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A Laboratory Study of the Effect of Wet Pressing and Pulp Freeness on the Hygroexpansivity of Sulphite Paper

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A LABORATORY STUDY OF THE EFFECT OF WET PRESSING AND PULP FREENESS ON THE HYGROEXPANSIVITY OF SULPHITE PAPER

by

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A dissertation submitted to
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SCOPE OF PRESENTATION

This paper contains in final form the written presentation of the more significant findings of the author while working on his senior thesis. The major areas presented are: the results of a literature survey made in the library at Western Michigan University; and the findings of experimental work done in the laboratories of the Department of Paper Technology at Western Michigan University.

ACKNOWLEDGEMENT

The author would like to sincerely thank Dr. R. A. Diehm for his ever present help while working on the thesis. There were many times when Dr. Diehm left his work to lead the author out of the labyrinth of an especially difficult problem and put him on the path to meaningful accomplishments.

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INTRODUCTION

Since so many of today's papers are used for applications which require a low hygroexpansivity this property of paper is becoming increasingly important. There are many different types of paper which must be stable against changes in dimensions. Papers used in such diverse applications as recording charts, punch cards, paper recording tapes, and packaging boxes all must be stable against dimensional changes in order to function properly in their usage. In the area of printing papers there is a big demand for dimensionally stable paper. Because offset paper is repeatedly exposed to a wet blanket during the color printing process it must be especially stable. If there is any change in the dimensions of the paper between color applications the whole printing job will be out of register. This is a very large waste and a high added expense. The manufacture of dimensionally stable paper is, therefore, an important concern of a large segment of the paper industry.

For thesis work the author desired to work on a problem which is important to a large portion of the paper industry. The problem of hygroexpansivity met all of the author's requirements for a suitable thesis topic. It is an important problem. It is a problem which has not been solved and over which there is much controversy. It is a problem with which the author was not familiar and therefore would be very educational. Finally, it is a problem with which the author is very interested.

Since the author is interested in developments which can be used directly in production, the areas of pulp freeness and pressure of wet pressing were chosen. Both of these are variables over which the production man has some control. The pressure used on the wet presses on the paper machine can be varied over a definite range without affecting the operation of the machine. The degree of refining and the severity of refining of the stock can be controled over a wide range. By making adjustments on these two variables the properties of the finished sheet can be changed considerably. It is the purpose of this investigation to find if there are any methods of pressing and refining which will lead to a more stable sheet of paper.

In order to make an intelligent laboratory investigation of the problem of hygroexpansivity it was necessary to first investigate the work that has been done on the problem by others. Therefore, a survey of the literature was made to find what previous laboratory investigations had been made, and what knowledge in general was known in relation to the problem.

LITERATURE SURVEY

A survey of the literature for information on hygroexpansivity of paper was made using the library facilities of Western Michigan University. The survey covered all English articles which were available which delt with the problem from 1930 to the present, 1961.

While making the literature survey several general observations in connection with hygroexpansivity were made. The first observation was that there is a plethora of articles dealing with the problem. Upon concluding the investigation of references and after beginning to read the articles another fact revealed itself. Most of the articles published on hygroexpansivity of paper deal with chemical alteration of the paper. These articles discuss chemical means of stabilizing paper such as impregnation with resins or chemically changing the cellulose. This left only a few remaining articles which delt with non-chemical methods of improving hygroexpansivity.

The remaining articles which delt with the areas of the problem the author was investigating divided themselves into two categories. The first type of articles which unfortunately composed the majority of the literature remaining was not very informative. The authors of these articles mostly discussed their observations of hygroexpansivity of production paper. They went on to give their educated opinions as to the causes of the observed phenomenon and some possible solutions. Mainly, these articles were testimony to the fact that a problem of hygroexpansivity does exist and that not much has been accomplished towards solving it.

The articles discussing actual laboratory investigations of the problem were singled out. These articles presented the methods of laboratory investigations, the observed data, and the conclusions as to the causes of hygroexpansivity. These articles were very useful in planning a laboratory experimental design. They furnished the necessary background information. By using this information the scope and coverage of the author's experiment was outlined.

A great deal of confusion resulted from the conflicts reported in the literature. On almost every point there was disagreement. Most of the disagreement was between the conclusions and findings of laboratory investigations and the conclusions and findings of machine observations. In the end an experimental design incorporating the findings of both areas of information was used. This was necessitated by the lack of support for either of the areas of information.

The following is a presentation of the most significant findings of the literature survey.

There is 100% agreement in all the literature that the relative humidity or moisture content of the atmosphere is the factor which causes paper to change its dimensions. This is a basic reason for calling the changes in dimensions hygroexpansivity.

The former TAPPI standard for hygroexpansivity is conducted by exposing paper to changes in humidity and measuring its changes in dimensions.

After this first point the agreement in the literature ends. There is a disagreement as to the influence of all other variables of paper. Here is a presentation of the influence of each factor on the hygroexpansivity of paper.

Basis Weight: According to Masterman (1) the hygroexpansivity varies inversely with the basis weight of paper. The lighter a sheet is, the worse will be its dimensional changes. On the other hand, Tongren (2) concludes that the basis weight has very little effect on hygroexpansivity. He found in a comparison of 13# and 20# sulphite sheets that there is no significant correlation between expansivity and basis weight. Lary and Libby (3) obtained the same results in their laboratory investigation. They found that the basis we'ght made only a small difference in the expansivity. However, light weight sheets had a slightly higher expansion than all the other sheets.

Beating Degree: In his work Calkins (4) found that a sheet with a very small amount of beating had a lower expansivity than a sheet with more beating. He believes that the large interstices between the fibers absorb the swelling of the fibers without transfering the swelling to the outside dimensions. But Lary and Libby found from work done by Weidner that beating decreases the amount of fiber swelling and opens up the fiber structure for water absorption. This results in a decrease in expansion with increased refining.

Bonding: As the moisture content of a sheet increases many of the hydrogen bonds between fibers are broken. This results in a more flexible fiber structure which expands. In a soft unbeaten sheet there is only a small amount of bonding and, therefore, only a few bonds which will be broken by increases in moisture. As a result there will be only a small dimensional change. Using this reasoning Calkins concludes that a lower degree of bonding will result in a more stable sheet. This holds true for most machine papers.

As a result of laboratory studies of porosity versus expansivity Libby and Lary come to the opposit conclusion. They found a definite correlation between the degree on bonding and the stability. A higher degree of bonding will give a more stable sheet.

Density: ccording to Calkins there is a correlation between densi y and hygroexpansivity. He found the higher the density the greater is the expansion. This effect is a function of density alone and not bonding. If two sheets of equal degree of bonding have different densities the sheet of lower density will be the most stable. Both Swanson and Tarkow support this view. Libby and Lary object to this view even though their labor tory work does not support their objection.

Fiber Length: Libby and Larry found that there is no correlation between fiber length and hygroexpansivity. Only in the case of long fibers was the expansion higher than all the other sheets. However, the sheets tested were le s dense and had poorer bonding than all the other sheets.

Fiber Sw lling: It is a well established fact that fibers themselves well upon increasing their moistur content. Upon swelling the length of a fiber changes very little while the diameter is enl rged considerably. Masterman and others claim that this plus the fiber orientation in the machine direction accounts f r the much larger hygro xpansivity in the cross machine direction. Calki s found that from 0% to 90% relative humidity fibers swell 12-15% in diameter. He believes that this 's only a small change in fiber volume. This small change does not cause changes in the outside dimensions of a sheet but only fills in the interstices.

