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The Effects of Variables on the Penetration and Pickup of Starch Applied at the Size Press

Leonard O. Eklund
Western Michigan University

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ABSTRACT

A literature research is presented concerning the pickup and penetration of starch at the size press. The literature research indicates there is very little quantitative results in this area. The objective of the experimental work is to determine the effect of starch temperature, sheet moisture, and machine speed on the penetration of starch into the sheet. The depth and quantity of penetration was obtained by using a spectrophotometer to determine the concentration of starch in microtomed samples.

The experimental results indicated that increased temperature of starch solutions and increased machine speeds increases penetration. Penetration also increases with increasing moisture content of the paper but only to an optimum moisture content. The effects of penetration and pickup on physical and optical test results are also discussed in the discussion section .

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To appreciate a paper written on the subject of sizing, it is first important to understand the reasons for sizing. The two broad categories would be to (1) improve the physical tests of the paper and to improve the surface of the sheet. The numerous reasons included in the above two categories include (2) the improvement of ink resistance, erasability, surface finish, water proofing, strength, and the reduction of wrinkles and cockles. More recently (2) the use of sizing as a base for subsequent coating, correction of color, two-sideness and actual coating has become more prevalent.

A good definition of sizing should include ways of correcting or minimizing the reasons for sizing. One such definition of surface sizing is (3) a treatment applied to the paper surface to improve finish, produce a surface better suited to printing, minimize scuffing, control densometer, prevent excessive or undersirable penetration of other finishing agents, decorate or improve appearance, and improve strength characteristics. A size would be expected to provide satisfactory fulfillment of the sizing objectives. One source defined size as (4) any chemical, other than bleach, fillers, pigments and dyes which are added to the papermaking furnish or subsequently applied after the web is formed, which alter those characteristics of the sheet that

relate to the transudation or absorption of liquids which come into contact with the web. This paper is interested only in the surface size, its pickup, and its penetration.

The theory of penetration, in most of the literature researched on this aspect (5) (6) (7), begins with the following formula:

$$l^2 = \frac{r\gamma \cos\theta t}{2u}$$

where
- l = depth of liquid penetration in cm.
- r = paper pore radius in cm.
- γ = surface tension of liquid in dynes/cm.
- $\cos\theta$ = cosine of angle taken by liquid in contact with solid
- t = time of penetration in sec.
- u = coefficient of viscosity in poises

The above formula for theory of penetration can be used to estimate the depth of penetration. The accuracy of this value for depth of penetration is unknown because there has been no quantitative experimentation in this area.

Penetration and the pickup of size are dependent upon the variables of the Size Press, sheet, size and the secondary variables of the paper machine. These variables will be discussed below as to how they are felt to affect the penetration and the pickup of size.

The two basic size presses are the horizontal and the verticle. In the verticle size press the rolls are placed in a verticle column with one movable roll to adjust nip pressure. A shower pipe sprays size into a pocket formed by the downward sloping sheet and the top roll. The horizontal size press has the rolls placed in a horizontal arrangement. A spout at the center with runoffs at the ends of the rolls. The sheet may be and usually is sized on both sides with the horizontal press. If it is desired to apply size to only one side of the sheet, (2) water is usually applied to the other side to counteract the moisture addition in the size. Experience indicates (8) that it is possible to apply heavier coatings with the horizontal press because the depth of the pond in the verticle press is very small so that any tendency to force the size into the sheet is due purely to absorption and such velocity pressure as can be built up in the nip. The horizontal press has a nip which is completely submerged and also subjected to a hydrostatic head.

The roll loading, diameter, crown, and hardness are other variables of the size press equipment. The higher the nip pressure (8) the less the amount of size pickup as the size is more effectively squeezed out, and the larger the roll, the more nip pressure

must be applied in order to squeeze out the same amount of size. The crowns are kept to a minimum and as the rubber covered roll is made softer, there will be a tendency (2) toward more size pickup due to the wider nip line which effectively reduces the contact pressures. Also the contact time varies directly with size pickup and penetration. By varying the angle of the sheet in the verticle press, this contact time can be varied.

The variables of the sheet which affect size pick-up and penetration are its moisture, density, internal sizing, and smoothness. The optimum moisture content for maximum absorption of size is realized when (3) (8) (9) the moisture is between five percent and twelve percent. At levels (3) both below and above this, less size is picked up by the sheet as it goes through the press. Sheet density (8) reduces the ability of the sheet to absorb as the density increases. This is due to the denser sheet reducing the size of the pores and therefore the capillary action. Usually the higher the smoothness the lesser the size pickup because (3) the sheet with protruding fibers will actually act as wicks for the size. The more internal sizing (2) (10) in the sheet the less sizing will be picked up at the size press probably due to the internal size filling some of the pores of the paper and thus preventing

as much capillary action.

The main size variable other than the type of size is the viscosity of the size. Starch is the type of size considered in this paper and will be kept constant. Size penetration varies inversely as the square root of viscosity in the previously written forumla. The less the viscosity (3) the greater the size pickup. The degree of polymerization would have an effect of varying viscosity. By lowering the degree of polymerization the viscosity can be lowered and as a consequence, the penetration can be increased.

The paper machine variables produce an effect by changing some of the previous variables mentioned. Therefore increasing the machine speed would decrease the dwell time and as previously stated, decrease the starch pickup and penetration. The temperature at the machine will probably have the effect of changing the viscosity of the size and therefore changing pickup and penetration. Previous pressing on the machine will effect the moisture content, density, and sheet surface. Previous drying will affect the moisture content. These secondary variables affect the previous variables mentioned, and for the reasons given for the previous variables, affect the size penetration and size pickup.

The large tonnage of starch has been made possible through the remarkable versatility of this raw material which permits its use in many different points in the papermaking process. Another important factor is the economics of starch usuage. It is cheaper than some pulps (11) and most grades of paper which often means that the cost of starch is more than off-set by the cost of the fiber it replaces. Starch applied at the size press increases the strength (12) of the paper, especially the surface strength, and smooths the sheet. Ink receptivity decreases as the amount of starch size (13) is increased. Starch sizing therefore performs as a versatile, economic size and it provides the characteristics necessary of a good size.

The main variables of a starch are its type or source (12) and its method of conversion. Corn starch is used extensively in the United States because of the abundance of corn and the economy of using it. Oxidized starches are being used principally because (14) they are whiter in color, and when compared to common starch, gelatinize at lower temperatures, have a shorter cooking time, and give pastes with greater clarity, increased adhesiveness, decreased viscosity, and lower rates of congealing.

The usual methods for identification and analysis of starch in paper describes only its presence, general character and amount (15) and tell nothing of the form, structure, distribution or relation to fiber or other materials. Lee's work consisted of experimentation and his conclusions are based on this experimentation rather than on theory or past experience. His procedure consisted of taking photomicrographs of sections of the sheet which had been stained. His results showed that the dryers can cause extensive migration to the surface, the starch does not form a continuous layer, and starch (15) does not penetrate the fibers. It bonds to the fibers in the spaces between them. Penetration and pickup were found to vary with the quantity of starch applied and the amount of previous sizing.

Dappen performed an experiment to determine the distribution of starch in coating on paper. He found it difficult (16) to specify the exact depth of penetration because of the paper surface being a series of hills and valleys. He gave a good (10) photocolorimetric procedure for determining the quantity of starch in a section.

