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The Effect of the Distance from the Size Press to the First Drier on Sheet Properties

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ABSTRACT

It is the purpose of this thesis to attempt to evaluate the effect of the distance from the size press to the first drier on penetration and sheet properties. At a constant machine speed, this has the same effect as varying the dwell time of the starch on the sheet.

It has been found that an optimum distance or dwell time exists for strength properties, namely , breaking length and burst factor. The effect on air resistance and tear, however, is much greater than the effect on the above. Tear was found to increase 20% with dwell time. Air resistance experienced a four fold increase. The strength properties changed because of a difference in penetration. Penetration was deep with short dwell time and decreased with extreme dwell time.

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I. Literature Survey

A. Historical Background

At the time of the preparation of the literature search on this topic, very little analytical work on size press variables had been conducted, except for the project at Western Michigan University. Since that time work at the Forest Products Laboratory has been conducted and will be referred to later. Even the Forest Products work, however, did not include a study of after size press drying. Earlier literature did shed additional light on the topic of size press drying.

O. R. Witworth (1) of Black Clawson investigated the area of size press drying and indicated that the amount of drying needed is determined by machine speed, starch temperature, sheet moisture and starch pick-up. Sheet weight, however, was not considered an important variable. A heavy sheet absorbed about the same amount of size per unit area as a lighter sheet. Differential drier temperature was considered to be important because sheet picking took place if the first drier was not run cooler than the rest of the driers.

James P. Casey (2) guessed that the distance between the press and the first drier is an important variable in size press operation, but offered no supporting evidence.

Analytical data was available for the drying of coated paper, and since the mechanisims were similar, a study was undertaken to investigate the effect of drying variables on coated paper. A. C. Eames (3) found that when coatings were applied to a porous substrate and dried with a hot blast of air, they retained more adhesive, but had less surface bonding strength.

This information indicates that the variable of drying is important in the surface application of a liquid on paper.

Heiser and Cullen (4) studied along the same line as Eames, but with emphasis on penetration rather than strength. Their study showed that at slow drying rates adhesive migrated toward the substrates of the paper, while at faster drying rates migration was toward both the substrate and the coated surface. The degree of binder migration toward the surface was proportional to the drying rate. This work was related to size press drying because the starch "solution" is made up of two components, water and starch. Starch migration toward the substrate would result in deeper penetration and possibly higher strength properties.

Up to now the variable of the drying process has been neglected. There are two main drying processes in common use, drum drying and infrared drying. Hansen and Wright (5) showed that drying rates as high as 13 lbs. per square foot could be obtained with infrared compared with a considerably lower rate for conventional drum dryers. This high rate can be explained by the mechanism of paper drying. Paper drying is divided into two rate classifications, the constant rate period, and the falling rate period. The constant rate period is that part of the drying process where external and surface conditions control, and that part where heat and mass transfer within the body of the sheet exert a strong influence on the drying rate. The constant rate period occurs early in the drier section when the paper is very wet. Here capillary forces are sufficient to keep the surface wetted.

However, when the moisture content of the sheet has fallen below the point when capillary flow has ceased to keep the surface wetted, we enter the period of falling rate. Moisture is now trapped in the interior of the sheet and the sheet serves as an insulator, blocking a high rate of heat transfer.

Radiant heat, on the other hand, can achieve a much higher overall rate of drying and heat transfer by increasing the rate of drying after capillary flow has ceased wetting the surface.

A faster drying rate will obviously increase production. Casey(2) noted, however, that too rapid drying results in cracking and checking of the surface starch film. The moisture of the sheet leaving the size press is about thirty to forty percent on light weight papers, therefore twenty-five percent of the moisture must be dried out a second time. Drying, therefore, is a critical phase of size press operation and study of variables is certainly justified.

B. <u>The Theory of Surface Sizing</u>

P. J. Shirley (6) defines surface sizing as a treatment to improve finish, produce a better surface for printing, and to improve strength characteristics. The two main factors associated with surface sizing are pickup and penetration.

Starch pickup is usually defined as gain in weight of starch treated sheet divided by the weight of the treated sheet. (8)

$$\% \text{ Starch pickup} = \frac{\text{wt. treated} - \text{untreated}}{\text{wt. treated}} \times 10^2$$

The weights involved can either be expressed as oven dry or conditioned. It should be noted, however, that fluctuations in the untreated sheet's weight will make the percent pickup inaccurate. A more accurate method of determining uniformity of pickup is Tappi method T 419 M-60 which is a colorimetric method. It involves a starch extraction and measurement of the absorbancy of a starch iodine complex. This percentage is not affected by fluctuations in the untreated sheet weight and will better reflect a constant starch pickup in a trial or industrial operation.

