#2020 THE INSTITUTE OF PAPER CHEMISTRY
(Pulp Evaluation by Fiber Length Index & Shrinkage) Project Reports

PROJECT REPORT FORM

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SIGNED Milton H. Voelker
Milton H. Voelker

AN EXPLORATORY STUDY OF FIBER LENGTH INDEX
AND HANDSHEET SHRINKAGE AS PULP EVALUATION TOOLS

Further considerations have indicated several alternate and advantageous methods for graphically representing certain of the data contained in Project Report One. These alternate methods may be demonstrated as follows:

<u>Relationship Between Fiber Length Index and Handsheet Shrinkage</u>

In Section One of Project Report One, relationships between the fiber length index and handsheet shrinkage properties of pulps produced by refining have been represented by means of log (handsheet shrinkage/fiber length index) vs. log (handsheet shrinkage) plots (see Figure <u>1-2</u> and pages 20 to 29 in Project Report One). Plots of this nature resulted in straight lines with positive slopes and could be conveniently represented by the following general form of equation:

$$FLx = FLo\left(\frac{So}{Sx}\right)^{A-1}$$

where: A= the slope of the straight line log (handsheet shrinkage/fiber length index) vs. log (handsheet shrinkage) plot.

FLo = the fiber length index of the unrefined pulp.

FLx = the fiber length index of the pulp after any given refining time of x minutes.

So = the handsheet shrinkage of the unrefined pulp

Sx = the handsheet shrinkage of the pulp after any given refining time of x minutes.

Thus, the specific equation for the data represented in Figure <u>1-2</u> of Project Report One would be:

$$FLx\ (\text{grams}) = 3.373\left(\frac{2.23}{Sx}\right)^{0.66}$$

An alternate and simpler method for expressing relationships between the fiber length index and handsheet shrinkage properties of pulps produced by refining would be by means of log (fiber length index) vs. log (handsheet shrinkage) plots (see Figure 1 in this report which represents the same data as presented in Figure 1-2 of Project Report One). Plots of this nature result in straight lines with negative slopes and may be conveniently represented by the following form of equation.

$$FLx = FLo \left(\frac{Sx}{So}\right)^{B}$$

where: B = the slope of the straight line log (fiber length index) vs. log (handsheet shrinkage) plot.

FLo, FLx, So, and Sx = same properties as previously-noted.

Thus, the specific equation for the data represented in Figure 1 of this report would be:

$$FLx\ (\text{grams}) = 3.373 \left(\frac{Sx}{2.23}\right)^{-0.66*}$$

Relationship Between Tensile Strength and Handsheet Shrinkage

In Section Four of Project Report One, relationships between the tensile strength and handsheet shrinkage properties of pulps produced by refining have been represented by means of (tensile strength X handsheet shrinkage) vs. (handsheet shrinkage) plots (see Figure 4-2 and pages 49-61 in Project Report One). Plots of this nature resulted in straight lines with positive slopes and could be conveniently represented by the following general form of equation:

$$Tx = A - \frac{C}{Sx}$$

*It should be noted that $FLx = 3.373 \left(\frac{Sx}{2.23}\right)^{-0.66}$ is equivalent to $FLx = 3.373\left(\frac{2.23}{Sx}\right)^{0.66}$ (see equations on page 1).

where: A = the slope of the straight line (tensile strength x handsheet shrinkage) vs. (handsheet shrinkage) plot.

C = the intercept of the straight line plot, expressed as a positive number.

S_x = the handsheet shrinkage of the pulp after any given refining time of x minutes.

T_x = the tensile strength of the pulp after any given refining time of x minutes.

Thus, the specific equation for the "Run A, B, and C" data represented in Figure 4-2 of Project Report One would be:

$$T_x \text{ (lb./in./100 lb.)} = 74.0 - \frac{150}{S_x}$$

An alternate manner for expressing relationships between the tensile strength and handsheet shrinkage properties of pulps produced by refining would be by means of (tensile strength) vs. (1/handsheet shrinkage) plots (see Figure 2 in this report which represents the same data as presented in Figure 4-2 of Project Report One). Plots of this nature result in straight lines with negative slopes and may be conveniently represented by the same general equation previously noted-i.e.,

$$T_x = A - \frac{C}{S_x}$$

In this case, however,

A = the intercept of the straight line (tensile strength) vs. (1/handsheet shrinkage) plot.

C = the slope of the straight line plot.

Sx and Tx - same properties as previously noted.

Thus, the specific equation for the "Run A,B, and C" data represented in Figure 2 of this report would be:

$$Tx\ (\text{lb./in./100 lb.}) = 74.0 - \frac{150}{Sx}$$

Relationship Between Tensile Strength and Filtration Resistance

In Section Five of Project Report One, relationships between the tensile strength and filtration resistance properties of pulps produced by refining have been represented by means of [tensile strength X log (filtration resistance)] vs. log (filtration resistance) plots (see Figure 5-1 and pages 64 to 70 in Project Report One). Plots of this nature resulted in straight lines with positive slopes and could be conveniently represented by the following general form of equation:

$$Tx = A - \frac{C}{\log FRx}$$

where: A = the slope of the straight line [tensile strength X log (filtration resistance)] vs. log (filtration resistance) plot.

C = the intercept of the straight line plot, expressed as a positive number.

FRx = the filtration resistance, (cm./g.) X 10^{-7}, of the pulp at any given pressure drop ΔP after any given refining time of x minutes.

Tx = the tensile strength of the pulp after any given refining time of x minutes.

Thus, the specific equation for the Coosa River 54 pulp represented in Figure 5-1 of Project Report One would be:

$$Tx\ (lb./in./100\ lb.) = 66.8 - \frac{36.0}{\log FRx}$$

An alternate manner for expressing relationships between the tensile strength and filtration resistance properties of pulps produced by refining would be by means of (tensile strength) vs. [1/log (filtration resistance)] plots (see Figure 3 in this report which represents the same Coosa River 54 pulp data as presented in Figure 5-1 of Project Report One). Plots of this nature result in straight lines with negative slopes and may be conveniently represented by the same general equation previously noted - i.e.,

$$Tx = A - \frac{C}{\log FRx}$$

In this case, however,

A = the intercept of the straight line (tensile strength) vs. [1/log (filtration resistance)] plot.

C = the slope of the straight line plot

FRx and Tx = same properties as previously noted.

Thus, the specific equation for the data represented in Figure 3 of this report would be:

$$Tx\ (lb./in./100\ lb.) = 66.8 - \frac{36.0}{\log FRx}$$

It is suggested that the alternate methods of plotting presented in this report may prove very beneficial when handling certain of the data presented in Project Report One. It should be noted, however, that the same information, results, and conclusions may be derived with either method of plotting. Thus, these alternate methods of plotting would not result in any additional or different information than already presented in Project Report One.