The quantitative work in the area of starch penetration has been very limited. The two quantitative projects listed above do not relate directly to pene-

tration of starch into the sheet. The basis for penetration of starch into the sheet has been explained either by theory or by conclusions drawn from experience. The efforts of this research report are to (1 explore past articles written on penetration to determine what had been done, (2 to provide a basis for the determining of effects of variables on size pick-up and penetration, and (3 to emphasize the necessity of future work in this area primarily because of the lack of previous work done.

Laboratory Procedure

Introduction

The main objective of the laboratory procedure and testing is to extend and obtain more data on John Hartman's (17) previous research in the area of starch penetration and pickup at the size press. The procedure for microtoming the samples is essentially the same as Mr. Hartman's (17). The procedure followed in starch determination is the same as the one outlined in T.A.P.P.I. (18) with changes (17) made only in concentration due to the small amount of starch in the sample.

Microtome Sample Cutting Procedure:

The samples are cut into sections parallel to the surface of the sheet. They are cut on a Spencer Mudd sliding type microtome.

1) Insert the knife in the knife holder and adjust the screws to give the desired tilt and clearance angle.
2) Place a pine block with one-half by one-fourth inch dimensions on the microtome sample holder. A second block is mounted behind the first block so that the sample block will be under a uniform mounting pressure.
3) The sample block is made smooth by taking several thin cuts until the blade is parallel to the block. A final cut of two microns is then made to complete the smoothing.
4) Samples of paper are cut from the sheet of paper to be tested. These samples should have dimensions slightly smaller than the dimensions of the block.
5) Duco Cement is used to hold the paper to the block.
6) A second pine block is used to spread the cement over the surface of the block.

7) A smooth glass plate weighted with a two-hundred gram weight is placed on the sample to bond the paper to the block and to keep the sample smooth. The weight is left on for seventy seconds.
8) After removing the weight and glass, an asbestos template is placed over the wood block to shield the microtome parts from heat, and to reduce expansion of the parts. An infrared lamp is placed about one-half inch from the sample and turned on for seventy seconds to dry the glue.
9) The samples are then sectioned into four sections ten microns thick. The four sections are then placed in separate crucibles with a camel's hair brush.
10) The same procedure is then followed for the next sample.

Determination of Starch in Paper

Apparatus:

1) Disintergrator
2) Centrifuge - fifty milliliter capacity
3) Fritted glass filters - fifty milliliters
4) Spectrphotometer
5) Suction flask - five-hundred milliter with three-

way cock.

6) Other equipment- fifty, one hundred, and five-hundred volumetric flasks; twenty-five and two and one half milliter pipete, hotplate.

Reagents:

1) Hydrochloric acid - concentrated, one to one, and one to ten ratios
2) Potassium iodide- iodine reagents- seven and one half grams potassium iodide and five grams iodine per liter. Dissolve the mixture in ten milliliters of water first and then dilute to one liter. Dilute one to fifty for use.
3) Cotton linters

Test Specimen:

1) A one gram sample of a representative experimental paper is first used to determine the moisture content of the paper. Samples of twenty to forty milligrams are then used in the starch determination

Procedure:

1) Place the specimen into the disintegrator with thirty plus or minus ten milliliters of distilled water.
2) Transfer quantitatively to a two hundred and fifty milliliter beaker, rinsing with enough water to make the total volume one hundred milliliters.
3) Heat to just below boiling on a hot plate for fifteen minutes.
4) Transfer the contents of the beaker to a suction crucible and wash with ten to twelve milliliters of hot water.
5) Turn the threeway cock to cut off suction and blow gently into the tube so as to create a slight back pressure in the flask and then turn the cock to cut off suction.
6) Add twelve and one-half milliliters of one to one hydrocloric acid to the filtering crucible and allow to stand for one hundred and seventy-five to one hundred and eighty seconds. Then apply suction.
7) Repeat steps five and six.
8) Apply back pressure and add twelve and one-half

millilters of concentrated hydrochloric acid, allowing to stand nineteen to twenty seconds.

9) Reapply suction and twirl the flask to mix the hydrochloric acid in the filtrate.

10) Wash the residue with about one-hundred millileters of hot water.

11) Test for completeness with dilute iodine solution- if any blue color appears repeat the extraction.

12) Transfer the starch solution to a two-hundred milliliter flask, cool to room temperature, and dilute to the mark with water.

13) Mix thoroughly and centrifuge fifty milliliters for ten minutes.

14) Place one-hundred milliliters of the clear liquid into a one-hundred milliliter volumetric flask, pipet milliliter of the potassium iodide- iodine reagent into the flask.

15) Measure the absorbance at five-hundred and eighty millimicrons against a reference solution prepared by diluting ninety-five milliliters of one to ten hydrochloric acid and one milliliter of potassium iodine reagent in a one-hundred milliliter volumetric flask.

16) Read the starch concentration from the calibration curve.

Calibration Curve

1) Weigh one-hundredth of a gram of starch corrected for moisture and ash and transfer to a two-hundred and fifty milliliter beaker adding one hundred milliliters of distilled water.
2) Heat solution for fifteen minutes just below the boiling point, add two hundredths of a gram of cotton linters, and repeat the heating procedure.
3) Decant with suction through the coarse fritted glass filter, wash once with hot water and refilter the water through the mat.
4) Follow steps four through thirteen in the starch determination procedure above.
5) Remove aliquots to prepare the calibration curve.
6) Follow steps fourteen and fifteen in the starch determination procedure above to prepare the calibration curve.

MACHINE RUN DATA TABLE

	Starch Solids	Starch Temp.	Dudley Viscosity	Moisture Content	Sheet Temp.	Machine Speed	Nip Loading	Dryer Temp.	Consumption lbs./ream
1)	11.65%	130	83 sec	2.89%	195	250 fpm	18 psi	210-210	.689
2)	11.56	140	71	2.89	195	250	18	210-210	2.42
3)	11.65	147	64	2.89	190	250	18	210-210	4.74
4)	11.65	140	67	6.68	190	250	18	215-215	1.84
5)	11.65	140	67	3.04	200	250	18	215-215	3.16
6)	11.65	140	67	2.89	150	100	18	215-215	.615
7)	11.65	140	67	2.89	185	400	18	215-215	4.01

Starch Cook 1-3

starch cook: 232

steam flow: 27%

100 cc Pulronic defoamer

Starch Cook 4-7

starch cook: 234

steam flow: 27%

130 cc Pulronic defoamer

Base Sheet Characteristics

1) 85% Jack Pine

2) 15% Broke

3) Small amount of internal rosin size

WMU SIZE PRESS PROJECT 1965
Physical and Optical Test Results

Summary

Run No.	(1)	(2)	(3)	(4)
O.D. Basis Wt. (g/m^2) (Moist. Free)	72.4	72.4	72.3	73.1
Tensile M.D.	19.0	20.5	22.4	22.0
Tensile C.M. (#/15mm)	11.4	11.8	11.7	10.1
Breaking Len. (M.D., in M)	7,940	8,570	9,540	9,110
B.L. C.M. (in M)	4,760	4,930	4,890	4,170
Fold M.D.	430	376	318	327
Fold C.M. (MIT)	444	302	297	302
Tear M.D. (Tappi Corr.)	85.4	87.5	87.9	88.6
Tear C.M.	95.7	99.1	96.9	103
Mullen (Tappi Corr.)	37.4	41.7	38.4	38.7
Stiffness M.D. (Gurley)	4.73	5.43	5.40	5.3
Stiffness C.M.	2.92	3.48	3.20	2.8
Brightness W.S. (I.P.C.)	80.0	80.2	79.7	80.0
Brightness Felt Side	81.7	81.8	81.0	81.5
Opacity	87.5	88.0	87.0	88.0
Gloss W.S. (B & L%)		15	14	14
Gloss Felt Side	15	14	13	13
Starch Pick-up %	1.53	5.14	9.62	3.92

WMU SIZE PRESS PROJECT 1965
Physical and Optical Test Results

Summary (cont.)

