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EFFECT OF HUMIDITY ON PHYSICAL PROPERTIES OF PAPER

By
FREDERICK T. CARSON

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PREFACE

The moisture in the atmosphere influences the behavior of paper in many ways, some properties being bettered while others are worsened by a given change in humidity. Considerable information has been published about the influence of humidity on paper, but much of it is scattered, or out of print, or not readily available. Because of the many uses of paper on which atmospheric humidity has some bearing, and the many inquiries about why paper behaves as it does, this Circular has been prepared as a brief account of the relation between humidity and some common properties of paper.

LYMAN J. BRIGGS, *Director.*

EFFECT OF HUMIDITY ON PHYSICAL PROPERTIES OF PAPER

By Frederick T. Carson

ABSTRACT

This is a review of the chief manifestations of change in the physical properties of paper with change in the hygrometric environment. The data presented are based primarily on work done a number of years ago at the National Bureau of Standards, supplemented by more recent data and information from various sources. The data, presented in seven tables and six graphs, show the variation with humidity of basic ream wieght, bursting strength, tearing resistance, folding endurance, tensile strength, and stretch.

CONTENTS

I. INTRODUCTION

The effect of atmospheric humidity on paper is a matter of perpetual concern in the multifarious uses of this material. Frequent requests are received by the National Bureau of Standards for information about the physical properties of paper under various conditions of temperature and relative humidity. A number of studies of this matter have been made on various kinds of paper and fiberboard. Most of these investigations have been somewhat limited in scope, but together they have covered a considerable variety of materials and testing conditions. About a hundred references to the literature on the subject have been listed by the Institute of Paper Chemistry [3],[1] with brief abstracts of many of them.

About 20 years ago the National Bureau of Standards made a study of the subject on a scale which in the meantime has not been duplicated, but unfortunately the report [2] of this work has long since been out of print.

[1] Figures in brackets indicate the literature references at the end of this paper.

To make information of this character more readily available, this review has been prepared. While it is based primarily on the earlier report, it does contain more recent data and is supplemented by reference to various other studies.

II. HYGROMETRIC STANDARDS

Inasmuch as varying temperature or humidity materially affects the moisture content of paper and those properties which are affected by moisture content, various groups have established convenient standard conditions to be used when paper is to be tested. The Technical Association of the Pulp and Paper Industry, for instance, prescribes a temperature of 23° C and a relative humidity of 50 percent.

The effect of temperature is a matter of less concern than is the effect of relative humidity. Under ordinary circumstances, an increase of 2 or 3° C has about the same effect on moisture content as a decrease of 1 percent of relative humidity [9]. It is advisable, however, to control the temperature, as well as the humidity, as closely as is convenient, in order to minimize the effect of variations in the hygrometric conditions. The Technical Association of the Pulp and Paper Industry allows ±2° C and ±2 percent of relative humidity. This is about as close control as is feasible with the usual installations and measuring instruments.

III. MOISTURE-CONTENT HYSTERESIS

The equilibrium moisture content of paper at a given temperature and relative humidity is less when the equilibrium is approached from a lower moisture content than it is when approached from a higher moisture content. This hysteresis in moisture content is reflected in all those properties of the paper that vary with content of moisture. Data have been presented [4, 5, 8, 9] showing that it is pointless to exercise close control over the hygrometric conditions unless the paper is brought to equilibrium from a definite direction. These data indicate that neglect of this detail can result in an error which is the equivalent of as much as a 10-percent error in relative humidity. Such a large uncertainty would not of course occur unless the conditioning and previous history of the paper were very different from the recommended sequence of moisure-content changes. The Technical Association of the Pulp and Paper Industry recommends approach from a drier state corresponding to about half the moisture content under standard conditions. Because the earlier studies, including that reported in reference [2], did not consider this effect, some of the minor inconsistencies of those data are probably chargeable to neglect of the hysteresis effect.

IV. PHYSICAL PROPERTIES AND HUMIDITY

Most of the familiar physical properties have been determined at various values of relative humidity for a considerable variety of papers and boards. In tables 1 to 7 are given the data obtained at the National Bureau of Standards some 20 years ago on 11 papers tested in the range from 15- to 83-percent relative humidity for basic ream weight

(weight of a given area of paper), bursting strength, tearing resistance, folding endurance, tensile breaking strength, and stretch to failure in tension. The temperature of the testing laboratory during these tests was 70° F (21° C), except for a few tests at 60° F. Sources of supplementary data are noted under the several properties considered.

