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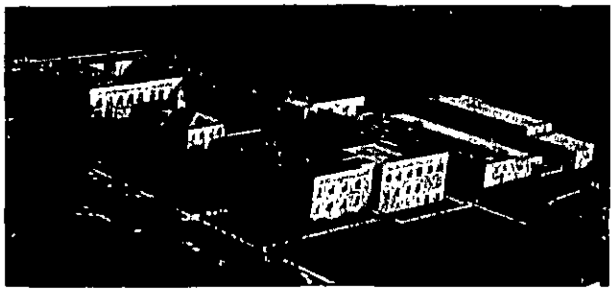

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

FACTORS AFFECTING DIAPHRAGM PRESSURE MEASUREMENTS. PART II. EFFECT OF DISTENTION ERROR, TEST APPARATUS AND OVERDISTENTION

Project 1108-26

Report Ten

A Preliminary Report

to

TECHNICAL COMMITTEE
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

April 15, 1963

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SUMMARY

A recent comparison of Institute and mill diaphragm pressure measurements indicated that substantial differences in diaphragm pressure may be obtained. For the ten participants, the differences ranged from +1.2 p.s.i. to -10.0 p.s.i. at the 0.375-inch distention level. These differences indicate that a standardized procedure for evaluating diaphragm pressure is essential to diaphragm standardization.

As a result, recent work has been directed toward determining possible causes for the larger differences noted above. This work was initiated in Report Nine when such variables as tester, platen cleanliness, air in manifold, etc., were studied. These variables did not appear to explain the larger between-laboratory differences. Therefore, this report discusses such additional variables as (1) distention height error, (2) distention transducer interchangeability, and (3) overdistention. In general, the results indicated that at 0.375 inch:

1. If between-laboratory diaphragm pressure differences are to be held to such tolerances as ± 0.5 or ± 1 p.s.i., then it appears that errors in distention height must be held to close tolerances also—perhaps ± 0.005 or ± 0.01 inch.
2. Based on intercomparisons of pressure measurements involving the Institute's two testers and their associated distention transducers it appears probable that only minor pressure differences may be associated with either the testers or transducers.

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3. Only one or two distentions beyond 0.710 inch are sufficient to markedly lower diaphragm pressures at either 0.375 or 0.710 inch distension for a new diaphragm. The changes in diaphragm pressure may be as great as 8 p.s.i. at 0.375 inch and 25 p.s.i. at 0.710 inch.

4. The relatively large differences encountered suggest that overdistension might be one cause for the large between-laboratory pressure differences.

5. Procedures for evaluating diaphragm pressure characteristics should either (a) incorporate a specified number of overdistentions to a given level in the prestressing procedure, or (b) specify that no overdistentions shall be permitted. These requirements would be applied when evaluating diaphragm pressure levels for standardization relative to molding, etc. On the other hand, when evaluating diaphragm pressure before or after bursting strength tests the user may prefer to follow other procedures.

INTRODUCTION

As one phase of the current investigation of factors affecting bursting strength results, the Institute and B. F. Perkins and Son Inc. initiated a study designed to determine the variability in commercially manufactured diaphragms. For this purpose, the Institute evaluated 65 diaphragms from a recent manufacturing order and the results were reported to the Technical Committee in Report Seven dated Sept. 1, 1962 (1). In brief summary, it was noted that the diaphragms exhibited pressures ranging from 36 to 40 p.s.i. gage at 3/8-inch distention.

After reviewing the results, the committee requested the Institute to forward a number of the diaphragms to each member for mill evaluation. Report Eight (2) to the Technical Committee summarized the replies received as of Dec. 4, 1962 and an up-to-date summary for all 10 participants is attached to this report as Appendix I. Of the ten companies, two reported diaphragm pressures in satisfactory agreement with the Institute results. The remaining mills reported pressures from 12 to 26% lower than those obtained by the Institute.

These results indicated that a procedure for evaluating diaphragm pressure which can be duplicated by everyone must be established if progress in diaphragm standardization is to be made. Therefore, work has been carried out directed toward determining possible causes for the larger differences noted above.

