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REACTIONS OF LITHOGRAPHIC PAPERS TO VARIATIONS IN HUMIDITY AND TEMPERATURE

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ABSTRACT

In studies previously reported, information was obtained relative to causes of serious economic waste in offset lithography resulting from misregister in color printing. At the request of the Lithographic Technical Foundation, which is cooperating with the Bureau of Standards, further studies were made to obtain scientific data on the reactions of lithographic papers to variations in atmospheric humidity and temperature. Paper is a hygroscopic substance. Its moisture content is determined by the hygroscopic condition of the surrounding air, and its properties, particularly dimensional, are governed to considerable extent by moisture content. Since precise register requires constant dimensions, the influence of atmospheric changes was closely studied.

The dimensions of the papers varied directly with the miosture content regardless of the cause of the moisture changes. Moisture content was influenced by relative humidity, temperature, and history of conditioning Humidity changes were most important. A 10-point change affected the moisture content sufficiently to alter the dimensions enough to cause serious misregister. Temperature effects were less important, but of sufficient magnitude to call for close control in printing. History of conditioning had an important influence on equilibrium moisture content, hence on dimensions.

The paper that gave best register in printing had the lowest coefficient of expansion in the machine direction, and the paper that gave the largest misregister had the highest. The papers with low expansion in the machine direction have correspondingly high expansion in the cross direction, which indicates the desirability of large directional difference in fiber formation of offset papers. The low coefficient of expansion in machine direction for the papers giving best register, indicated that distortion in printing which affects register is caused largely by moisture content variations.

The usual sizing materials had little influence on the moisture content response of paper to changing relative humidity except with respect to the rate of change. Both surface sizing and mineral coatings increased the total dimensional changes per unit of moisture content change. The effects of ordinary atmospheric changes on strength properties were not of sufficient magnitude to be of significance in lithography.

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I. INTRODUCTION

Results obtained in studies of register in offset printing made at the Bureau of Standards in cooperation with the Lithographic Technical Foundation, and reported in a previous article,[1] made apparent the need of more exact data relative to the behavior of paper with changing atmospheric conditions. The avidity of paper for moisture, and the fact that its properties and dimensions vary with its hygroscopic state, have long been known, and numerous articles [2] containing information on the subject may be found in the literature. However, practically no information was available on the exact physical behavior of large sheets of paper when exposed to atmosphere at variance with the hygroscopic state of the paper; the influence of initial moisture content on conditioning; the exact relation of moisture content to dimensions; the separate effects of temperature and relative humidity; or the importance of small atmospheric changes. In order to obtain such information, specially prepared papers of known history, and known response to the offset-printing process, were studied at various humidites and temperatures. Success in offset printing cannot be attained if paper changes in dimensions to any appreciable extent during the interval between printing the first and last colors. Since the moisture content of paper is determined by the surrounding air and all changes are accompanied by dimensional changes, particular attention was given to the influence of humidity and temperature on the moisture content, and to the resulting dimensional changes. In considering the test results, it should be remembered that both the rate and the extent of reactions of paper caused by changes in atmospheric moisture and temperature, are influenced by components of paper and its physical characteristics. Comparatively soft porous papers, such as the lithographic papers, would absorb moisture more rapidly and with less change in their dimensions than harder and denser paper, such as bond.

II. DESCRIPTION OF PAPERS AND METHODS OF STUDY

The papers studied were those used in the register experiments reported in Bureau of Standards Research Paper No. 480, and have the same identification numbers. In addition, two rosin-wax sized papers, made in the Bureau's experimental mill, were included. Test data for the papers studied and a description of the papers are contained in table 1.

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[1] Weber, and Cobb, B.S. Jour. Research, vol. 9, p. 427 to 440, September 1932.

[2] Griffin, Paper Trade Jour. 85, TS 43, 1927. Houston, Carson, and Kirkwood; Paper Trade Jour. 76, no. 15, p. 237, April 12, 1923. Jarrell, Paper Trade Jour. 85, TS 23, 1927. Kiely, Paper Trade Jour., 80, no. 6, p. 207, Feb. 5, 1925. Kress and McNaughton, Paper, 22, no. 24, p. 11, Aug. 21, 1918. Kress and Silverstein, Paper, 19, no. 25, p. 13, Feb. 28, 1917. Reed, Handbook of air conditioning for lithographers, Lithographic Tech. Found. Carson, Paper Trade Jour. 93, no. 18, p. 71 to 74. Oct. 29, 1931. Carson and Worthington, Paper Trade Jour., 94, no. 2, p. 34 to 42, Jan. 14, 1932. McKee and Shotwell, Paper Trade Jour., 94, no. 22, p. 33 to 37, June 21, 1932. McKee and Shotwell, Paper Trade Jour., 97, no. 6, p. 33 to 42, Aug. 10, 1933.