TABLE 1.—*Description of papers referred to by number in tables 2 to 7*

Paper number	Kind of paper	Weight at 50% relative humidity 500 (25 × 40)	Thickness	Ash	Rosin	Fiber
		lb.	*Mils*	*Percent*	*Percent*	
1	Book, sized and supercalendered.	53	2.9	9.6	1.4	Wood, bleached, chemical.
2	Book, machine finished	71	4.4	24.4	1.0	Do.
3	Writing	53	3.4	2.9	2.2	Do.
4	do	78	5.1	0.8	1.2	Cotton.
5	Bond	58	4.0	1.0	1.0	Do.
6	do	69	4.1	0.2	1.0	Do.
7	Ledger	78	4.6	.6	1.7	¾ cotton, ¼ wood, bleached, chemical.
8	do	162	10.7	.9	1.2	Cotton.
9	Index bristol	264	15.7	1.0	1.7	½ cotton, ½ wood, bleached, chemical.
10	Kraft	59	4.9	0.3	1.3	Wood, coniferous, unbleached.
11	Rope manila	89	6.0	1.6	1.5	¼ wood, coniferous, ¾ manila and jute, unbleached.

Sometimes data such as are given in this paper are used to convert to standard or given conditions test results which are obtained at any convenient uncontrolled humidity and temperature, in the absence of control equipment. Some of the earlier writers recommended such use. Such practice is, however, a very poor substitute for testing paper under controlled atmospheric conditions, and is not likely to result in reliable information because (a) papers frequently differ in their behavior patterns over a humidity range to such an extent that it is difficult to generalize; (b) when the previous history of the paper is unknown and uncontrolled, the uncertainty associated with hysteresis is unpredictable; (c) the natural humidity in a room is variable with time, in consequence of which it is unlikely that a paper tested under such conditions would have attained a moisture-content equilibrium characteristic of the humidity measured.

1. MOISTURE CONTENT

Variation in moisture content, the basic cause of variation in other properties, has been most frequently studied [1, 5, 6, 8, 9, 11]. For paper in general, a typical sigmoid curve is obtained when moisture content is plotted against relative humidity. Weber and Snyder [9] of the National Bureau of Standards have reported a very interesting study of the moisture content of lithographic papers at relative humidity values from 27 to 73 percent, including also effects of moisture-content hysteresis and the relation of some other physical properties to moisture content. The effect which moisture has on the properties of paper appears to be determined by the moisture content, regardless of temperature (within the ordinary use range of paper) or direction of approach to equilibrium [8, 9]. The change in moisture content is very nearly proportional to the change in basic ream weight, since the percentage change in dimensions of the paper is small.

2. BASIC REAM WEIGHT

The manner in which the weight per unit area varies with humidity is shown by the data in table 2 and figure 1. In figure 1 the percentage