The initial work was directed toward determining the reproducibility of pressure measurements at the Institute as affected by tester, lower platen, and platen cleanliness. In addition, investigations were made as to (1) the effect of air in the tester manifold, and (2) a comparison of results obtained with two size gages. The results obtained were summarized in Report Nine (3).

In general, the results indicated that at 0.375-inch distention:

1. Neither tester nor lower platen appeared to markedly affect diaphragm pressures. Some differences occurred between testers but they appeared to be a function of the order of testing and may have been associated with repeated removal and insertion of the same diaphragm.
2. The differences between trials, testers, or other conditions were, in general, reasonably small (usual range 0-2 p.s.i.) and did not approach the large differences noted previously between Institute and some mills.
3. Thorough cleaning of lower platen and diaphragm in distilled water and acetone to remove possible surface contaminants did not materially improve reproducibility.
4. Neither air in the manifold nor gage capacity had a significant affect on the diaphragm pressure measurements.

Somewhat similar trends were obtained at 0.710-inch distention but the differences tended to be larger—both absolutely and on a percentage basis—indicating that more work would be required in this area.

Because the above work failed to locate possible causes for the large Institute-mill differences, additional work was initiated to:

1. Determine the effect of errors in distention height on diaphragm pressure.
2. Compare pressure measurements obtained using two distention sensing heads.
3. Compare "automatic" and "manual" methods of evaluating diaphragm pressure.

4. Evaluate the possible effects of diaphragm distention beyond 0.71 inch on diaphragm pressure measurements.

The results obtained are summarized herein.

PROCEDURES

PART I. EFFECT OF ERRORS IN DISTENTION HEIGHT ON DIAPHRAGM PRESSURE

For this phase, diaphragm pressures were determined for errors in distention height of 0.004, 0.008, and 0.012 inch at both the 0.375 inch and 0.710-inch distention heights. The changes in distention height were obtained by inserting shims of the appropriate thickness under the edge of the distention sensing probe. Five pressure measurements were made at each distention height after distending the diaphragm 10 times to 0.71 inch. Two diaphragms were employed and two trials were made with each diaphragm.

PART II. COMPARISON OF PRESSURE MEASUREMENTS OBTAINED USING TWO DISTENTION SENSING TRANSDUCERS

Each of the Institute's testers is equipped with its own automatic diaphragm pressure measuring apparatus. Since the testers are of different ages and differ somewhat in design, it was thought desirable to determine if the distention-sensing transducers could be interchanged between testers without materially affecting test results. For this purpose, trials were made using each transducer alternately on each of two testers. The same diaphragm was used for determinations on both testers. Five diaphragm pressure measurements were made at each condition and each distention level after initially distending the diaphragm ten times to 0.71 inch. The measurements were repeated using two diaphragms.

PART III. EFFECT OF DIAPHRAGM DISTENTION BEYOND 0.71 INCH ON DIAPHRAGM PRESSURE MEASUREMENTS

During the above work it was noted that accidental distention of the diaphragm beyond 0.710 inch could produce major changes in the diaphragm pressure at either 0.375 or 0.710 inch as might be expected. To study the magnitude of the effect an overdistention height of 0.832 inch was arbitrarily selected. The following schedule of diaphragm pressure measurements was then followed using a number of diaphragms.

Distention Numbers	Procedure
1 thru 15	Diaphragm pressure measured at selected distention
16	Overdistention to 0.832 inch
17 thru 20	Diaphragm pressure measurement
21	Overdistention to 0.832 inch
22 thru 25	Diaphragm pressure measurement
26	Overdistention to 0.832 inch
27 thru 30	Diaphragm pressure measurement

The above was then repeated after allowing the diaphragm to relax in the tester for (a) 1 hour, and (b) either 16 or 142 hours.

Three diaphragms were evaluated using the 0.710-inch distention height and two diaphragms were evaluated using the 0.375-inch distention height.

Because of the large changes obtained due to overdistention it was thought that certain anomalous results obtained in Report Nine might be attributed to overdistention. It was thought desirable, therefore, to repeat the reproducibility study described in Part II of the procedure in Report Nine. For this study the same procedure was employed; however, only three instead of four diaphragms were evaluated.