Penetration is defined as the perpendicular distance traveled by the starch into the sheet. It is defined mathematically by: (7)

$$l = \left(\frac{r \gamma \cos \theta \, t}{2u} \right)^{\frac{1}{2}}$$

where l = the depth of liquid penetration in cm.

r = the paper pore radius in cm.

γ = surface tension of the starch in dynes / cm.

$\cos \theta$ = cosine of the angle θ taken by the liquid in contact with the solid.

t = time of penetration in seconds.

u = coefficient of viscosity in poises.

The above formula for the theory of penetration can be used to estimate the depth of penetration of a liquid such as starch into a porous solid such as paper. The parameters, however, are so difficult to measure that another method must be used. . The formula is more valuable in explaining the effect of operational variables on starch penetration.

The only extensive analytical work other than the size press project at Western Michigan University was conducted at the Forest Products

Laboratory (8) early this year. They showed the importance of the moisture content at the time of starch application and the penetration of starch into the sheet. Microscopic examinations of cross sections of the treated papers showed that applications to low moisture webs resulted in very little penetration of the starch into the sheet. Most of it remained on the surface. With increase in moisture content, more of the starch penetrated into the sheet, and at a web moisture of fifteen to twenty per cent the sheet was completely penetrated. In relating this property, moisture, to the equation on the previous page, we run into difficulty. Moisture content is not a variable in the equation. Therefore, if we accept the validity of the equation and the Forest Product results, moisture must affect one of the equation variables. In the writer's opinion, moisture increases the surface tension and therefore increases the depth of penetration, since penetration is proportional to surface tension.

Forest Product's report also showed that pickup was dependent on starch concentration, starch viscosity, and temperature. All of the above variables must be held constant in order to isolate drying variables and their effect on sheet properties.

The general methods of analysis of starch in paper concentrate only on quantity. Lee's (9) work consisted of taking photomicrographs of sheet sections which had been stained with dilute iodine. His results showed that conventional dryers on a paper machine can cause extensive migration of starch to the sheet surface. He also showed that starch does not form a continuous layer, and it does not penetrate the fibers.

It bonds the fibers in the spaces between them. Penetration and pickup were found to vary with the quantity of starch applied (i. e. concentration) and the amount of previous sizing. The last conclusion agrees with the Forest Products Laboratory study.(8)

It is therefore the purpose of this thesis to evaluate the drying variable of the size press and its effect on sheet properties. It should then be possible to compare the results with previous work and shed additional light concerning starch absorption in paper.

II. Experimental Procedure

A. Machine Trial

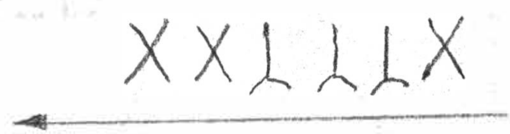
Size press application and drying was conducted on a Keegan pilot coater using a pickup roll and metering rod to apply the starch and infrared ceramic drying units to dry the sheet. All the previously mentioned variables were kept under control as much as was possible under the circumstances of the trial. Numerous runs were made to establish the fact that the applicator set up would give a reasonably constant pickup and that temperature could be controlled in the applicator pan. After one successful run preceeded by many failures, it was assumed that the variables were under control.

The starch used in the trial was Penick and Ford "Penford 280" cooked to 190 F for twenty minutes and cooled to 130 F for application. Starch solids were 11.7% with a Dudley viscosity of 64 seconds at 147° F.

The shaft speed of the pilot coater was held at 44 r. p. m. The starch temperature in the pan during the run was held to 120° F + 2°. The distance from the pickup roll to the first infrared drier was varied by using three driers at a time and progressively switching in new driers and turning off old ones.

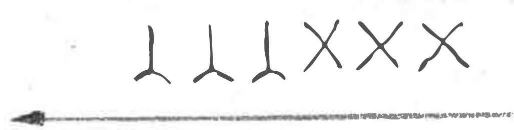
The procedure is illustrated below:

Run 1. Used the first three driers



Run 2. Used this combination

Run 3.



Run 4.

The effect was actually one of increasing the distance from the "size press" to the first drier. Because the machine was run at constant speed, this had the effect of increasing the dwell time discussed in the penetration equation. (page 4)

B. Tests

Breaking length, tear factor, and burst factor were run according to T 220 m60. Starch in paper was determined according to T 460 m60. Air resistance measured according to T 460 m 49.