In their laboratory investigation Libby and Lary found that fiber swelling cor elates with moisture content very well up to 60% moisture where the swelling rate begins to slow down. They believe t t only a porti n of the fiber swelling is transferred to the external dimens'ons of the paper.

Freeness: Libby and Lary found that the freeness made little difference in the hygroexpansivity of paper. At very high freeness, above 600 C.S., the expansion was slightly higher. They believe that the lower density and the poorer bonding of a very free sheet are the causes of the increased expansion. On the other side of the question is George (5) who came to the conclusion based on his work that at high freeness the stability should be improved because there are more voids into which the fibers can expand.

Furnish: Tongren states that the type of pulp used in a furnish does not affect the hygroexpansivity of paper. Libby and Lary agree with this theory when it is applied to long fibered pulps. However, George has found that unbleached sulphite pulp is the most stable.

Internal Strains: The theory that the relaxation of internal strains in a sheet cause hygroexpansivity is proposed by Calkins. On the basis of his laboratory work he postulates that at high relative humidity the moisture that gets into paper relaxes the strained bonds. This allows the fibers to become more mobile. As a result the paper expands. In support of this theory he cites the case of paper from the edge of a paper machine. Because of the high amount of shrinkage this paper has a high degree of internal strains. It also has a higher expansivity than paper from the center of a machine.

Pulp Purity: Tongren found in his investigation that the purity of the pulp affects hygroexpansivity. The higher the purity of the pulp the greater will be its expansion. As the purity is increased lignin and other materials are removed and there are more channels for moisture to reach the cellulose.

Wet Pressing: In their work with laboratory papers Libby and Lary found excellent correlation between the pressure of wet pressing and hygroexpansivity. They made handsheets and pressed them at different pressures ranging from 0 psi to 80 psi. On testing it was discovered that expansion decreases with increasing pressure of wet pressing. This seems to indicate that higher bonding and higher density do increase stability. It also lends support to the theory that hygroexpansivity involves interfiber relationships. The fiber swelling remained constant but the expansion decreased with increased pressure.

Unfortunately, the above is exactly the opposite of the findings of Swainson (6) in his investigation of machine made paper. He found that there is no correlation between pressure and hygroexpansivity.

As a conclusion here in outline form is a summary of the different fields of thought on hygroexpansivity. According to one set of investigators:

High freeness
High bonding
Long fibers — All lead to high hygroexpansivity.
High pressure
High density

But according to many other investigators:

High freeness
High bonding
Long fibers — All lead to low hygroexpansivity.
High pressure
High density

Even though a great deal of work has been done on the problem there is very littleagreement as to the causes of the problem. No one has been able to, as yet, produce a method of decreasing hygroexpansivity significantly using non chemical means.

However, the literature survey gave the author a wealth of past knowledge to use and an appreciation of the difficulties involved in working on the problem. From the information gained an experimental design was prepared and then the author's laboratory investigation was made.

EXPERIMENTAL DESIGN

From the literature survey it was learned that there is no well established pattern for the influence of pulp freeness and pressure of wet pressing on the hygroexpansivity of paper. For this reason a basic experiment is proposed. The purpose of this experiment is to find the effect of these two variables on hygroexpansivity.

It must be remembered that freeness is a measure of the amount of refining which has been done to the pulp. As refining is increased several changes take place. Fibrillation and hydration are increased while fiber length is decreased. Therefore, freeness is not a measure of a single property, but it is a measure of the sum of changes which take place with refining. Some of the effects of increased refining on the finished sheet are; an increase in fiber bonding as measured by mullen, an increase in density and a decrease in caliper. No attempt will be made to experimentally determine which of the above specific variables is responsible for any observed changes in hygroexpansivity.

A similar phenomenon is observed with wet pressing although it is not as complicated. No change in the fibers themselves takes place. As a sheet is pressed with more pressure the caliper decreases and the density increases. There is also a small increase in bonding. Again there will be no experimental procedure established to determine which of the single above variables is responsible for any change in hygroexpansivity.

Any such procedure would be much too complicated and time consuming to include in an investigation of this scope.

This experiment, therefore, will be confined to an investigation of what effect changes in wet pressing pressure and refining as measured by pulp freeness will have on hygroexpansivity.

The following procedure will be used. Sulphite pulp will be refined in a TAPPI laboratory beater. Samples will be removed at different freeness levels and made into hand sheets. Four levels of freeness will be used. After the third sample has been removed the pulp will be transferred to a Mead Laboratory refiner for the remainder of refining. At each level of refining, hand sheets will be made in a British sheet mold and will be pressed at four different pressures.

After forming, the sheets will be evaluated. The hygroexpansivity will be measured according to the former TAPPI standard in a Neenah expansiometer. Basis weight, caliper and mullen will be evaluated in the usual manner following TAPPI standards.

EXPERIMENTAL INVESTIGATION

Preparation of Pulp

The first step in the laboratory investigation consisted of refining the pulp. For this experiment Weyerhaeuser bleached sulphite pulp was used. First, 400 grams of as is pulp was so ked in 10 liters of water for three hours. After soaking, the pulp was dispersed by an Atlas press stirrer for five minutes. The soaking and pre-refining dispersment of the pulp ensured equal refining action on all parts of the pulp from the start of refining.

The dispersed pulp was put into a Vall y beater and water added to bring the total volume to 23 liters. The standard TAPPI procedure was followed during refining For five minutes the beater was run without any weights to bring the pulp to uniform consistency. Then the consistency and freeness were determined. It was found that the consistency was 1.70% and the freeness was 773 Canadian Standard. Weights totaling 5500 grams were put on the beater and refining was started. Freeness samples were taken at 670 C.S. and 600 C.S. A 4 liter pulp sample was removed at the 600 C.S. freeness and stored in a large air-tight glass jar. This will be referred to as pulp A. "Downside" preservative was added to the beater and mixed in before the sample was taken.

Refining was continued and the pulp freeness was measured at 519 C.S. and 431 C.S. At the later freeness a second 4 liter sample was removed and placed in a large glass jar. This will be referred to as pulp B. Following the same procedure, the pulp was refined down to 303 freeness. At this time nother 4 liter sample was t ken and stored in a glass jar. This will be known as pulp C. The remaining pulp was transfered to the Mead laboratory refiner. This final pulp sample, pulp D, was refined to 132 C.S. freeness. Table 1 contains the data pertinent to the preparation of the pulp.

TABLE 1

Preparation of Pulp

Method of Refining	Time (Minutes)	Freeness (Canadian Standard)	Sample
Valley Beater	0	773	
" "	10	670	
"	15	600	Pulp A
" "	20	519	
"	24	431	Pulp B
"	29	303	Pulp C
Mead Refiner	29:15	240	
" "	29:40	132	Pulp D

All at 1.70% Consistency

Formation of Handsheets

As a precautionary m asure the consistency of each pulp sample was checked before making handsheet . Enough pulp wa weighed out and diluted to 0.16% in a total of 12 liters. This diluted sample was dispersed on an Atlas drill press for five minutes. Four handsheets were made from each pulp sample A, B, C and D.