TABLE 1.—*Test data of the papers studied*

Sample number	Weight, 25 by 40 inches, 500 sheets	Thickness	Bursting strength	Folding endurance [2]		Tensile properties [3]				Water resistance—dry-indicator method	Ash	Opacity	Description
				Machine direction	Cross direction	Breaking load		Elongation at rupture					
						Machine	Cross	Machine	Cross				
	Pounds	*Inch*	*Points* [1]	*Double folds*	*Double folds*	*Kg*	*Kg*	*Percent*	*Percent*	*Seconds*	*Percent*	*Percent*	
1	78.1	0.0049	24.3	52	15	6.9	3.3	1.5	3.2	53.7	9.9	96.2	Machine-finish litho, light beating, light jordanning.
2	74.3	.0042	21.1	18	11	5.5	3.0	1.6	3.7	31.9	11.7	96.2	Machine-finish litho, light beating, heavy jordanning.
3	73.8	.0044	21.4	25	10	5.9	3.0	1.1	2.6	44.1	9.9	95.2	Machine-finish litho, normal beating, light jordanning.
4	69.2	.0040	20.7	14	11	5.2	2.9	1.3	3.9	31.5	11.5	94.4	Machine-finish litho, normal beating, heavy jordanning.
5	79.8	.0048	33.0	62	29	8.5	4.1	1.7	3.7	48.4	9.5	95.2	Number 1 surface sized with starch.
6	82.0	.0049	25.9	12	15	7.6	3.9	1.5	3.8	63.3	12.1	96.1	Number 2 surface sized with starch.
7	77.7	.0047	27.9	46	17	8.0	3.8	1.3	3.7	43.4	9.1	94.4	Number 3 surface sized with starch.
8	76.6	.0047	25.1	14	10	7.1	3.8	1.5	4.2	55.3	10.5	95.6	Number 4 surface sized with starch.
9	70.2	.0032	21.7	55	10	5.5	2.6	2.3	3.1	19.1	35.7	95.1	Coated litho, no sizing in raw stock.
11	76.2	.0037	21.2	38	12	5.4	2.6	2.1	3.4	26.3	35.2	96.4	Coated litho, normal sizing in raw stock.
13	56.3	.0033	20.0	28	12	5.9	2.8	1.5	3.3	12.1	7.2	87.7	Extra strong machine-finish litho with no sizing.
14	54.4	.0034	19.6	24	10	5.5	2.5	1.6	3.4	19.3	8.0	88.4	Extra strong machine-finish litho with one half normal sizing.
16	56.9	.0036	27.0	160	230	7.1	4.4	2.0	5.5	35.2	--------	83.3	Bond type paper, sized with rosin-wax size.
17	55.6	.0037	27.0	140	240	7.8	4.3	1.5	5.5	27.9	--------	80.7	Bond type paper, sized with rosin-wax size.

[1] Bursting pressure in pounds per square inch through a circular orifice 1.2 inches in diameter.
[2] For test specimen 15 mm wide and 90 mm between jaws.
[3] For test specimen 15 mm wide and 100 mm between jaws.

The studies were made in a room of approximately 1,080 cu.ft. in which humidity and temperature were controlled by means of a humidifying-dehumidifying unit, capable of conditioning air at the rate of 2,500 cu.ft. per minute, thus providing a change of air every 30 sec. Great care was exercised in measuring the humidity. A continuous record was kept by means of a hygrothermograph which was checked at frequent intervals with an aspiration-type psychrometer equipped with sensitive calibrated thermometers, motor driven suction fan, reading glass, and wick feed for wet bulb.[3] The papers