Figure 1

ALTERNATE METHOD OF PLOTTING FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE DATA

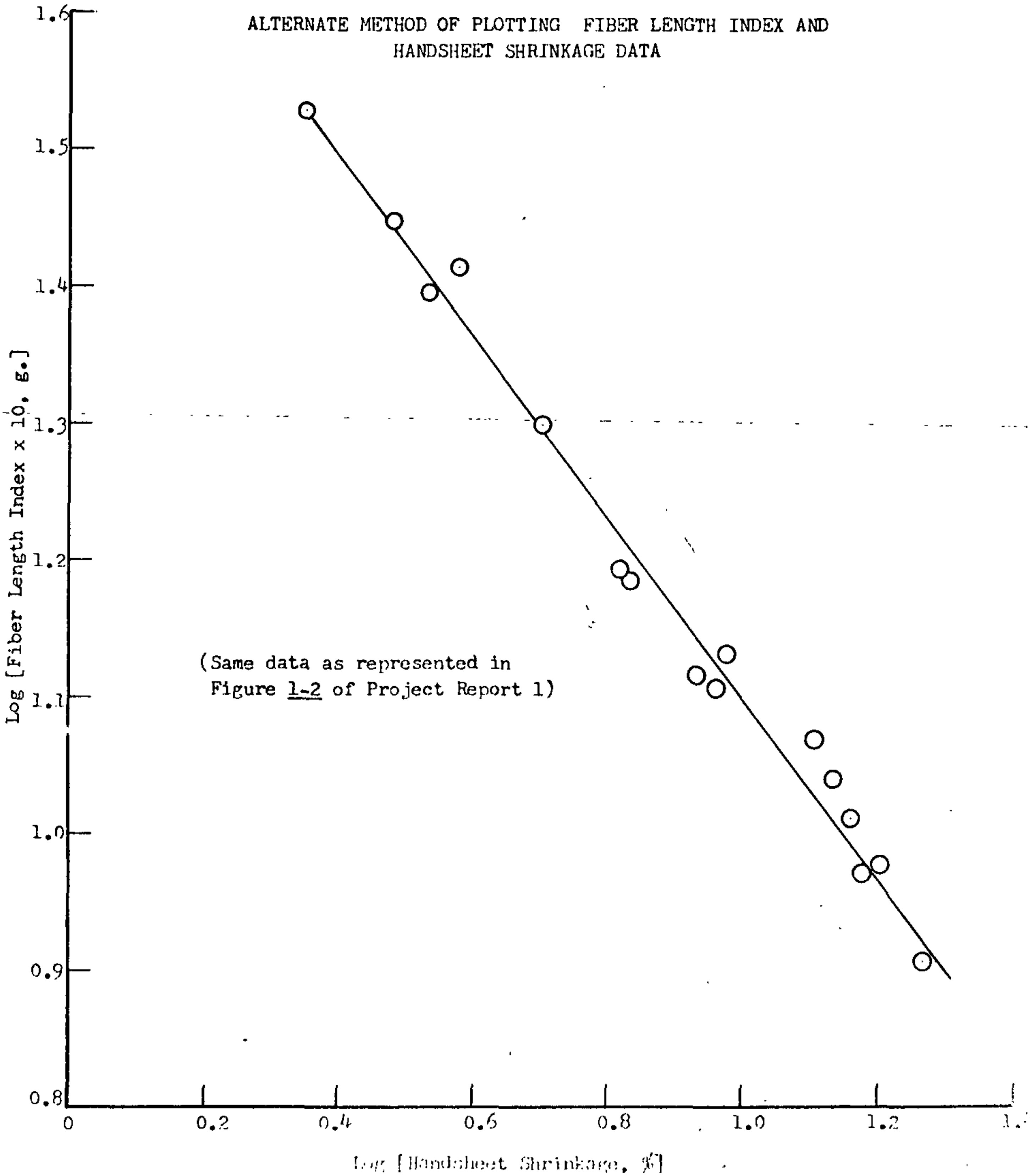


Figure 2

ALTERNATE METHOD OF PLOTTING TENSILE STRENGTH VS. HANDSHEET SHRINKAGE DATA

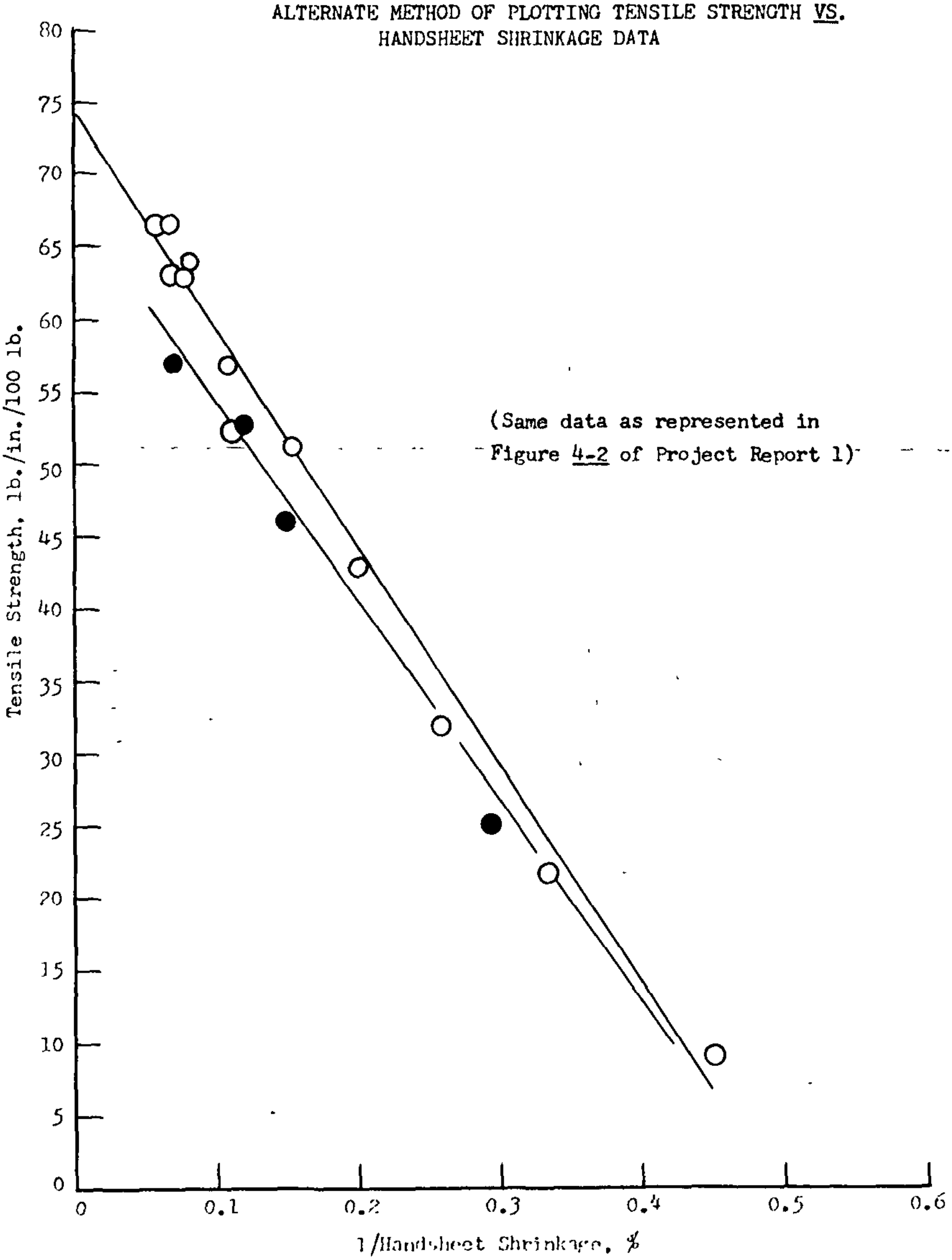
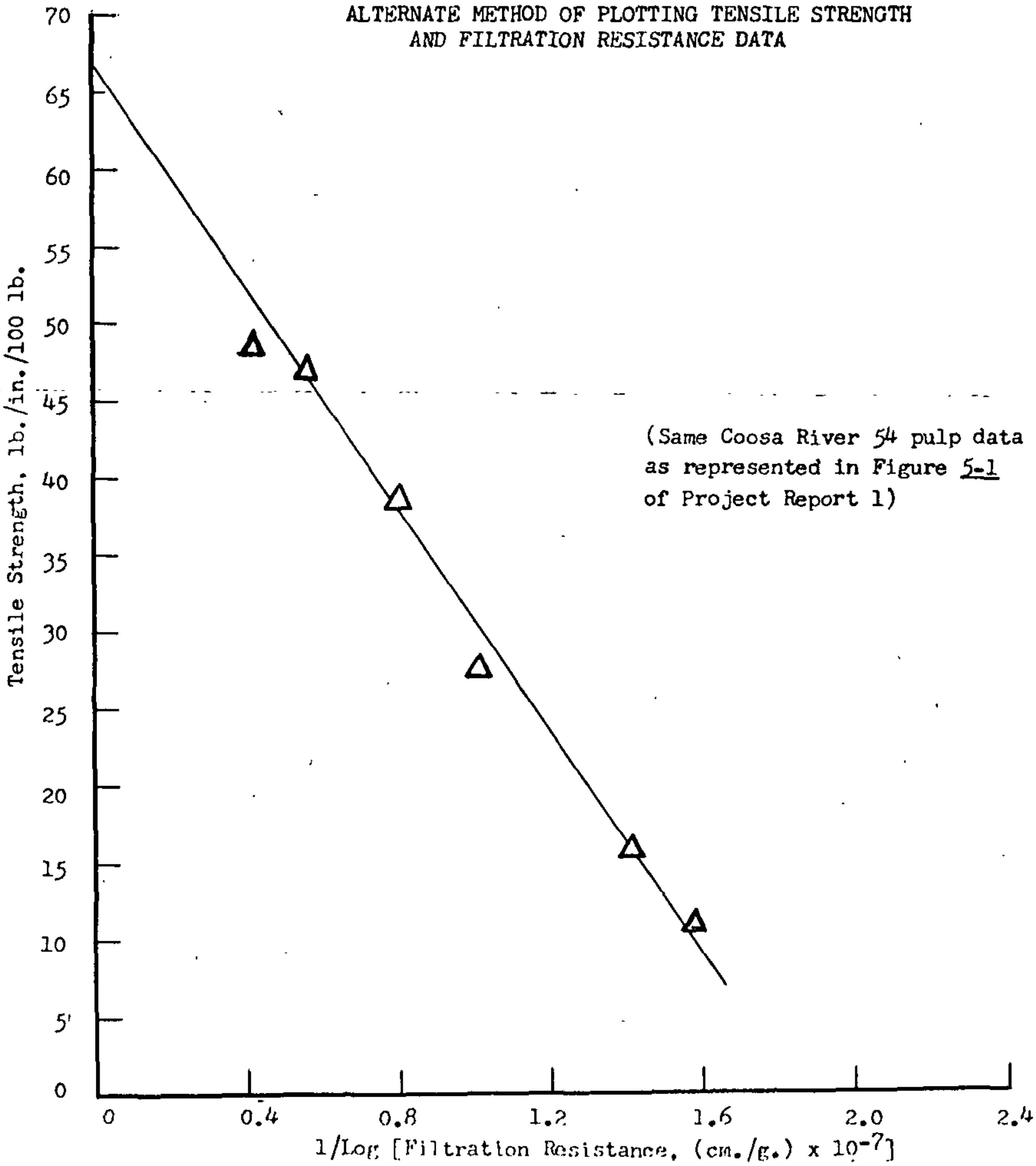