PART IV. COMPARISON OF "AUTOMATIC" AND "MANUAL" METHOD OF DETERMINING DIAPHRAGM PRESSURE

After distending the diaphragm ten times to 0.710 inch, five pressure measurements were obtained at the selected distention using the "automatic" apparatus. Measurements of diaphragm pressure were then made by manually shutting the machine off as the diaphragm contacted a diaphragm height gate [similar to that pictured in Fig. 6 of Reference (4)]. These trials were continued until five apparently satisfactory readings were obtained, i.e., if obvious under- or over-distention occurred the reading was discarded.

A number of trials were made using the above procedure on different diaphragms. It may be noted that some bias may be present because the determinations involving the "automatic" apparatus always preceded the "manual" measurements. This was done to avoid the possibility of "overdistentions" occurring during the course of the "manual" measurements which might seriously affect the comparisons.

In addition to the above, a limited comparison of the reproducibility of diaphragm pressure measurements as affected by test operator was also undertaken. Three experienced personnel participated in the trials using the procedures described above.

DISCUSSION OF RESULTS

As mentioned previously, the results in Report Eight or Appendix I indicate that substantial differences in measured diaphragm pressures may be obtained between laboratories. For example, in Appendix I it may be noted that the average difference between Institute and mill evaluation of diaphragm pressure at 0.375 inch ranged from +1.2 to -10.0 p.s.i. gage. Differences for individual diaphragms ranged up to 16 p.s.i. gage. The reasons for such large differences are not known. Therefore, the previous report was specifically concerned with the evaluation of factors associated with diaphragm pressure measurement which might cause such differences. The present report continues this phase of the work.

PART I. EFFECT OF ERRORS IN DISTENTION HEIGHT ON DIAPHRAGM PRESSURE

One factor which directly influences the diaphragm pressure measurement is the diaphragm distention. If the distention is below the specified level, then the measured pressure will also be low. The converse occurs if the distention is above the desired level. Since small errors may easily occur—particularly when attempting to manually halt the diaphragm at the desired level—it was thought desirable to investigate the effect of small errors in distention height on diaphragm pressure.

Diaphragm pressure measurements are shown in Table I for the following conditions:

Change in Distention Height, inch	Distention Height, inch
0	0.375
+0.004	0.379
+0.008	0.383
+0.012	0.387
0	0.710
+0.004	0.714
+0.008	0.718
+0.012	0.722

TABLE I

EFFECT OF SMALL ERRORS IN DISTENTION HEIGHT ON DIAPHRAGM PRESSURE

Distention, inches	Diaphragm Pressure at Indicated Distention, p.s.i.					
	Unlubricated Diaphragm			Lubricated Diaphragm		
	Trial I	Trial II	Av.	Trial I	Trial II	Av.
	0.375-inch Distention Level					
0.375	34.7	34.0	34.4	24.5	25.2	24.8
0.379	34.7	33.7	34.2	24.6	26.2	25.4
Diff.	0.0	-0.3	-0.2	+0.1	+1.0	+0.6
Diff. %[a]	0.0	-0.9	-0.6	+0.4	+4.0	+2.4
0.383	35.1	34.4	34.8	24.9	26.4	25.6
Diff.	+0.4	+0.4	+0.4	+0.4	+1.2	+0.8
Diff. %[a]	+1.2	+1.2	+1.2	+1.6	+4.8	+3.2
0.387	35.4	34.7	35.0	25.1	26.6	25.8
Diff.	+0.7	+0.7	+0.6	+0.6	+1.4	+1.0
Diff. %[a]	+2.0	+2.1	+1.7	+2.4	+5.6	+4.0
	0.710-inch Distention Level					
0.710	81.6	73.6	77.6	40.2	40.4	40.3
0.714	83.2	76.6	79.9	41.0	41.0	41.0
Diff.	+1.6	+3.0	+2.3	+0.8	+0.6	+0.7
Diff. %[a]	+2.0	+4.1	+3.0	+2.0	+1.5	+1.7
0.718	88.0	77.4	82.7	41.4	41.2	41.3
Diff.	+6.4	+3.8	+5.1	+1.2	+0.8	+1.0
Diff. %[a]	+7.8	+5.2	+6.6	+3.0	+2.0	+2.5
0.722	90.0	83.4	86.7	41.4	41.4	41.4
Diff.	+8.4	+9.8	+9.1	+1.2	+1.0	+1.1
Diff. %[a]	+10.3	+13.3	+11.7	+3.0	+2.5	+2.7

[a]Based on 0.375 or 0.710-inch distention.

