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THE EFFECT OF SURFACE TENSION
AND VISCOSITY ON WET-WEB STRENGTH /

by

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A Thesis submitted to the
Faculty of the Department of Paper Technology
in partial fulfillment
of the
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I wish to express appreciation to Dr. R. A. Diehm
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C

ABSTRACT

A study of the effects of surface tension and viscosity on wet-web strength shows that they are related. Hand sheets were made and pressed on the Noble and Wood Sheet Mold. Tests were run on sheets with solids varying from 18 to 28 percent. The Instron Tensile Tester gave more consistent results for wet-web testing than did the Brecht Tester. Carboxy propyl methyl cellulose, a cationic starch, oleic acid, and sodium hydroxide were used to vary the surface tension and viscosity of the entrained water in the web. It was found that as the surface tension was lowered, the wet-web strength went down, and that an increase in viscosity also lowered the wet-web strength.

TABLE OF CONTENTS

INTRODUCTION -----	1
HISTORICAL BACKGROUND AND DEVELOPMENT -----	2
Factors Influencing Wet-Web Strength -----	2
Background Work -----	2
Fiber Bonding -----	3
EXPERIMENTAL DESIGN -----	4
General Introduction -----	4
Preparation of Materials -----	5
Sheet Formation -----	6
Testing of Wet-Web Strength -----	6
Measurement of Viscosity and Surface Tension -----	7
DISCUSSION -----	8
Extrapolation of Data -----	8
Surface Tension Effects -----	8
Viscosity Effects -----	9
CONCLUSIONS -----	10

INTRODUCTION

The initial web strength or the so-called wet-web strength has been approached from two different application view points. First, it has been used as a method to study the paper making process with the final goal being its application to production control. It is known that the strength and general flexibility of the sheet as it passes from the wire to the dryer section are major factors in influencing the efficient operation of the manufacture of light weight grades of paper. For this reasons its application to production control is of extreme importance. Secondly, this measurement of wet-web strength has been used as a research tool for the study of the mechanisms of the strength development and fiber bonding in the sheet of paper.

HISTORICAL BACKGROUND AND DEVELOPMENT

Factors Influencing Wet-Web Strength

The behavior of the wet-web is measured by the ability of the sheet to withstand stresses and strains. These factors, as defined by McCullum (4), fall into five major groups:

1. Mechanical factors.
2. Formation and basis weight uniformity.
3. Intrinsic strength of the pulp.
4. Properties of the liquid phase.
5. Drainage capacity of the machine and drainage properties of the pulp.

It is the purpose of this paper to evaluate the properties of the liquid phase in the wet-web strength and try to maintain the first three of the above mentioned properties as constant as possible. It should be noted that by changing the physical properties of the liquid phase the drainage rate will also be changed. The liquid phase properties are influenced by the amount and type of chemicals in solution and by the temperature of that phase.

Background Work

The ground work for wet-web strength research was provided by Lyne and Gallay (3). A considerable amount of research has been done concerning stress-strain relationships as the sheet loses moisture. This research has provided much knowledge about the associated and immobile water in the sheet from 40 to

90 percent solids.

Research on wet-web strength (4) has produced the four following conclusions:

1. For a given dry basis weight, wet-web strength increases with decreasing moisture content. Between 8 and 22 percent solids, the relationship is essentially linear.
2. Except for light weight sheets, wet-web strength is proportioned to the oven dry basis weight for a given moisture content.
3. Chemical pulps are generally stronger than ground wood.
4. The wet-web strength is sensitive to the fiber size distribution.

In addition to the above general conclusions, it has been found that changing stock temperature, age, or pH has little effect upon the wet-web strength. A critical study of various additives which was undertaken at Western Michigan University and presented as part of the study on "Utilization of Michigan Hardwoods", showed that small amounts of additives affected the wet-web strength very little (Table I).

Fiber Bonding

Brecht reported that the basis for wet-web strength, between 10 and 35 percent solids, was interfiber friction and surface tension. This was most pronounced in the 18 to 35 percent solids range (Figure 1). It was conclusively shown by

Lyne that interfiber bonding effects do not take place until about 30 to 35 percent solids. This was done by using glass fibers and observing the decrease or increase in wet-web strength (3) through the use of bonding and anti-bonding agents. Therefore, it has been established that it is the nature of the fiber and its entrained water that explains the nature of the wet-web strength below 30 to 35 percent solids. Surface tension has been shown to be a factor in this strength, but several authors have been quick to point out that viscosity could also effect the wet-web strength, but fail to correlate any data to it.