Figure 3

ALTERNATE METHOD OF PLOTTING TENSILE STRENGTH AND FILTRATION RESISTANCE DATA



PROJECT REPORT FORM

cc: The Files
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Project	2020
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Report	1
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AN EXPLORATORY STUDY OF FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE AS PULP EVALUATION TOOLS

TABLE OF CONTENTS

SUMMARY

The primary objective of this project was to investigate the fiber length index and handsheet shrinkage properties of pulps and determine the possible utility and potential of these properties for purposes of pulp evaluation and mechanical refining process control. To attain this objective, a variety of pulps were refined by a number of different refining actions and a rather extensive analysis was made of the properties of the refined pulps. Also, whenever applicable, the scope of the project was expanded to include data from various other projects.

The results of the project work indicate that the handsheet shrinkage and fiber length index properties of pulps, both by themselves and in conjunction with other pulp properties, could prove useful for evaluating pulps, characterizing mechanical refining actions, and controlling mechanical refining processes. In addition, certain experimental relationships, between handsheet shrinkage, fiber length index, filtration resistance, and strength properties of pulps, could be applied for purposes of characterizing a mechanical refining action, controlling a refining process, evaluating pulps, and reducing the experimental data required to define the refining characteristics of a pulp.

INTRODUCTION

Previous exploratory work undertaken for Project 1513 (see Project 1513, Project Report 24), has indicated that fiber length index and handsheet shrinkage measurements might provide useful indications of important pulp changes taking place during mechanical refining. This exploratory work was of a relatively limited nature, however, and consequently it appeared desirable to further investigate the utility of these particular measurements. As a result, the present project was initiated for the purpose of more fully investigating the fiber length index and handsheet shrinkage properties of pulps and determining the possible potential of these properties as tools for the evaluation of pulps and the control of mechanical refining processes.

EXPERIMENTAL WORK

Briefly, the experimental work consisted of refining a variety of different pulps in a variety of different mechanical refining instruments. (The pulps, refining equipment, and refining conditions are described in the "Experimental Data" section of this report.) Samples were obtained at various refining levels for each specific pulp and each specific refining instrument. These samples, consisting of the equivalent of at least 40 grams of ovendry pulp, were subsequently processed in the following manner:

(1) The sample was diluted to a consistency of about 0.25% and the actual consistency was accurately determined by duplicate consistency determinations (Institute Method 413).

(2) Two 2-g. (ovendry basis) samples of pulp were removed for duplicate Schopper-Riegler freeness determinations (Institute Method 414).

(3) Two 10-g. (ovendry basis) samples of pulp were removed for a fiber length index determination. (This determination was made according to Pulping Group Procedure 66. However, only 2 pulp samples were tested instead of the 3 specified in the procedure.)

(4) TAPPI standard handsheets were formed from a portion of the remaining slurry and tested for basis weight, caliper, apparent density, tearing strength, bursting strength, tensile strength, zero-span tensile strength, and formation.

(5) Three shrinkage sheets were formed from the remaining slurry and tested according to Institute Method 406. (In this work, the wet sheets were pressed between blotters, marked, dried in an oven, cooled, and again pressed for 5 minutes at 50 p.s.i. before making the final shrinkage measurement.)

For purposes of completeness, the scope of this project was expanded to include data obtained from various other projects. These data, and the circumstances under which they were obtained, are discussed in the "Experimental Data" and "Experimental Results and Conclusions" section of this report.

EXPERIMENTAL DATA

The experimental data accumulated for this report have been presented in Tables I through VIII. Briefly, these tables contain the following information.

Table I--Refining of Weyerhaeuser Bleached Sulfite Pulp (Standard Pulp) in Valley beater No. 2. This table represents a comprehensive study of a complete refining cycle--i.e., extensive data were obtained over a refining range extending from an unbeaten pulp to a pulp beaten to a Schopper-Riegler freeness of 145 ml.