Penetration was studied by microtome sectioning of the sheets into 15 micron sections and observing the color density of the sections after staining with dilute iodine solution. This was an adaptation of the method used by J. L. Hartman (10) in his thesis.

III. Presentation of Data

A. Data Summary

Test	Control	1	2	3	4
% Moisture	5.35	5.88	5.85	6.06	5.99
Basis weight in g/m oven dry	67.37	70.65	70.12	70.27	69.69
Distance from the size press in inches	——	6.25	11.70	17.20	29.70
Breaking length in meters	6,410	6,506	6,533	6,305	6,292
Burst Factor	24.5	26.0	26.4	26.4	25.8
Opacity			0.89		0.88
Air Resistance in seconds x 2	17		253		1,070
Tear Factor			125		150
% starch added to sheet	——	3.45	3.94	3.53	3.94
Penetration, average depth in microns			60		45

B. Detailing of Data

Tensile Strength

First Test

	C	1	2	3	4
1.	13.7	16.0	15.8	15.0	13.6
2.	15.5	15.0	15.8	15.2	15.6
3.	13.8	15.8	14.6	15.7	15.0
4.	13.8	15.5	15.1	15.4	15.4
5.	14.1	15.4	14.2	15.0	14.0
6.	14.5	15.8	16.8	14.0	14.8
7.	14.5	14.8	17.7	13.5	14.6
8.	14.2	14.4	14.6	13.0	13.6
9.	13.5	16.0	14.9	13.2	15.8
10.	13.8	13.2	17.0	14.0	14.8
Avg.	14.1	15.2	15.6	14.4	14.8

Second Test

	C	1	2	3	4
1.	13.0	15.2	14.4	13.6	14.4
2.	14.4	15.0	15.0	13.6	15.0
3.	14.4	15.1	15.0	15.0	15.2
4.	14.8	15.4	16.2	13.2	12.6
5.	15.0	15.1	14.0	15.2	14.2
6.	12.4	16.4	13.4	16.0	14.4
7.	15.2	14.6	16.0	14.2	13.6
8.	15.6	15.1	15.9	16.2	13.4
9.	15.0	15.0	16.0	16.0	15,0
10.	14.2	15.2	15.6	16.1	14.4
Avg.	14.4	15.2	15.1	14.9	14.2