EXPERIMENTAL DESIGN

General Introduction

Previous studies have shown that five important variables are present in the evaluation of the wet-web strength. These are, as listed by Lyne:

1. Strip width.
2. Basis weight.
3. Rate of loading.
4. Solids content.
5. Deviations in the sheet making procedure.

In this study the strip width and rate of loading were constant. The Brecht strip former was used in the Noble and Wood sheet mold for the production of the uniform and consistent sized strips. The rate of elongation was maintained at a constant 20 centimeters per minute by the Instron Tensile Tester. This is a

major improvement over the use of the Brecht model where this rate varies considerable. The Instron also gives a recorded value on chart paper of the test results. Basis weight of the tests sheets were maintained within reasonable limits, being $2.50 \pm .20$ grams per sheet, so that a linear correction factor could be applied to each sheet. The solids content was measured on each sheet by dividing the oven dry basis weight of the sheet by the initial wet weight of the sheet. The standard procedure for making Noble and Wood hand sheets was used. The sheet making and forming process is one of the critical points in evaluating wet-web strength. Extreme care must be exercised to make all sheets identical. Large deviations will result if the sheet forming procedure is not strickly adhered to.

Preparation of Materials

Deionized water was used in all phases of experimentation. This water was at room temperature and, therefore, the sheet formation, pressing, and testing were also done at that temperature. Cel Gar, a softwood beached Kraft was used for testing purposes. The pulp was prepared by soaking 80 grams in deionized water for 24 hours and then dispersing it in the TAPPI disintegrator for 1200 counts with a total of 2.5 liters of water. The stock was then diluted to 2.0 percent consistency and refined in the laboratory Mead refiner for 2.0 minutes.

Dow Methocel HG at 15,000 centipoises, a hydroxyl propyl methyl cellulose, was prepared by adding the dry powder to

85°C. water with agitation. A 5 percent solution was prepared and after 5 minutes at 85°C. with continued agitation, it was diluted to 1 percent with cold water.

The cationic starch, Cato 15, was prepared by making a 5 percent cold dispersion of the starch and then heating the starch to 180°F. in a double boiler and maintaining that temperature, with agitation for 10 minutes.

Sheet Formation

In order to obtain meaningful results for a given viscosity and surface tension at least four sheets had to be made at a given level. Therefore, enough water for making at least five Noble and Wood hand sheets was put into the white water tank and all the additives to change the viscosity and surface tension were added at this point. The water was then pumped to the sheet mold from this tank prior to the making of each sheet.

The strips for testing were formed by placing the stainless steel Brecht mold directly on the top of the wire and then, following the standard procedure, the sheet was formed. It is important to note that the felt was always pre-conditioned before the pressing of each sheet. The sheet was then kept in the felt and transferred to the constant humidity room for testing on the Instron Tensile Tester.

Testing of the Wet-Web Strength

The Instron Tensile Tester was adapted with the air type

jaw clamps to facilitate easy and quick clamping of the moist strips. The sample tested was three centimeters wide and the jaw separation was 5 centimeters. The tests were run at a constant loading of 20 centimeters per minute which facilitated a total clamping and testing time of less than 10 seconds for each strip. The Instron is equipped with an automatic recorder which gave accurate and consistent results.

Measurement of Viscosity and Surface Tension

Samples for determination of viscosity and surface tension were removed from the tank which contained water for their respective runs. The surface tension was measured by the DuNoy ring method which gives the surface tension directly in dynes per centimeter. The viscosity was measured by an Oswald viscosimeter and the viscosity was calculated by the following formula (1):

$$\frac{N_1}{N_2} = \frac{P_1 t_1}{P_2 t_2}$$

where:

n_1 = viscosity co-efficient of standard

n_2 = viscosity co-efficient of solution

P_1 = density of standard

P_2 = density of solution

t_1 = time of standard

t_2 = time of solution

DISCUSSION

Extrapolation of Data

The wet-web strength of a sheet is a linear function of the solids content of a sheet in the range of 10 to 20 percent and after a change in the slope at about 22 percent it is again essentially a linear function to 28 or 32 percent depending upon the system involved. Therefore, a constant parameter of percent solids can be used in order to obtain data for comparisons.

The data for extrapolation at a constant parameter of 24 percent solids is shown in Table II and Table III, as are the extrapolated values as obtained from Figure 2 and 3. The figure of 24 percent solids was chosen because in this range the wet-web strength is dependent significantly upon the liquid phase of the sheet as pointed out earlier. A problem would have occurred if a lower solids content would have been chosen. The sheets that were made with low surface tension water had much higher solids content than for pure water at an equivalent press weight. Extrapolation to a lower solids content, 20 percent for example, would have resulted in a negative value for wet-web strength of the low surface tension samples. However, since the slopes of the lines varied little, the data would have shown the same overall results.