Table II--Refining of Weyerhaeuser Bleached Sulfite (Standard Pulp) in Various Refining Equipment. This table represents a study of the properties developed in a given pulp when it is subjected to a variety of different refining actions. For this study the data obtained in the present work was supplemented by certain pertinent information previously reported in Project 1513, Project Report 24. Two laboratory Valley beaters, the Jokro mill and the Lampén mill, were included in the investigation.

Table III--Refining of Pulps other than Weyerhaeuser Sulfite Standard Pulp. This table represents a study and comparison of the properties imparted to several different pulps when they are subjected to similar and dissimilar refining actions. Certain pertinent data from Project 1513, Project Report 24, were included in this table and the study involved a laboratory Valley beater, the Jokro mill, a Mosinee kraft pulp, a Bloedel kraft pulp, a softwood sulfite pulp, and cotton linters.

Table IV--Refining Studies Involving Mixtures of Weyerhaeuser Sulfite Standard Pulp and Bloedel Kraft Pulp. This table represents a study of the effects produced when a mixture of two dissimilar pulps is refined, and a study of the effects produced when two dissimilar pulps are separately refined and subsequently mixed in various ratios.

Table V--Additional Refining Data Obtained from Project 2028. This table represents a study of the pulp properties produced when Weyerhaeuser sulfite standard pulp is refined in the laboratory Morden Stock Maker. The data have been included in this report to supplement the data and information presented in Table II.

Table VI--Additional Refining Data Obtained from Project 2027, Progress Report One. Project 2027 involved a very comprehensive study of the refining characteristics of four kraft pulps. Because of the extensive nature of the data available from this project, it was decided to subject the same pulps to handsheet shrinkage determinations and investigate the relationship of handsheet shrinkage properties to the other pulp properties determined in the Project 2027 work.

Table VII--Additional Refining Data Obtained from Project 2025, Progress Report One. Project 2025 involved a very comprehensive study of the refining characteristics of three kraft pulps. Because of the extensive nature of the data available from this project, it was decided to subject the same pulps to handsheet shrinkage determinations and investigate the relationship of handsheet shrinkage properties to the other pulp properties determined in the Project 2025 work.

Table VIII--Additional Refining Data Obtained from Project 1513, Progress Reports Thirteen and Sixteen. On the basis of the present Project 2020 work, it appeared desirable to further investigate certain possible relationships between the filtration resistance characteristics and the tensile strength characteristics of pulps. Both the filtration resistance and tensile strength data were already available from previous Project 1513 work, and consequently these data were included in this report.

TABLE I

REFINING OF WEYERHAEUSER BLEACHED SULFITE PULP (STANDARD PULP) IN VALLEY BEATER 2
(Refining Conditions = 1.57% consistency and 5500-g. bedplate loading)

Run	A		B		C		D	
Schopper-Riegler freeness, ml.	50[1]	430	0[1]	870	10[1]	860	15[1]	850
	61	290	20	830	30	785	45	605
	71	200	50	420	40	670	55	430
	81	145	70	200	60	290	80	170
Fiber length index, g.	50	1.273	0	4.308[2]	10	2.805	15	2.490
	61	1.096	20	2.594	30	1.991	45	1.536
	71	0.950	50	1.352	40	1.556	55	1.299
	81	0.807	70	0.935	60	1.176	80	1.036
Handsheet shrinkage, %	50	9.08	0	2.23	10	3.00	15	3.40
	61	13.60	20	3.88	30	5.03	45	6.70
	71	15.86	50	9.42	40	6.58	55	8.54
	81	17.10	70	15.11	60	12.68	80	14.42
Basis weight (25x40--500), lb.	50	46.6	0	46.1	10	47.9	15	44.3
	61	46.9	20	46.1	30	45.7	45	46.7
	71	46.1	50	46.1	40	45.4	55	47.1
	81	45.9	70	46.3	60	45.9	80	45.6
Caliper, mils	50	3.1	0	4.6	10	4.3	15	3.8
	61	3.0	20	3.8	30	3.6	45	3.2
	71	2.8	50	3.1	40	3.2	55	3.2
	81	2.8	70	3.0	60	3.0	80	3.0
Apparent density, lb./mil./25x40--500 ream	50	15.0	0	10.0	10	11.1	15	11.7
	61	15.6	20	12.1	30	12.7	45	14.6
	71	16.5	50	14.9	40	14.2	55	14.7
	81	16.4	70	15.4	60	15.3	80	15.2
Apparent density, g./cc.	50	0.83	0	0.55	10	0.61	15	0.65
	61	0.86	20	0.67	30	0.70	45	0.81
	71	0.91	50	0.82	40	0.79	55	0.81
	81	0.91	70	0.85	60	0.85	80	0.84

TABLE I CONT'D.

Run	A		B		C		D	
Tear factor	50[1]	0.92	0[1]	1.19	10[1]	2.28	15[1]	2.10
	61	0.85	20	1.58	30	1.14	45	1.07
	71	0.76	50	0.82	40	0.95	55	0.89
	81	0.76	70	0.78	60	0.74	80	0.83
Tensile strength (25x40--500 ream), lb./in./100 lb.	50	52.4	0	9.1	10	21.8	15	25.3
	61	62.9	20	32.0	30	42.9	45	46.0
	71	66.7	50	56.9	40	51.3	55	52.9
	81	66.7	70	63.1	60	64.0	80	57.6
Zero-span tensile strength (25x40--500 ream), lb./in./100 lb.	50	83.3	0	65.9	10	74.7	15	83.5
	61	78.5	20	80.5	30	87.7	45	93.6
	71	80.7	50	87.0	40	89.4	55	89.6
	81	82.6	70	82.5	60	92.6	80	76.8
Thwing formation, units	50	--	0	41.4	10	48.9	15	46.2
	61	--	20	51.4	30	49.9	45	41.0
	71	--	50	33.2	40	44.3	55	33.4
	81	--	70	27.0	60	24.7	80	23.2
Log (S, %)*	50	0.958	0	0.348	10	0.477	15	0.531
	61	1.134	20	0.589	30	0.702	45	0.826
	71	1.200	50	0.974	40	0.818	55	0.931
	81	1.233	70	1.179	60	1.103	80	1.159
Log [(S/F)*, (%/ml.) x 10^{-3}]	50	1.324	0	0.408	10	0.543	15	0.602
	61	1.671	20	0.669	30	0.807	45	1.045
	71	1.899	50	1.350	40	0.992	55	1.299
	81	2.070	70	1.878	60	1.640	80	1.928
Log [(S/FL)*, (%/g.) x 10]	50	1.853	0	0.714	10	1.029	15	1.134
	61	2.093	20	1.176	30	1.403	45	1.639
	71	2.223	50	1.843	40	1.623	55	1.818
	81	2.326	70	2.210	60	2.033	80	2.143
FL/S, (g./%) x 10	50	1.40	0	19.3	10	9.35	15	7.32
	61	0.806	20	6.68	30	3.96	45	2.29
	71	0.599	50	1.44	40	2.38	55	1.52
	81	0.472	70	0.619	60	0.927	80	0.718
T* x S, (lb./in./100 lb.) x % x 10^{-1}	50	47.6	0	2.03	10	6.54	15	8.60
	61	85.5	20	12.4	30	21.6	45	30.8
	71	106.0	50	53.6	40	33.8	55	45.2
	81	114.0	70	95.3	60	81.2	80	83.1

[1]Refining time, min.

