-08, TIP 0404-09, TIP 0404-12, TIP 0404-14, TIP 0404-15, TIP 0404-16, TIP 0404-40, TIP 0404-42, and TIP 0404-56.

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      Dick Reese, Dick Reese and Associates
      Greg Wedel, Kadant Johnson

Literature cited

1. *Steam Tables. Thermodynamic Properties of Water Including Vapor, Liquid, and Solid Phases (English Units),* Keenan, J. H., Keyes, F. G., Hill, P. G., and Moore, J. G., John Wiley & Sons, New York, 1969.

2. *Steam Tables. Thermodynamic Properties of Water Including Vapor, Liquid, and Solid Phases (International System of Units — S. I.),* Keenan, J. H., Keyes, F. G., Hill, P. G., and Moore, J. G., John Wiley & Sons, New York, 1978.

Table 1. Saturated steam temperatures (English units).

Press. (psia)	°F	Press. (psia)	°F	Press. (psia)	°F	Press. (psia)	°F
1	101.70	41	268.76	81	312.93	121	341.93
2	126.04	42	270.22	82	313.78	122	342.55
3	141.43	43	271.66	83	314.62	123	343.17
4	152.93	44	273.07	84	315.46	124	343.78
5	162.21	45	274.46	85	316.29	125	344.39
6	170.03	46	275.82	86	317.11	126	344.99
7	176.82	47	277.16	87	317.92	127	345.59
8	182.84	48	278.47	88	318.72	128	346.19
9	188.26	49	279.76	89	319.52	129	346.78
10	193.19	50	281.03	90	320.31	130	347.37
11	197.73	51	282.28	91	321.10	131	347.96
12	201.94	52	283.52	92	321.87	132	348.54
13	205.87	53	284.73	93	322.64	133	349.12
14	209.55	54	285.92	94	323.41	134	349.70
15	213.03	55	287.10	95	324.16	135	350.27
16	216.31	56	288.26	96	324.91	136	350.84
17	219.43	57	289.40	97	325.66	137	351.40
18	222.40	58	290.53	98	326.40	138	351.97
19	225.24	59	291.64	99	327.13	139	352.53
20	227.96	60	292.73	100	327.86	140	353.08
21	230.57	61	293.81	101	328.58	141	353.63
22	233.08	62	294.88	102	329.29	142	354.18
23	235.49	63	295.93	103	330.00	143	354.73
24	237.82	64	296.98	104	330.71	144	355.28
25	240.08	65	298.00	105	331.41	146	356.35
26	242.26	66	299.02	106	332.10	148	357.42
27	244.37	67	300.02	107	332.79	150	358.48
28	246.42	68	301.01	108	333.47	152	359.52
29	248.41	69	301.99	109	334.15	154	360.56
30	250.34	70	302.96	110	334.82	156	361.58
31	252.23	71	303.91	111	335.49	158	362.59
32	254.06	72	304.86	112	336.16	160	363.60
33	255.85	73	305.79	113	336.81	162	364.59
34	257.59	74	306.72	114	337.47	164	365.58
35	259.30	75	307.63	115	338.12	166	366.55
36	260.96	76	308.54	116	338.77	168	367.52
37	262.59	77	309.44	117	339.41	170	368.47
38	264.18	78	310.32	118	340.04	172	369.42
39	265.74	79	311.20	119	340.68	174	370.36
40	267.26	80	312.07	120	341.30	176	371.29

Table 2. Saturated steam temperatures (S. I. units).