Run No.	(5)	(6)	(7)	Control
O.D. Basis Wt. (g/m^2) (Moist. Free)	74.0	73.5	74.1	66.6
Tensile M.D.	22.4	22.1	22.5	[illegible]
Tensile C.M. (#/15mm)	9.7	9.1	10.6	[illegible]
Breaking Len. (M.D., in M)	9,150	9,100	9,180	7,446 meters
B.L. C.M. (in M)	3,970	4,080	4,330	4,264 meters
Fold M.D.	447	312	416	112
Fold C.M. (MIT)	471	284	417	63
Tear M.D. (Tappi Corr.)	87	93	82	140
Tear C.M.	103	112	94	155
Mullen (Tappi Corr.)	37.4	40.1	42.3	25.9
Stiffness M.D. (Gurley)	5.5	5.8	4.8	4.4
Stiffness C.M.	2.8	3.1	2.6	2.7
Brightness W.S. (I.P.C.)	80.0	79.8	79.3	81.4
Brightness Felt Side	81.2	81.2	80.8	82.8
Opacity W.S. (Tappi)	88.0	88.0	87.0	89
Opacity Felt Side	88.0	88.0	87.0	90
Gloss W.S. (B & L%)	14	12	17	8
Gloss Felt Side	14	13	16	7
Starch Pick-up %	6.61	1.36	8.25	-

MICROTOME SAMPLES

Run #		Absorbance	mg. Starch	mg. O.D. Paper	Av. of W & F % Starch
1	F-1	.047	.68	15.1	4.64
	2	.030	.32	7.61	4.22
	3	.031	.34	11.8	3.38
	4	.040	.536	15.6	3.01
1	W-1	.034	.4	8.37	
	2	.031	.34	8.0	
	3	.031	.34	8.3	
	4	.022	.14	6.76	
2	F-1	.025	.21	20.4	1.73
	2	.020	.10	23.1	.856
	3	.017	.03	9.65	1.03
	4	.017	.03	7.14	1.00
2	W-1	.032	.36	12.5	
	2	.026	.226	15.0	
	3	.023	.17	9.7	
	4	.021	.12	7.85	
3	F-1	.036	.444	21.1	1.835
	2	.026	.226	16.4	1.66
	3	.022	.140	6.56	1.62
	4	.022	.140	8.65	.861
3	W-1	.026	.226	15.4	
	2	.024	.186	8.37	
	3	.026	.226	15.4	
	4	.017	.03	11.1	
4	F-1	.034	.4	15.6	2.04
	2	.019	.08	7.6	.849
	3	.017	.03	7.32	.38
	4	.017	.03	11.2	.457
4	W-1	.021	.122	10	
	2	.018	.056	16.2	
	3	.017	.030	8.45	
	4	.018	.056	7.6	

MICROTOME SAMPLES (cont.)

Run #	Absorbance	mg. Starch	mg. O.D. Paper	Av. of W & F % Starch
5 F-1	.020	.10	7.52	2.06
2	.021	.122	4.94	2.47
3	.022	.14	8.85	1.00
4	.017	.030	7.71	.394
5 W-1	.034	.4	16.8	
2	.037	.47	16.9	
3	.017	.030	8.18	
4	.017	.03	7.52	
6 F-1	.022	.140	9.68	2.03
2	.021	.122	6.72	1.90
3	.017	.03	4.59	1.60
4	.017	.03	4.16	1.04
6 W-1	.024	.186	6.37	
2	.021	.122	6.12	
3	.021	.122	4.92	
4	.018	.056	4.11	
7 F-1	.055	.856	19.3	3.87
2	.045	.680	11.3	5.02
3	.036	.444	7.62	4.25
4	.032	.360	6.09	3.88
7 W-1	.040	.534	16.6	
2	.034	.400	18.2	
3	.027	.256	9.8	
4	.028	.272	10.3	

Example of Run # Symbols

5 F-1 stands for the fifth run - felt side - top 10 micron sample

CALIBRATION CURVE DATA

milliliters starch solution used	starch concentration milligrams per liter	absorbance
2.0	.9136	.026
5.0	2.284	.035
10.0	4.568	.058
15.0	6.852	.081
20.0	9.136	.100
25.0	11.420	.1175

SAMPLE CALCULATIONS OF RESULTS

I. Weight of starch in milligrams for calibration curve:

Weight of air dry starch (g) X % moisture = weight of oven dry starch (g)

.0125 g air dry starch X 8.65% moisture = .01142 g oven dry starch or 11.42 mg oven dry starch

II. Weight of starch per liter for calibration curve:

$$\frac{\text{mg O.D. starch}}{\text{250 ml dilution}} \times \frac{\text{ml aliquot used}}{\text{100 ml dilution}} \times \frac{\text{1000 ml}}{\text{liter}} = \frac{\text{mg O.D. starch}}{\text{liter}}$$

(From 5 milliliter aliquot)

$$\frac{\text{11.42 mg starch}}{\text{250 ml}} \times \frac{\text{5 ml starch sol.}}{\text{100 ml}} \times \frac{\text{1000 ml}}{\text{liter}} = 2.284 \frac{\text{mg starch}}{\text{liter}}$$

III. Weight of starch in microtome sample:

The absorbance reading of the microtome sample can be used to determine the concentration of starch in the sample by taking the coordinate of the absorbance reading from the calibration curve.

$$\frac{\text{mg starch}}{\text{liter}} \times \frac{\text{200 ml sample}}{} \times \frac{\text{1 liter}}{\text{1000 ml}} = \text{mg starch in sample}$$

(From sample 1 F-1)

The absorbance reading of .047 gives 3.4 mg/l starch as the concentration of starch in the sample.

$$\frac{\text{3.4 mg starch}}{\text{liter}} \times \frac{\text{200 ml sample}}{} \times \frac{\text{1 l}}{\text{1000 ml}} = .68 \text{ mg starch in sample}$$