*S = handsheet shrinkage
FL= fiber length index

F = Schopper-Riegler freeness
T = tensile strength

Table II

NING OF WEYERHAEUSER BLEACHED SULFITE PULP (STANDARD PULP) IN VARIOUS REFINING EQUIPMENT

pparent Density, b./mil./25x40--500 ream	Apparent Density, g./cc.	Bursting Strength (25x40--500 ream), pt./100 lb.	Tear Factor	Tensile Strength (25x40--500 ream), lb./in./100 lb.	Zero-Span Tensile Strength (25x40--500 ream), lb./in./100 lb.	Thwing Formation, units	Log (S, $)**	Log [(S/F),($/ml.) x 10³]	Log [(S/FL), ($/g.) x 10]	FL/S, (g./$) x 10	T x S (lb./in./100 lb.) x $ x 10⁻¹
Valley Beater 2--1.57% Consistency, 5500-g. bedplate loading*											
12.7	0.70	57	1.62	33.8	--	--	0.627	0.698	1.288	5.14	14.3
13.5	0.75	83	1.22	46.3	--	--	0.740	0.854	1.498	3.18	25.5
14.8	0.82	104	0.93	56.0	--	--	0.870	1.158	1.732	1.84	41.4
13.4	0.69	58	1.65	34.5	--	--	0.636	0.711	1.321	4.77	14.9
14.2	0.79	96	1.05	53.2	--	--	0.804	0.980	1.649	2.25	33.8
14.8	0.82	105	0.94	56.2	--	--	0.870	1.188	1.748	1.79	41.6
15.9	0.83	104	0.91	57.8	--	--	0.954	1.373	1.871	1.35	51.9
Lloyd (P.Chem.) Laboratory Valley Beater--1.57% consistency, 5500-g. BPL*											
12.2	0.68	51	1.78	31.0	--	--	0.606	0.674	1.274	5.33	12.5
13.8	0.76	83	1.11	47.0	--	--	0.766	0.899	1.626	2.36	27.4
14.9	0.82	96	0.99	53.7	--	--	0.924	1.240	1.916	1.22	45.0
15.4	0.85	96	0.82	55.1	--	--	1.008	1.476	2.066	0.864	56.1
Jokro Mill--6% consistency, 150 r.p.m.*											
13.1	0.72	60	1.27	38.0	--	--	0.524	0.586	1.312	4.88	12.4
15.1	0.84	81	0.86	51.1	--	--	0.770	0.950	1.876	1.33	30.1
15.8	0.87	89	0.80	57.6	--	--	0.851	1.179	2.128	0.748	40.8
17.0	0.94	92	0.69	58.0	--	--	0.938	1.418	2.366	0.432	50.2
13.2	0.73	61	1.31	39.8	87.8	63.6	0.534	0.606	1.284	5.20	13.6
14.5	0.80	79	0.84	53.6	94.6	59.2	0.564	0.794	1.632	2.33	24.7
15.6	0.86	87	0.75	57.6	97.4	55.5	0.777	1.013	1.942	1.15	34.4
17.0	0.94	90	0.67	55.8	97.7	44.8	0.923	1.398	2.323	0.476	46.7
Lampen Mill--3% consistency*											
14.6	0.81	53	0.96	41.9	--	--	0.617	0.714	1.742	1.81	17.3
15.7	0.87	69	0.83	47.9	--	--	0.710	0.864	2.018	0.957	24.5
16.9	0.94	67	0.72	49.6	--	--	0.942	1.243	2.511	0.309	43.4
16.8	0.93	64	0.66	47.4	--	--	1.002	1.378	2.756	0.175	47.6
16.9	0.94	64	0.70	49.4	--	--	1.032	1.431	2.874	0.134	53.2
15.6	0.86	64	0.64	44.4	92.8	50.2	0.774	0.948	2.128	0.744	26.4
16.9	0.94	68	0.76	53.1	94.5	41.9	0.966	1.312	2.710	0.195	49.1

· length index   T = te-sile strength

TABLE III

REFINING OF PULPS OTHER THAN THE WEYERHAEUSER SULFITE STANDARD PULP

Run	Refining Time, min.	Schopper-Riegler Freeness, ml.	Fiber Length Index, f.	Handsheet Shrinkage, %	Basis Weight (25x40--500), lb.	Caliper, mils	Apparent Density, lb./mil./25x40--500 ream	Apparent Density, g./cc.	Bursting Strength (25x40--500 ream), pt./100 lb.	Tear Factor	Tensile Strength (25x40--500 ream), lb./in./100 lb.	Zero-Span Tensile Strength (25x40--500 ream), lb./in./100 lb.	Thwing Formation, units	Log (S, %)**	Log [(S/F), (%/ml.) x 10³]**	Log [S/FL, (%/g.) x 10]**	T X S ** (lb./in./100 lb.) x % x 10⁻¹
												--	--	0.598	0.676		
						Mosinee Kraft Pulp--Valley Beater 2--1.57% consistency, 6500 g. bedplate loading*											
7	20	835	1.64[illegible]	3.96	47.4	3.8	12.5	0.69	124	1.56	64.8	--	--	0.598	0.676	1.380	25.7
	50	695	1.40[illegible]	5.72	46.3	3.3	14.0	0.78	165	1.19	77.5	--	--	0.758	0.916	1.610	44.3
	60	410	1.25[illegible]	7.36	46.5	3.1	15.0	0.83	168	1.10	83.0	--	--	0.896	1.284	1.798	65.2
	90	325	1.15[illegible]	9.26	46.8	3.1	15.1	0.84	169	1.05	85.0	--	--	0.967	1.455	1.894	78.7
						Bloedel Kraft Pulp--Valley Beater 2--1.57% consistency, 6500-g. bedplate loading											
E	0	855	3.556	2.02	44.7	4.8	9.3	0.51	15	1.99	15.1	88.6	35.7	0.306	0.369	0.754	3.05
	20	730	2.74[illegible]	3.06	47.7	4.2	11.4	0.63	78	2.35	43.8	106.0	35.8	0.486	0.567	1.042	13.4
	50	590	1.825	5.58	47.2	3.6	13.1	0.72	133	1.45	70.9	112.0	27.3	0.746	0.976	1.486	39.6
	70	270	1.49[illegible]	8.26	47.1	3.3	14.3	0.79	135	1.27	73.3	110.0	21.5	0.918	1.486	1.744	60.5
						Bloedel Kraft Pulp--Jokro Mill--6% consistency, 150 r.p.m.											
I	15	835	2.18	2.92	46.4	3.9	11.9	0.66	84	2.07	54.7	104.0	40.4	0.466	0.544	1.124	16.0
	30	740	1.55[illegible]	3.91	47.4	3.7	12.8	0.71	105	1.73	65.8	97.2	41.0	0.592	0.723	1.392	25.7
	50	505	1.24[illegible]	4.91	47.3	3.5	13.5	0.75	115	1.48	71.6	98.1	37.9	0.692	0.989	1.597	35.2
	75	270	0.52[illegible]	6.84	47.8	3.2	14.9	0.82	125	1.21	70.9	93.7	32.3	0.835	1.404	1.918	48.5
						Softwood Sulfite Pulp--Jokro Mill--6% consistency, 150 r.p.m.											
F	0	870	2.14[illegible]	1.86	46.9	4.2	11.2	0.62	14	1.28	12.2	72.9	68.2	0.270	0.331	0.939	2.27
	15	765	0.602	4.58	46.8	3.0	15.6	0.86	85	1.00	56.2	94.6	77.4	0.661	0.777	1.882	25.7
	25	680	0.527	5.24	45.9	2.9	15.8	0.87	90	0.83	58.7	86.3	70.0	0.719	0.887	1.998	30.8
	45	430	0.34[illegible]	7.27	45.1	2.8	17.2	0.95	91	0.77	63.3	76.9	53.9	0.862	1.228	2.323	46.0
	60	275	0.245	9.92	47.2	2.7	17.5	0.97	83	0.74	64.7	70.3	44.1	0.997	1.556	2.602	64.1
						Cotton Linters Pulp--Jokro Mill--4.75% consistency, 150 r.p.m.											
J	75	840	1.350	1.50	46.5	4.3	10.9	0.60	20	1.34	17.1	81.0	70.0	0.177	0.250	1.046	2.56
	130	480	0.174	2.48	47.0	3.8	12.4	0.69	20	0.68	20.0	79.1	88.7	0.394	0.714	2.153	4.96
	210	180	0.00[illegible]	8.70	47.0	3.0	15.7	0.87	29	0.36	30.2	67.9	65.6	0.940	1.684	4.038	26.3

*Data obtained from Project 1513. Project Report 24.