Mullen

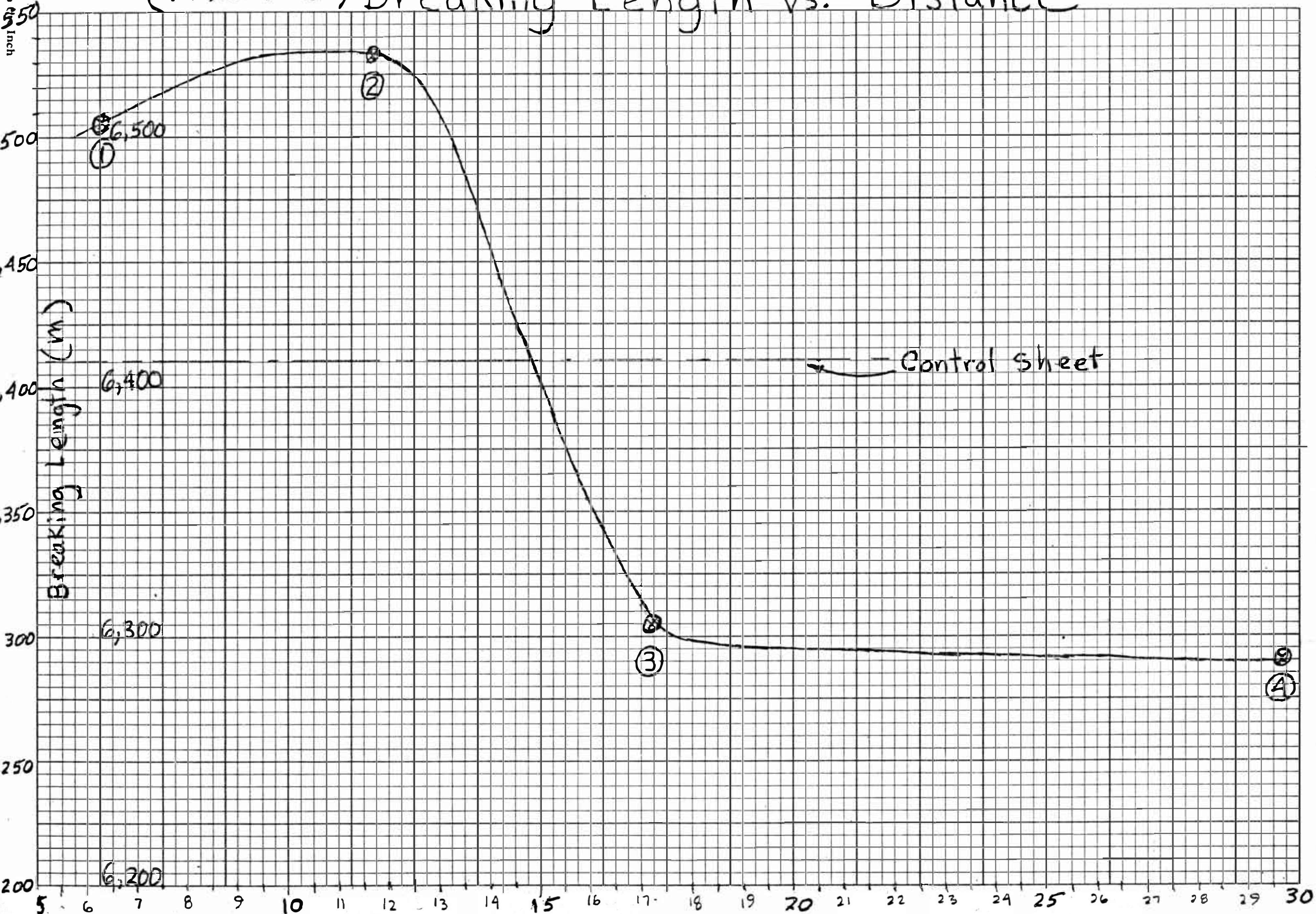
First Test

	C	1	2	3	4
1.	24.5	24.5	24.0	28.0	31.0
2.	24.5	26.7	25.1	29.0	24.2
3.	23.8	29.3	25.9	24.4	29.0
4.	23.0	25.8	27.2	29.8	25.5
5.	22.0	29.2	28.6	26.8	23.0
6.	26.0	28.0	26.0	27.5	23.0
7.	22.0	25.5	30.4	25.6	23.3
8.	23.9	27.2	24.2	24.3	23.0
9.	22.0	28.0	28.0	31.0	27.0
10.	25.0	25.0	29.0	29.9	26.8
Avg.	23.7	26.9	26.8	27.6	25.6