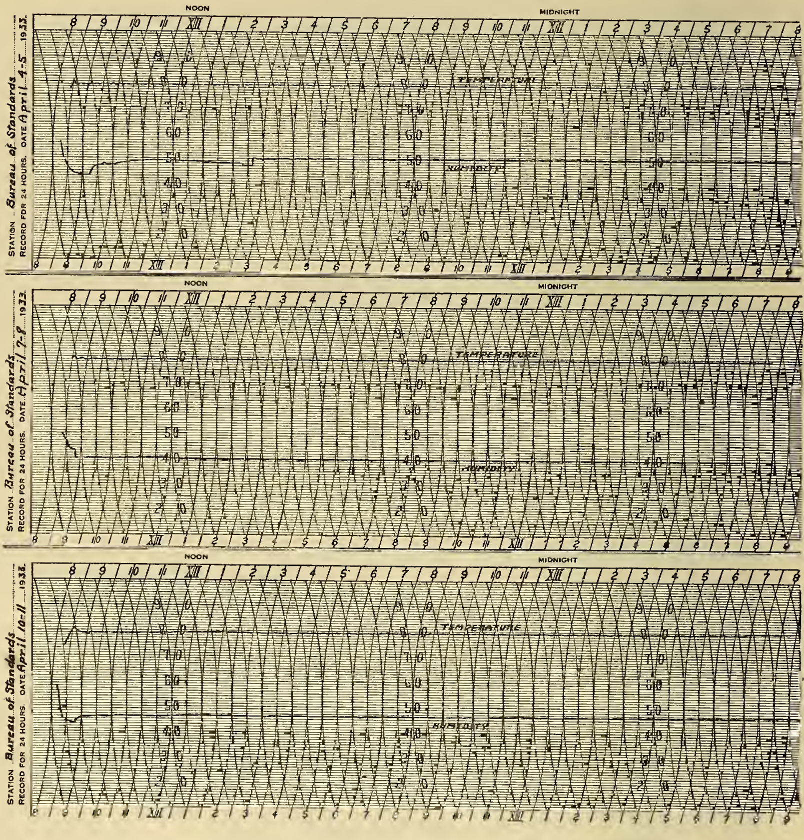

FIGURE 1.—*Three typical temperature humidity records.*

were conditioned at approximately 5 ft. above the floor and were tested on a bench about 2 ft. below the space in which they were conditioned. In conditioning the specimens, they were hung from their corners so as to expose both sides of every sheet. The humidity was controlled to within ±0.5 percent and the temperature to within ±0.5° F. The typical hygrothermograph records reproduced in figure 1 illustrate the control maintained.

The reactions of the papers were determined by conditioning test specimens until hygroscopic equilibrium was reached, and then measuring the changes in their properties. The specimens were kept in

[3] Carson and Worthington, Paper Trade Jour. 94, no. 2, p. 34 to 42, Jan. 14, 1932.

sealed containers while humidity or temperature changes were being made in the room. Dimensional measurements were made accurately to 0.002 of an inch on specimens 24 by 24 inches, by means of a micrometer rule.[4] Separate specimens, weighing approximately 15 grams each, were used for moisture determinations. Their weights were determined accurately to 0.1 mg, at each atmospheric condi-

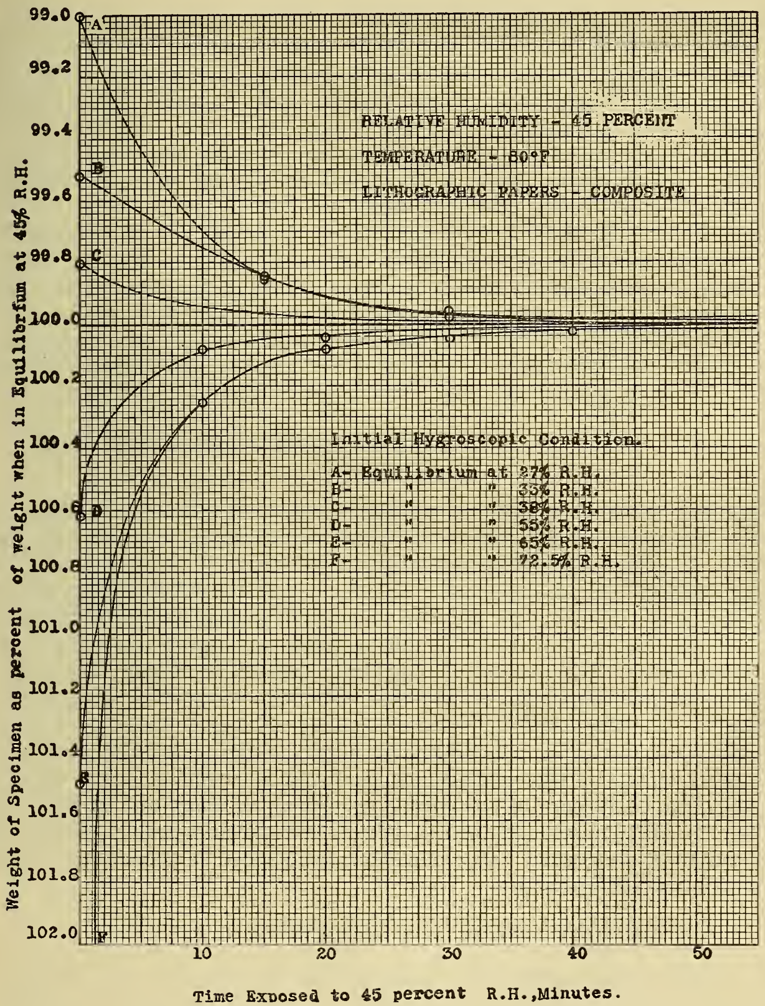

Figure 2.—*Rate of conditioning for papers with different moisture contents.*

tion, and their moisture contents were computed from the oven dry weights obtained at the conclusion of experiments. All samples were exposed 18 to 20 hours, although, in all cases, the weights of the specimens were practically constant in less than one third of that time. The precision with which the work was done is illustrated by the regularity of the curves shown later in the article. Numerous