** S = handsheet shrinkage F = Schopper-Riegler freeness FL = fiber length index T = tensile strength

TABLE IV

ɔ ST˜DIES INVOLVING MIXTURES OF WEYERHAEUSER SULFITE STANDARD PULP AND BLOEDEL KRAFT PULP

Apparent Density lb./mil./25x40--500 ream	Apparent Density, g./cc.	Bursting Strength (25x40--500 ream), pt./100 lb.	Tear Factor	Tensile Strength (25x40--500 ream), lb./in./100 lb.	Zero-Span Tensile Strength (25x40--500 ream), lb./in./100 lb.	Thwing Formation, units	Log (S, $)*	Log [(S/F), ($/ml.) x 10³]	Log [S/Fl. $/g.) x 10]	T X S (lb./in./100 lb.) x $ x 10⁻¹ *
rhaeuser Sulfite Standard Pulp + 50% Bloedel Kraft Pulp--Valley Beater 2--1.57% Consistency										
9.9	0.55	12	1.83	10.4	80.7	37.5	0.329	0.389	0.793	2.22
11.1	0.61	49	2.49	32.4	95.1	36.8	0.478	0.548	1.058	9.72
12.4	0.69	90	1.53	47.8	101.0	35.5	0.650	0.757	1.382	21.3
13.9	0.77	118	1.10	64.7	105.0	29.3	0.856	1.193	1.684	46.4
Weyerhaeuser Sulfite Standard Pulp--Valley Beater 2--1.57% consistency, 5500-g. Bedplate Loading										
13.6	0.75	84	1.03	48.7	94.7	48.4	0.715	0.826	1.520	25.3
Bloedel Kraft Pulp--Valley Beater 2--1.57% consistency, 5500-g. Bedplate Loading										
13.1	0.72	130	1.41	72.7	103.0	27.4	0.764	1.029	1.532	42.2
e· 25% Weyerhaeuser Pulp from Run G-A, 75% Bloedel Pulp from Run G-B (No Additional Refining										
13.2	0.73	120	1.28	64.7	103.0	31.1	0.758	1.013	1.538	37.1
e· 50% Weyerhaeuser Pulp from Run G-A, 50% Bloedel Kraft Pulp from Run G-B (No Additional Refining										
13.3	0.74	106	1.19	62.0	104.0	36.8	0.746	0.960	1.570	34.5
e. 75% Weyerhaeuser Pulp from Run G-A, 25% Bloedel Kraft Pulp from Run G-B (No Additional Refining										
13.7	0.76	95.0	1.17	51.3	97.3	41.4	0.740	0.901	1.544	28.2

'iber length index   T = tensile strength

TABLE V

ADDITIONAL REFINING DATA OBTAINED FROM PROJECT 2028 (MORDEN STOCK-MAKER)

ight 00).	Caliper, mils	Apparent Density, lb./mil./ 25x40--500 ream	Apparent Density, g./cc.	Bursting Strength (25x40--500 ream), pt./100 lb.	Tear Factor	Tensile Strength (25x40--500 ream), lb./in./100 lb.	Log (S, $)*	Log [(S/F), ($/ml.) x 10]*	Log [(S/FL), ($/g.) x 10]*	T X S (lb./in./100 lb.) x $ x 10^{-1}
RUN 2028-1: Weyerhaeuser Sulfite Standard Pulp--Morden Stock-Maker-- 2% Consistency										
	4.1	12.5	0.69	57	1.60	33.6	0.634	0.719	1.406	14.4
	3.6	14.1	0.78	79	0.97	43.6	0.774	0.947	1.752	25.9
	3.4	14.9	0.82	84	0.79	51.1	0.880	1.199	2.037	38.7
	3.[illegible]	15.2	0.90	88	0.66	56.2	1.041	1.522	2.382	51.8

Freeness   FL = fiber length index   T = tensile strength

TABLE VI

ADDITIONAL REFINING DATA OBTAINED FROM PROJECT 2027, PROGRESS REPORT ONE

nce	Log Filtration Resistance at ΔP = 90 cm. H_2O (cm./g.) x 10^{-7}	Handsheet Properties: Handsheet Shrinkage, %	Handsheet Properties: Basis Weight (25x40--500 rm.), lb.	Handsheet Properties: Tensile Strength (25x40--500 ream), lb./in./100 lb.	Handsheet Properties: T X S* (lb./in./100 lb.) x % x 10^{-1}	Handsheet Stock Properties: Log Filtration Resistance at P = 10 cm. H_2O, (cm./g.) x 10^{-7}	Handsheet Stock Properties: Log Filtration Resistance at P = 50 cm. H_2O, (cm./g.) x 10^{-7}	Handsheet Stock Properties: Log Filtration Resistance at P = 90 cm. H_2O, (cm./g.) x 10^{-7}	(Log FTR_{50})* ST**
1 Georgianier Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load									
	0.749	2.32	46.4	8.2	1.90	0.233	0.534	0.664	0.438
	0.594	2.76	44.4	16.7	4.61	0.326	0.651	0.790	1.09
	1.127	3.53	44.1	35.6	12.6	0.476	0.835	0.990	2.97
	1.453	4.49	44.3	47.4	21.3	0.704	1.107	1.279	5.25
	2.004	6.13	45.3	55.2	33.8	1.043	1.496	1.678	8.26
	2.465	9.16	45.3	59.8	48.8	1.600	2.094	2.287	12.5
xas Pulp and Paper Co. Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load									
	--	2.79	44.4	16.4	4.58	--	0.621	--	1.02
	--	3.14	45.4	24.0	7.54	--	0.717	--	1.72
	--	4.28	45.5	40.4	17.3	--	0.904	--	3.65
	--	5.47	46.3	51.8	28.3	--	1.265	--	6.55
	--	7.39	44.9	59.6	43.3	--	1.700	--	9.96
	--	9.75	44.8	62.3	60.7	--	2.296	--	14.3
1 Coosa River 55 Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load									
	--	3.11	44.8	16.7	5.19	--	0.695	--	1.16
	--	3.77	44.7	28.0	10.6	--	0.792	--	2.22
	--	5.00	45.7	40.7	20.4	--	1.000	--	4.07
	--	6.86	46.4	50.2	34.4	--	1.342	--	6.74
	--	9.49	44.9	56.3	53.4	--	1.867	--	10.5
	--	12.00	46.3	61.8	74.2	--	2.447	--	15.1
Coosa River 54 Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load									
	--	2.81	46.2	11.0	3.09	--	0.631	--	0.694
	--	3.07	49.4	16.0	4.91	--	0.706	--	1.13
	--	4.30	46.9	27.5	11.8	--	0.904	--	2.49
	--	5.85	46.9	38.6	22.6	--	1.247	--	4.81
	--	8.40	46.7	47.1	39.6	--	1.790	--	8.43
	--	11.57	46.1	48.8	56.5	--	2.352	--	11.5