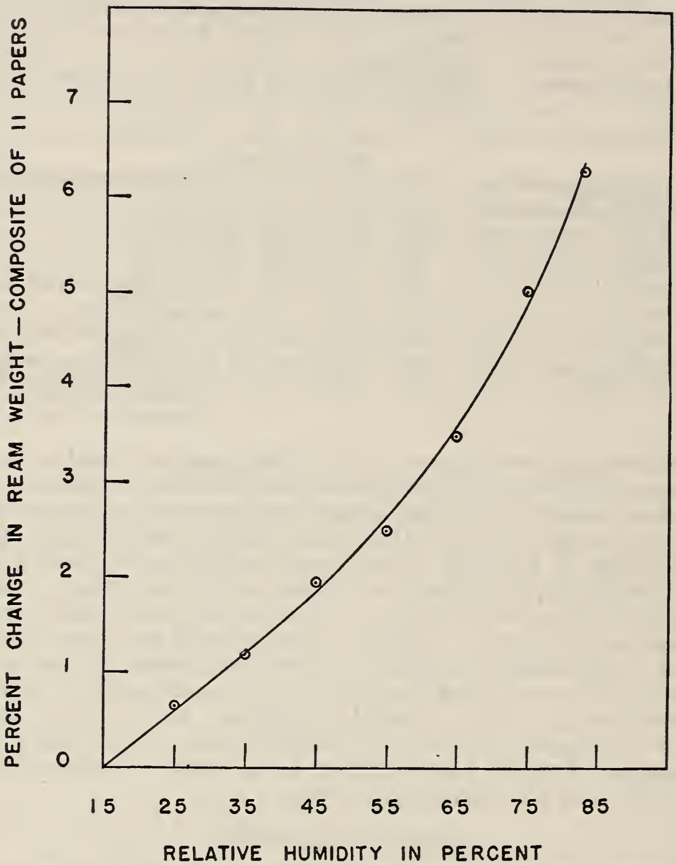

Figure 1.—*Increase in basic ream weight (weight of a given area of paper) with humidity, expressed as the percentage increase over the weight at 15-percent relative humidity.*

Each point is the composite of data for 11 papers.

increase in basic ream weight over that at 15-percent relative humidity (the lowest humidity attained) is plotted against relative humidity in percent, for the composite sample (average of 11 papers). The form of this curve brings to mind the one for the moisture content of paper.

TABLE 2.—*Weight in pounds of 500 sheets, 25 inches wide and 40 inches long*

Relative humidity	Basic ream weight of paper number (table 1)—										
	1	2	3	4	5	6	7	8	9	10	11
Percent	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
15	51.7	69.7	51.3	76.3	56.4	67.1	76.2	157.7	260.0	57.4	86.6
25	52.3	70.0	52.0	77.2	57.1	67.9	76.7	158.6	259.7	58.1	87.4
35	52.4	70.3	52.2	77.5	57.5	68.1	77.3	159.8	262.1	58.5	87.7
45	52.8	70.8	52.6	77.9	57.7	68.4	78.0	161.2	263.7	59.1	88.6
55	53.0	71.2	53.0	78.3	58.0	68.8	78.3	162.0	264.7	59.5	89.0
65	53.5	71.6	53.6	79.0	58.8	69.2	78.7	163.0	268.9	60.0	89.6
75	54.1	72.5	54.4	80.0	59.7	70.2	79.9	165.3	273.1	61.1	91.3
83	54.9	73.2	55.2	80.8	60.9	70.7	80.7	166.8	277.0	62.0	92.9

3. BURSTING STRENGTH

The data in table 3 and in figure 2, and many other studies, show that bursting strength is at a maximum between 30- and 50-percent relative humidity. Bursting strength decreases fairly rapidly at high humidities. In the neighborhood of the standard relative

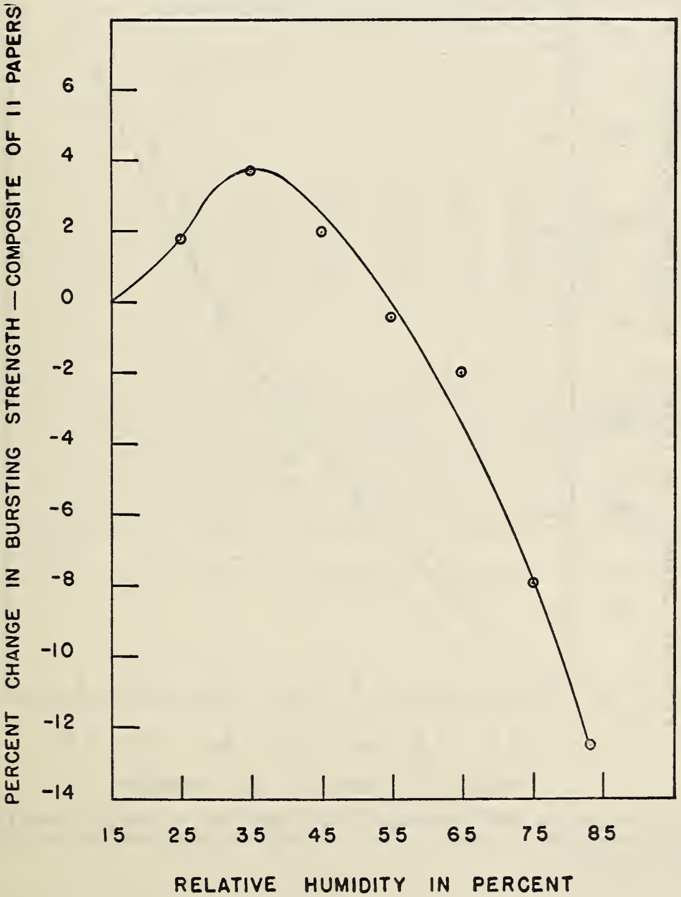

FIGURE 2.—*Change in bursting strength with humidity, expressed as percentage change from the bursting strength at 15-percent relative humidity.*