Surface Tension Effects

Figure 4 relates wet-web strength to surface tension. The

graph shows that as surface tension is lowered, wet-web strength is also lowered. The function is not a perfect straight line, but the relationship is significant. Therefore, one can expect if chemicals are added to the sheet that will lower the surface tension of the water in the sheet, the wet-web strength will be decreased.

The significance of what causes a lowering in the surface tension is important to understand at this point (2). A chemical will lower the surface tension of a liquid only if it tends to concentrate at the liquid, air or liquid solids interfaces. Therefore, as can be seen from the data, the methocel had a far greater tendency to lower the surface tension than did Cato 15, because it concentrated at the interfaces much more. The surface tension is also controlled in degree by the size and shape and position of the molecule at the interface.

Examination of the data in Table II and of Figure 4 shows that the Cato 15, reduced the wet-web strength to a larger degree than should have been expected. One must note, however, that the starch is in the system and will give a uniform film between the fibers rather than a film of varying concentration as did the Methocel. One would, therefore, expect that a further relationship or variable is inherent in the system.

Viscosity Effects

Figure 5 shows a linear relationship between viscosity and the wet-web strength. The conclusion drawn from this graph is

that as viscosity is increased, the wet-web strength is decreased. An increase in the viscosity of the solution means that the fibers have a better lubricating film between them. The data indicates that it does not make any difference if the increased viscosity is obtained from Cato 15 or Methocel. The points which fell off the linear function on Figure 4 fall very close to the relationship in Figure 5. One point not shown on Figure 5, which appears in the data, is the point which was obtained from a high concentration of Methocel. It was noted at the time of running this sample that the sheets were extremely sticky from the high Methocel content. Therefore, this point was disregarded in establishing the relationship between wet-web strength and viscosity.

CONCLUSIONS

Two conclusions have been arrived at due to the evaluation of the effects of Methocel and Cato 15, oleic acid and sodium hydroxide upon the wet-web strength. As surface tension is lowered, wet-web strength is lowered, and as the viscosity of the solution goes up, the wet-web strength is lowered.

TABLE I

Additive	Level of Addition (%)	Point of Addition ¹	Order of Addition ²	Level Alum (%)	Level Rosin (%)	pH	Retention Time of Additive (Sec.)	Consistency of Stock at Addition (%)	Control ³ Wet-Web (grams)	Additive Wet-Web (grams)
Epic N	0.5, 1.0, 2.0	1	RHAAL	2.0	1.0	5.0	60	.023	75	75
Reten 210	0.5	1	RHAAL	2.0	1.0	5.0	60	.023	73	73
Reten 210	2.0	1	RHAAL	2.0	1.0	5.0	60	.023	73	78
Kymene 557	.5	1	RHAAL	2.0	1.0	5.0	60	.023	73	69
Kymene 557	2.0	1	RHAAL	2.0	1.0	5.0	60	.023	78	72
Cato 108	2.0	1	RHAAL	2.0	1.0	5.0	60	.023	73	64
Cato 15	2.0	1	RHAAL	2.0	1.0	5.0	60	.023	73	61
Cato 8	2.0	1	RHAAL	2.0	1.0	5.0	60	.023	73	67
Cato 8	2.0	2	RHAAL	2.0	1.0	5.0	60	.5	73	65
Methocel ⁴	2.0	2	RHAAL	2.0	1.0	5.0	60	.5	81	55
Methocel ⁵	2.0	2	RHAAL	2.0	1.0	5.0	60	.5	81	63
Casein	2.0	2	RHAAL	2.0	1.0	5.0	60	1.0	70	63
Casein	2.0	2	RHAAL	2.0	1.0	7.3	60	1.0	70	65
Rhoplex	2.0	2	RHAAL	2.0	1.0	4.5	60-80	1.0	73	73
Aerocol	2.0	2	RHAAL	2.0	1.0	4.5	60-80	1.0	73	73
CMC,+Kymene	.25+1.0	2	RKCMCAL	2.0	1.0	7.3	6	1.0	78	71
CMC,+Kymene	.25+2.0	2	RKCMCAL	2.0	1.0	7.3	6	1.0	78	67
CMC,+Kymene	.25+3.0	2	RKCMCAL	2.0	1.0	7.3	6	1.0	78	65
Resin 2386	0.5	2	RALA	2.7	1.0		90	1.0	74	74
Resin 2386	0.5	2	RALA	3.4	1.0		90	1.0	155	161
Kymene 557	0.5	2	RAAL	2.0	1.0	7.3	60	1.0	160	155
Reten 210	0.5	2	RAAL	2.0	1.0	7.3	60	1.0	155	161