Referring to the table it may be noted that at 0.375-inch distention relatively small errors in diaphragm pressure were associated with these small changes in distention height. The errors ranged from +0.4 to +1.2 p.s.i. at 0.008-inch distention error and from 0.7 to 1.4 p.s.i. at 0.012-inch distention error. Thus, considerably greater errors in distention height would be required to explain the large between-laboratory differences mentioned above. On the other hand, if between-laboratory differences are to be held within close tolerances such as ± 0.5 or ± 1 p.s.i., then it appears that distention errors must be held to close tolerances also—perhaps ± 0.005 or ± 0.01 inch.

At 0.710-inch distention it may be noted that the unlubricated diaphragm which gave relatively high pressures was quite sensitive to the errors in distention height. For example, an error of +0.012 inch in distention height corresponded to a 9.1 p.s.i.g. increase in diaphragm pressure. On the other hand, the lubricated diaphragm which gave pressures in the normal 40-45 p.s.i. range was much less sensitive to errors in distention height. In fact, the differences in pressure on an absolute basis were roughly about the same as those obtained at 0.375 inch. In general, it appears that errors in distention height should be held to a minimum when measuring pressures at 0.710 inch—particularly if the pressures are high.

PART II. COMPARISON OF PRESSURE MEASUREMENTS OBTAINED USING TWO DISTENTION SENSING TRANSDUCERS

Each of the Institute's testers is equipped with its own automatic diaphragm pressure-measuring apparatus. Since the testers are of different ages, they differ in design and it was thought desirable to determine if the distention-sensing transducers could be interchanged between testers without materially affecting diaphragm pressure measurements.

In this connection in Report Nine it was found that somewhat different pressure measurements were obtained when a given diaphragm was evaluated in the two testers. This was attributed to a diaphragm effect because the differences appeared to depend on which tester was used first to evaluate the diaphragm. However, these differences tended to obscure possible differences between testers. Therefore, it was believed desirable to carry out a separate study of the transducer-tester differences.

The results obtained are shown in Table II. In general, it may be noted that at 0.375-inch distention the two transducers appeared to give about equal results with the first diaphragm. However, somewhat greater differences were encountered for the second diaphragm with transducer B-105 seeming to give higher results on both testers. The latter differences were much less marked at 0.710-inch distention. Taken as a whole it appears probable that only minor diaphragm pressure differences may be associated with either the distention transducers or testers.

TABLE II

EFFECT OF DISTENTION TRANSDUCER AND TESTER ON DIAPHRAGM PRESSURE

Diaphragm No.	Distention Transducer	Diaphragm Pressure at Indicated Distention, p.s.i. — 0.710-Inch Distention Tester DE35	DE105	Diff.	0.375-Inch Distention Tester DE35	DE105	Diff.
1	A-35	94.0(1)	93.6(5)	0.4	33.0(2)	34.0(6)	1.0
	B-105	91.8(3)	93.6(7)	1.8	32.2(4)	34.8(8)	2.6
	Diff.	2.2	0.0		0.8	0.8	
2	A-35	89.0(7)	87.2(3)	1.8	32.2(8)	33.0(4)	0.8
	B-105	89.2(5)	89.8(1)	0.6	35.0(6)	35.0(2)	0.0
	Diff.	0.2	2.6		2.8	2.0	

Note: The figure in parentheses indicates the test order.