TABLE 3.—*Bursting strength in points (bursting pressure in Mullen tester in pounds per square inch)*

Relative humidity	Bursting strength of paper number (table 1)—										
	1	2	3	4	5	6	7	8	9	10	11
Percent	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*	*Points*
15	17.3	17.2	20.9	58.9	39.5	58.0	41.0	86.4	92.0	39.3	85.2
25	16.8	17.3	21.0	59.5	40.4	58.9	42.3	88.3	94.9	40.7	85.1
35	17.4	16.6	21.1	59.6	40.8	59.3	43.2	88.8	96.2	40.9	92.4
45	17.0	16.0	21.3	60.2	39.8	59.8	42.4	88.2	94.6	41.2	85.8
55	15.6	15.5	21.3	59.5	39.3	58.8	40.3	85.6	91.2	40.5	85.7
65	15.2	15.0	19.9	58.9	38.8	56.1	39.6	85.8	91.5	41.9	82.2
75	15.3	14.9	20.2	55.8	37.2	55.1	38.7	76.0	77.2	38.6	82.8
83	13.1	11.9	18.6	53.6	34.2	55.3	37.9	73.0	76.3	38.9	73.8

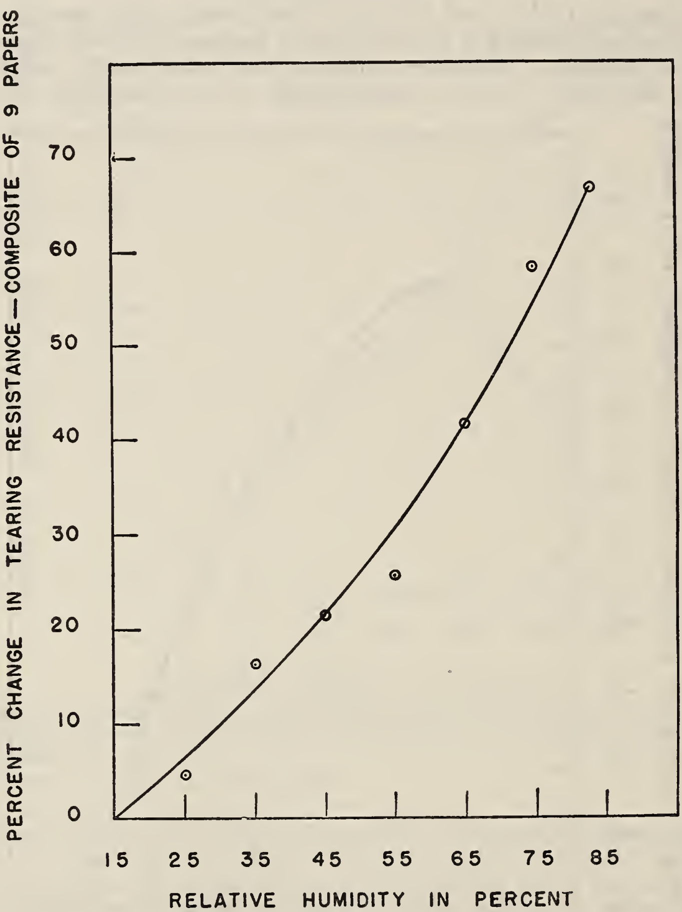

FIGURE 3.—*Increase with humidity of the resistance to tearing paper in the machine direction, expressed as the percentage increase over that at 15-percent relative humidity.*

humidity (50 percent) the bursting strength is altered about 1 or 2 percent by a change of 10-percent relative humidity. Seborg, Doughty, and Baird 8], of the Forest Products Laboratory, show the interesting relation that relative bursting strength (percentage of maximum) when plotted against moisture content exhibits almost identical behavior for different papers and different ways of reaching moisture-content equilibrium. Other sources of information: [4, 7, 9, 10] [2].