The sheets were pressed with a chrome plate on one side and a blotter on the other side. A pressing time of five minutes on the first cycle and two minutes on the second cycle was used. In between cycles the wet blotters were replaced by dry blotters. This first set of handsheets was pressed in the Tappi press with 10 pounds of pressure per square inch. A code number -1 will be used to refer to these sheets. Thus, the sheets pressed in this set will be referred to as A-1, B-1, C-1 and D-1.

The same procedure was followed in making the other handsheets. A pressure of 20 psi was used on the second set which has the code number -2. The third set which has the code number -4 was pressed with 40 psi. A pressure of 70 psi was used on the final set which has the code number -7.

Handsheets were made under 16 different conditions. Four freeness levels were used with four different pressures being used at each freeness. After pressing, the sheets and chrome plates were put in rings and allowed to ir dry in the constant humidity room at 70°F and 50% relative humidity.

Testing of Handsheets

The handsheets were tested for hygroexpansivi.y, basis weight, caliper and mullen. With the exception of hygroexpansivity all of the tests made are common paper tests and TAPPI standards were followed.

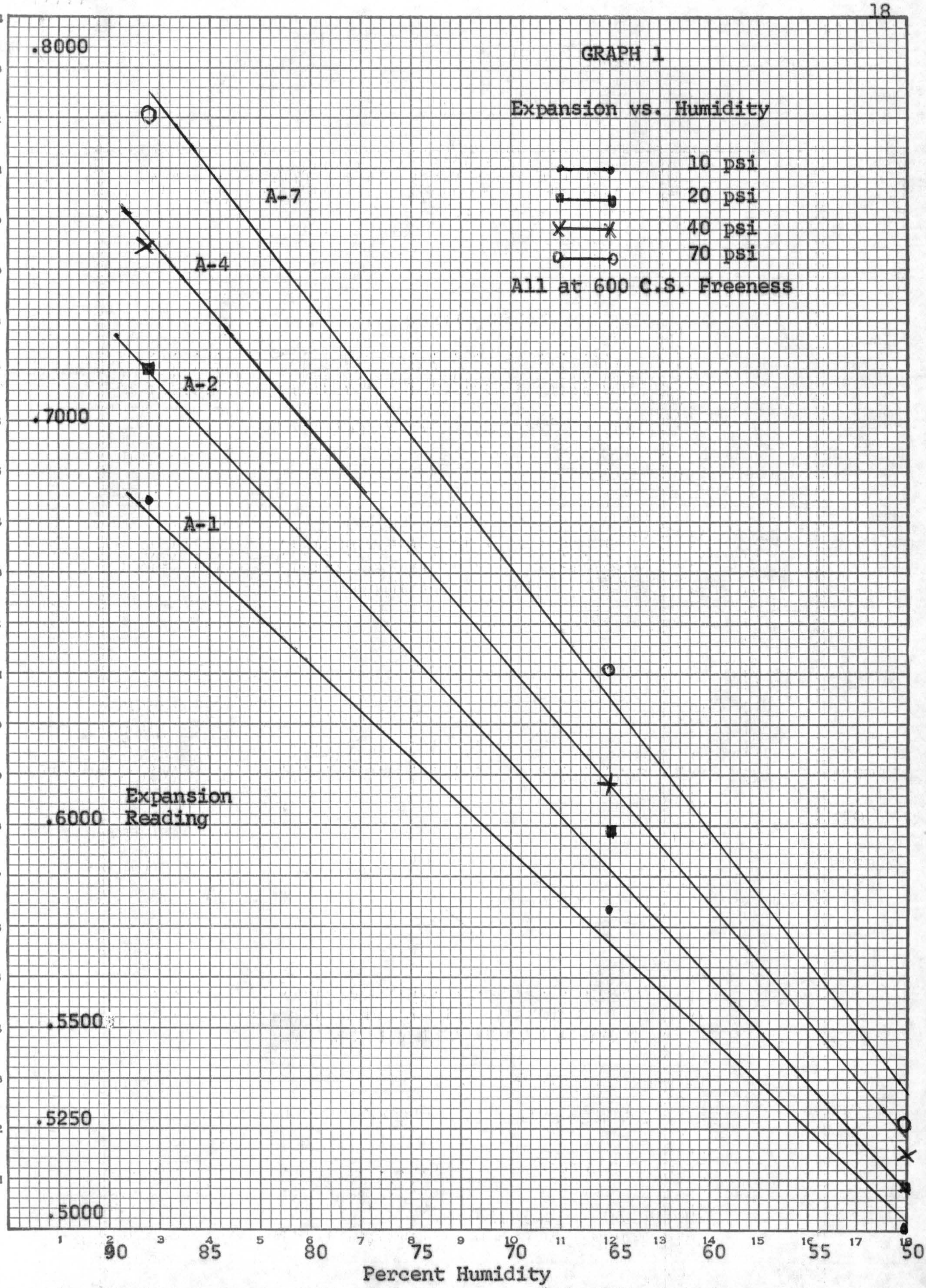
Since hygroexpansivity is not a well known test it will be described. The test is performed in a Neen h Expansimeter. A measured strip of paper one inch by five inches is placed vertically in the expansion cabinet. The top end of the strip is fastened to a micrometer while the bottom end is placed in a level. The humidity is controlled by circulating the air over a saturated salt solution and back into the cabinet.