Press. (kPa)	°C	Press. (kPa)	°C	Press. (kPa)	°C	Press. (kPa)	°C
10	45.81	210	121.78	420	145.40	820	171.46
15	53.97	215	122.53	430	146.26	830	171.97
20	60.06	220	123.57	440	147.10	840	172.47
25	64.97	225	124.00	450	147.93	850	172.96
30	69.10	230	124.71	460	148.74	860	173.46
35	72.69	235	125.41	470	149.54	870	173.94
40	75.87	240	126.10	480	150.32	880	174.43
45	78.73	245	126.77	490	151.10	890	174.90
50	81.33	250	127.44	500	151.86	900	175.38
55	83.72	255	128.09	510	152.60	910	175.85
50	85.94	260	128.73	520	153.34	920	176.31
65	88.01	265	129.37	530	154.06	930	176.78
70	89.95	270	129.99	540	154.78	940	177.24
75	91.78	275	130.60	550	155.48	950	177.69
80	93.50	280	131.21	560	156.17	960	178.14
85	95.14	285	131.81	570	156.86	970	178.59
90	96.71	290	132.39	580	157.53	980	179.03
95	98.20	295	132.97	590	158.20	990	179.47
100	99.63	300	133.55	600	158.85	1000	179.91
105	101.00	305	134.11	610	159.50	1020	180.77
110	102.31	310	134.67	620	160.14	1040	181.62
115	103.58	315	135.22	630	160.77	1060	182.46
120	104.80	320	135.76	640	161.39	1080	183.28
125	105.99	325	136.30	650	162.01	1100	184.09
130	107.13	330	136.83	660	162.61	1120	184.89
135	108.24	335	137.35	670	163.21	1140	185.68
140	109.31	340	137.87	680	163.81	1160	186.46
145	110.36	345	138.38	690	164.39	1180	187.23
150.	111.37	350.	138.88	700	164.97	1200	187.99
155	112.36	355	139.38	710	165.55	1220	188.74
160	133.32	360	139.87	720	166.11	1240	189.48
165	114.26	365	140.36	730	166.67		
170	115.17	370	140.84	740	167.23		
175	116.06	375	141.32	750	167.78		
180	116.93	380	141.79	760	168.32		
185	117.79	385	142.26	770	168.86		
190	118.62	390	142.72	780	169.39		
195	119.43	395	143.18	790	169.91		
200	120.23	400	143.63	800	170.43		
205	121.02	410	144.53	810	170.95		
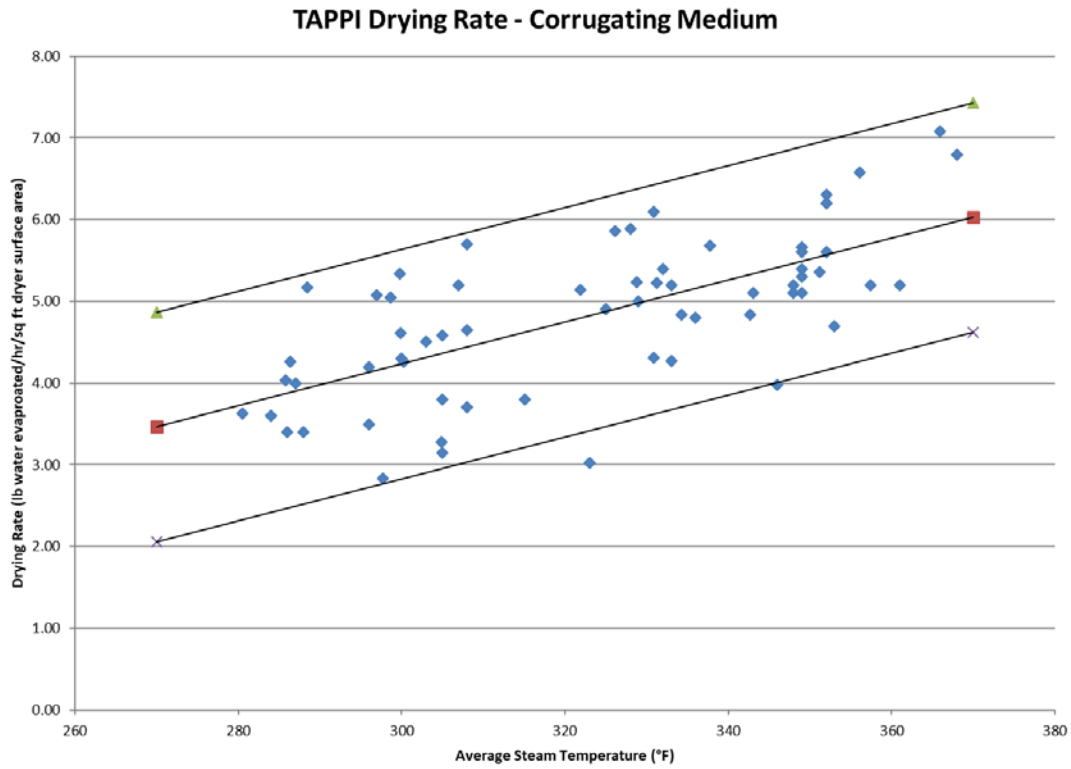
Fig. 1E. Corrugating medium (English units)
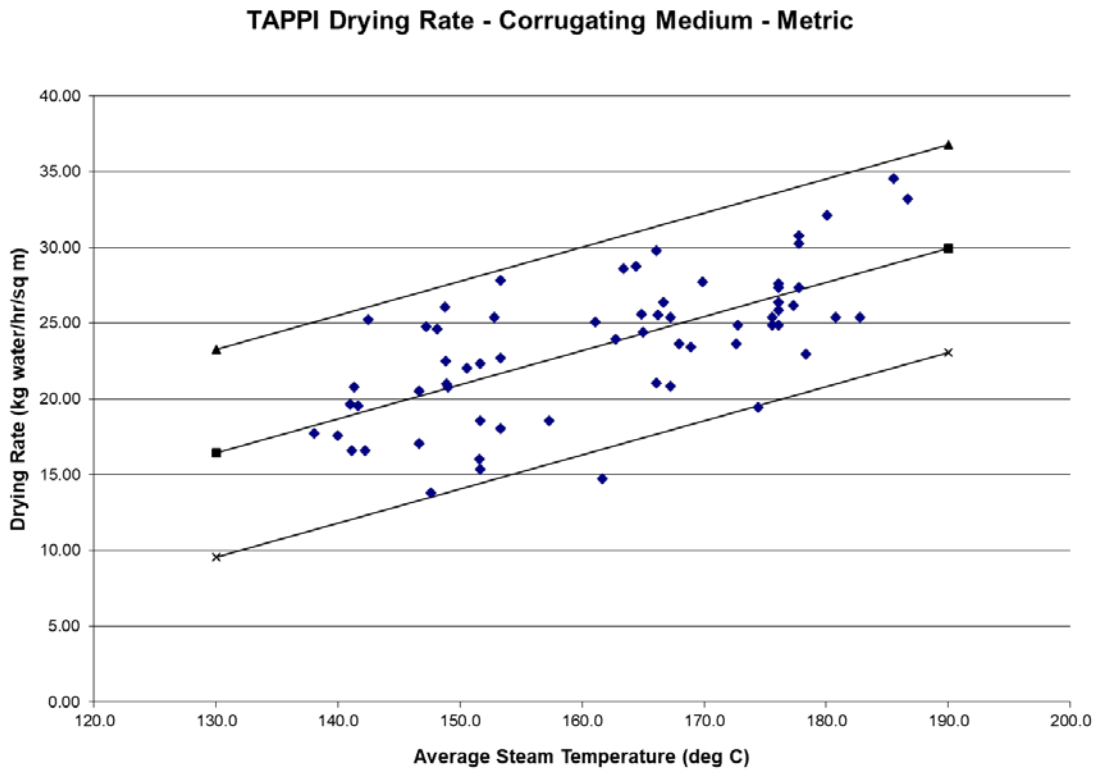
Fig. 1M. Corrugating medium (metric units)
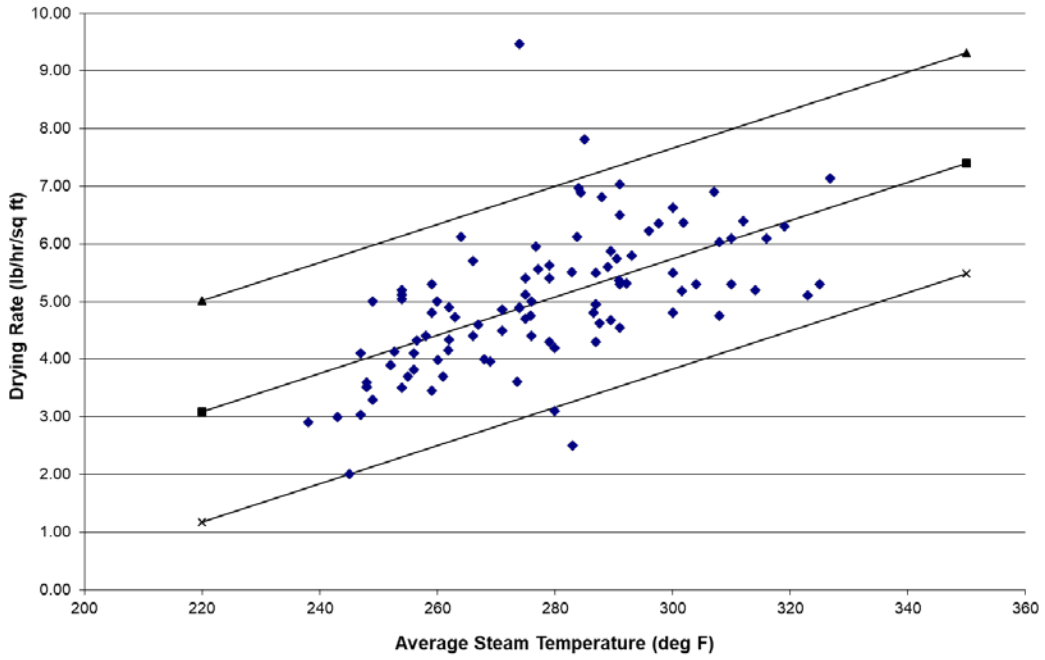
Fig. 2E. Woodfree printing and writing (English units)
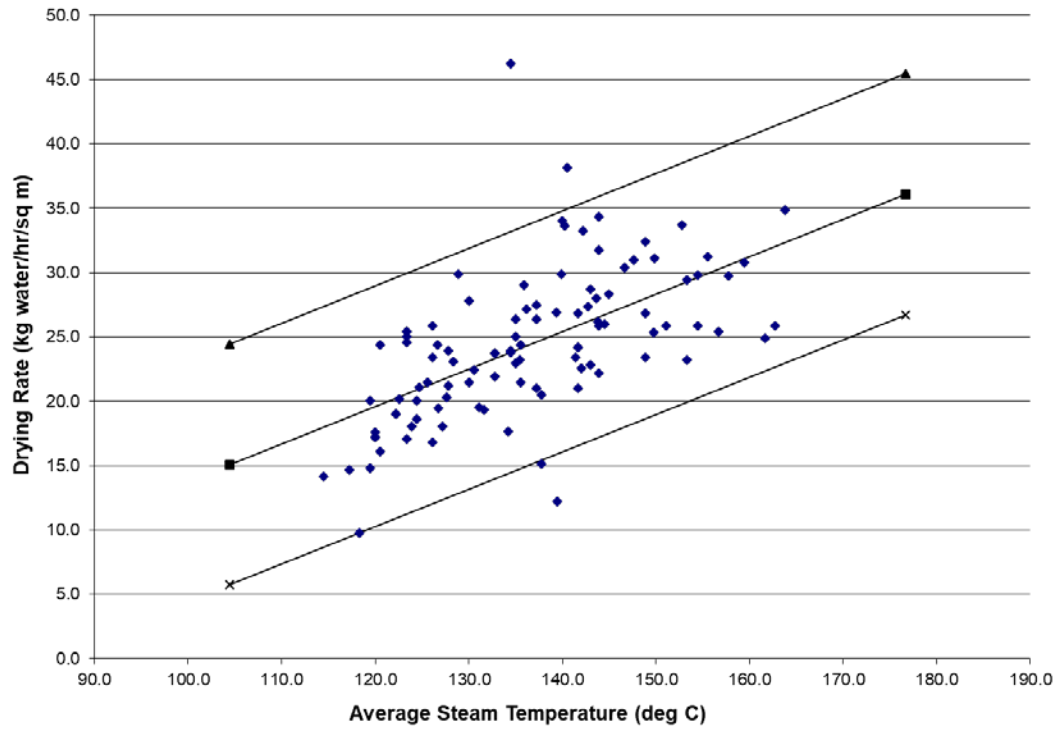
Fig. 2M. Woodfree printing and writing (metric units)