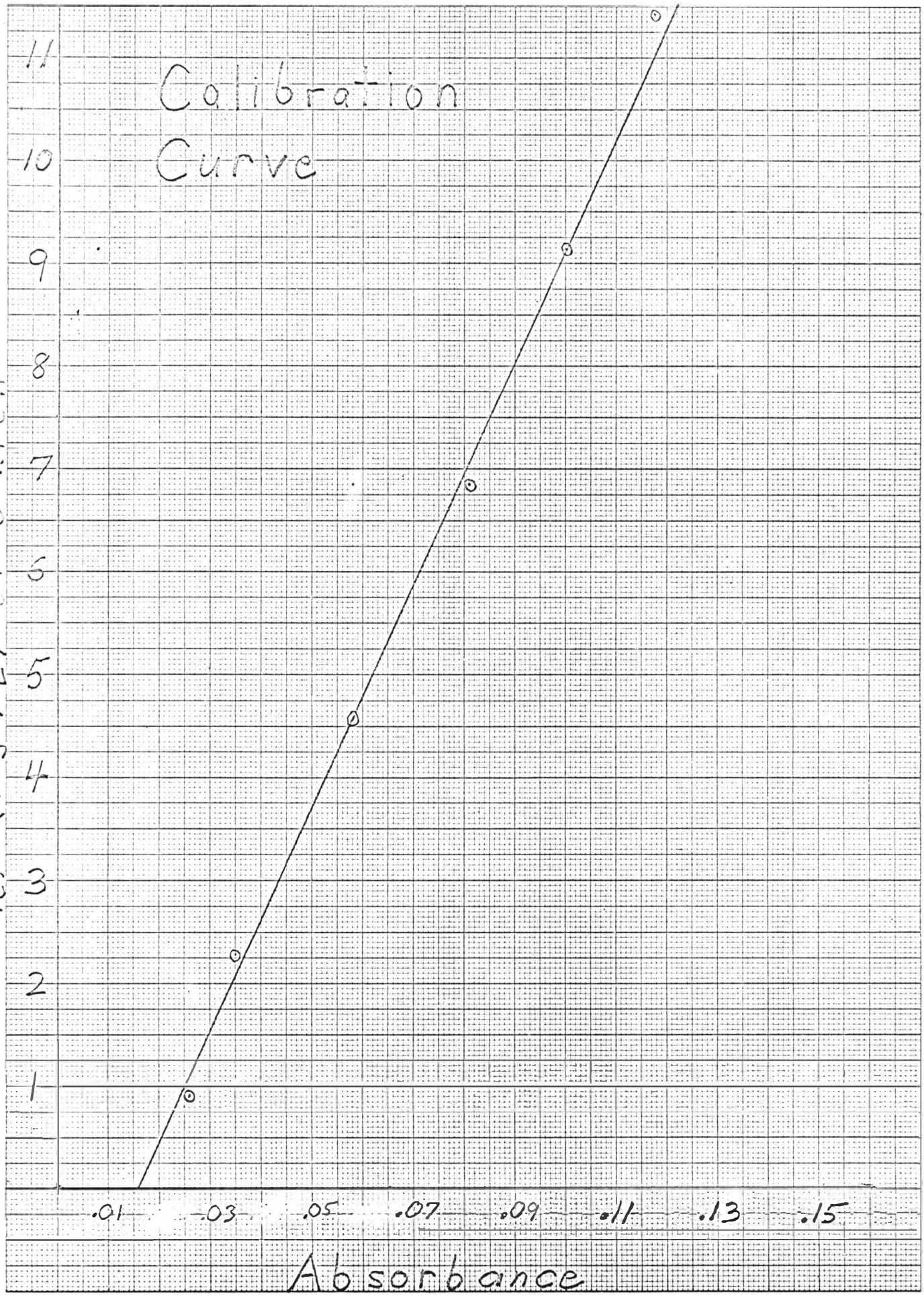
IV. Per cent starch in paper:

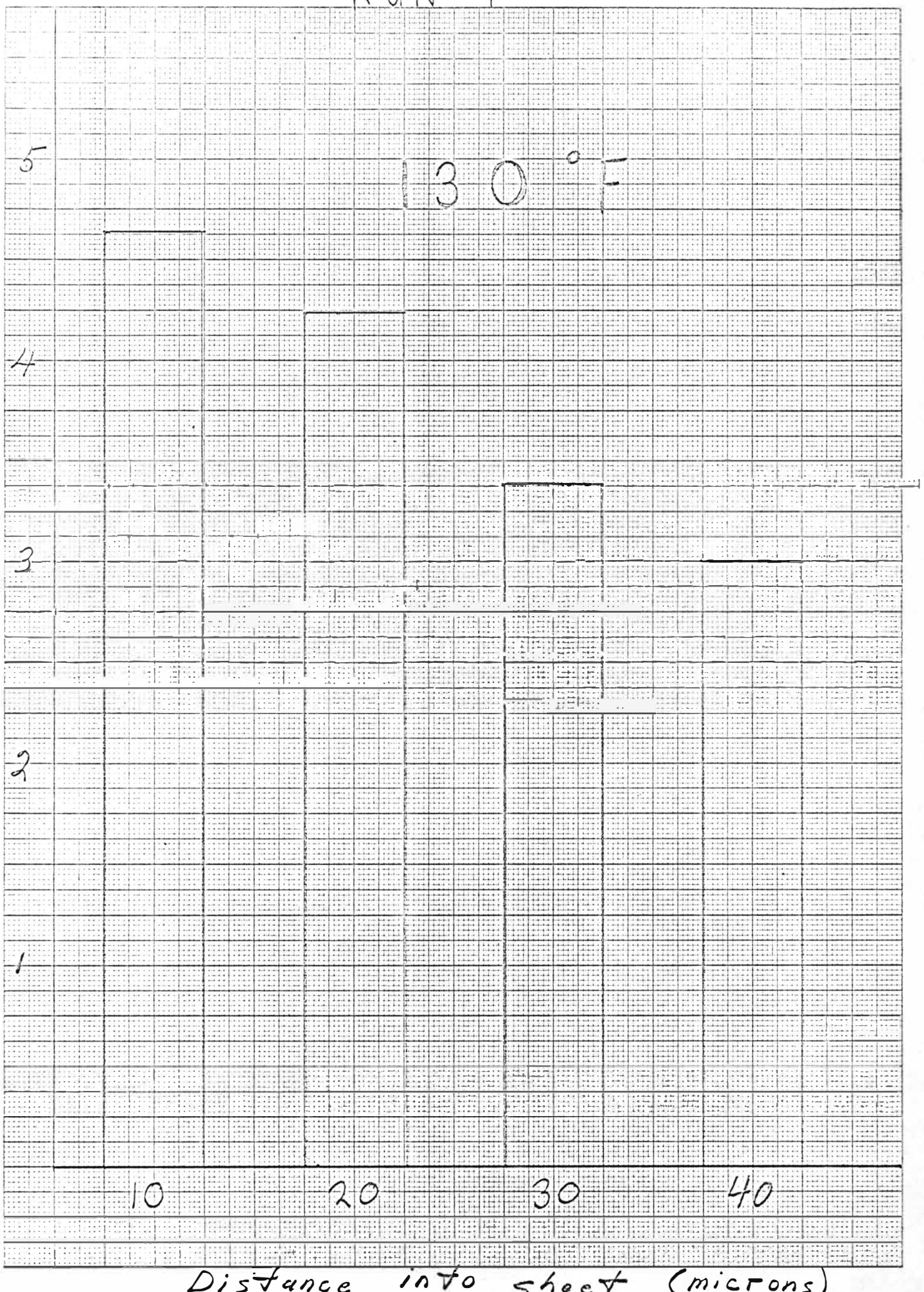
1) Weight air dry paper X per cent moisture = weight oven dry paper