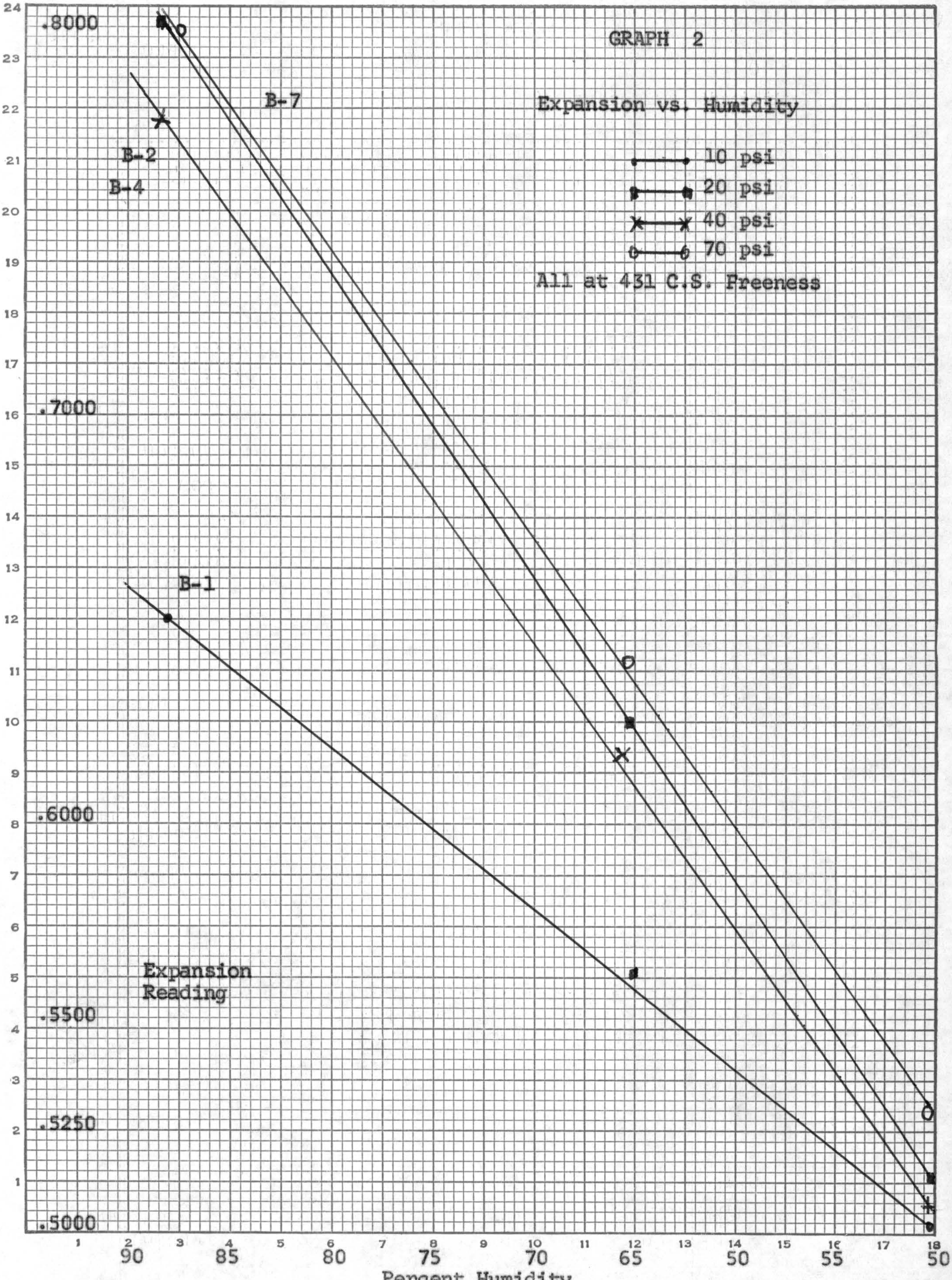
In operation the samples are placed in the cabinet and brought to equilibrum with a 50% relative humidity solution. After leveling all the samples the solution is changed to 85% R. H. When the samples are again in equilibrum they are leveled and the expansion is read from the micrometer. By obtaining 3 points in this fashion a graph of the sample length versus percent humidity is constructed. The change in length between 50% R.H. and 65% R.H. is divided by the total length and reported as percent change.