Table from Western Michigan University Study - Utilization of Michigan Hardwoods

- (1) Point of addition in relationship to head box (1) at and (2) before
- (2) Explanation of symbols R-rosin, H-acid, A-additive, AL-alum
- (3) All tests except final 3 additives run at 20 percent solids, last 3 at 30 percent solids level.
- (4) 15,000 Centipoises
- (5) 100 Centipoises
- (6) All three CMC+Kymene runs retention times as follows:
 - (a) Kymene 6-8 min.
 - (b) CMC - 1 min.
 - (c) Alum - 1 min.

TABLE II

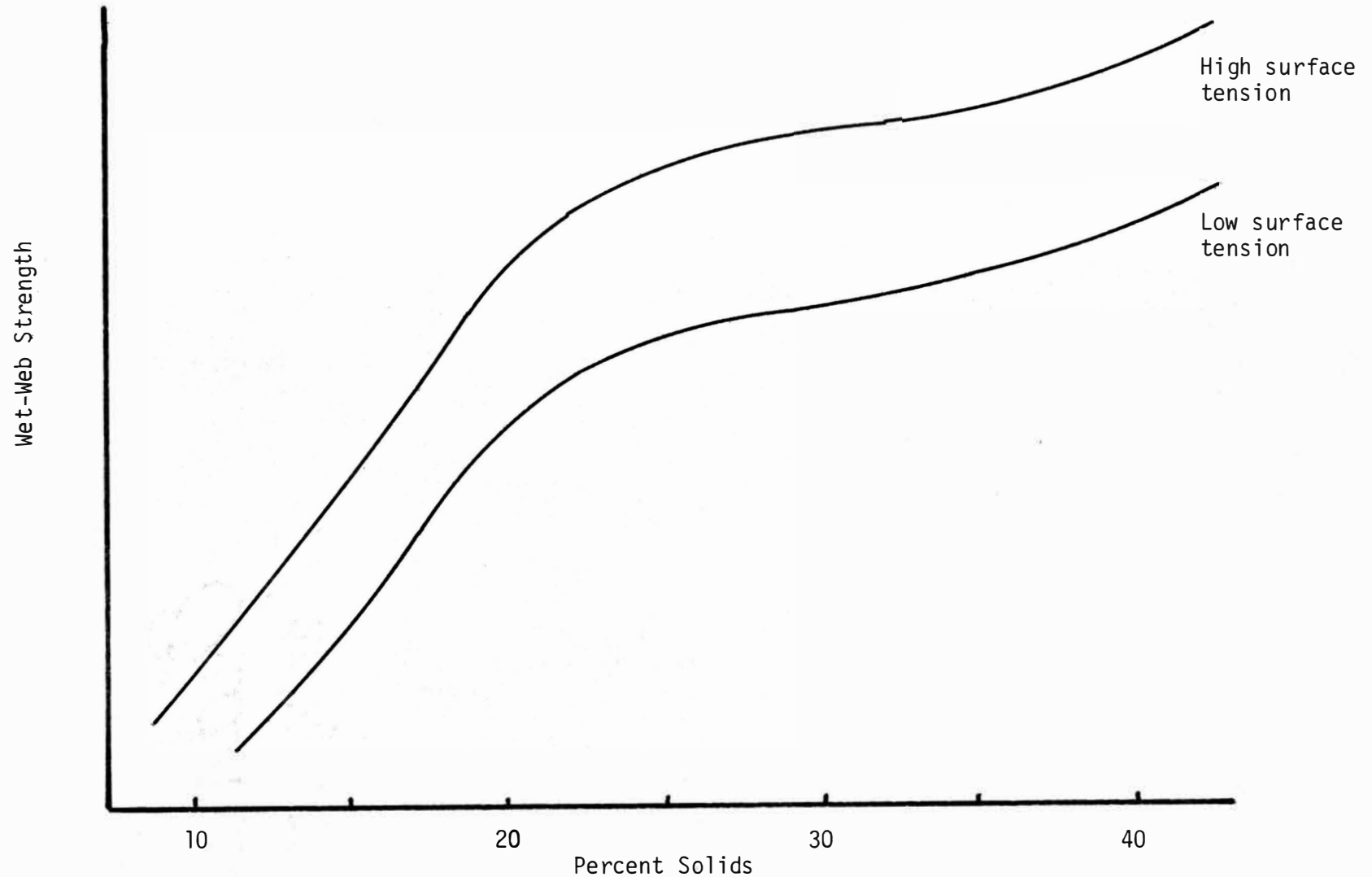
	Percent Solids	Wet-Web (grams)	Viscosity Centipoises	Surface Tension Dynes/cm	Extra Polated Value at 24 percent Solids grams*
Control Sheet for Methocel	20.5	365	1.00	71.0	530
	20.7	362			
	21.9	434			
	22.9	436			
	20.6	403			
Methocel Approx. .01% Solution	22.0	287	1.04	53.2	418
	23.8	380			
	23.7	370			
	25.0	410			
3X Methocel Approx..03% Solution	24.5	245	1.50	53.6	390
	23.5	339			
	24.1	369			
	25.0	374			
Methocel Oleic Acid	22.6	284	1.17	35.9	379
	24.6	394			
	25.3	419			
	26.3	411			
Methocel Oleic Acid Sodium Hydroxide	24.5	213	1.20	31.9	218
	25.2	258			
	26.5	321			
	27.3	338			