Second Test

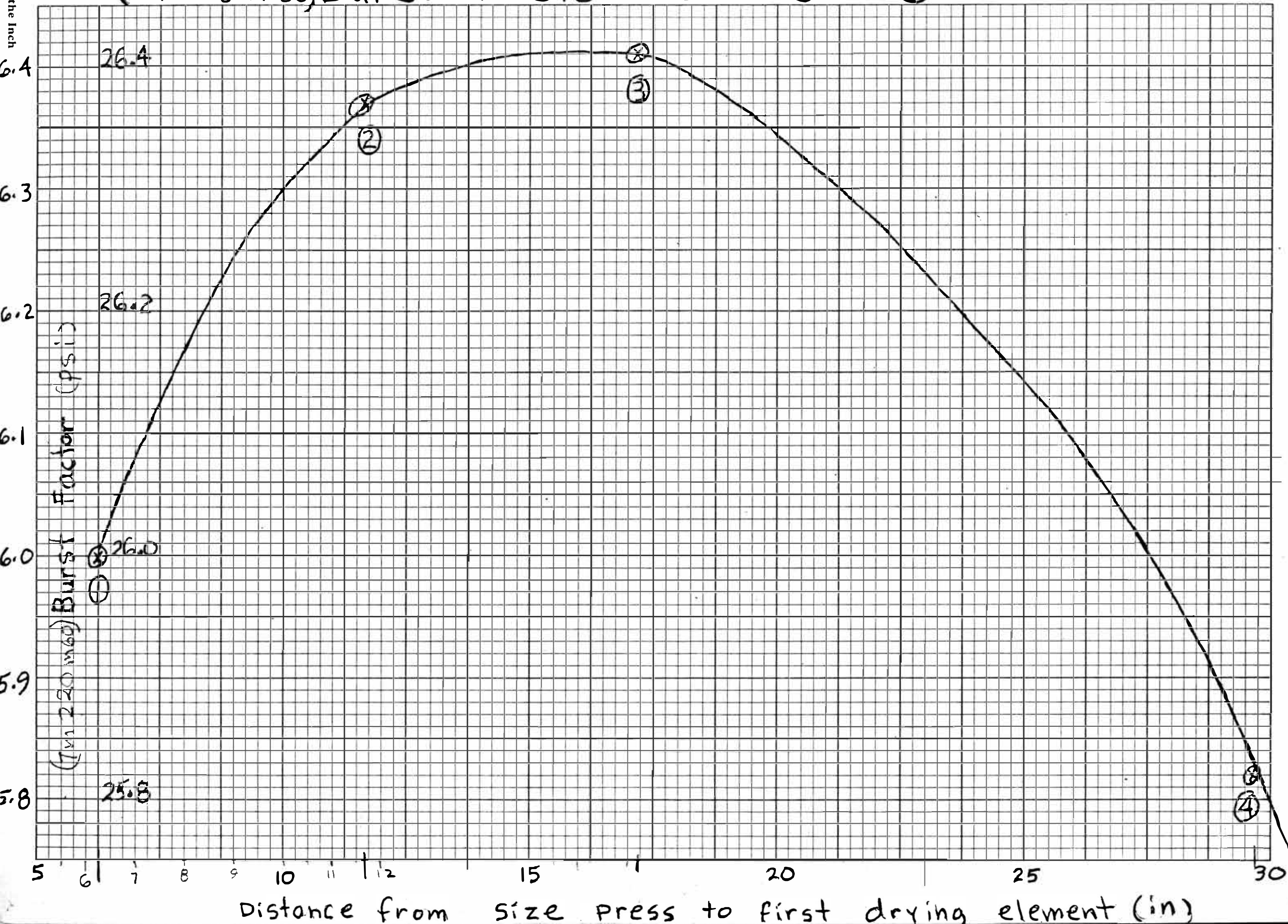
	C	1	2	3	4
1.	20.0	25.5	26.0	29.6	25.6
2.	22.5	23.0	27.5	24.5	26.1
3.	26.6	27.0	24.5	29.5	22.0
4.	20.6	25.6	29.5	24.5	24.2
5.	22.0	21.2	24.0	27.0	26.0
6.	26.9	26.0	24.0	23.6	23.1
7.	24.0	23.0	27.1	27.0	29.0
8.	26.4	26.6	26.6	25.5	27.4
9.	23.0	25.9	26.0	27.0	27.6
10.	22.0	29.0	23.0	23.6	24.5
Avg.	23.4	25.3	25.8	26.1	25.6