[4] Weber and Cobb, B.S. Jour. Research, vol. 9, p. 431, September 1932.

check tests were made with respect to moisture content determinations, and in these tests the average variations from the original values was less than 0.1 percent.

III. RESULTS OF STUDIES OF THE PAPER REACTIONS

1. RATE OF CONDITIONING

The papers studied reached constant weight in an atmosphere of 45 percent relative humidity and 80 F quite rapidly. Samples having moisture contents corresponding to relative humidities of 28, 33, 38, 55, 65, and 72.5 percent, respectively, were exposed in an atmosphere of 45 percent relative humidity and 80 F, and weighed at 10-minute intervals until practically constant weight was reached. In all cases, 75 percent or more of the total change in moisture content took place within 10 minutes, and nearly constant weight was reached within 1 hour. It must be remembered, of course, that the rate of conditioning will vary greatly with different types of papers, therefore, these results should not be considered as indicative of the rate of conditioning of papers in general. Rate of air flow around the samples will also be a factor influencing conditioning time. The time required to condition papers with different initial moisture contents to equilibrium at 45 percent relative humidity is illustrated in figure 2.

2. INFLUENCE OF RELATIVE HUMIDITY ON STRENGTH PROPERTIES

Inasmuch as the strength of paper varies with changes in moisture content, the papers were tested for bursting strength, tensile breaking strength, tearing strength, and folding endurance at 7 humidities, ranging from 27 to 72.5 percent. In the region of 45 percent relative humidity, a change of ± 10 percent relative humidity resulted in variations in the values obtained for the various properties approximately as follows: Bursting strength, 1 percent; tensile breaking strength, 5 percent; tearing strength, 10 percent; folding endurance, 10 percent. In general, folding endurance and tearing strength varied directly, while bursting strength and tensile strength varied inversely, with the relative humidity. The changes in strength were of such low magnitude that the influence of humidity on strength does not appear significant for lithographic plants in which the atmosphere is controlled within reasonable limits. The strength properties at different humidities are shown in figure 3.

3. TEMPERATURE AND MOISTURE CONTENT

With the relative humidity constant at 45 percent, variations in temperature within the range 69 to 110 F were found to have a well-defined and regular influence on moisture content. Over the range studied, the average moisture content varied inversely with the temperature. The percentage of moisture content varied at the rate of 0.15 per 10 F change in temperature. A temperature effect of such magnitude makes temperature control to within ± 5 F appear essential in plants having conditioned air, if the full benefits of humidity control are to be obtained. It also indicates the importance of close control of temperature in the physical testing of paper. The relation of temperature to moisture content is illustrated in figure 4.

4. RELATIVE HUMIDITY AND MOISTURE CONTENT

Paper reacts to a change in the relative humidity of the surrounding air by a readjustment of moisture content, and changes in its properties result. Although many investigators have studied the effects of