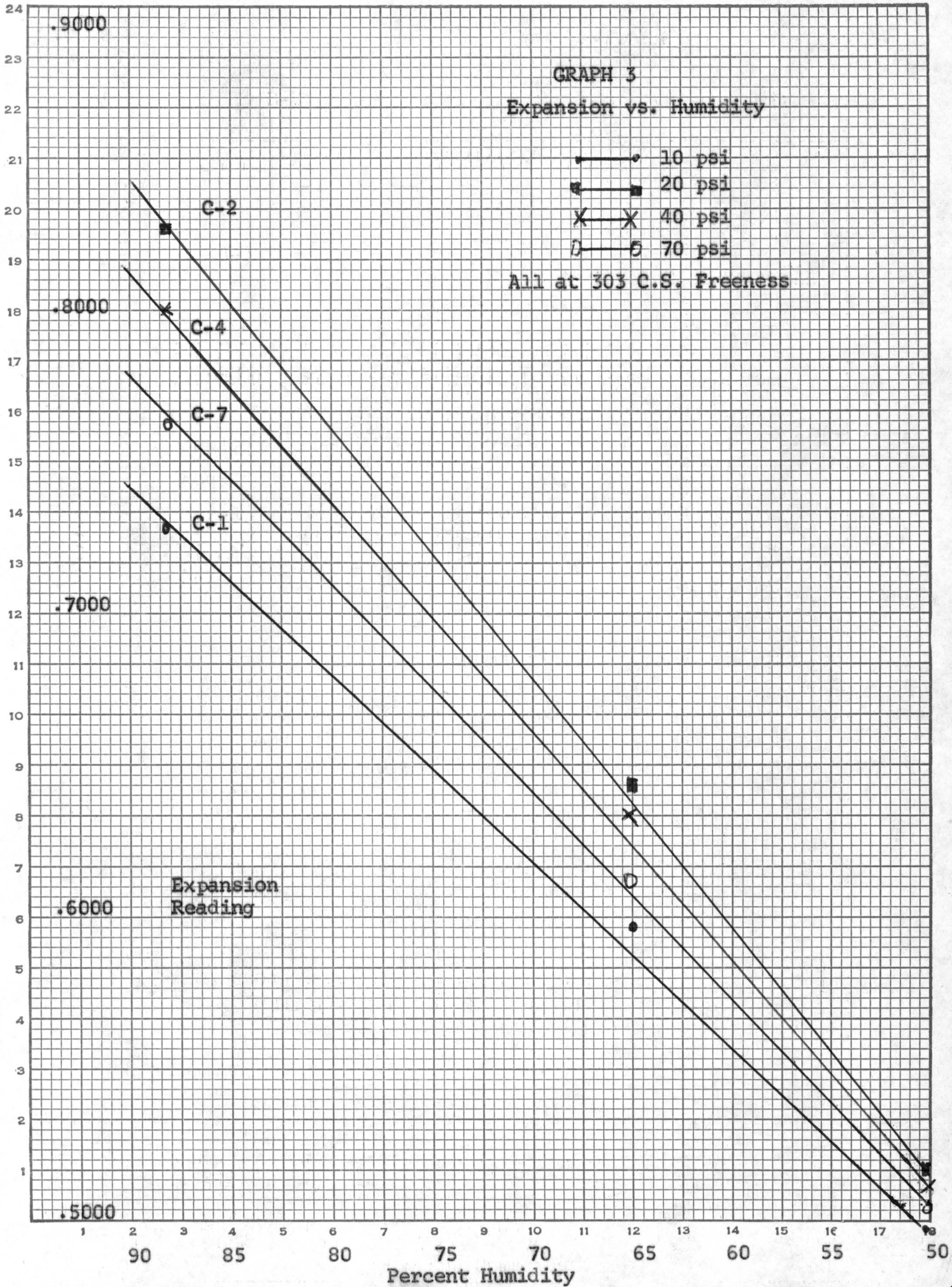
TABLE 2

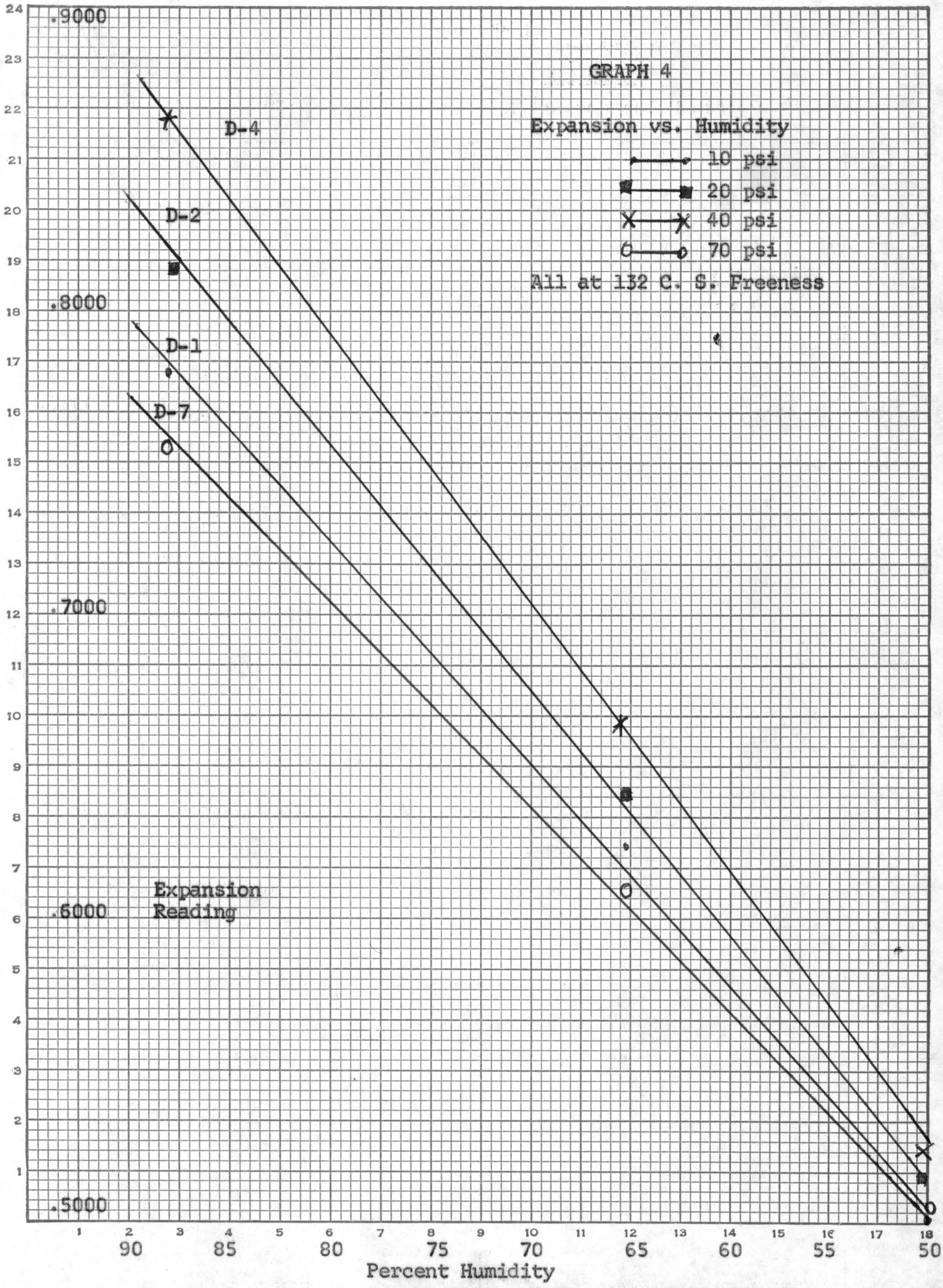
Experimental Results

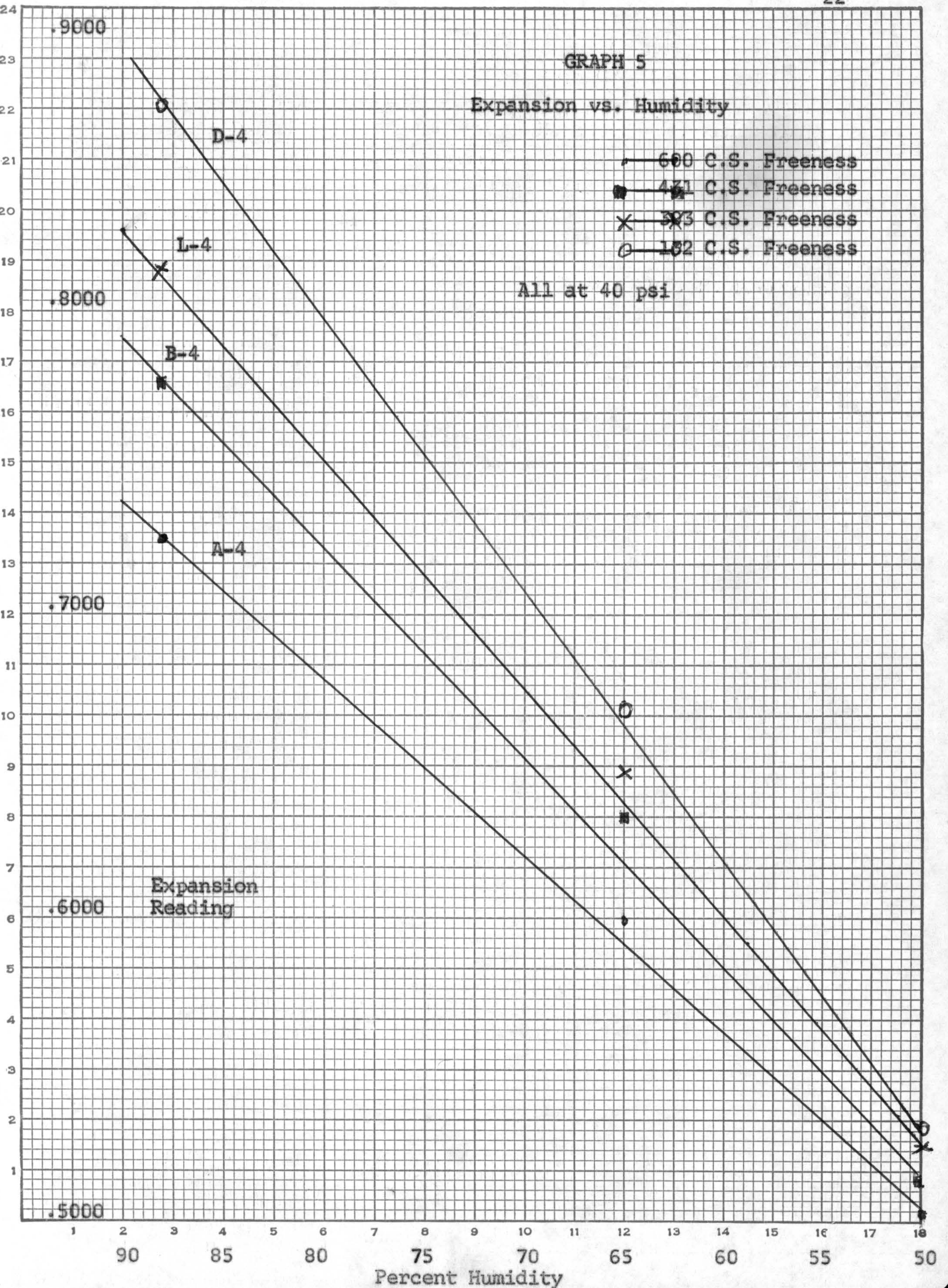
Sample	Percent Expansion	Caliper in mills	Basis Weight Pounds (25x40-500)	Density	Mullen (Points / pound)
A-1	.13%	4.5	44.1	.542	.500
A-2	.16%	4.0	44.8	.619	.502
A-4	.17%	3.7	43.4	.648	.512
A-7	.18%	3.5	43.9	.697	.588
B-1	.12%	4.1	51.8	.699	.610
B-2	.23%	3.8	47.5	.690	.758
B-3	.21%	3.8	51.8	.756	.710
B-4	.22%	3.7	50.2	.750	.817
C-1	.18%	3.8	50.0	.736	.675
C-2	.25%	3.7	50.9	.760	.745
C-3	.23%	3.7	51.4	.770	.842
C-4	.20%	3.5	51.5	.814	.858
D-1	.23%	3.2	44.8	.773	.680
D-2	.24%	3.3	47.8	.800	.753
D-4	.25%	3.2	48.2	.835	.904
D-7	.20%	3.1	49.3	.884	.840