tion resistance of handsheet stock at ΔP = 50 cm. H_2O

TABLE VII

ADDITIONAL REFINING DATA OBTAINED FROM PROJECT 2025, PROGRESS REPORT ONE

Handsheet Properties			Handsheet Stock Properties		Additional Properties	
ght)0).	Tensile Strength (25x40--500 ream), lb./in./100 lb.	$T^* \times S^*$ (lb./in./100 lb.) x % x 10^{-1}	Log Filtration Resistance at ΔP = 50 cm. H_2O, (cm./g.) x 10^{-7}	$(\text{Log } FTR_{50})^* \times T$, Units for FTR_{50} = (cm./g.) x 10^{-7} Units for T = (lb./in./100 lb.) x 10^{-1}	Log Handsheet Shrinkage, %	Log [(S/FI)*, (%/g.) x 10]
Run 2025-1 Riegel Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load						
	23.1	6.49	0.669	1.54	0.449	0.969
	33.6	10.9	0.772	2.59	0.509	1.064
	47.3	19.8	0.936	4.43	0.622	1.270
	55.3	29.9	1.228	5.79	0.732	1.428
	64.7	44.1	1.645	10.6	0.833	1.570
	66.4	54.2	1.892	12.6	0.912	1.723
Run 2025-2 Jesup Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load						
	16.0	4.30	0.558	0.893	0.430	0.869
	24.0	7.46	0.658	1.58	0.493	0.996
	39.1	15.1	0.845	3.30	0.586	1.140
	52.0	25.9	1.120	5.82	0.697	1.326
	59.1	37.9	1.[illegible]65	9.26	0.807	1.509
	64.4	51.6	1.929	12.4	0.904	1.649
Run 2025-3 Harmac Pulp--Valley Beater 1--1.57% Consistency, 5500-g. Bedplate Load						
	13.3	3.46	0.642	0.854	0.415	0.763
	22.7	6.63	0.763	1.73	0.465	0.889
	36.0	13.5	0.958	3.45	0.573	1.068
	53.1	23.8	1.201	6.38	0.652	1.250
	60.0	33.7	1.589	9.53	0.749	1.425
	66.0	43.2	1.886	12.4	0.816	1.548

FTR_{50} = filtration resistance of handsheet stock at 50 cm. H_2O FL = fiber length index

TABLE VIII

ADDITIONAL REFINING DATA OBTAINED FROM PROJECT 1513, PROGRESS REPORTS 13 AND 16

Pulp Handsheet Stock		Properties of Classified Pulp Handsheet Stock (Handsheets Prepared from Beaten Pulps After Removal of Fines Capable of Passing 150-mesh Screen		
rength ream), 00 lb.	(Log FTR_{50})* X T*, Units for FTR_{50}= (cm./g.)x10^{-7} Units for T= (lb./in./100 lb.)x10^{-1}	Log Filtration Resistance at ΔP = 50 cm. H_2O, (cm./g.)x 10^{-7}	Tensile Strength (25x40--500 ream), lb./in./100 lb.	(Log FTR_{50}) X T, Units for FTR_{50}= (cm./g.)x10^{-7} Units for T = (lb./in./100 lb.)x10^{-1}
user Sulfite Pulp Especially Procured for Integrated Studies--Ball Mill--3% Consistency				
5	2.54	0.630	26.4	1.66
8	5.06	0.825	40.6	3.35
7	7.17	0.951	45.0	4.28
6	9.68	1.227	53.5	6.56
4	11.5	1.415	54.9	7.77
9	13.3	1.550	58.2	9.02
2	15.8	1.740	61.9	10.8

0 cm. H_2O

EXPERIMENTAL RESULTS AND CONCLUSIONS

This report contains a substantial quantity of comprehensive information concerning the pulp properties and the balance between pulp properties which are produced by various refining actions. Thus, the report may serve as a readily available source of data and an accumulation of information which may find numerous applications for specific purposes and interests. The immediate and primary objective of this project, however, is the investigation of fiber length index and handsheet shrinkage measurements as potential and useful indicators of important pulp changes taking place during mechanical refining. Thus, the scope of the discussions and conclusions presented will be primarily limited to such considerations. It should be realized, however, that there are other interesting aspects of the data which would have general utility.

For ease of presentation, this part of the report has been divided into several sections, each of which deals with separate and specific effects of the mechanical refining process. The content of these several sections may be briefly summarized as follows:

Section 1--Effect of Mechanical Refining on the Fiber Length Index and Handsheet Shrinkage Properties of Pulps.

Section 2--Effect of Mechanical Refining on the Filtration Resistance and Handsheet Shrinkage Properties of Pulps.

Section 3--Effect of Mechanical Refining on the Tensile Strength and Fiber Length Index Properties of Pulps.

Section 4--Effect of Mechanical Refining on the Tensile Strength and Handsheet Shrinkage Properties of Pulps.

Section 5--Effect of Mechanical Refining on the Tensile Strength and Filtration Resistance Properties of Pulps.

Section 6--Effect of Mechanical Refining on the Properties of Pulp Mixtures.

Section 7--Effect of Mechanical Refining on the Schopper-Riegler Freeness and Handsheet Shrinkage Properties of Pulps.

Section 8--Effect of Mechanical Refining on the Tensile Strength, Schopper-Riegler Freeness, and Handsheet Shrinkage Properties of Pulps.

Section 9--Effect of Mechanical Refining on the Tearing Strength, Fiber Length Index, and Handsheet Shrinkage Properties of Pulps.

SECTION 1

EFFECT OF MECHANICAL REFINING ON THE FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

SECTION 1

EFFECT OF MECHANICAL REFINING ON THE FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

NATURE OF FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The changes which fiber length index and handsheet shrinkage properties undergo as a result of mechanical refining have been presented in Figures 1-1 through 1-5. These figures indicate that:

(1) When a pulp is subjected to a Valley beater refining action, the handsheet shrinkage properties of the pulp progressively increase and the fiber length index properties progressively decrease (see Figure 1-1 and note that the fiber length index scale has been reversed).

(2) For a given pulp and a given refining action, there is a fixed relationship between fiber length index and handsheet shrinkage properties which exist over the entire refining cycle--i.e., down to a Schopper-Riegler freeness range of about 145 ml. (see Figure 1-2).