2) From 1 F-1 and 1 W-1 sample

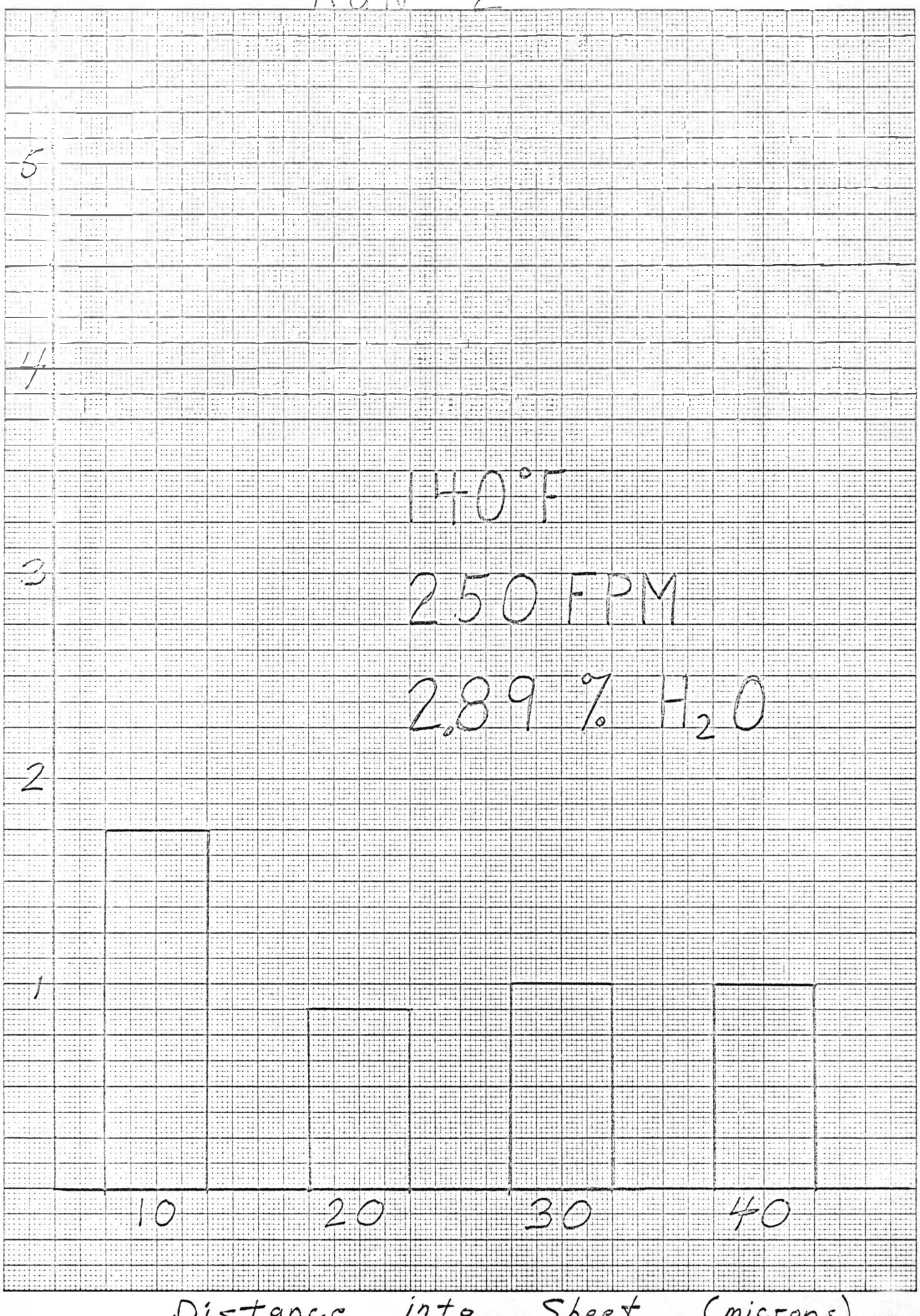
$$\frac{\text{mg starch in 1 F-1} + \text{mg starch in 1 W-1}}{\text{mg paper in 1 F-1} + \text{mg paper in 1 W-1}} \times 100\% = \text{\% starch in paper}$$

$$\frac{.68 \text{ mg starch in 1 F-1} + .4 \text{ mg starch in 1 W-1}}{15.1 \text{ mg paper in 1 F-1} + 8.37 \text{ mg paper in 1 W-1}} \times 100\% = 4.64\% \text{ starch}$$

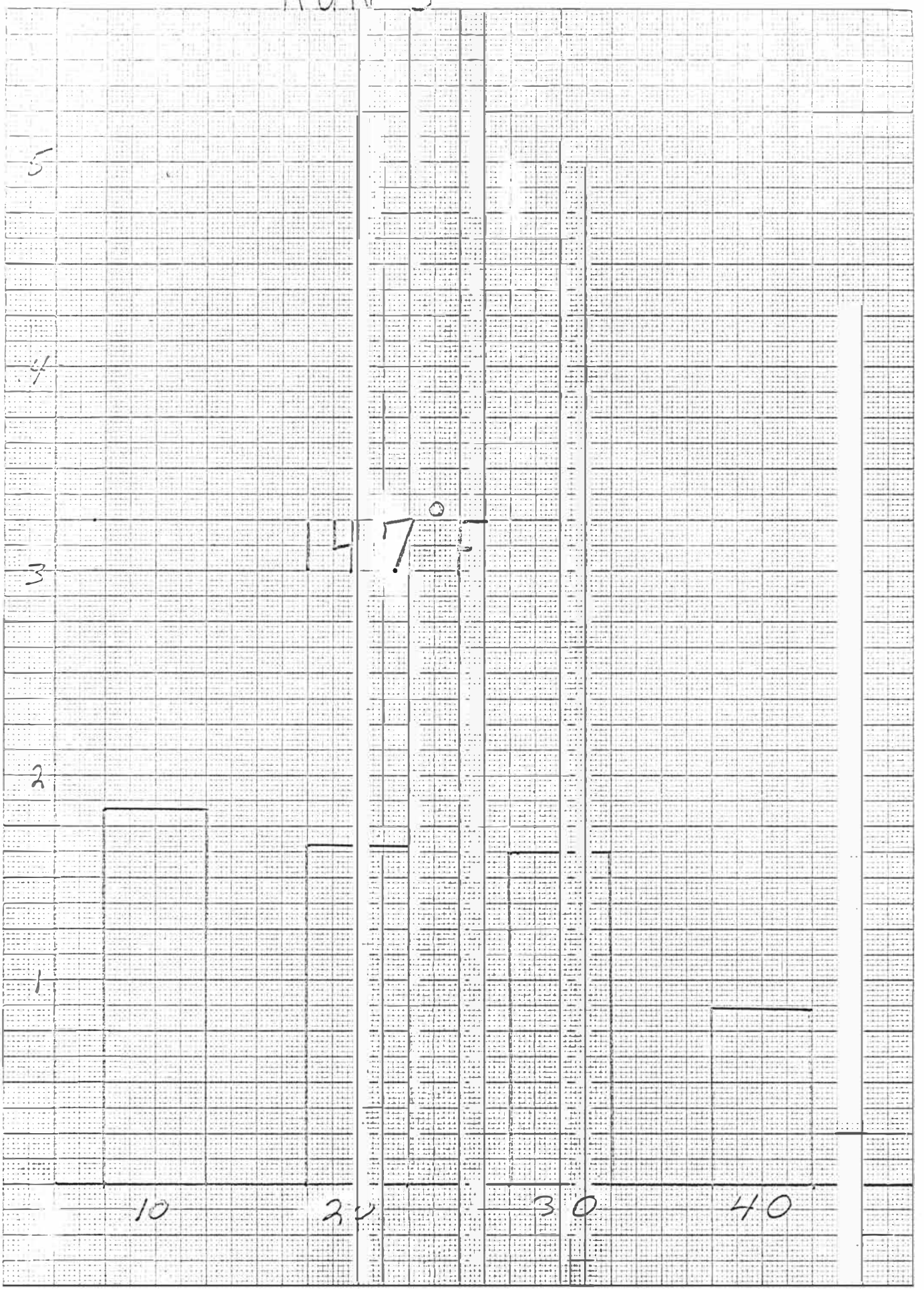

Calibration Curve
Conc. (m.g./L) of Starch
11
10
9
8
7
6
5
4
3
2
1
.01
.03
.05
.07
.09
.11
.13
.15
Absorbance