TAPPI Drying Rate - Linerboard
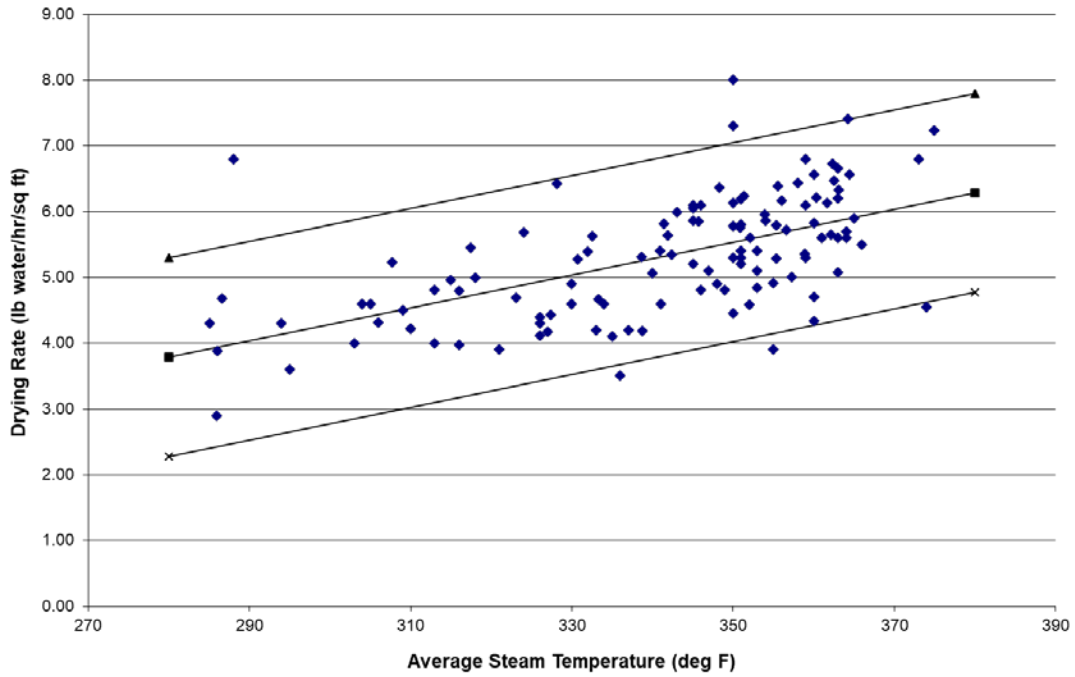
Fig. 3E. Linerboard (English units)
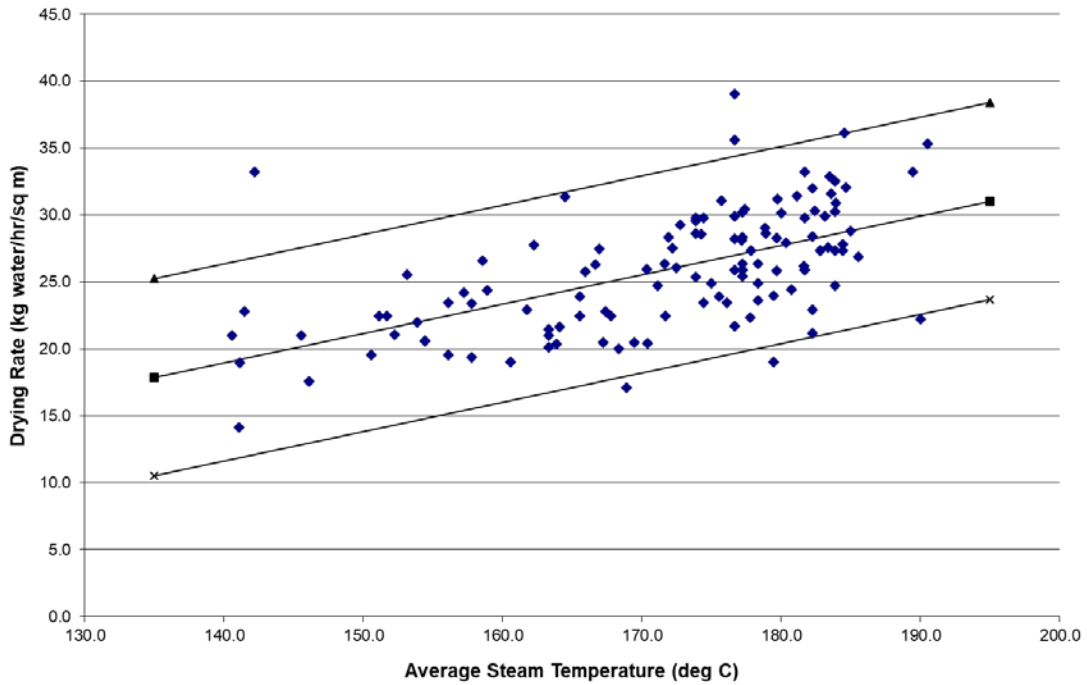
TAPPI Drying Rate - Linerboard - Metric
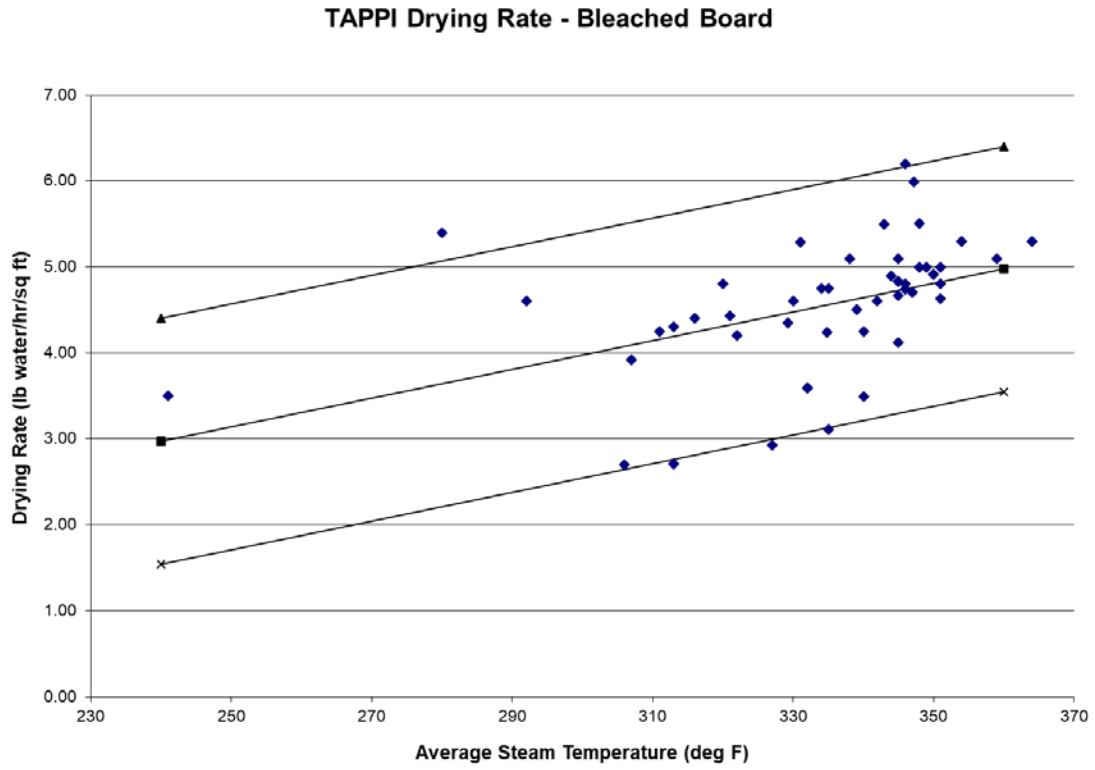

Fig. 3M. Linerboard (metric units)

TAPPI Drying Rate - Bleached Board

Fig. 4E. Bleached board (English units)