(T220 m-60) Breaking Length vs. Distance *

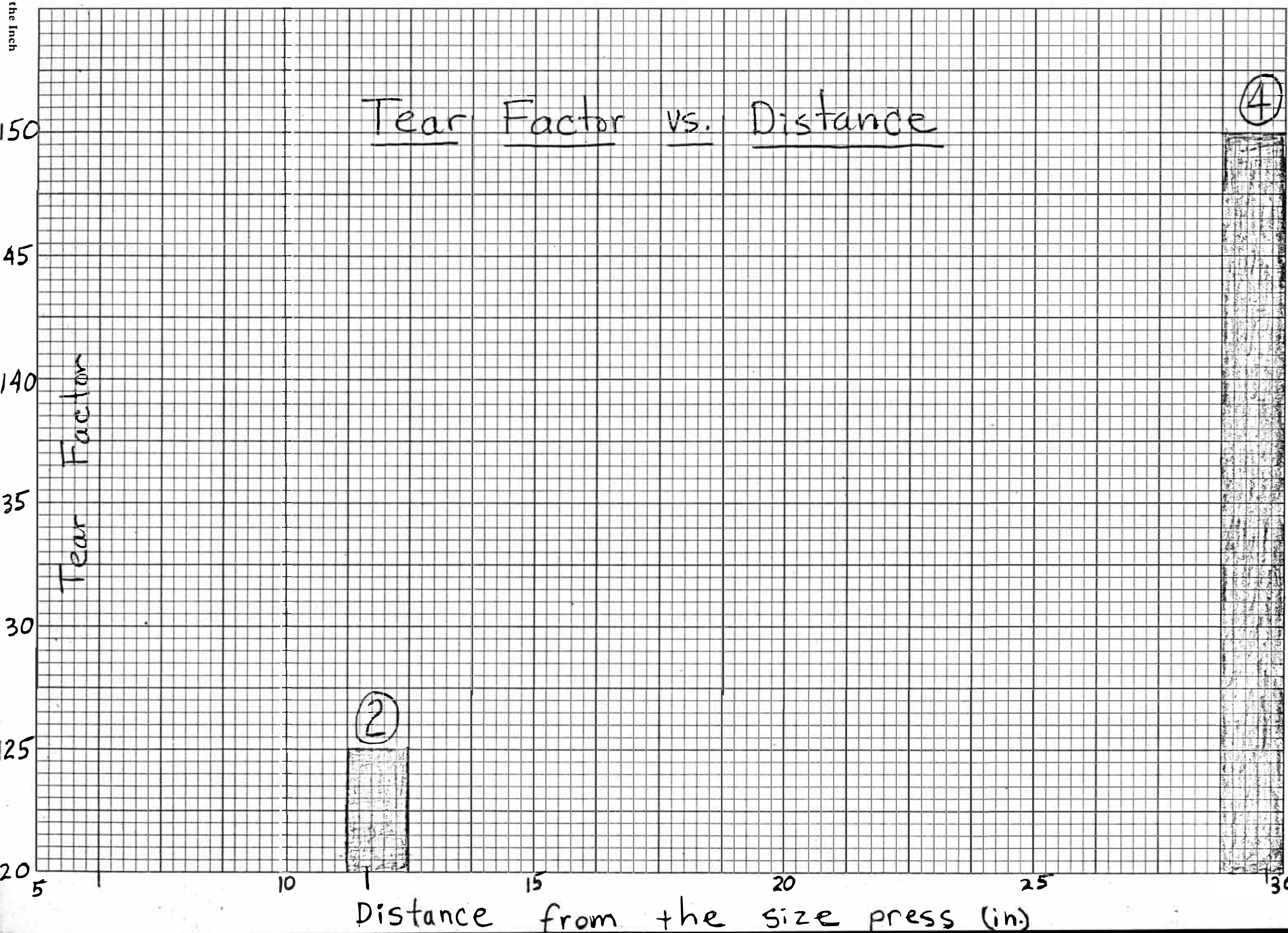


* Distance from size press to first drying element (in.)

(T 220 m-60) Burst Factor vs. Distance



Tear Factor (T220 m-60)



IV. Discussion of Results

Although the differences in tensile and Mullen are quite small, a brief statistical analysis shows that they are significant. The standard deviation for the tensile strength on the control sheet is + 0.58 lb./15 mm. The maximum difference between runs in the first testing is 1.2 lb./15 mm. This difference is 2.06 standard deviations which means that 5% of the time the difference in physical strength can be explained by variations in the control sheet. 95% of the time it is due to other factors, which must be starch pickup or penetration. Since the starch pickup or penetration. Since the starch pickup did increase between run 1 and run 2, the values for runs 2 and 4 were chosen for more detailed study because they had identical starch pickup. One might argue that run 4 showed a drop in strength because it had the lowest basis weight. This fluctuation in basis weight, however, was adjusted for in the burst and tear factor computation. This means that 95% of the time the difference in strength was due to a difference in penetration.

Accordingly, reference was made to the Forest Products article to find tests which would show dramatically a difference in penetration. Their report stated that air resistance, tear, and opacity are significantly affected. They found that air resistance decreased as the degree of penetration increased. The results of this thesis of 253 seconds for run 2 and 1,070 seconds for run 4 suggest that penetration is deeper in run 2. N o significant conclusion can be drawn from the opacity since the difference is almost equal to the reading uncertainty of the opacimeter used in the testing.

The above tests suggested that penetration is deeper in run 2. An attempt to verify this was made by microtoning the sheets into 15 micron sections and staining with dilute iodine. This method again suggested that penetration was deeper in run 2, however, the results of this test should be verified by Hartman's (10) method.

V. Conclusions

The results of this thesis indicate that strength properties are maximum at relatively short dwell time. Tear and air resistance are effected more significantly than breaking length and burst factor. Penetration is deepest where burst factor and breaking length are the highest. It is most difficult to explain why penetration would be deepest at a short dwell time, on the basis of the previous equation (page 4). This would suggest that penetration would increase to a maximum if dwell time was increased indefinitely. The results suggest that the mechanism involved is much more complex than defined by the previous equation (page 4). The other factors which must be considered are the fact that infrared drying was used and the same migration theory proposed by Lee (9) will not necessarily hold true. Temperature is also competing with surface tension and viscosity. Initially coming out of the size press the starch has a higher temperature, lower surface tension and lower viscosity. If the decrease in viscosity overrides the decrease in surface tension, a deeper penetration would be expected.

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