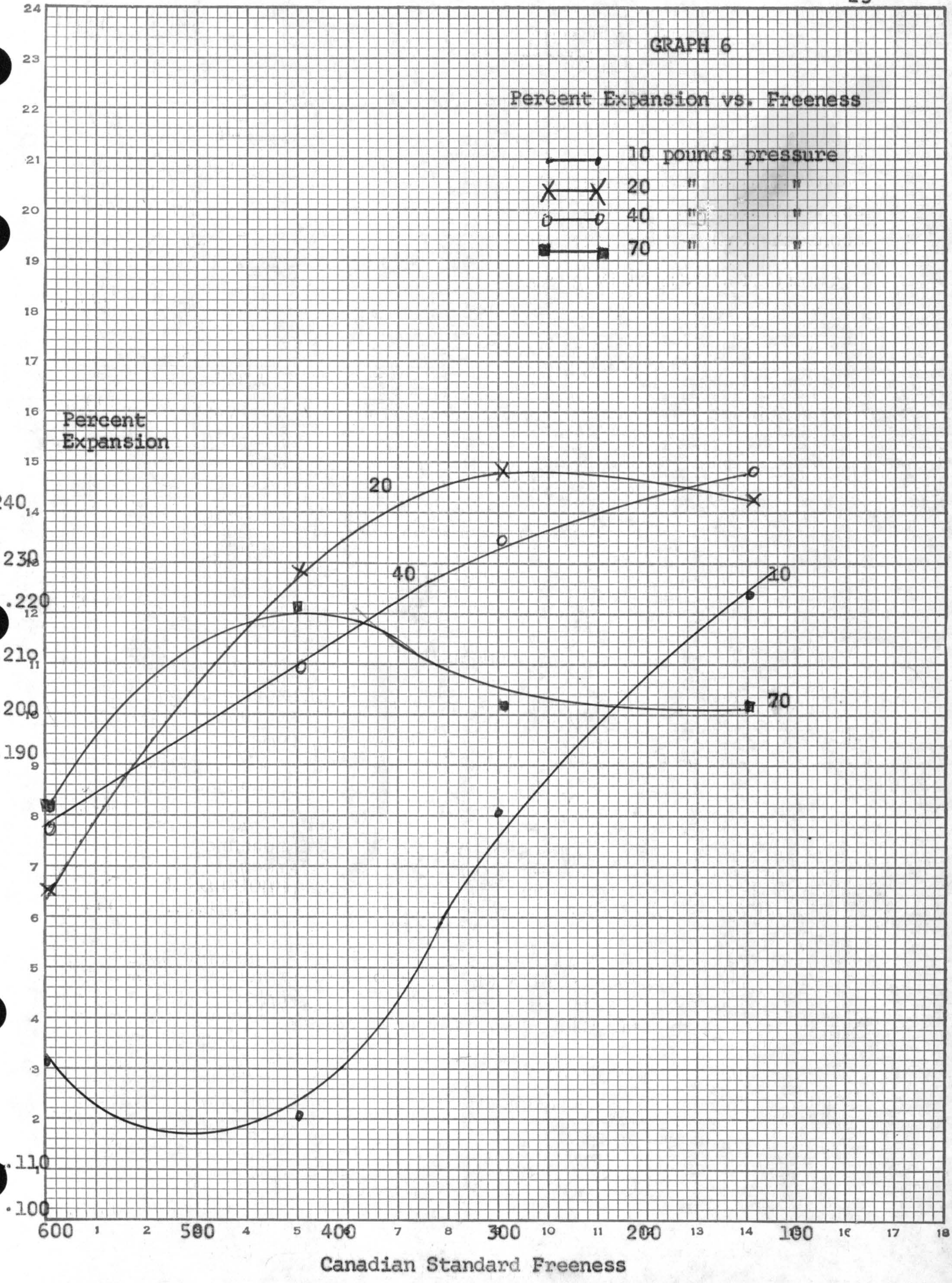

GRAPH 1
Expansion vs. Humidity
10 psi
20 psi
40 psi
70 psi
All at 600 C.S. Freeness
A-7
A-4
A-2
A-1
Expansion Reading
.8000
.7000
.6000
.5500
.5250
.5000
90
85
80
75
70
65
60
55
50
Percent Humidity