TAPPI Drying Rate - Bleached Board - Metric
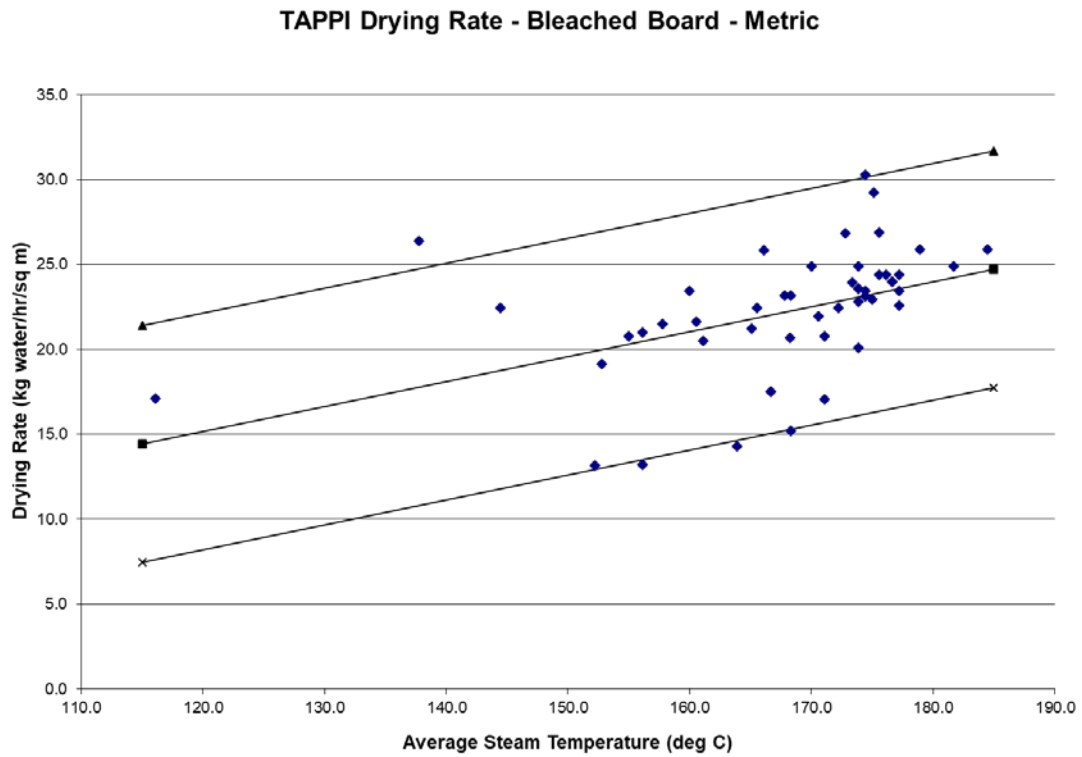
Fig. 4M. Bleached board (metric units)

TAPPI Drying Rate - Newsprint
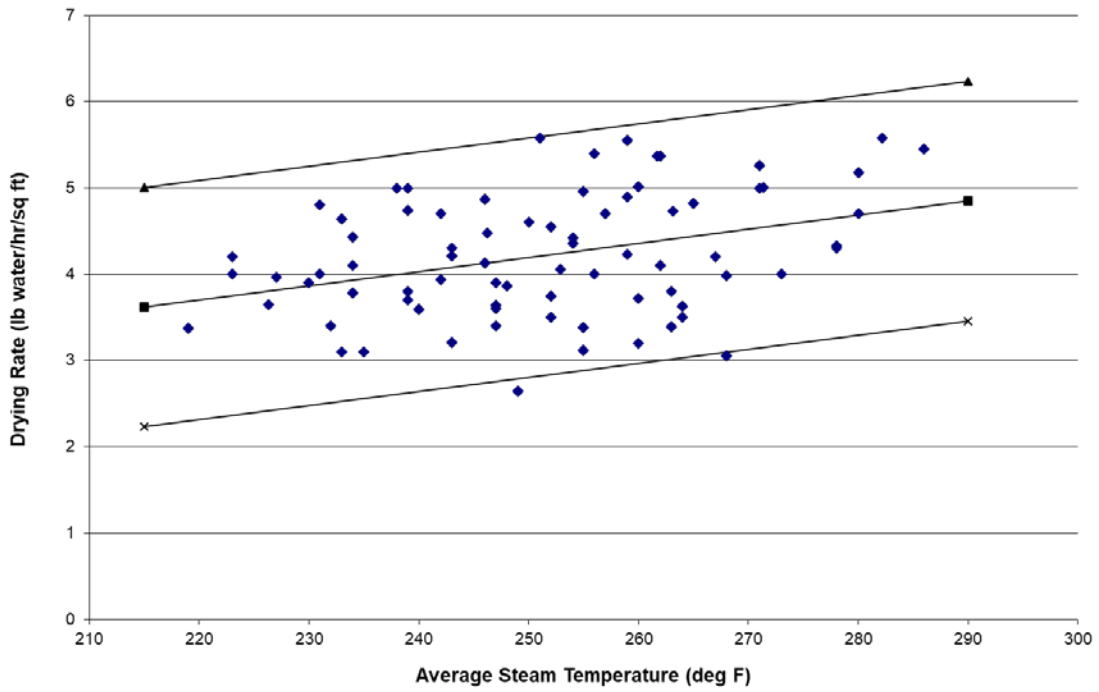
Fig. 5E. Newsprint (English units)

TAPPI Drying Rate - Newsprint - Metric
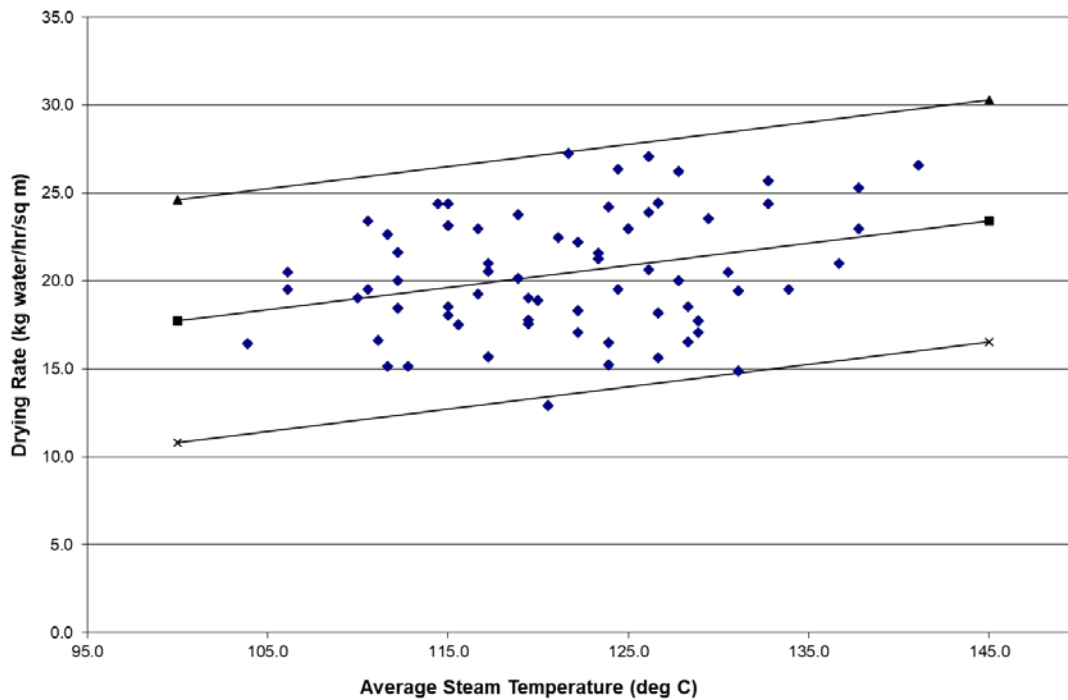
Fig. 5M. Newsprint (metric units)

TAPPI Drying Rate - Kraft Paper
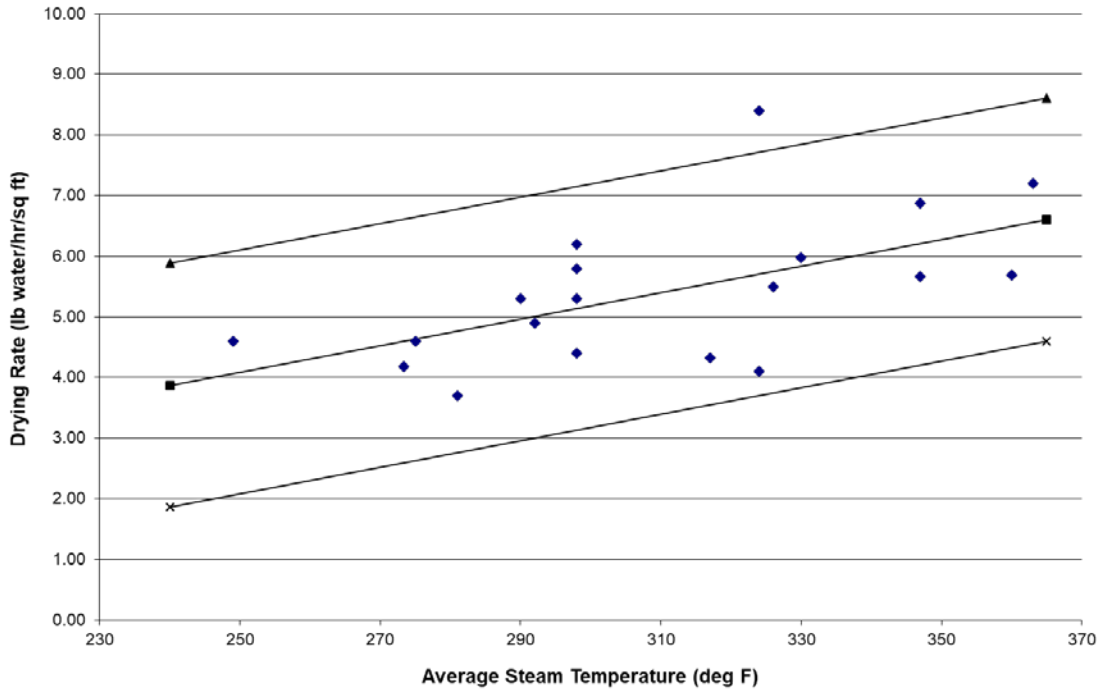
Fig. 6E. Kraft papers (English units)