* Corrected to the same basis weight as Cato 15 (see Table III).

TABLE III

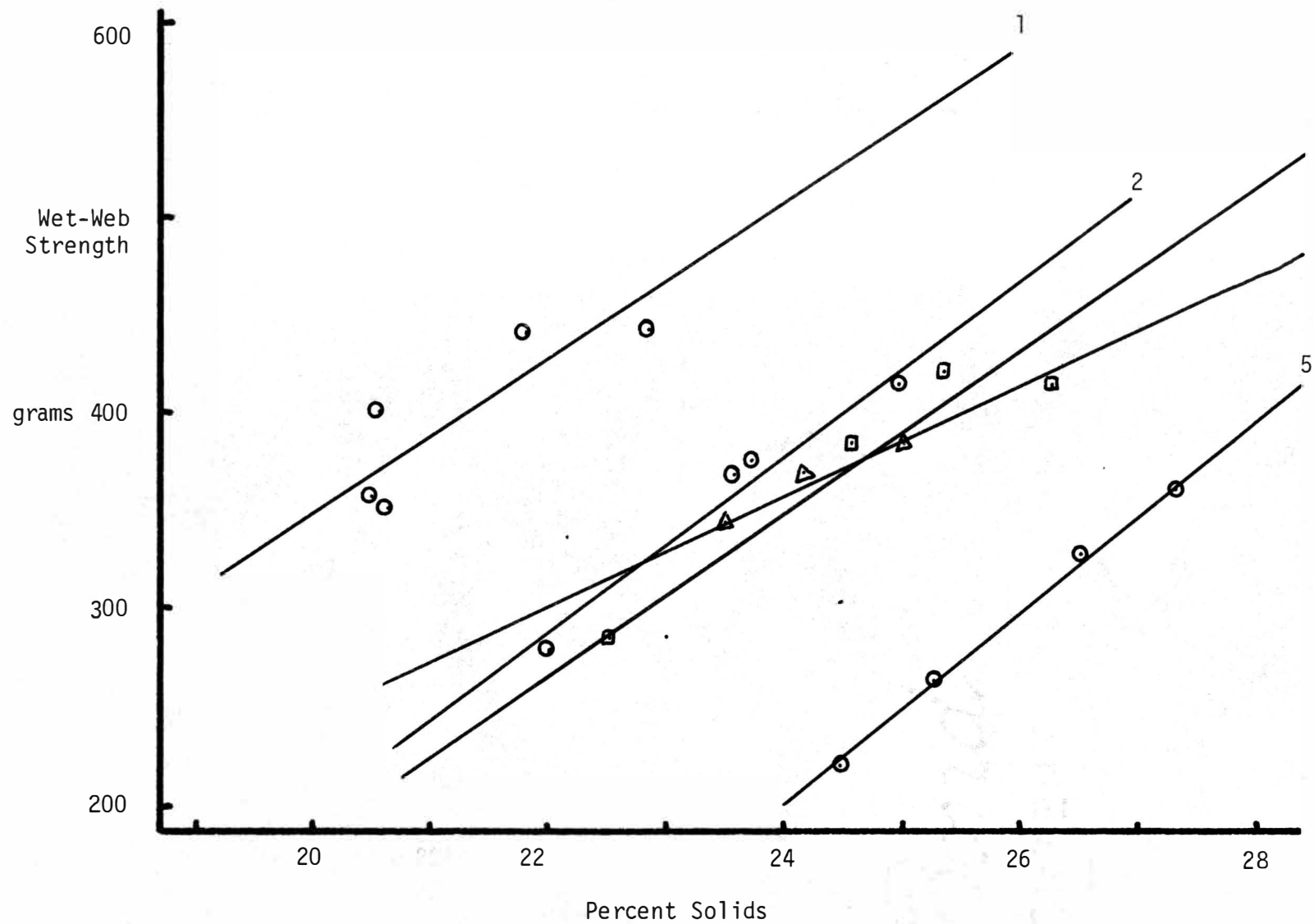
	Percent Solids	Wet-Web (grams)	Viscosity Centipoises	Surface Tension Dynes/cm	Extra Polated Value at 24 percent Solids grams
Control Sheets for Cato 15	19.0	335	1.00	72.5	530
	20.4	436			
	22.5	537			
	24.6	581			
Cato 15 Approx. .03% Solution	22.8	323	1.09	71.2	400
	24.6	384			
	25.7	453			
	26.2	455			
3X Cato 15 Approx. .1% Solution	22.0	189	1.18	61.8	260
	23.8	254			
	24.7	270			
	25.7	313			
Cato 15 Oleic Acid	23.7	334	1.09	35.2	340
	25.5	375			
	26.3	413			
	27.1	438			
Cato 15 Oleic Acid Sodium Hydroxide	22.8	308	1.08	44.3	340
	26.2	396			
	27.1	434			
	27.8	440			