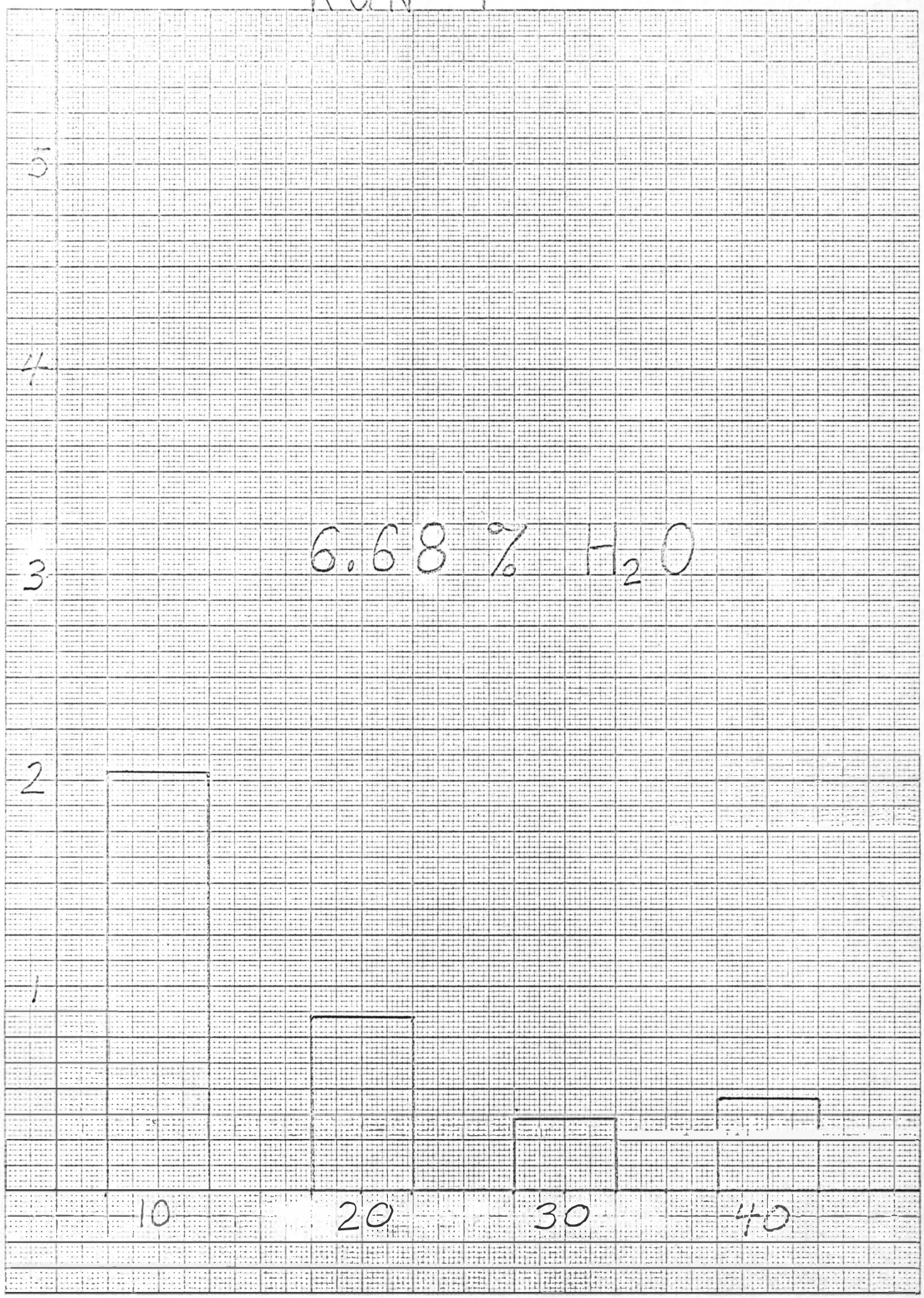
RUN 2


5
4
3
2
1
140°F
250 FPM
2.89 % H_2O
% Starch.
10
20
30
40
Distance into Sheet (microns)