PART III. EFFECT OF DIAPHRAGM DISTENTION BEYOND 0.71 INCH ON DIAPHRAGM PRESSURE MEASUREMENTS

As mentioned previously, it was observed that the distention transducers occasionally failed to operate and the diaphragm in these instances would be distended beyond 0.710 inch. The same situation could occur in the case of manual measurements if the operator overran the 0.710-inch distention. The general effect would be expected to be the same, i.e., a marked lowering of the diaphragm pressure on subsequent determinations could occur if the diaphragm were relatively new.

Before installation of the "automatic" devices for halting the tester pump at either 0.375 or 0.710-inch distention, the Institute's testers were equipped with high level stops so as to halt the tester at 0.710-inch distention. These stops are shown in Fig. 5 and 7 of Reference (4). When the new devices were installed, the high level pumping stops interfered with determinations at 0.710 inch. Therefore, they were reset to permit a greater distention of about 0.83 inch. This was somewhat arbitrarily chosen because it prevented interference with the new apparatus. Thus, accidental overruns of the 0.710-inch distention height were and are limited by the setting of the high level pumping stops—at present at 0.83 inch.

To illustrate the effect of an accidental distention of a diaphragm to distentions greater than 0.710 inch, a new diaphragm was installed and 15 distentions to 0.71 inch were made. As shown in the top graph in Fig. 1 the diaphragm pressure was constant at 97 p.s.i. on the 15th distention. On Distention no. 16 the diaphragm was distended to 0.83 inch giving a pressure of 115 p.s.i. (this is represented in the figure by a vertical dashed line extending to the pressure