TAPPI Drying Rate - Kraft Paper - Metric
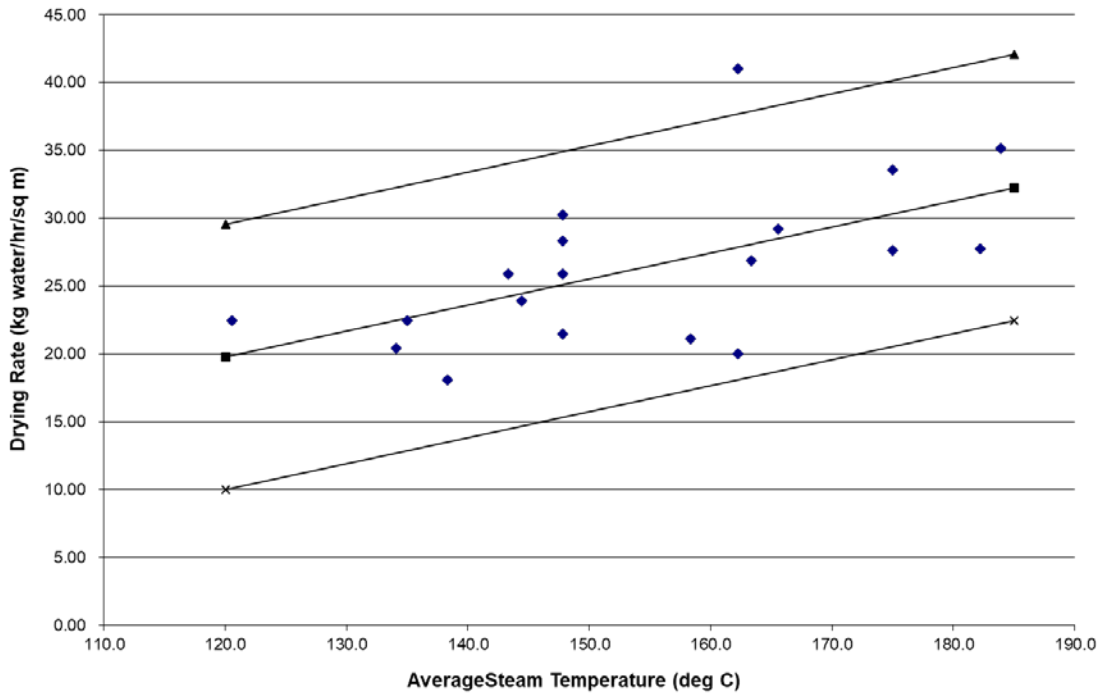
Fig. 6M. Kraft papers (metric units)

TAPPI Drying Rate - Wood-Containing Paper
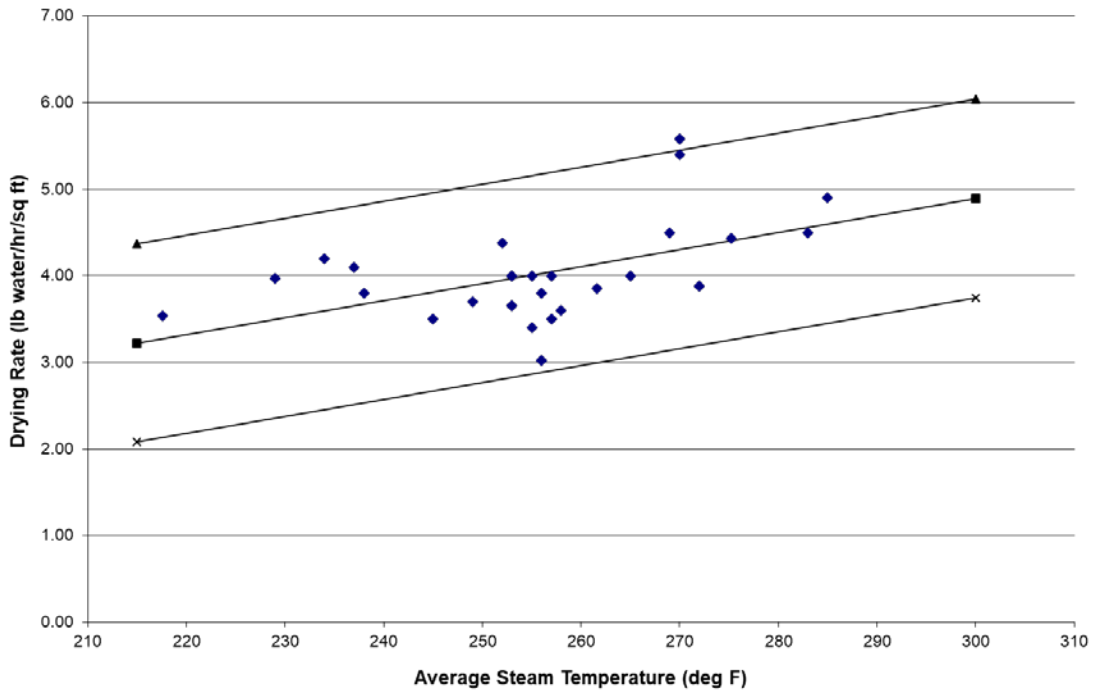
Fig. 7E. Wood-containing paper (English units)

TAPPI Drying Rate - Wood-containing Paper - Metric
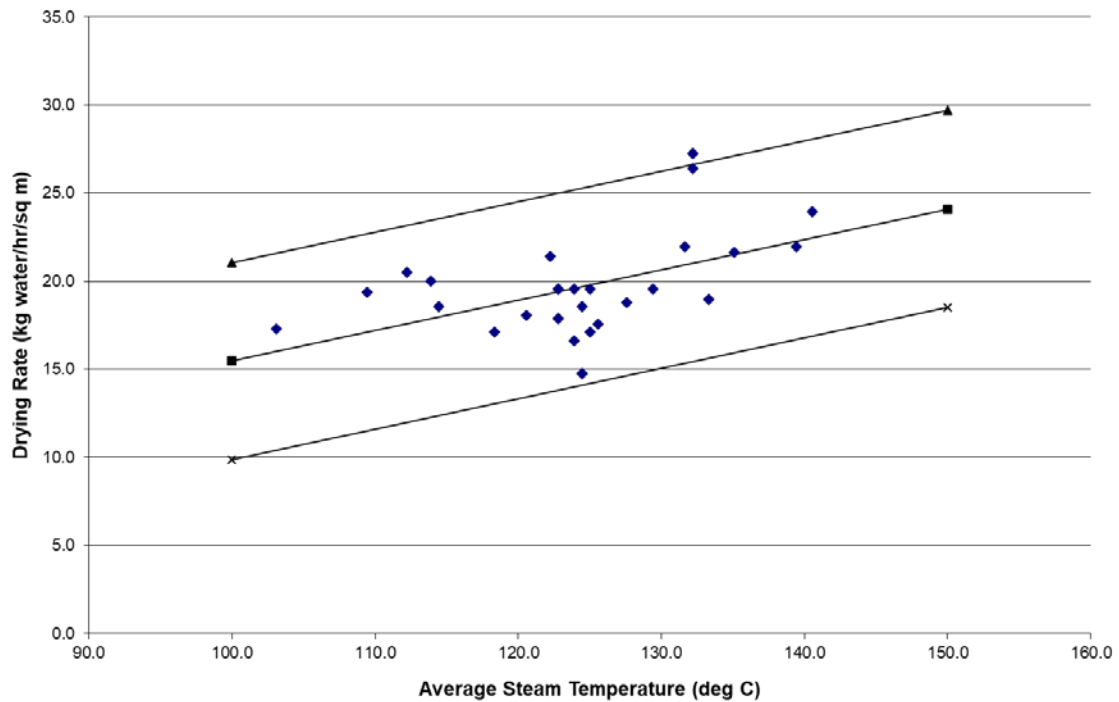
Fig. 7M. Wood-containing paper (metric units)