4. TEARING RESISTANCE

Table 4 gives the resistance to tearing in the machine direction of nine papers. In general, tearing resistance increases with increase in relative humidity. The increase with humidity in the composite values (fig. 3) is fairly uniform for the range studied. The amount of change in tearing resistance for a change of 10-percent relative humidity in midscale is of the order of 10 percent, but the papers differ greatly among themselves. [4, 9, 10].

TABLE 4.—*Tearing resistance, Elmendorf (average force in grams required to sustain the tearing of one sheet along the direction indicated)*

Relative humidity	Resistance to tearing [1] in the machine direction of paper number (table 1)—								
	1	2	3	4	5	6	7	10	11
Percent	*g*	*g*	*g*	*g*	*g*	*g*	*g*	*g*	*g*
15	18.4	24.4	25.0	80.0	47.6	84.0	54.4	53.6	96.8
25	21.6	28.8	29.0	82.4	49.6	81.6	58.4	53.6	101.6
35	23.4	31.4	31.0	91.2	52.4	88.8	69.6	60.0	114.4
45	24.0	33.2	31.8	90.4	53.6	96.0	80.0	58.4	120.0
55	24.8	34.0	33.6	89.6	55.2	100.0	81.6	63.2	126.4
65	26.4	37.6	34.4	92.0	58.4	104.8	96.8	88.0	147.2
75	29.2	37.6	38.4	107.2	64.4	124.0	109.6	93.6	162.4
83	29.6	37.8	37.6	125.6	69.2	131.2	116.0	82.4	177.6

[1] *Resistance to tearing in the cross direction was not measured.*

Further data of this character are contained in a report by the Institute of Paper Chemistry [4] on several varieties of paper in the range 40- to 75-percent relative humidity. Also, Kress and Silverstein [7] of the Forest Products Laboratory have reported on kraft, sulfite, and sulfite-groundwood papers between 41- and 82-percent relative humidity. Wells [10], of the same laboratory, has reported on container boards between 48- and 97-percent relative humidity.

[2] The scope of the studies has been indicated in the references to the same sources in sections 1 and 2 above.

5. FOLDING ENDURANCE

Values of the folding endurance of eight papers at relative humidities from 15 to 75 percent are given in table 5. The folding endurance is the most unpredictable of the familiar physical properties of paper. In general, it increases with increase in humidity. Papers are extremely individual in their behavior in this test, however. The composite curve (fig. 4) indicates that the rate of change in folding

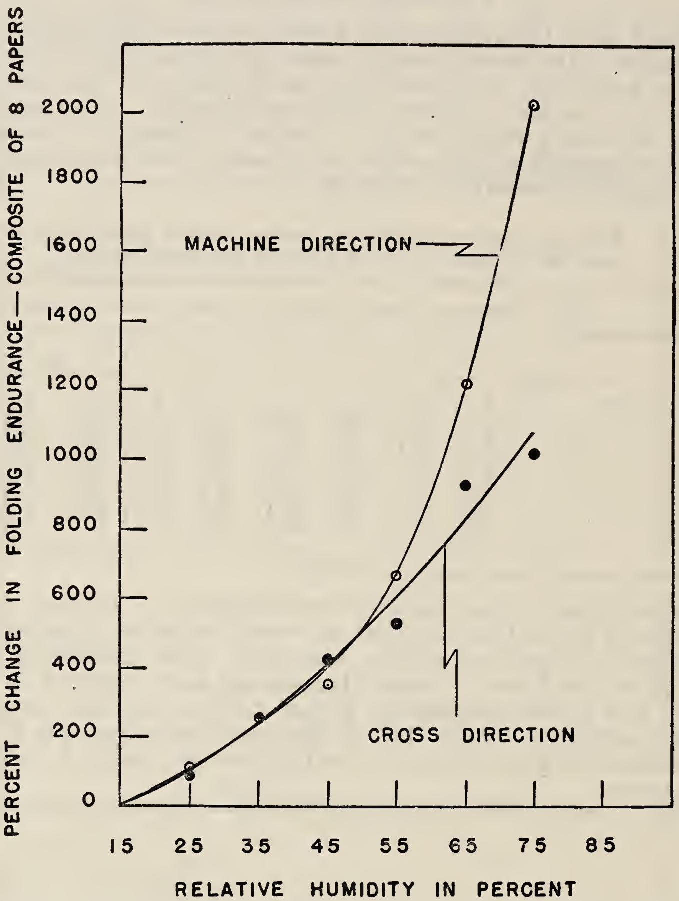

FIGURE 4.—*Increase in folding endurance with humidity, expressed as percentage increase over the folding endurance at 15-percent relative humidity.*