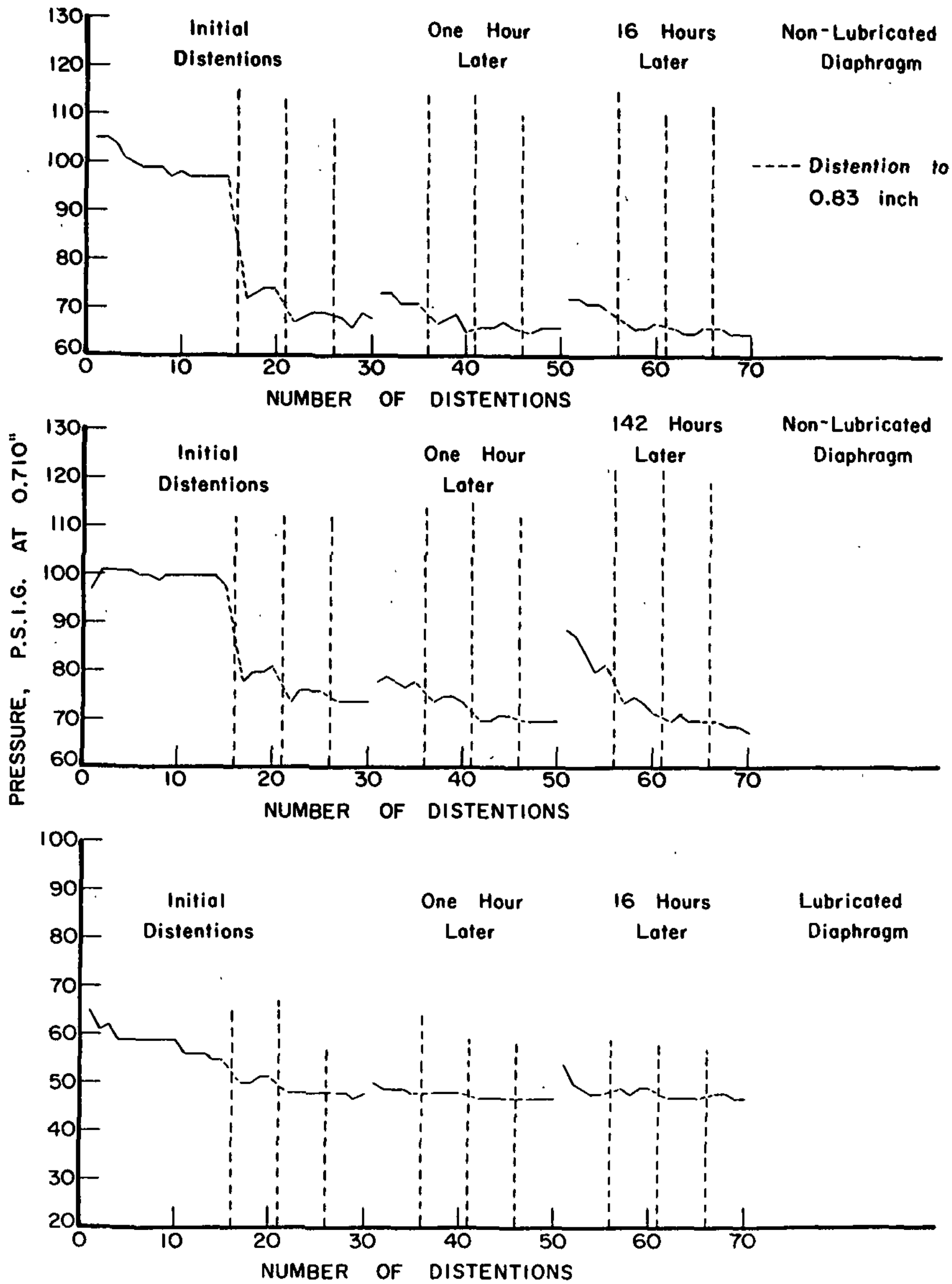

Figure 1. Effect of Overdistension on Diaphragm Pressure at 0.710 Inch

level obtained). On Distentions 16 thru 20 to 0.71 inch it may be noted that the diaphragm pressures ranged from 72 to 74 p.s.i. Thus, one distention to 0.83 inch reduced the diaphragm pressure at 0.71 inch by from 23 to 25 p.s.i. A second over-distention was then made and the pressure at 0.71 inch decreased to 67 to 69 p.s.i. A third overdistention had little effect, however, as the diaphragm pressures ranged from 66 to 69 p.s.i. on Distentions 27 through 30.

The diaphragm was then allowed to relax for an hour. When measurements were then taken, a small increase in diaphragm pressure to the 71 to 73 p.s.i. range was observed; however, one or two overdistentions were sufficient to bring the pressure down to a relatively constant level near 65 to 67 p.s.i. Relaxation again occurred when the diaphragm was allowed to rest for 16 hours; however, one overdistention was sufficient to again attain the 65 to 67 p.s.i. pressure range.

The middle graph in Fig. 1 illustrates the same trends for a second diaphragm while the lower graph in Fig. 1 shows results obtained with a diaphragm lubricated with graphite. The effects of overdistention were smaller in the latter case; however, the same trends occurred.

The behavior at 0.375-inch distention is illustrated in Fig. 2 for normal (nonlubricated) and lubricated diaphragms. In the case of the nonlubricated diaphragm, one overdistention was sufficient to lower the pressure from 44 p.s.i. to 36 p.s.i.—a decrease of 8 p.s.i. Further overdistentions had only a minor effect as diaphragm pressures only decreased to about 34 p.s.i. during the later treatments.

The lubricated diaphragm exhibited little or no effect due to overdistention and pressures after 1 hour and 16 hours tended to run from 1 to 2 p.s.i. higher than during the initial tests. No reasons for this slight rise are known.