Figure 1 Wet-Web Strength vs. Percent Solids*



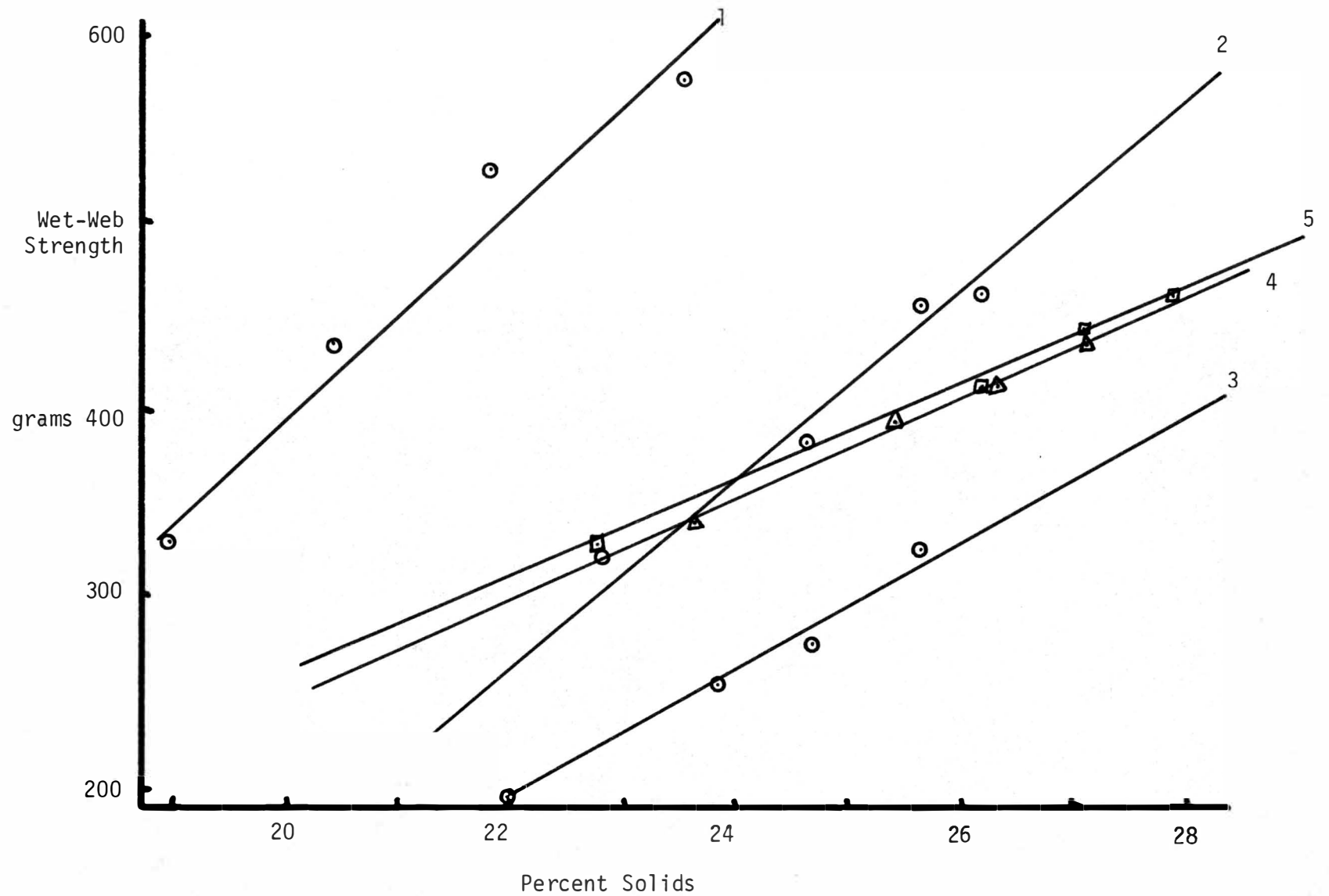
*Redrawn from: Lyne, T. M. & Gallay, W. "Studies in the Fundamentals of Wet-Web Strength" Pulp and Paper Magazine of Canada, Vol. 55, No. 10, Oct. 1954.