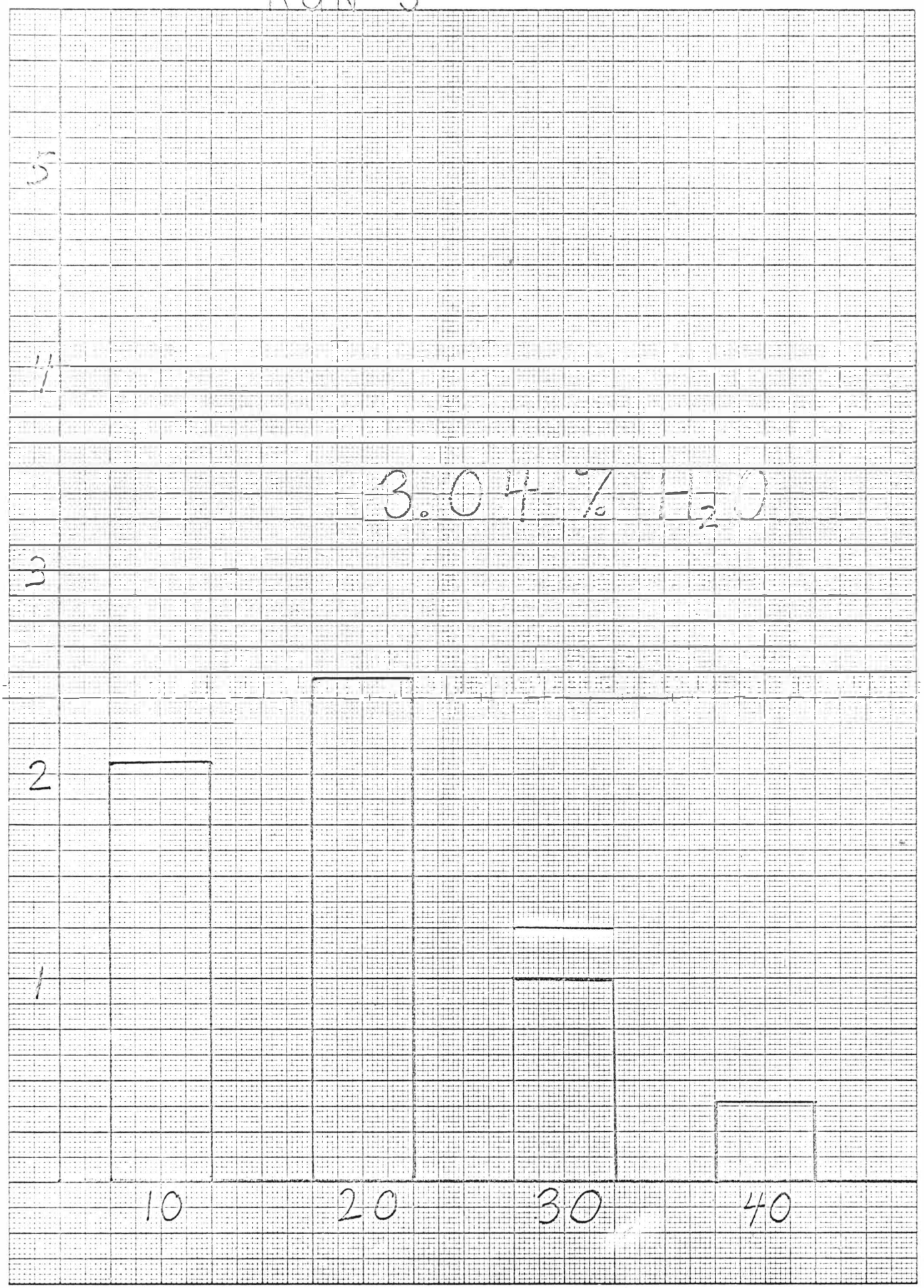
RUN 3



RUN 4



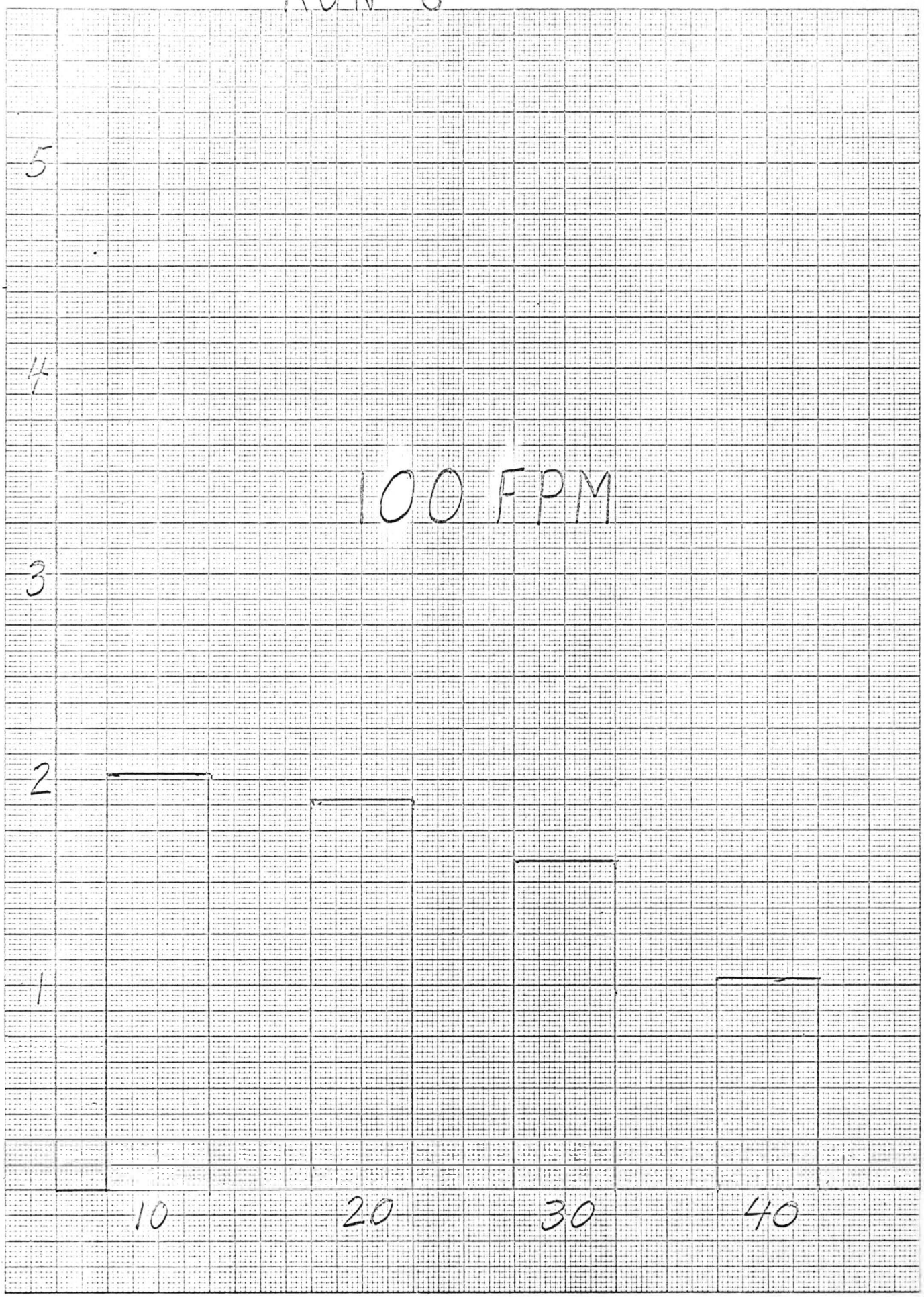
RUN 5



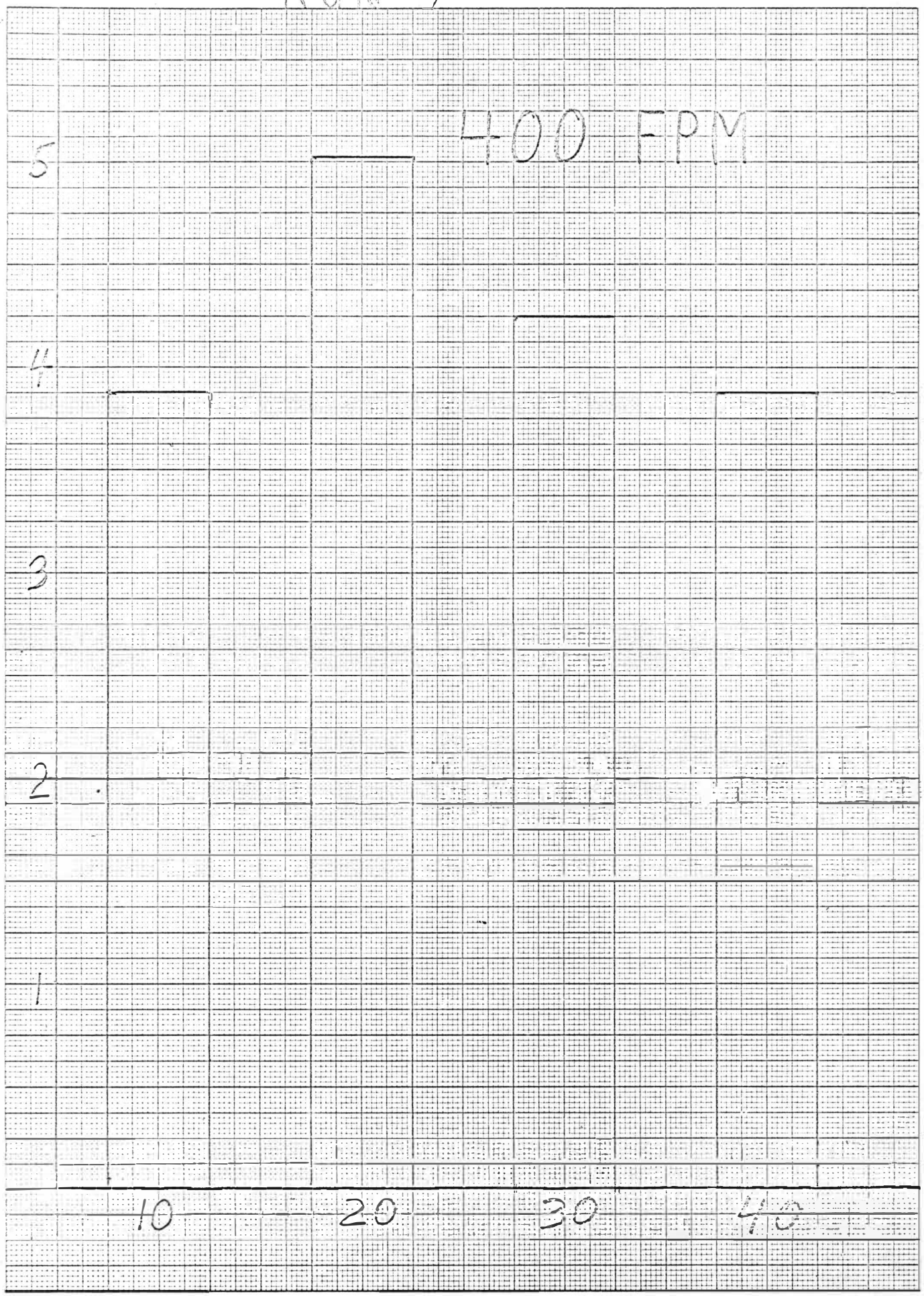
% Starch.

Millimeters to the Centimeter

RUN 6


5
4
3
2
1
% Starch
100 FPM
10
20
30
40
meters to the Centimeter
Distance into sheet (microns)

RUN 7



imeters to the Centimeter

DISCUSSION OF RESULTS

I. Relative Penetration and Per Cent Pickup:

The temperature of the starch solutions, moisture content of the sheet, and machine speed were the variables studied for both penetration and pickup of starch. When a variable such as temperature was studied all other variables were held constant. Graphs of per cent starch versus distance into the sheet at the four microtome depths are included. The pickup data for the samples were obtained from the machine runs (19) rather than the penetration data. The penetration data would be difficult to relate to pickup because the total forty micron depth is only approximately halfway through the sheet. Therefore, although the graphs are plotted as percentage starch in each layer, this percentage can only be used to discuss penetration.

1) Penetration and pickup of starch versus temperature of starch solution (runs 1, 2, 3)

From the graphs it can be seen that at the lowest temperature (130°F) there is a larger amount of starch at the surface of the sheet with penetration decreasing almost linearly as the depth into the sheet increases. At 140°F there is still a large amount of starch in the top layer, but the distribution

of starch in the inner three layers is fairly uniform with very good relative penetration. At the highest temperature (147°F) the distribution of starch in the top three layers is uniform with less penetration into the inner layer.

The temperature of the starch solution therefore has a direct effect on the penetration of starch at the size press. As the temperature increases the relative penetration into the paper increases. This can probably be explained by the reduction in viscosity of the starch solution. The equation by Cobb given in the literature research explains this result to some degree. Cobb's equation states that penetration is inversely proportional to the square root of viscosity.

It was also found that as the temperature of the starch solutions increased the pickup increased. The temperature had a very pronounced effect on pickup, ranging from 1.53% at the lowest temperature to 9.62% at the highest temperature. The pickup increase with temperature increase can be attributed to the greater penetration of the starch into the sheet and the reduction of the shearing of the starch off the paper surface at the lower viscosities.

2) Penetration and pickup of starch versus moisture of the paper (runs 2, 4, 5)

The sheet with the lowest moisture (2.89%) contained a large percentage of starch in the first ten micron sample. In the next three sections the starch was fairly evenly distributed, but at a much lower per cent than in the first or top sample. At the median moisture (3.04%) the relative penetration increased to include both the first and second ten micron samples within the greater pickup area. The inner two sections contained less starch, and were comparable to the lowest per cent moisture sample. In the sheet with the greatest moisture (6.68%) the starch concentrated at the surface with the inner two layers receiving very small amounts.