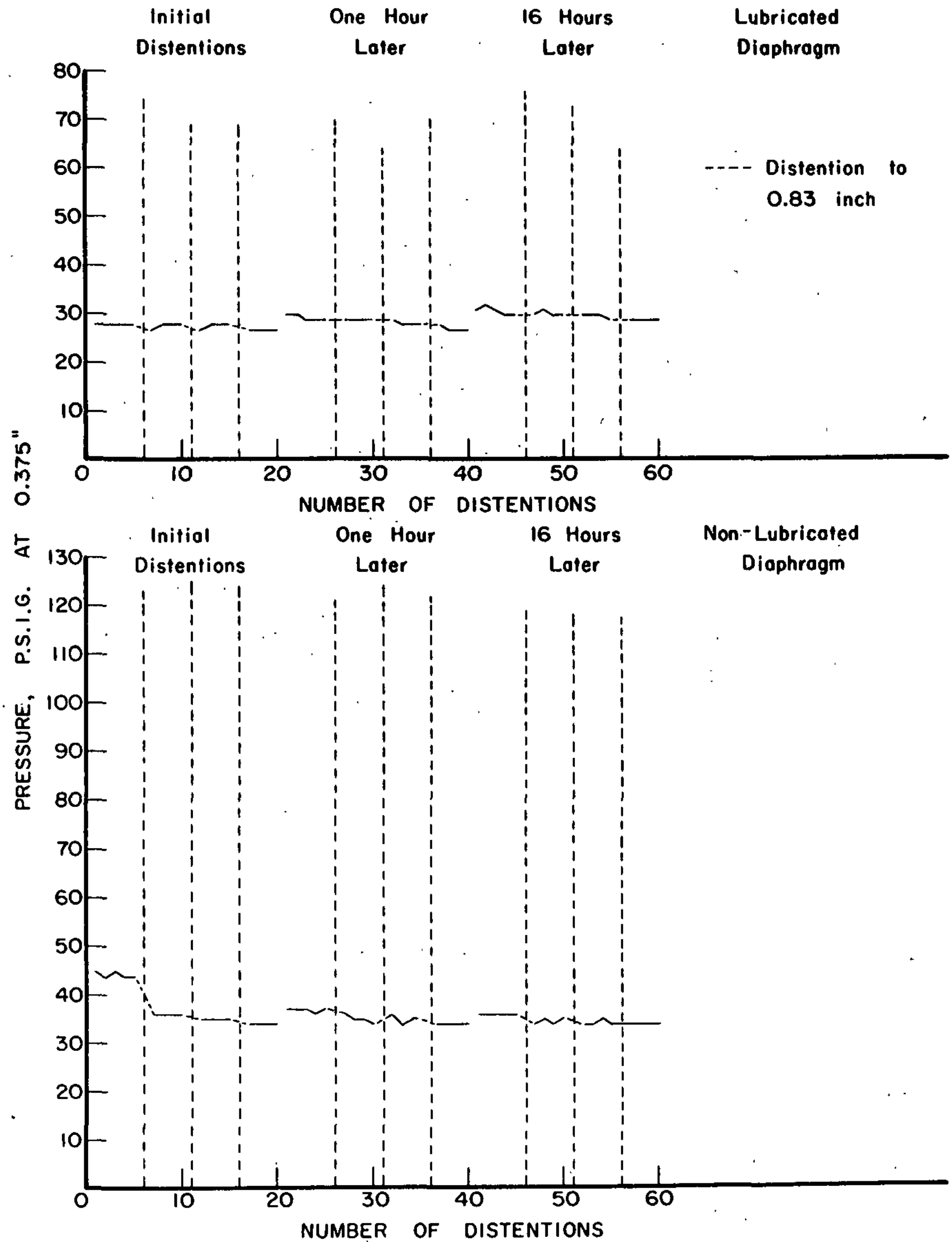

Figure 2. Effect of Overdistension on Diaphragm Pressure at 0.375 Inch

The above results may be summarized briefly as follows:

1. Only a few distentions beyond 0.710 inch are sufficient to markedly lower diaphragm pressures at either 0.375 or 0.710 inch for a fresh diaphragm. The changes in diaphragm pressure may be as great as 8 p.s.i. at 0.375 inch and 25 p.s.i. at 0.710-inch distention. Greater overdistentions might produce even larger effects.
2. The relatively large differences encountered suggest that overdistention might be one cause for the large between-laboratory pressure differences. Any overdistention of the diaphragms during the mill evaluation would have the probable effect of producing a large difference between Institute and mill results.
3. Because a few overdistentions appear to lower pressure on an almost permanent basis, the procedure could conceivably be used to permit use of diaphragms which ordinarily would be rejected as having too high a pressure.
4. Procedures for evaluating diaphragm pressure should either (a) incorporate a specified number of overdistentions to a given level in the prestressing procedure, or (b) specify that no overdistentions in the prestressing procedure shall be permitted.