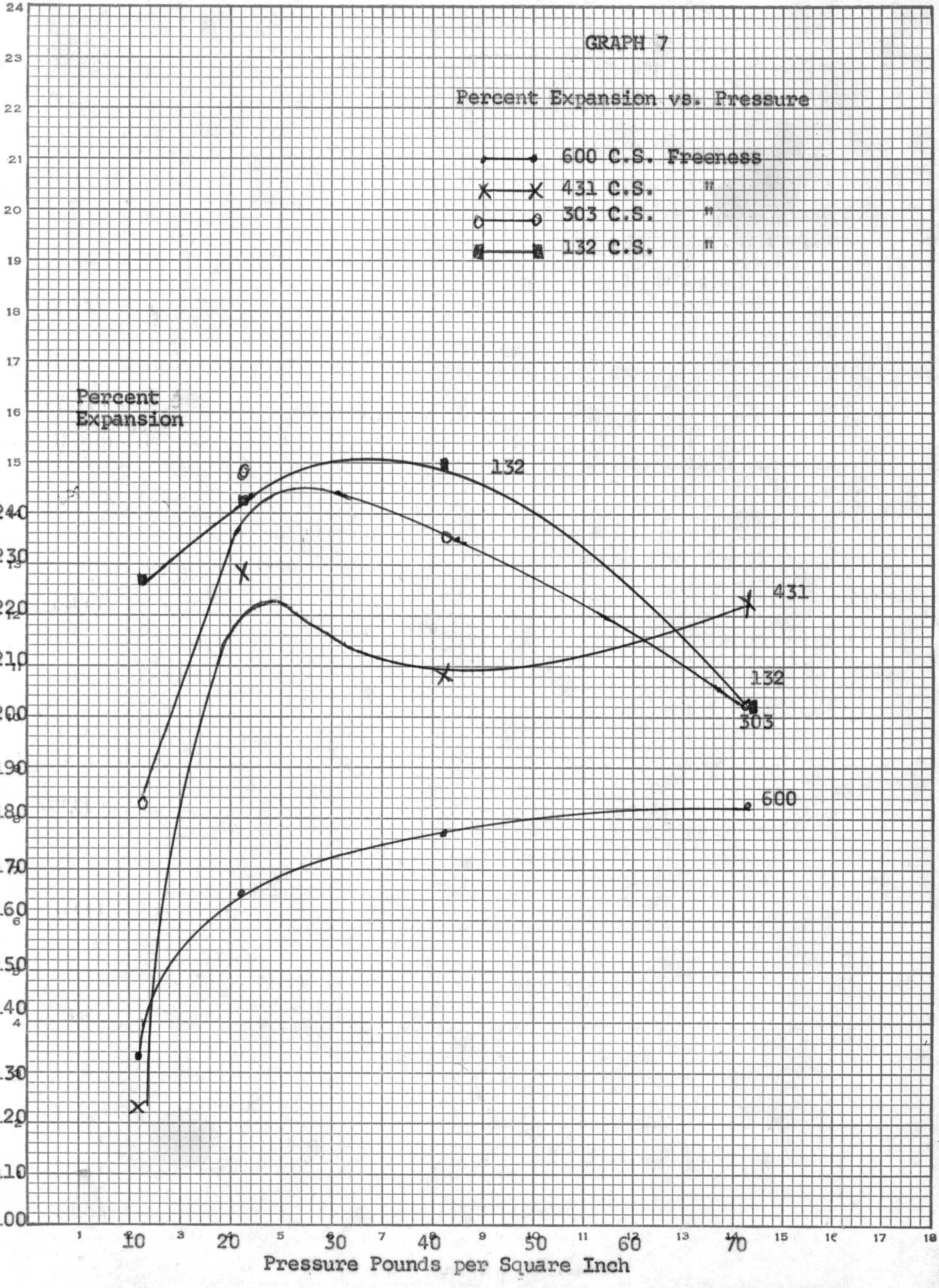

GRAPH 2
Expansion vs. Humidity
10 psi
20 psi
40 psi
70 psi
All at 431 C.S. Freeness
B-7
B-2
B-4
B-1
Expansion
Reading
.8000
.7000
.6000
.5500
.5250
.5000
Percent Humidity
90
85
80
75
70
65
50
55
50


GRAPH 3
Expansion vs. Humidity
10 psi
20 psi
40 psi
70 psi
All at 303 C.S. Freeness
C-2
C-4
C-7
C-1
Expansion
Reading
.9000
.8000
.7000
.6000
.5000
90
85
80
75
70
65
60
55
50
Percent Humidity


GRAPH 4
Expansion vs. Humidity
10 psi
20 psi
40 psi
70 psi
All at 132 C. S. Freeness
D-4
D-2
D-1
D-7
.9000
.8000
.7000
.6000
.5000
Expansion Reading
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
90
85
80
75
70
65
60
55
50
Percent Humidity


GRAPH 5
Expansion vs. Humidity
600 C.S. Freeness
C.S. Freeness
C.S. Freeness
C.S. Freeness
All at 40 psi
D-4
L-4
B-4
A-4
Expansion
Reading
.9000
.8000
.7000
.6000
.5000
90
85
80
75
70
65
60
55
50
Percent Humidity


GRAPH 6
Percent Expansion vs. Freeness
10 pounds pressure
20 " "
40 " "
70 " "
Percent
Expansion
20
40
10
70
Canadian Standard Freeness
600
500
400
300
200
100



GRAPH 7
Percent Expansion vs. Pressure
600 C.S. Freeness
431 C.S. "
303 C.S. "
132 C.S. "
Percent Expansion
132
431
132
303
600
10
20
30
40
50
60
70
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
Pressure Pounds per Square Inch

DISCUSSION OF EXPERIMENTAL RESULTS

In order to facilitate the interpretation of the experimental results several graphs have been prepared.

Graphs 1-5 are the working graphs which were prepared from the expansimeter data in order to calculate the percent expansion. The micrometer readings from the expansimeter are plotted against the measured humidity in the cabinet. The expansion from 50% to 65% is read from the graph and divided by the sample length to obtain the percent expansion. These graphs are significant in themselves because the slope of the lines gives a qualitative comparison between expansions.

From Graph No. 1 it can be seen that for pulp at 600 C.S. freeness which has not been refined much the expansion increases in proportion to increases in pressure. The expansion is quite low for this pulp at all pressures.

Graph No. 2, and the following graphs, are not so simple. At a freeness of 43 C.S. and 10 pounds pressure the expansion remains low. At the three higher pressures the expansions are much higher and all within a narrow range. The influence of pressure on expansion is mixed at the higher pressures.

In Graph No. 3 which deals with pulps at 303 C.S. freeness the sample pressed with 10 pounds pressure has the lowest expansion. The sample pressed with 20 pounds pressure turned out to have the greatest expansion with the other two samples intermediate.

For pulps at a freeness of 132 C.S., Graph No. 4 shows that the sample pressed with 10 pounds pressure no longer has the lowest expansion. Sample D-7 which was pressed with 70 pounds pressure has a slightly lower expansion. The other samples have higher expansions and this time appear in order, as would be expected.

Graph No. 5 contains the same information as the former Graphs, however, the relationships have been reversed. This Graph shows the influence of freeness on papers which have all been pressed with 40 pounds pressure. In effect this Graph is a comparison between all of the former Graphs. When plotted in this manner the data shows that for a given pressure of pressing the expansion is inversely proportional to the freeness. The lowest expansion was obtained at a freeness of 600 C.S., while the greatest expansion was obtained with a freeness of 132 C.S.

Graph No. 6 is a plot of the percent expansion against pressure of pressing. Graph No. 7 contains the plots of percent expansion against freeness. These two graphs present the same information in different form. For this discussion these graphs will be used only to show that the relationships involved are complicated. The former graphs will be used for an interpretation of the data.

Generalized Interpretation

From Graphs No. 1-4 the following generalizations were made. For most all freeness levels a low pressure of pressing will result in a low percent of expansion. At high freeness levels around 600 C.S. the percent expansion is proportional to the pressure of pressing. At low freeness levels of 431 and under, and at pressures of 20 pounds and higher, no simple correlation between pressure of pressing, freeness and percent expansion was found. From these generalizations Chart No. 1 was constructed. This chart shows the above relationships visually.

By referring to Graph No. 5 and Table No. 2 a similar chart was prepared. Chart No. 2 shows the relationships involved based on freeness. A low percent expansion is obtained with a pulp at a high freeness regardless of the pressure of pressing used. For most pressures under 70 pounds the percent expansion is inversely proportional to the freeness of the pulp.

By combining Charts 1 and 2 the total relationship between freeness, pressure of pressing and hygroexpansivity is obtained. Chart No. 3 contains a combination of the former two charts, and is a very good summary of the experimental findings.

Conclusions

For most pressures of pressing under 70 pounds hygroexpansivity is inversely proportional to the pulp freeness.

For most freeness levels of 600 C.S. and above the hygroexpansivity is proportional to pressure.

A low hygroexpansivity can be obtained in two ways. Either a high freeness or a low pressure must be used.

In the other areas there was no predictable correlation found.