endurance increases with increasing humidity. The rate of change in figure 4 seems very large, since the change is expressed in percentage of the comparatively small folding endurance at 15-percent relative humidity, in order to have this figure correspond in form with the others. A value for the rate of change in folding endurance in the neighborhood of the standard humidity, to be comparable with that given for other properties, should however be referred to a midscale value of folding endurance. For example, the rate of change between 45- and 55-percent relative humidity, expressed in percentage of the folding endurance at 45-percent relative humidity, is of the order of 20 percent (see table 5). Additional sources of information on this are [7, 9, 10].

TABLE 5.—*Folding endurance, Schopper (number of double folds required to reduce the breaking strength of the specimen, 15 mm wide, to 1 kg)*

Relative humidity	Folding endurance (double folds), machine direction, of paper number (table 1)—							
	4	5	6	7	8	9	10	11
Percent								
15	59	10	209	13	3	253	4	260
25	84	29	465	33	10	612	20	498
35	115	36	627	184	43	870	58	914
45	219	58	1, 180	61	93	1, 070	132	2, 126
55	276	69	1, 497	67	484	1, 262	152	2, 486
65	468	93	2, 298	104	1, 037	1, 139	582	5, 007
75	697	121	2, 500	109	1, 649	1, 257	933	10, 000+
	Folding endurance (double folds) in cross direction							
15	42	23	262	29	44	51	9	163
25	66	35	456	41	164	111	25	280
35	160	82	715	92	286	235	140	504
45	171	97	1, 118	85	477	253	227	835
55	229	80	1, 141	79	648	247	358	1, 156
65	366	120	1, 727	107	1, 183	270	1, 252	1, 427
75	444	124	1, 710	130	1, 269	327	1, 378	1, 596

6. TENSILE STRENGTH

The tensile strength of paper is commonly expressed as breaking force per unit width, frequently called tensile breaking strength, or simply breaking strength, although the strength is sometimes expressed as breaking length, which is equivalent to the ratio of breaking strength to the weight per unit area. In table 6 are shown the values

TABLE 6.—*Tensile breaking strength (load in pounds required to beak a strip 1 inch wide)*

Relative humidity	Tensile breaking strength, in machine direction, of paper number (table 1)—										
	1	2	3	4	5	6	7	8	9	10	11
Percent	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*	*lb/in.*
15	[a]17. 6	17. 0	19. 2	40. 7	29. 9	40. 7	34. 0	64. 8	78. 2	37. 5	72. 2
25	17. 9	17. 6	19. 9	41. 1	31. 0	40. 9	36. 2	70. 0	84. 0	37. 5	75. 5
35	18. 1	18. 1	19. 9	42. 5	32. 8	41. 1	37. 1	71. 1	85. 6	36. 9	78. 8
45	18. 3	17. 9	20. 3	41. 3	31. 5	40. 7	37. 1	70. 0	86. 0	37. 1	78. 0
55	17. 6	16. 8	19. 2	40. 2	29. 7	40. 5	34. 0	64. 4	77. 3	36. 7	72. 0
65	17. 0	16. 1	18. 8	37. 8	27. 9	39. 6	31. 5	64. 4	70. 8	34. 2	68. 4
75	16. 3	15. 2	17. 9	30. 4	24. 6	29. 7	29. 5	51. 0	61. 7	32. 2	62. 6
83	15. 0	12. 5	16. 8	27. 2	23. 0	28. 6	25. 5	49. 6	56. 3	29. 7	61. 9
	Tensile breaking strength in cross direction										
15	13. 0	11. 8	13. 2	27. 9	20. 8	23. 7	22. 3	50. 5	52. 1	18. 3	19. 9
25	13. 0	12. 1	13. 9	28. 2	21. 0	23. 9	23. 0	52. 1	54. 8	18. 8	21. 2
35	13. 2	12. 1	14. 3	28. 4	21. 0	23. 9	23. 2	52. 5	56. 8	18. 6	21. 9
45	13. 0	12. 3	14. 1	28. 4	21. 2	23. 5	22. 8	52. 3	56. 1	19. 0	21. 4
55	12. 3	11. 2	12. 7	27. 7	19. 4	23. 0	21. 7	49. 8	52. 3	17. 9	20. 1
65	9. 8	6. 0	12. 3	24. 6	17. 9	22. 6	19. 2	45. 4	46. 5	17. 7	17. 7
75	8. 9	5. 1	10. 1	13. 9	13. 6	20. 6	16. 5	39. 8	40. 5	16. 3	16. 8
83	8. 3	4. 2	9. 8	14. 1	12. 1	19. 2	15. 4	38. 2	39. 3	16. 1	15. 9