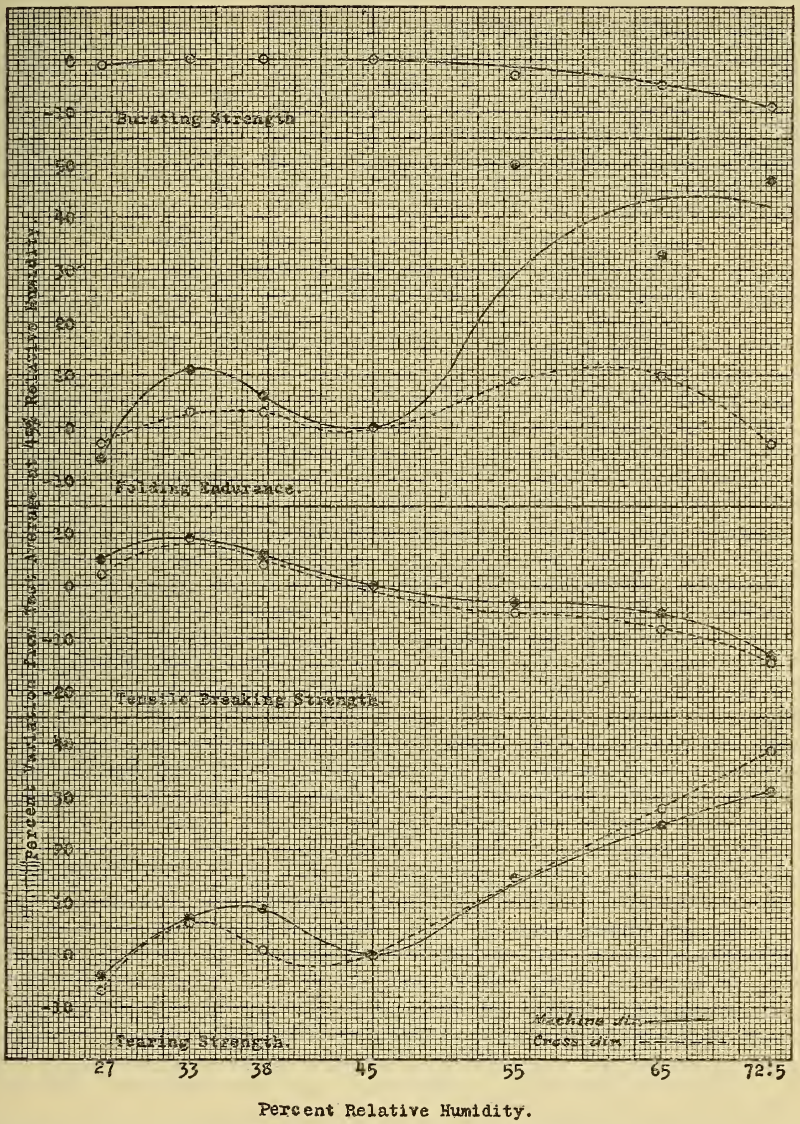

FIGURE 3.—*The influence of variations in relative humidity on strength properties of lithographic papers with constant temperature, 80 F Composite —13 lithographic papers.*

humidity on the moisture content of paper and other fibrous materials, no complete data were available to indicate exactly how the history of the hygroscopic state of paper determines its equilibrium condition for the range of conditions commonly encountered. Hence the hysteresis effects of adsorption and desorption of moisture on equilibrium moisture content were studied. The range studied was 34 to 71 percent relative humidity at 80° F. temperature. Specimens dried in the oven and others saturated over water were taken through regular cycles of relative humidity. The possibility that drying in the oven would change the hygroscopic properties was considered and the effects studied. Specimens dried in the oven were conditioned with undried specimens of the same paper at widely separated humidities and they were found to reach the same equilibrium moisture content. Hence drying in the oven apparently had no permanent effect on the hygroscopic properties.

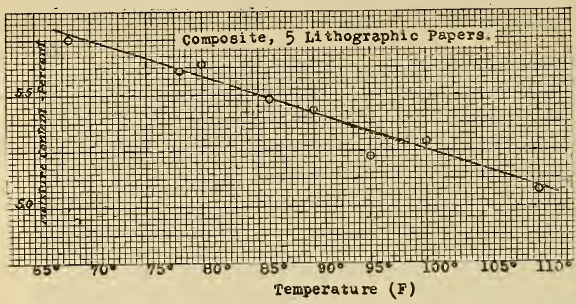

Figure 4.—*Relation of temperature to moisture content of paper with constant relative humidity 45 percent.*

To find maximum hysteresis effects, and the hysteresis effects for a definite humidity range within the limits commonly encountered, two complete cycles were studied. Saturated specimens were conditioned at various humidities in order of decreasing values down to 34 percent, then in order of increasing values back to 71 percent. Specimens dried in the oven were conditioned at humidities in order of increasing values up to 71 percent, then in order of decreasing values back to 34 percent relative humidity. In figure 5 the resulting changes in moisture content equilibrium are shown graphically. The curve showing moisture loss for the saturated specimens and that showing moisture gain for the oven-dry samples apparently represent,