TAPPI Drying Rate - After-Size Dryers
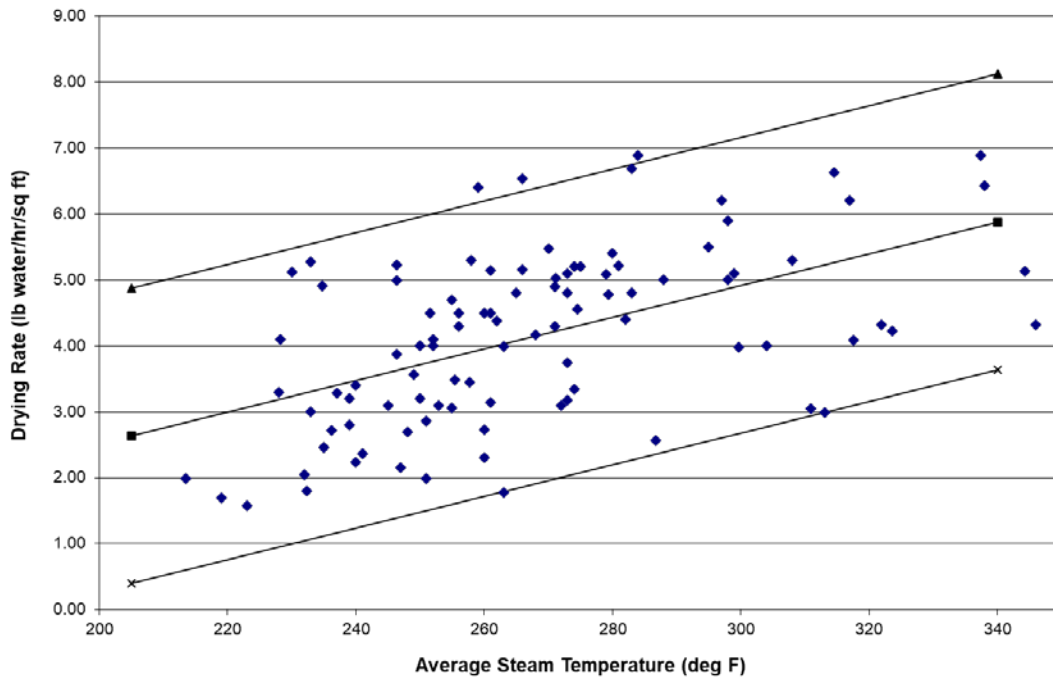
Fig. 8E. After-size press drying (English units)

TAPPI Drying Rate - After-size Dryers - Metric
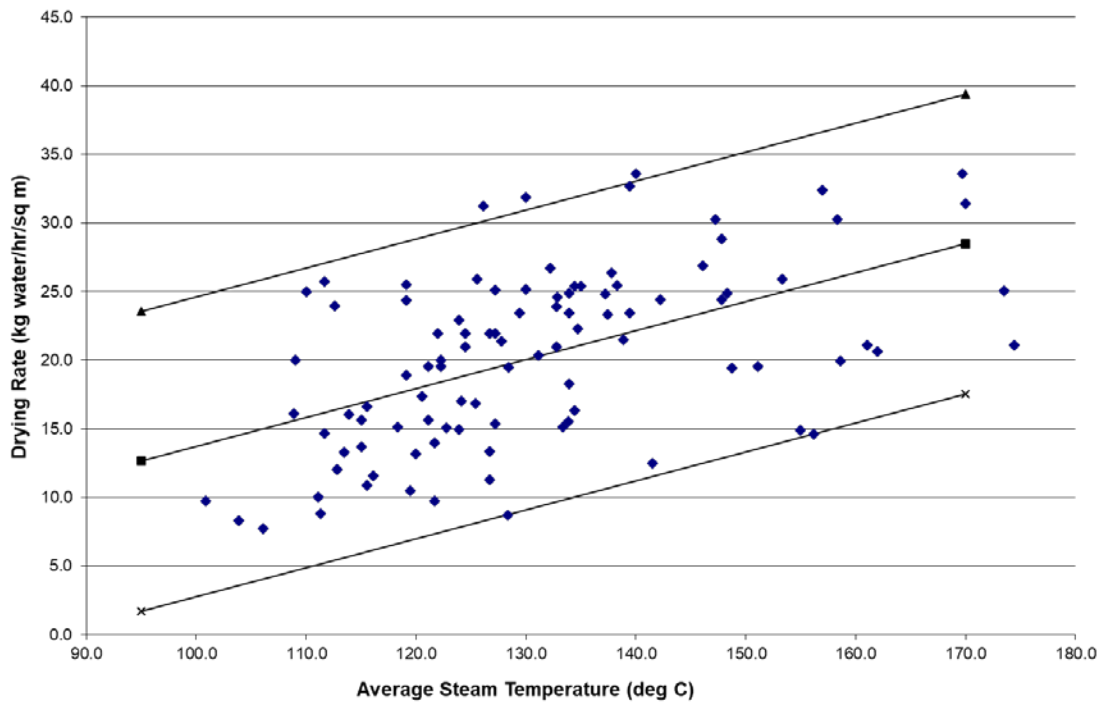
Fig. 8M. After-size press drying (metric units)

TAPPI Drying Rate - Pulp (Cylinder Dryers)
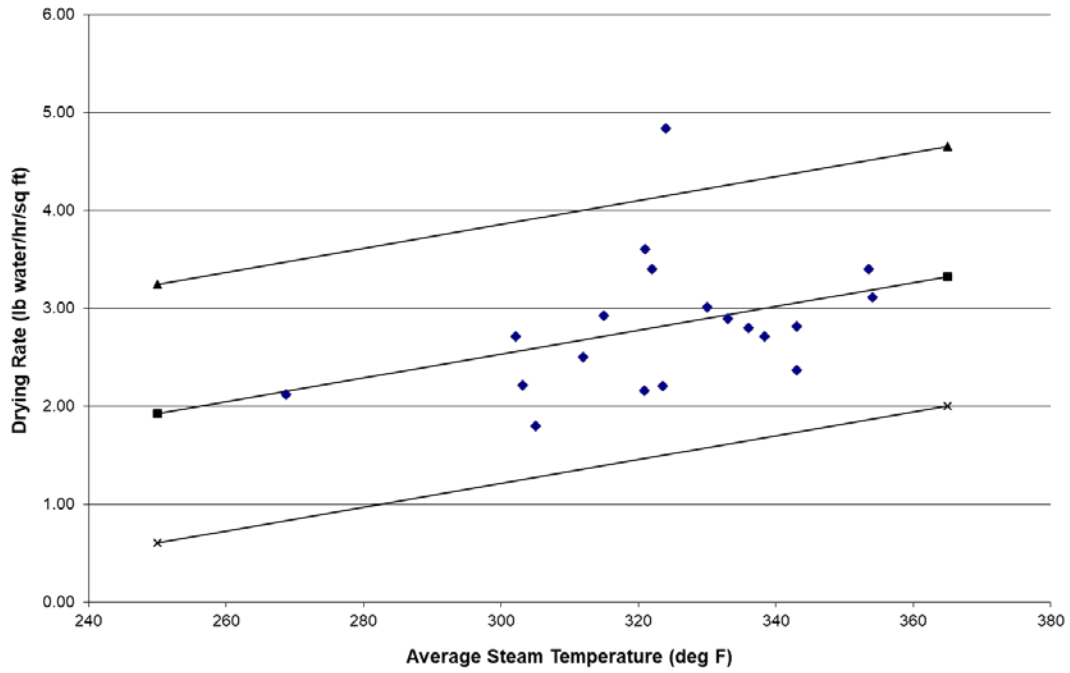
Fig. 9E. Pulp (cylinder dryers) (English units)