[a] lb/in.×0.18=kg/cm, and lb/in.×0.27=kg/15 mm.

of the breaking strength of 11 papers. In figure 5 the percentage change in breaking strength from that at 15-percent relative humidity is plotted against relative humidity for the composite sample. The change with relative humidity is similar in character to that of bursting strength, except that it is somewhat greater, of the order of 5 percent for a change of 10-percent relative humidity in midscale. Additional

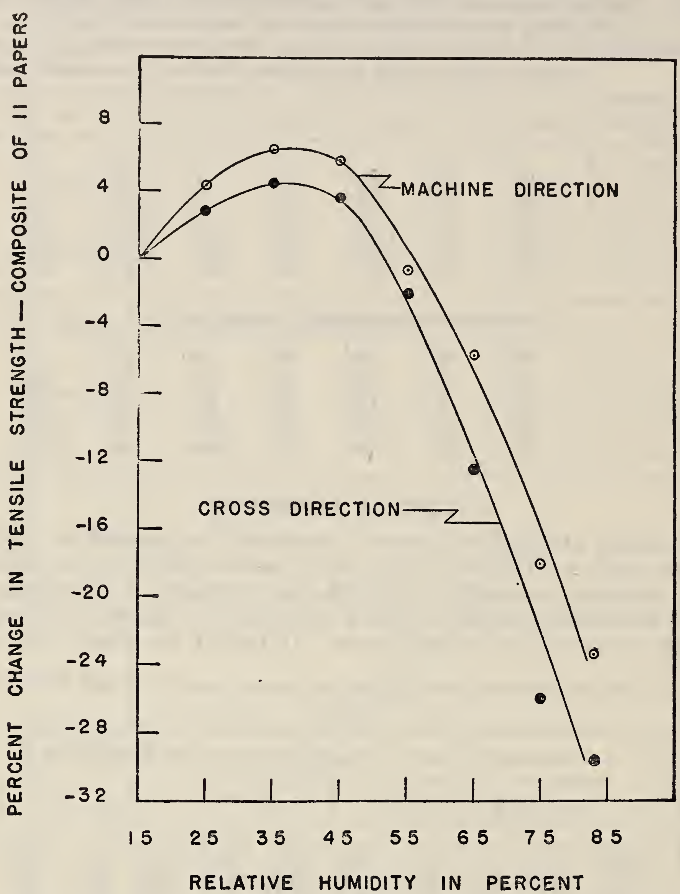

FIGURE 5.—*Change in tensile strength with humidity, expressed as percentage change from the tensile strength at 15-percent relative humidity.*

data have been reported on the breaking length of container boards [10] and on the breaking strength of various papers [4, 7, 9] at several humidities.

7. STRETCH

The percentage increase in length at failure in the tensile test, commonly called stretch, is given in table 7 for 11 papers. The increase in stretch over that at 15-percent relative humidity is plotted in figure 6 for the composite sample. The data indicate a fairly uniform increase in stretch with increasing humidity. At high humidities,

TABLE 7.—*Stretch (percentage increase in length at failure in the tensile test)*