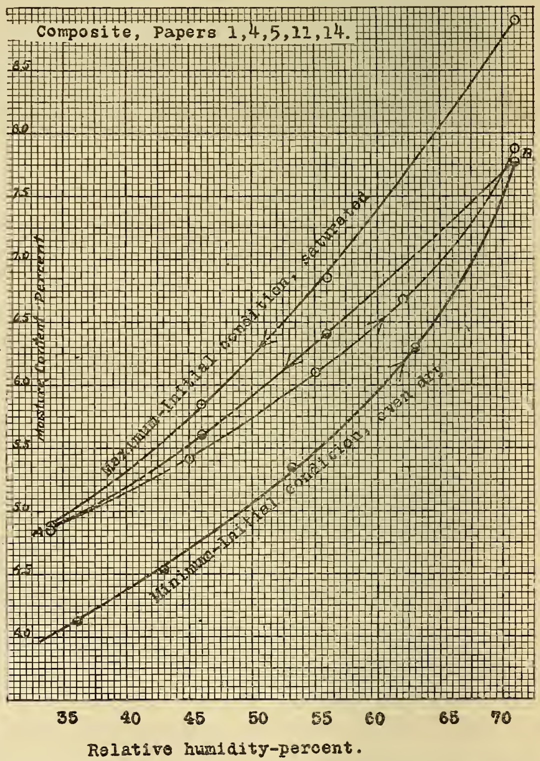

Figure 5.—*Equilibrium moisture content of papers at different relative humidities.*

respectively, maximum and minimum moisture content values for these papers within the ordinary humidity range. Therefore the distance between the maximum and minimum curves at any point indicates the maximum hysteresis effect at that humidity.

It will be noted that the specimens with maximum and minimum moisture equilibriums at 71 percent humidity reached the same equilibrium moisture content after conditioning downward to 34 percent to *A*. Likewise, the specimens with maximum and minimum at the low humidity, 34 percent, reached identical equilibrium states after conditioning upward through a humidity range of 36 percent to *B*. From a consideration of this behavior, it appears that the region inclosed between the curves joining *A* and *B* represents the maximum hysteresis range for papers conditioned within the range of 34 to 71

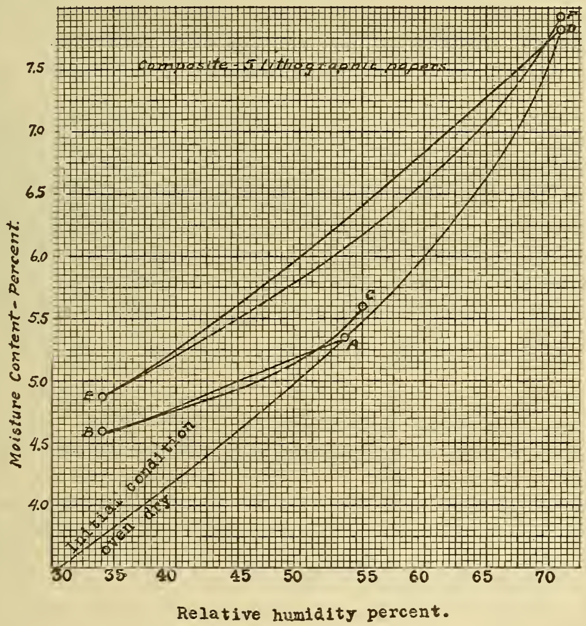

FIGURE 6.—*Influence of magnitude of humidity changes on slope of moisture-content, relative-humidity curves, and hysteresis effects.*

percent relative humidity, provided they are preconditioned at 34 percent for adsorption or at 71 percent for desorption. The small hysteresis range for these particular conditions in contrast with the large hysteresis range for the extreme conditions of preconditioning, emphasize the desirability of a definite conditioning procedure rather than neglecting the effect of previous history. This point will be found of greatest importance in lithography in cases where papers are conditioned between printings to restore the hygroscopic condition to that at the first printing, or in precise testing where paper is conditioned for the purpose of obtaining a standard hygroscopic condition. Separating *A* and *B* on the humidity scale should increase the hysteresis range. Bringing them closer together should decrease it. The range of 34 to 71 percent relative humidity, which represents the extremes conveniently obtained with good control apparatus, covers ordinary practice without excessive hysteresis.

The effects of small humidity changes on moisture content, and the influence of the magnitude of the total equilibrium change on hysteresis, were studied. Oven-dry specimens were conditioned first at 40 percent R.H. and then at 48, 40, 45, 40, 42.5, 40, 37, 40, 35, and 40 percent, in that order, and the moisture content determined for each condition. The slope of the curve for relative humidity and moisture content was found to depend on the magnitude of the total humidity change. Increasing the total change increased the moisture content change per unit of humidity change until the limit as represented by the maximum and minimum moisture content curves was reached. Also, the magnitude of the hysteresis effect depended upon the total humidity change involved; it increased with increase in the total humidity change until the maximum hysteresis, shown as the distance between the maximum and minimum moisture content curves in figure 5, was reached. The influence of the magnitude of the total humidity change on the slope of the moisture-content relative-humidity curve, also its effect on hysteresis, is illustrated in figure 6.