TAPPI Drying Rate - Pulp (Cylinder Dryers) - Metric
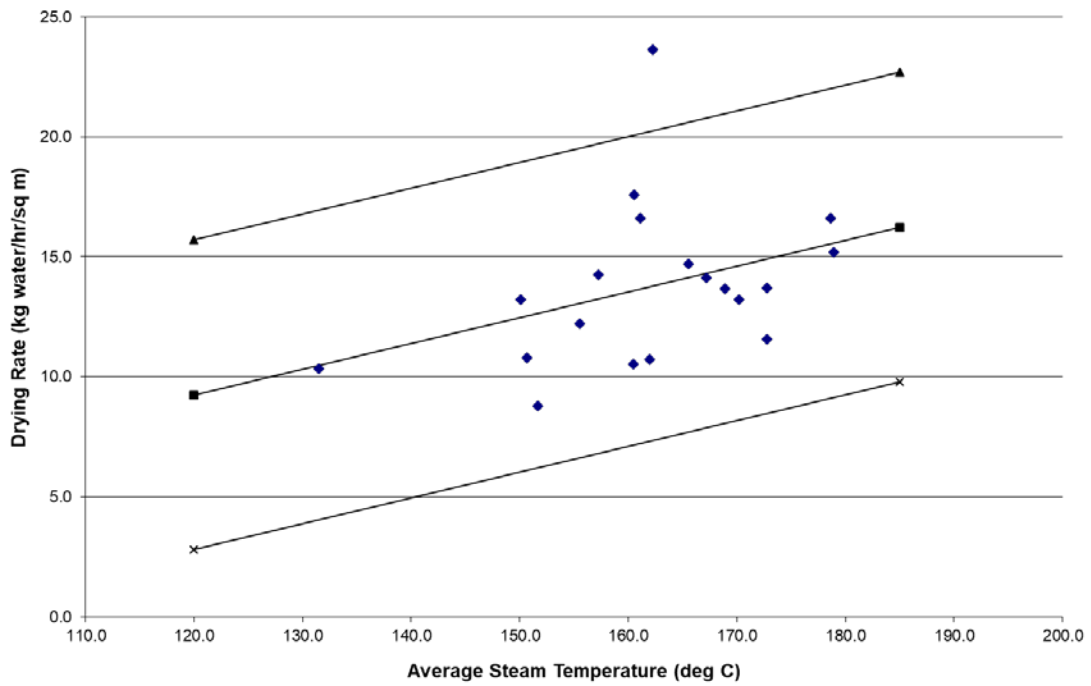
Fig. 9M. Pulp (cylinder dryers) (metric units)

TAPPI Drying Rate - Pulp (Air Dryers)
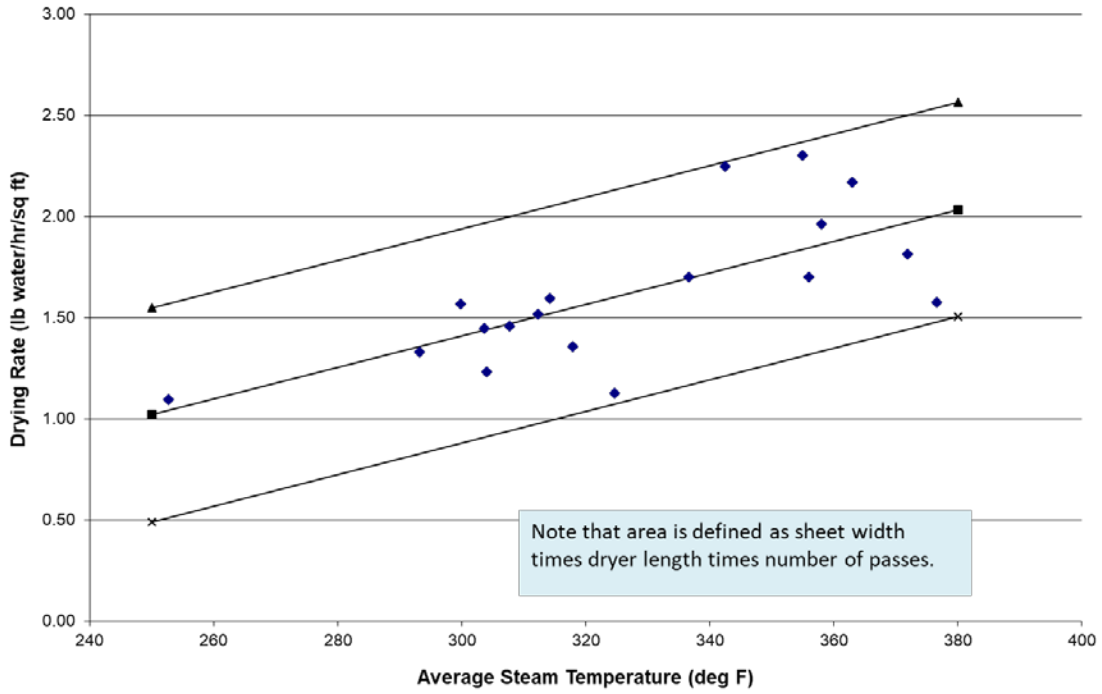
Fig. 10E. Pulp (air dryers) (English units)

TAPPI Drying Rate - Pulp (Air Dryers) - Metric
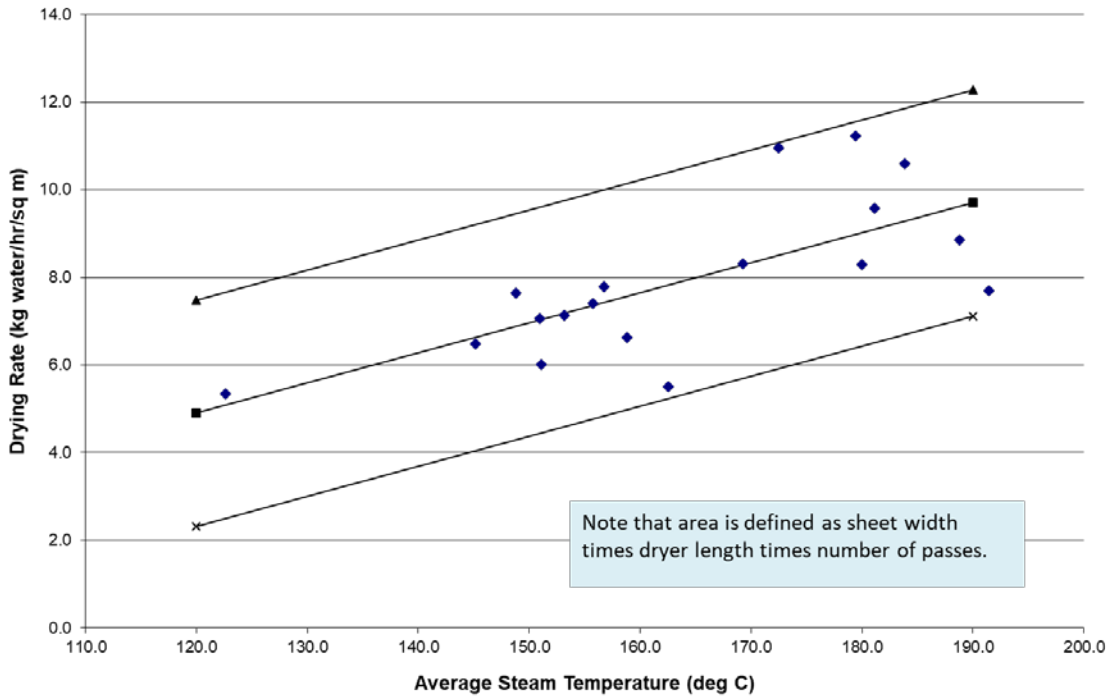
Fig. 10M. Pulp (air dryers) (metric units)
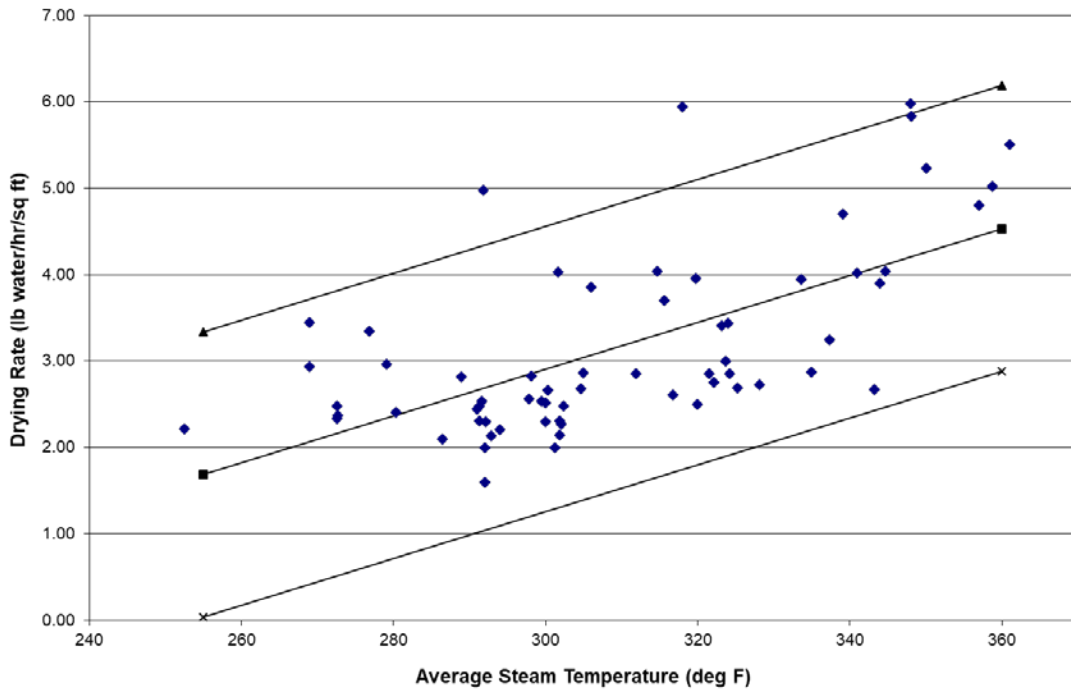
TAPPI Drying Rate - Paperboard