Relative humidity	Stretch in machine direction of paper number (table 1)—										
	1	2	3	4	5	6	7	8	9	10	11
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
15	0.4	0.5	0.6	1.5	1.3	1.5	1.0	1.3	0.7	0.5	1.0
25	.5	.5	.7	1.7	1.5	1.9	1.6	1.5	.8	.6	1.2
35	.6	.7	.8	2.6	2.0	2.9	2.3	2.1	.9	.6	1.6
45	.8	.7	.8	2.6	2.0	3.1	2.6	2.5	.9	.6	1.6
55	.9	.9	.9	2.8	2.2	3.4	2.6	2.9	1.1	.8	1.7
65	1.0	1.0	1.0	3.5	2.2	4.7	3.0	3.2	1.3	.9	1.7
75	1.4	1.2	1.5	4.5	3.4	4.9	4.0	4.0	2.0	1.2	3.0
83	1.9	2.0	1.8	5.7	4.9	6.5	4.9	5.5	3.0	2.0	4.0
	Stretch in cross direction										
15	0.7	0.7	0.8	2.8	2.8	3.4	2.8	2.5	2.0	1.5	4.0
25	.9	.9	.9	3.4	3.4	4.0	3.4	3.1	2.4	1.7	5.2
35	1.5	1.5	1.0	3.8	3.7	5.0	4.2	3.9	2.9	2.0	6.5
45	1.3	1.4	1.1	4.6	4.6	5.0	4.2	4.5	3.3	2.2	7.1
55	1.7	1.7	1.4	5.1	4.9	6.5	4.7	4.9	4.0	2.3	8.3
65	1.8	2.0	1.8	6.0	5.2	7.8	5.0	5.5	4.4	2.4	9.7
75	2.4	2.7	2.3	7.3	6.0	9.4	6.0	6.9	4.8	3.5	13.0
83	3.8	3.5	4.5	8.6	8.0	10.5	9.0	9.0	6.5	4.4	14.5

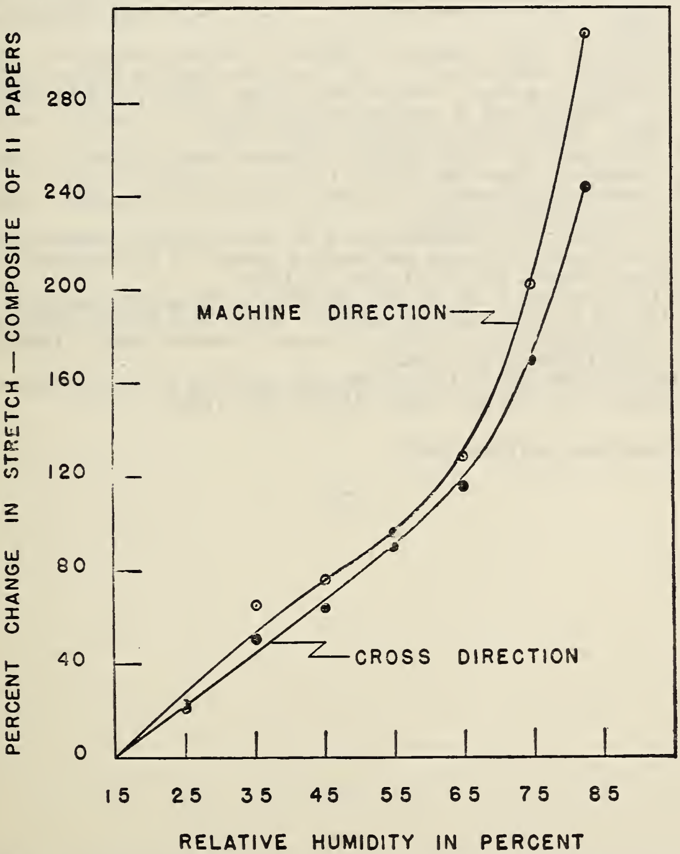

FIGURE 6.—*Increase in stretch with humidity, expressed as percentage increase of stretch over that at 15-percent relative humidity.*

however, the rate of increase becomes greater. The form of the typical curve is similar to that for moisture content. Other sources of information are [4, 7, 10].

8. OTHER PROPERTIES

The changes in length and width of paper, although numerically small, are very important in some uses of paper. Weber and Snyder [9] of this Bureau have shown that the percentage of expansion is proportional to the change in moisture content.

The effect of humidity on gloss has been reported by the Institute of Paper Chemistry [4]. A decrease in gloss with increasing humidity was found.

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