PART IV. COMPARISON OF "AUTOMATIC" AND "MANUAL" METHODS OF EVALUATING DIAPHRAGM PRESSURE

Diaphragm pressure measurements at 0.375-inch distention have traditionally been determined manually by the test operator, i.e., the operator halts or reverses the machine when the diaphragm reaches the desired height. The same scheme may be used at 0.710-inch distention although a number of organizations, including the Institute, may have installed high limit pumping stops on their machines to stop the distention at 0.71 inch. The manual method, of course, relies entirely on the operator's alertness and experience.

With the above in mind, a limited comparison of "automatic" and "manual" methods of evaluating diaphragm pressure was made. The results obtained are shown in Table IIIA. In general, relatively good agreement between methods was obtained.

TABLE IIIA

COMPARISON OF AUTOMATIC AND MANUAL METHODS OF EVALUATING DIAPHRAGM PRESSURE
(Single Operator)

Diaphragm	Diaphragm Pressure, p.s.i. Automatic	Manual	Diff.
	0.710 inch		
1	95.2	95.4	+0.2
2	64.0	69.2	+5.2
3	44.6	44.6	0.0
3[a]	45.2	45.2	0.0
3[b]	40.0	39.8	-0.2
	0.375 inch		
1	32.5	32.1	-0.4
2	32.5	33.1	+0.6
3	27.5	27.7	+0.2
3[a]	27.4	27.4	0.0
3[b]	24.9	25.0	+0.1

[a]Repeat trial.

[b]After lubrication of diaphragm.

This work was extended to compare results obtained by three experienced operators as shown in Table IIIB. Quite satisfactory agreement was attained in this comparison also.

TABLE IIIB

INTERCOMPARISON OF OPERATORS

Operator	Diaphragm Pressure, p.s.i. Automatic	Manual	Diff.
	0.710 inch		
1	45.2	45.2	0.0
2	47.8	46.6	-1.2
3	47.8	47.6	-0.2
	0.375 inch		
1	27.5	27.7	0.0
2	27.7	28.9	+1.2
3	27.8	27.6	-0.2

Thus, the results indicate that the larger Institute-mill differences were not necessarily associated with any substantial difference between "automatic" and "manual" methods. On the other hand, it should not be inferred that measurements by inexperienced personnel would result in such close agreement.

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THE INSTITUTE OF PAPER CHEMISTRY

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APPENDIX I

COMPARATIVE EVALUATION OF DIAPHRAGMS BY INSTITUTE AND MILL

	Gage Capacity	Diaphragm Pressure at 3/8 Inch, p.s.i. g.						Difference,	
		Diaphragm No.							
		1	2	3	4	5	Average	p.s.i. g.	%[b]
IPC[a]	60	38	37	39	38	38	38.0		
Mill A	200	39	38	38	39	38	38.4	+0.4	+1.1
IPC[a]	60	38	39	37	40	39	38.6		
Mill B	400	39	40	40	40	40	39.8	+1.2	+3.1
IPC[a]	60	39	38	39	38	37	38.2		
Mill C	200	28	29	29	30	28	28.8	-9.4	-24.6
IPC[a]	60	38	39	37	38	37	37.8		
Mill D	60	30	31	31	31	34	31.4	-6.4	-16.7
IPC[a]	60	38	39	39	37	37	38.0		
Mill E	200	29	30	32	32	30	30.6	-7.4	-19.5
IPC[a]	60	37	38	37	39	38	37.8		
Mill F	60	33	34	34	34	31	33.2	-4.6	-12.2
IPC[a]	60	38	39	38	37	38	38.0		
Mill G	200	35	33	33	33	33	33.4	-4.6	-12.1
IPC[a]	60	37	38	39	37	37	37.6		
Mill H	--	27	29	29	32	35	30.4	-7.2	-19.1
IPC[a]	60	38	39	38	38	38	38.2		
Mill I	60	33	35	32	30	30	32.0	-6.2	-16.2
IPC[a]	60	37	40	37	39	38	38.2		
Mill J	--	31	24	29	33	24	28.2	-10.0	-26.1

[a] Taken from Report Seven, Project 1108-26 and rounded to nearest p.s.i.

[b] Based on Institute results as reference.