Fig. 11E. Paperboard (English units)
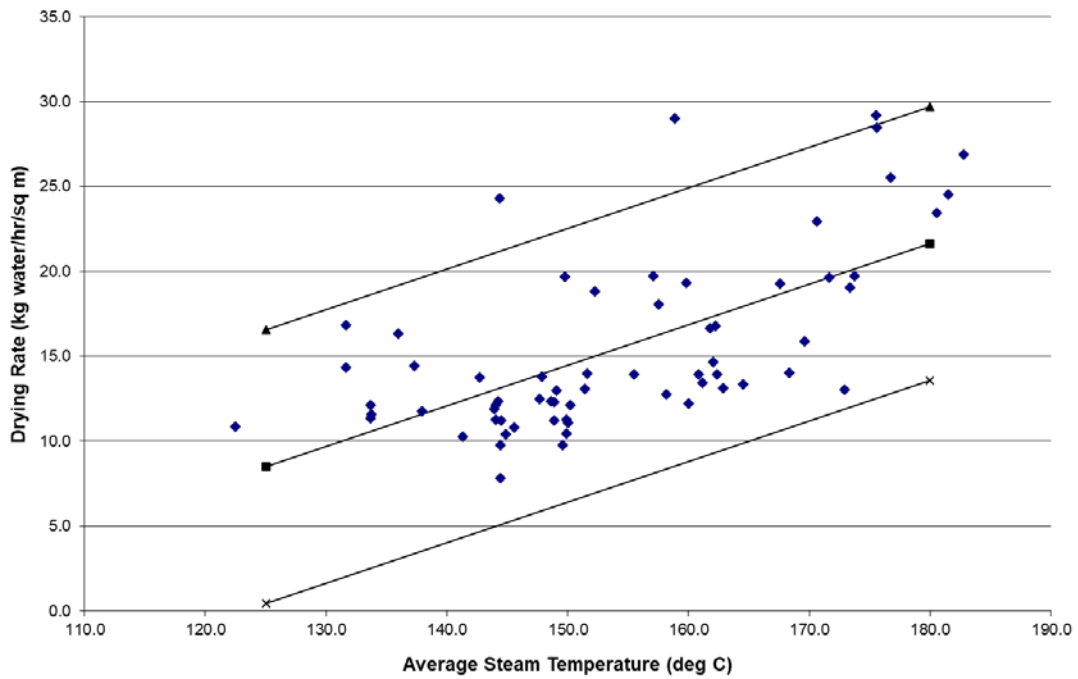
TAPPI Drying Rate - Paperboard - Metric

Fig. 11M. Paperboard (metric units)

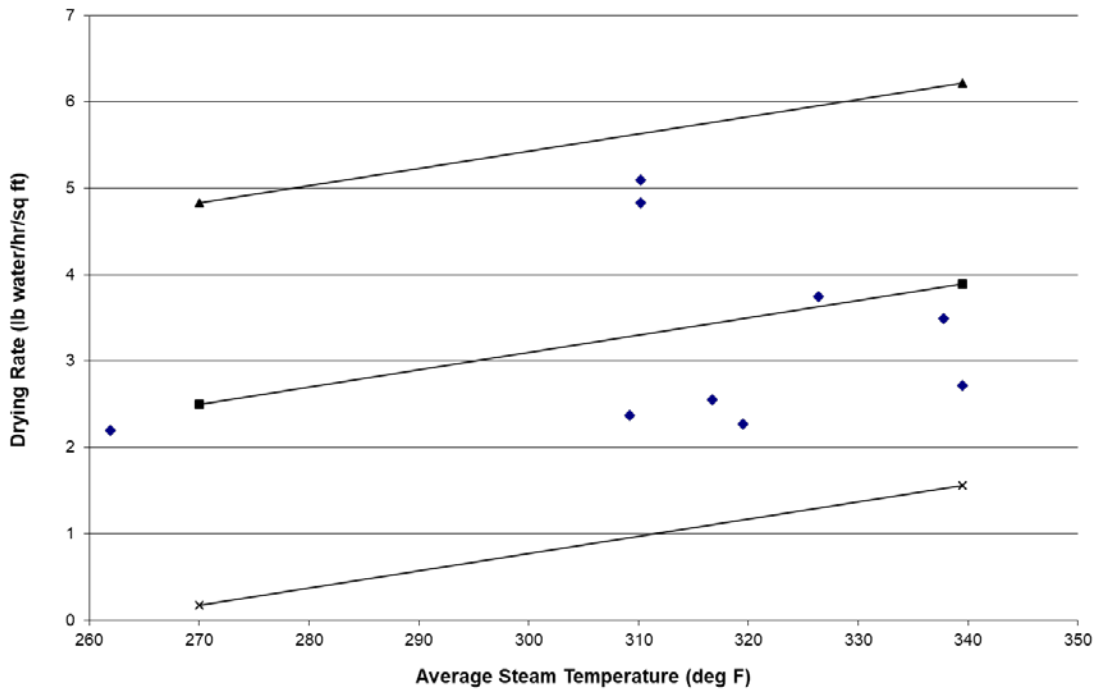**TAPPI Drying Rate - Gypsum Wallboard**

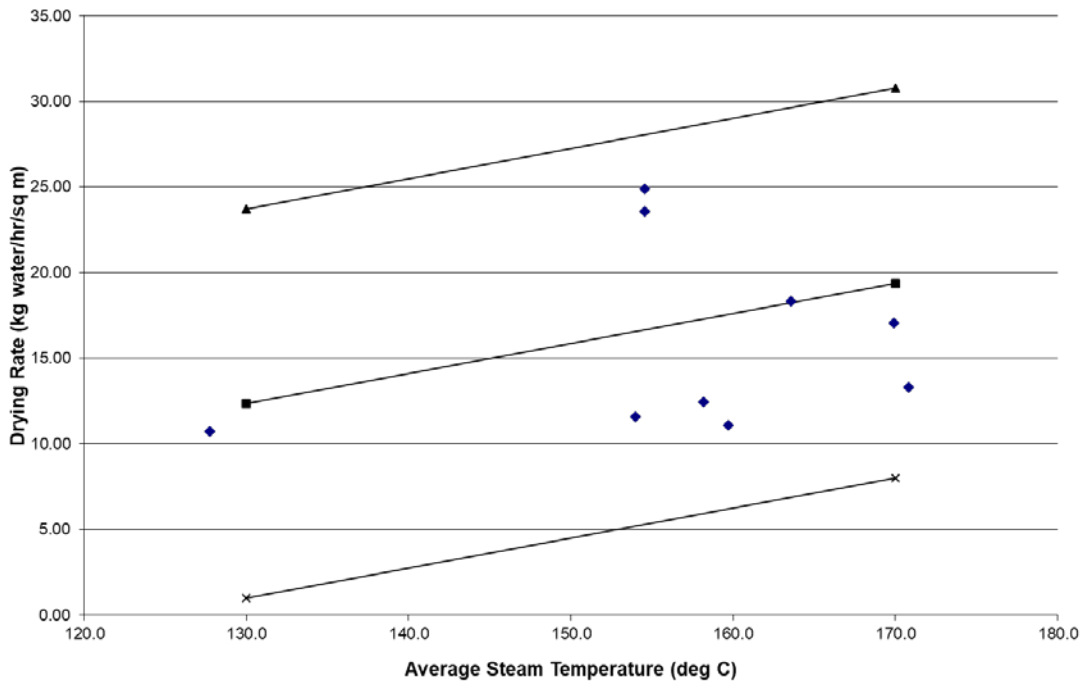**Fig. 12E.** Gypsum wallboard (English units)

TAPPI Drying Rate - Gypsum Wall Board - Metric

Fig. 12M. (Gypsum wallboard (metric units)