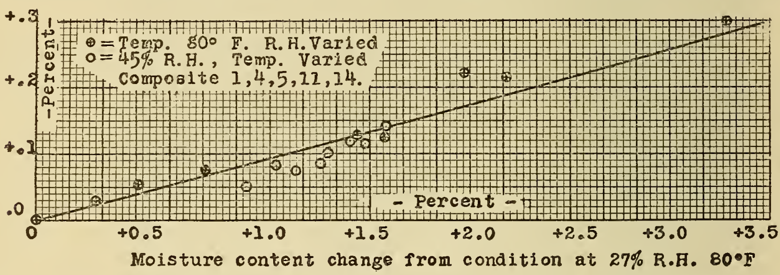

FIGURE 7.—*Influence of moisture content on dimensions of lithographic papers, variations in both temperature and humidity.*

The percentage values at the left are dimensional changes as variation from dimensions at 27 percent R.H. and 80° F. temperature,

This chart shows graphically the results of conditioning specimens to 34 percent humidity from two different points on the minimum curve, then conditioning back to approximately the initial humidity. The differences between the slopes of the curves in the cycle *A-B-C*, where the humidity range was only 20 percent, and those in cycle *D-E-F*, with a total humidity range of 37 percent, may be seen by comparing curve *A-B* with *D-E*, and *B-C* with *E-F*.

5. INFLUENCE OF MOISTURE CONTENT ON DIMENSIONS

The dimensions of paper are influenced by its hygroscopic moisture through a swelling of the individual fibers. The data obtained in this study indicate that, within the range of atmospheric conditions ordinarily encountered, the dimensions vary directly with the moisture content irrespective of the cause of the moisture change. Figure 7 illustrates the influence of the hygroscopic state on the dimensions of lithographic papers. The values used are averages for papers 1, 4, 5, 11, and 14 which represent the different types of lithographic papers studied. It will be noted that the data obtained for different humidities with constant temperature, and for different temperatures with constant humidity, result in a single regular curve.

Of papers 1, 2, 3, and 4, which differed only with respect to degree of mechanical treatment of fibers in manufacture, no. 1, which was prepared with the minimum of beating[5] and jordanning,[6] changed least in the machine direction of the paper (the direction parallel to the forward movement of the paper machine), or, as it is often termed, "with the grain", with variations in moisture content. In figure 8 the dimensional changes of paper no. 1 are shown in comparison with the average for the group comprising papers, 1, 2, 3, and 4. These results corroborate the evidence obtained in the printing tests[7] that paper prepared with the minimum of beating and jordanning is best suited to multi-color offset printing because it changes

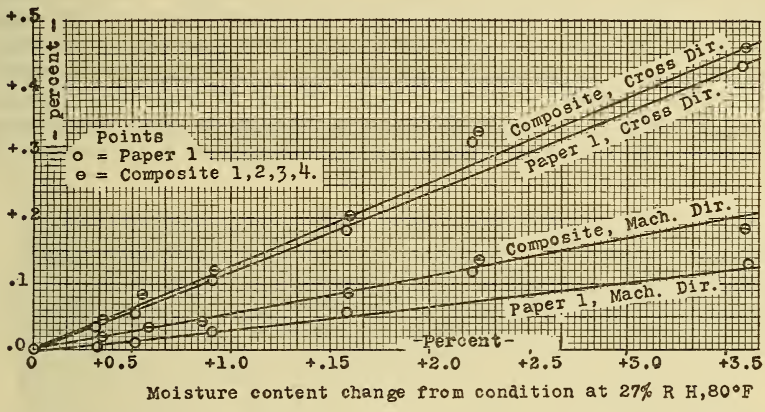

Figure 8.—*Influence of moisture-content variations on dimensions of lithographic papers. Comparison of paper no. 1 with the average of no. 1, no. 2, no. 3, no. 4.*

Values at the left are dimension changes as variation from dimensions at 27 percent R.H. and 80 F. temperature.

least along the "back edge", as the printer terms it (a machine direction change), in successive printings. Since the paper having the lowest rate of dimensional change in the machine direction with moisture content changes, gave best register, and the paper with the highest rate of change gave the poorest register of prints,[8] it is apparent that the paper distortions which most seriously affect register of prints, result from moisture content changes, rather than from mechanical stresses of the press.

It is particularly significant to note in connection with the moisture-content dimensional relationship illustrated in figure 5, that the large directional difference with respect to expansion in the case of paper 1 is indicated by the physical strength values shown in table 1. In folding endurance, the ratio of the machine direction strength to the cross direction strength, is about 3.5 to 1 for paper 1 as compared to 2 to 1 for the average of papers 1, 2, 3, and 4. This is to be expected since large directional difference in strength indicates that a relatively large percentage of the fibers are parallel to the machine direction. Since the dimensional change of an individual fiber with adsorption

[5] Beating is the term applied to the mechanical treatment given to papermaking materials, suspended in water, to prepare them for forming a sheet on the paper machine. Beating separates, brushes, and frays-out the fibers, and causes them to absorb water.