Figure 2 Wet-Web Strength vs. Percent Solids



* See Table II for code numbers.

Figure 3 Wet-Web Strength vs. Percent Solids



* See Table III for code numbers.

Figure 4 Surface Tension vs. Wet-Web Strength

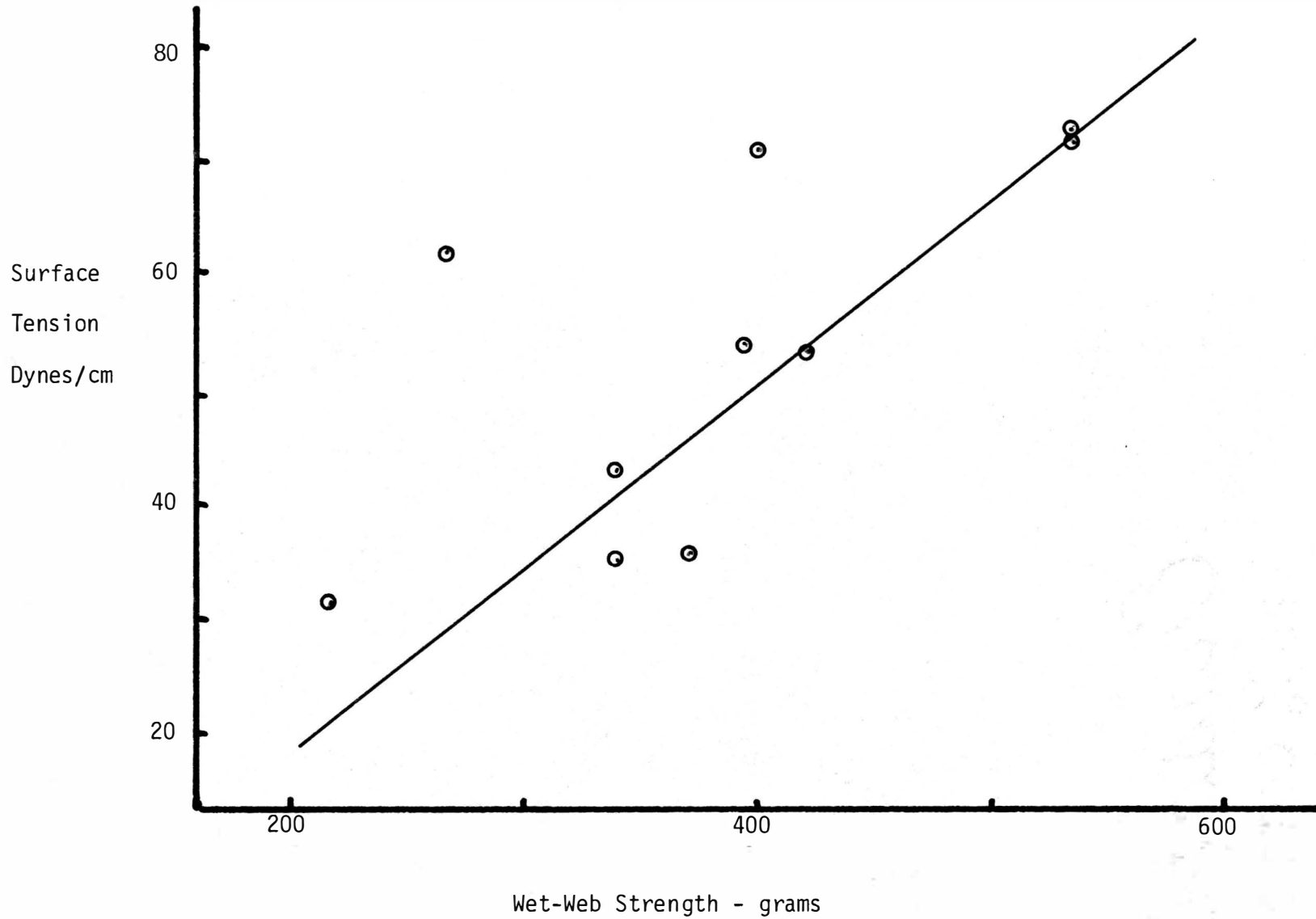
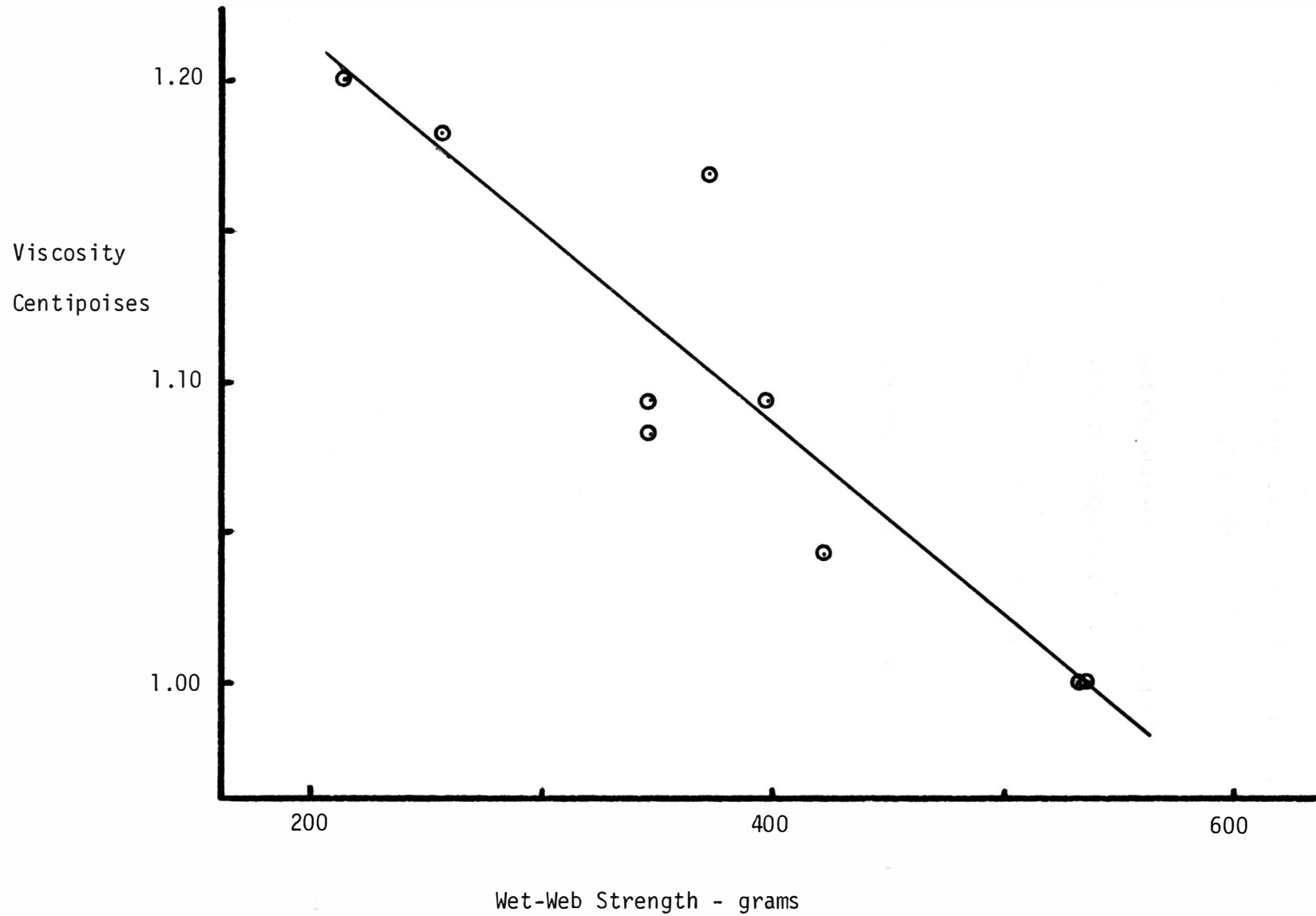


Figure 5 Viscosity vs. Wet-Web Strength



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