Chart 1

Relationship between freeness, pressure of pressing and hygroexpansivity

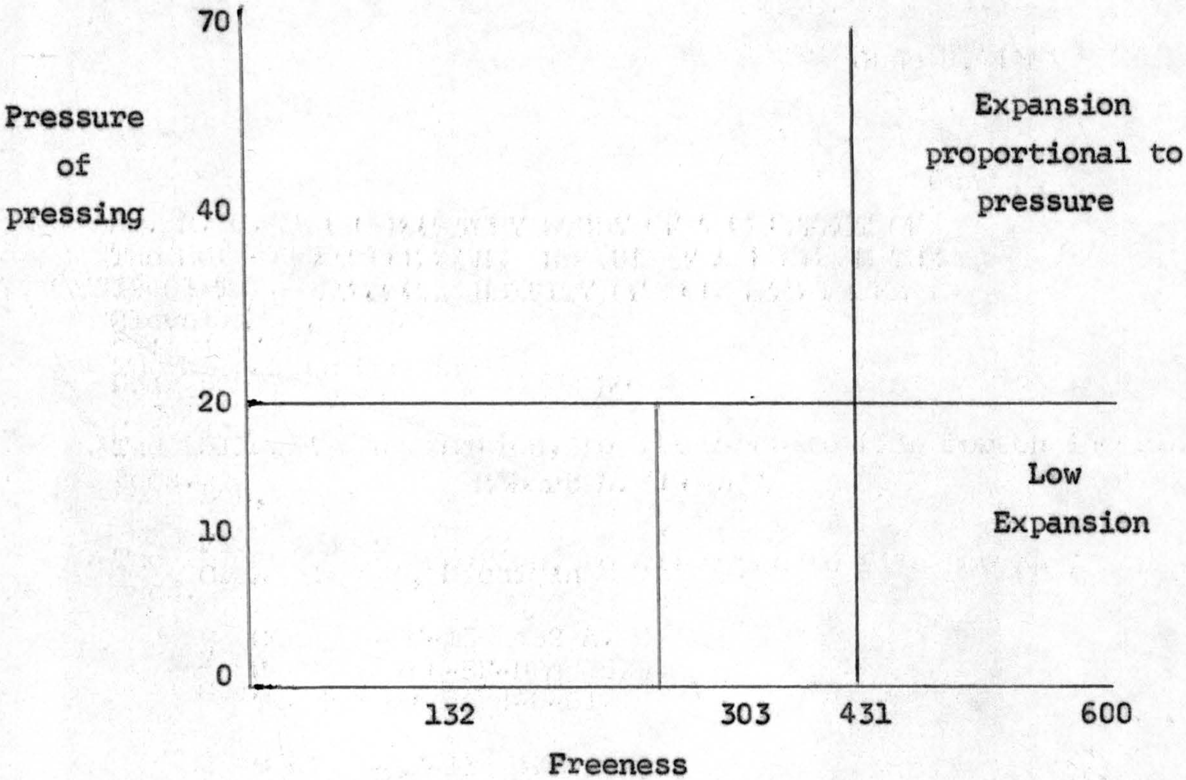


Chart 2

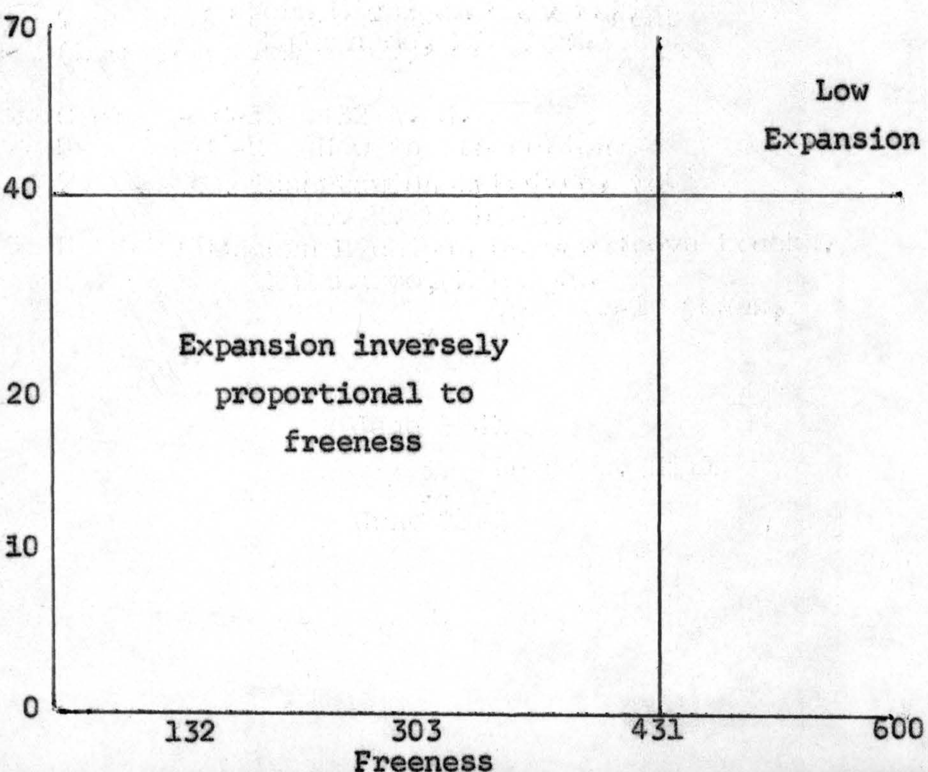
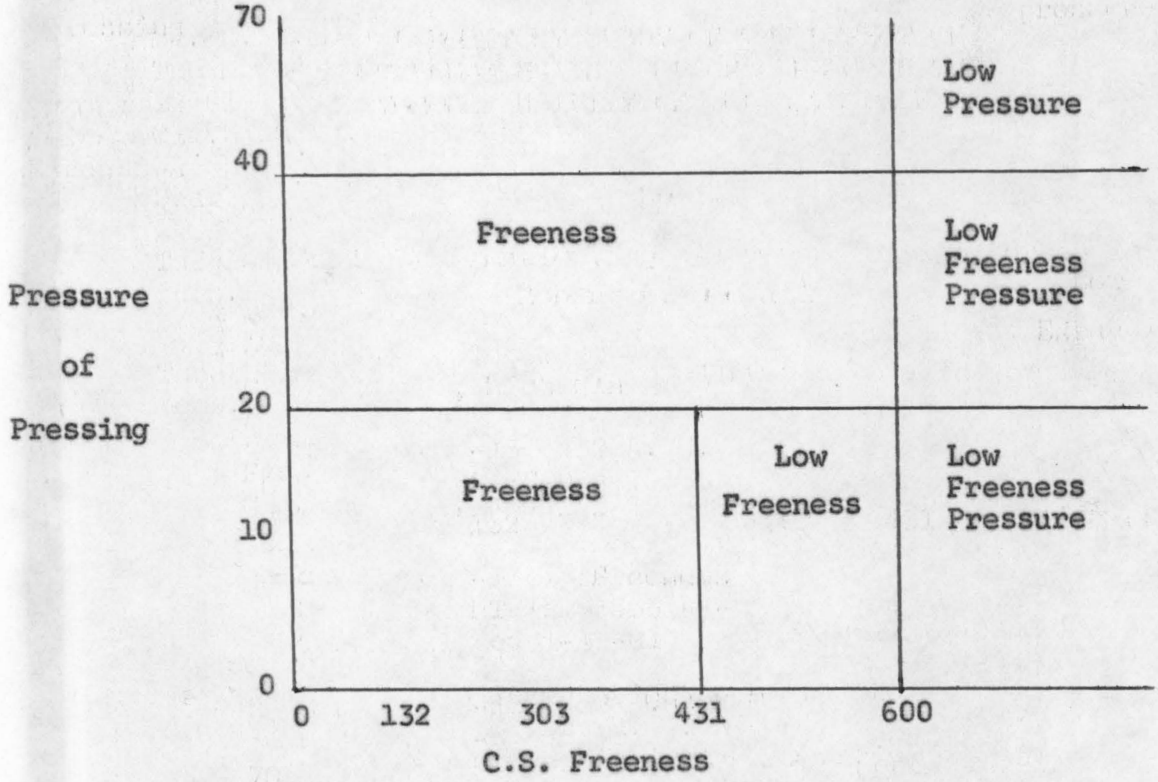


Chart 3

Relationship between freeness, pressure and hygroexpansivity.



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