[6] Jordanning is a refining process that usually follows beating to complete the preparation of the materials for forming a paper of the desired character. In the jordan the fibers are freed from lumps and cut to the desired length.

[7] Weber and Cobb, B.S. Jour. Research, vol. 9, pp. 437 to 438, September 1932.

[8] Register Studies in Offset Lithography, B.S. Jour. Research, vol. 9, pp. 437 to 439, September 1932.

or desorption of moisture is largely a diameter change, the paper having the greatest number of fibers parallel to the machine direction will have the lowest dimensional change in that direction, and a correspondingly large change in the cross direction, as this direction is parallel to the diameter of the largest number of fibers. Hence it appears that large directional difference in strength properties of paper is an indication of good sheet formation for offset printing.

Of the different types of paper studied, the coated paper had the largest dimensional change per unit of moisture content variation, and the machine finished offset papers had the lowest. Surface sizing with starch increased the dimensional changes slightly. The wax-sized papers 16 and 17, behaved about the same as the average machine-finished, beater-sized papers, which may indicate that some benefit was imparted by the wax, since 16 and 17 were much harder papers and therefore would be expected to change their dimensions somewhat more than the offset papers. Figure 9 shows compara-

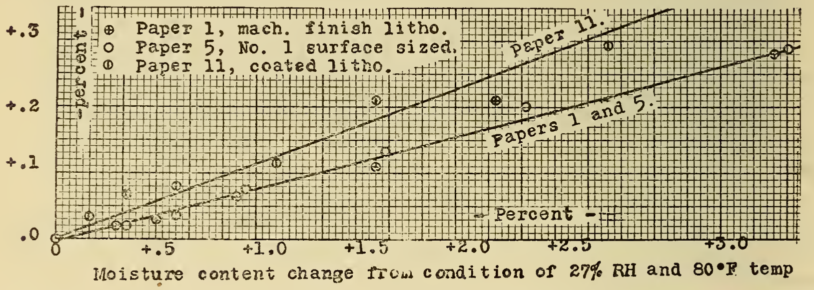

Figure 9.—*Influence of moisture content on dimensions of lithographic papers Comparison of machine finished, surface sized, and coated papers.*

Values at the left are dimension changes as variation from dimensions at 27 percent R.H. and 80 F. temperature.

tively the relation of the moisture content to dimensions of machine finished lithographic paper 1, paper 5, which is paper 1 surface sized with starch, and paper 11, a coated paper.

IV. RECOMMENDATIONS

From a consideration of the influence of humidity and temperature on the moisture content of the papers, it is obvious that precise register in lithography requires atmospheric control within narrow limits. The relative humidity should be controlled to ±2.5 percent and temperature to ±5° F. Air-conditioning apparatus for lithographic plants should be designed to control within those limits.

The hysteresis effects of adsorption and desorption of moisture were found to be important. In precise testing, where paper is conditioned to obtain a standard hygroscopic condition for a given relative humidity, or in printing where the paper is reconditioned between printings to restore the hygroscopic condition to that at first printing, a definite conditioning procedure should be established and followed.

Sheet formation of paper was found extremely important with respect to machine direction distortion with hygroscopic changes. Paper for multicolor offset printing should be made with an absolute minimum of beating and jordanning of fibers, and should be so formed as to obtain the greatest possible directional difference by having the length of the greatest possible number of fibers parallel to the machine direction.

Surface sizing and surface coating of paper increased somewhat the distortion with hygroscopic changes. Hence, for most precise register of prints, machine-finish papers are recommended.

Tests of lithographic papers should include the folding endurance test as the directional difference is reflected sharply in the folding endurance.

Additional definite recommendations must await further printing plant studies. Determination of the influence on register in printing exerted by the conditioning factors already found important, development of information on commercial scale paper conditioning, and further fundamental study of the relation of fiber properties to distortion of paper in printing are planned for future study. The development of specifications that will adequately define the properties required for optimum printing results is the ultimate goal in this work.

Acknowledgment is made of the invaluable assistance of the advisory committee of the Lithographic Technical Foundation under the chairmanship of Prof. R. F. Reed, also of the advice and assistance of B. W. Scribner, chief of the paper section of the Bureau of Standards, and F. T. Carson, and R. W. Carr of the paper section.

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