After an optimum moisture content had been reached the penetration decreased as moisture content of the sheet increased, although the opposite was true before this optimum moisture. The optimum moisture content in these samples is somewhere between 3.04% and 6.68% moisture. The moisture in the paper acts as a sponge and provides a medium for the starch to travel into the sheet, but at higher moistures the sponge effect is decreased and the excess moisture acts as a saturation and

concentration gradient which forces the starch to remain toward the surface.

Pickup data was very consistant with the penetration data given above. The amount of pickup at various moisture contents of the sheet therefore seemed to depend primarily on the amount of penetration.

The moisture in the base sheet was increased by applying water to it, therefore the water may show a slight pattern of being more concentrated at the surface due to low penetration. This would give a higher optimum moisture content and would explain the relatively low penetration into the inner two sections because of their lower moisture content.

3) Penetration and pickup of starch versus machine speed (runs 2, 6, 7)

In the lowest machine speed (100 F.P.M.) samples, the starch pickup was greater in the first two sections with penetration decreasing as the depth into the sheets increased. At 250 F.P.M. the first layer received the most starch with the last three layers having uniform penetration. The highest machine speed (400 F.P.M.) showed the best penetration and uniformity.

These results imply that increases in machine speed also increase both the penetration and the uniformity of the starch distribution in the sheet. This can be explained by both the dwell time and the hydraulic effect of the higher machine speeds. At the lower machine speed there was a longer dwell time and the penetration was good in the first two layers. At the higher machine speed the greater penetration can be attributed to the hydraulic effect.

An increase in machine speed also showed a large increase in starch pickup. This is also explained by the hydraulic effect of faster speeds pulling the starch onto the sheet.

II. Pickup and Penetration of Starch Versus Physical and Optical Test Results:

Tensile, fold, and mullen test results all showed that as starch pickup increased test results increased. These tests also showed starch on the surface increased test results much more than starch which had penetrated into the sheet. The burst can be explained by surface film properties. The starch would increase the density of the surface and the film properties therefore increasing the mullen. The tensile and fold would be increased mainly by

the bonding of the starch to the fiber surfaces.

Stiffness also increases with increasing pick-up and with high starch concentration on the surface. Starch is less flexible than fibers therefore increasing the stiffness. Also the more starch bonding and concentration on the surface, the stiffer the paper should be because the starch will prevent the bending of the fiber more if it covers the entire fiber surface.

Tear decreases as starch pickup increases and decreases as starch penetration increases. This is reasonable because tear decreases with increased bonding.

Brightness, opacity and gloss stay fairly constant, but at higher starch pickup they usually decrease. There is no outstanding correlation between penetration and opacity, but gloss increases slightly with higher penetration.

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