(3) For a given pulp, the relationship of fiber length index to handsheet shrinkage properties varies depending upon the type of refining action to which the pulp is subjected. Again, however, for any given type of refining action, a fixed relationship exists over the entire refining cycle. This may be seen from Figure 1-3 which indicates that various refining instruments produced different refining actions. As an example, the Lampén mill produced lower fiber length index properties at a given handsheet shrinkage level than the Jokro mill, and the Jokro mill in turn produced lower

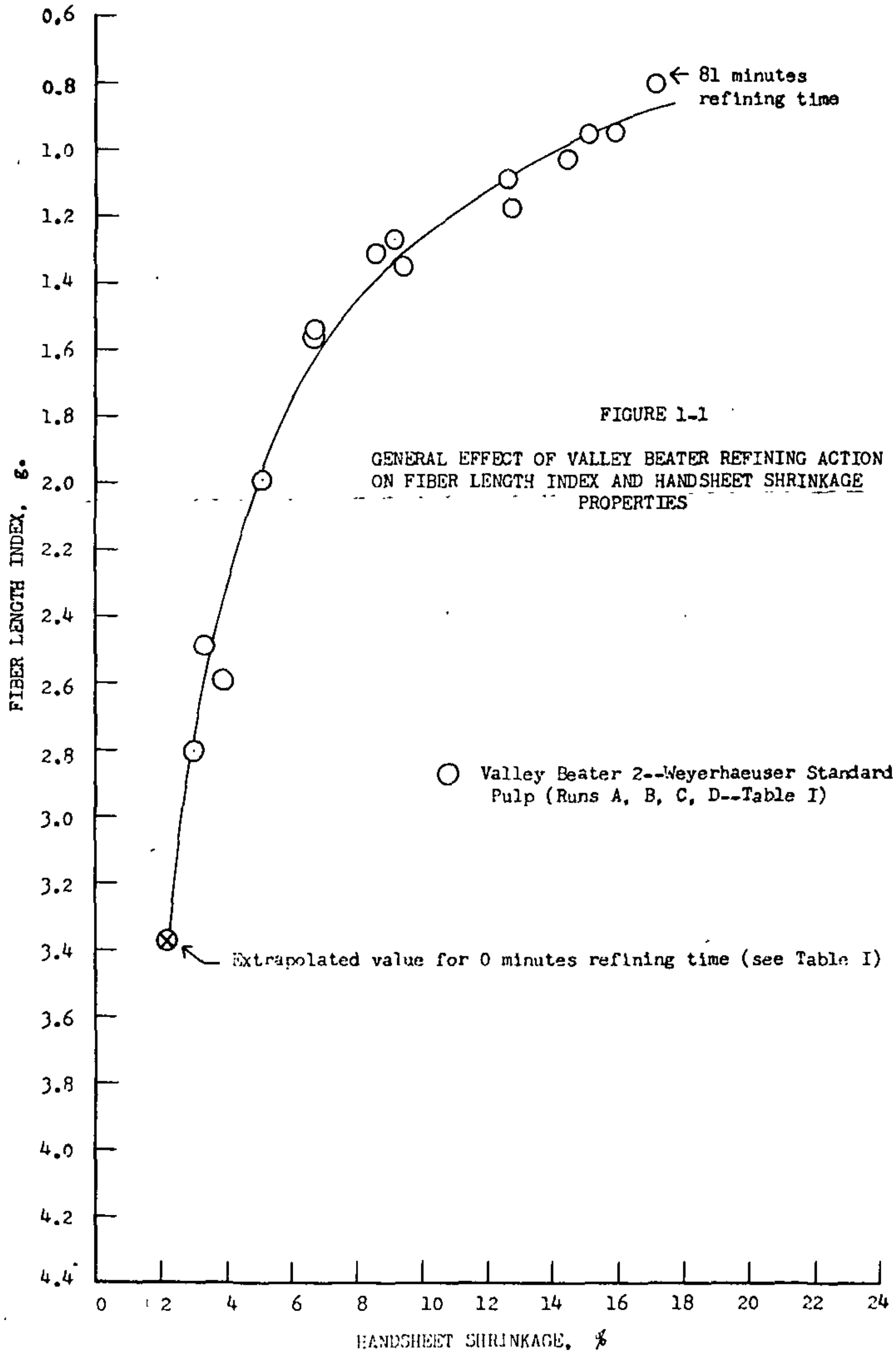


FIGURE 1-1

GENERAL EFFECT OF VALLEY BEATER REFINING ACTION ON FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES

FIGURE 1-2

GENERAL EFFECT OF VALLEY BEATER REFINING ACTION ON FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES

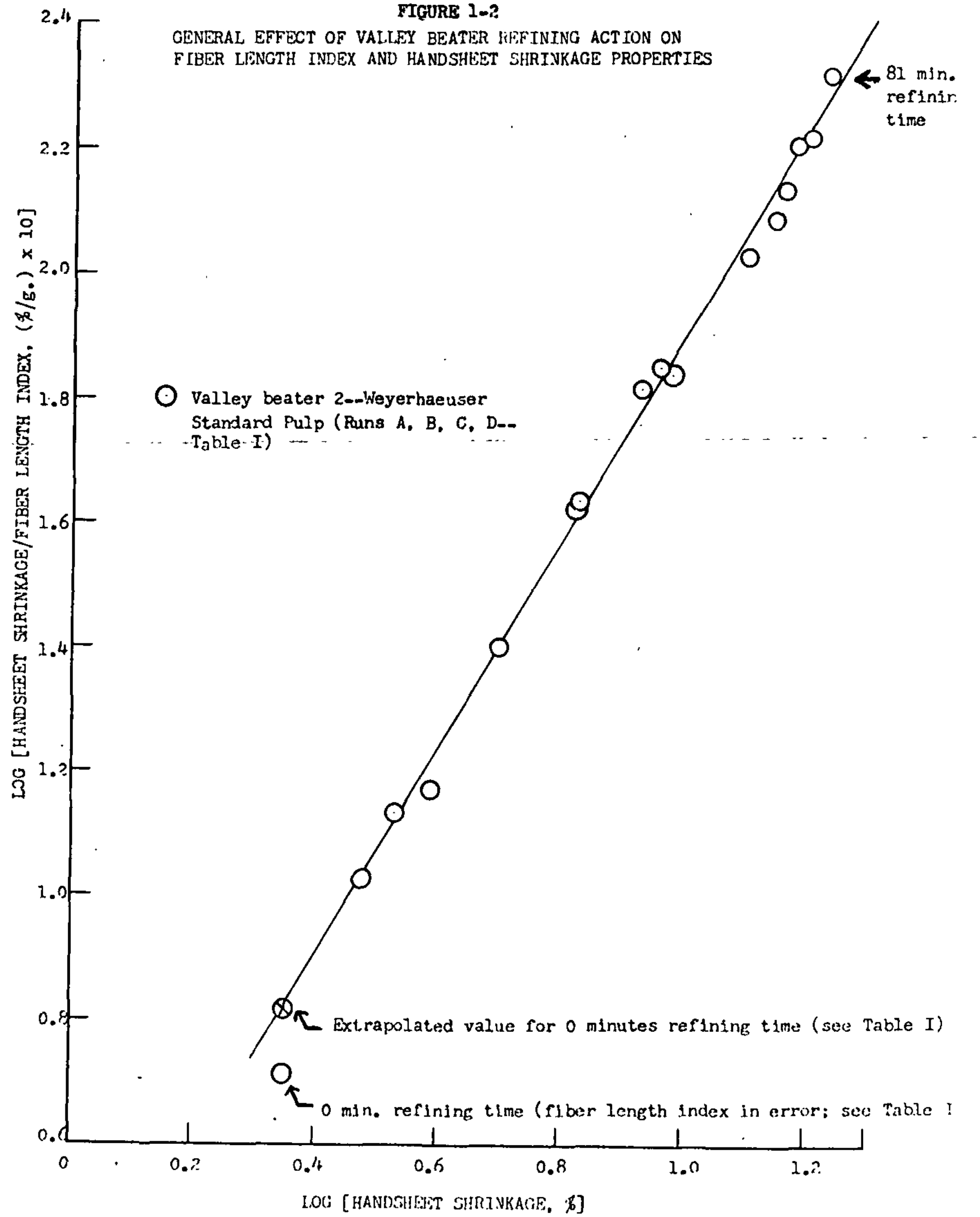
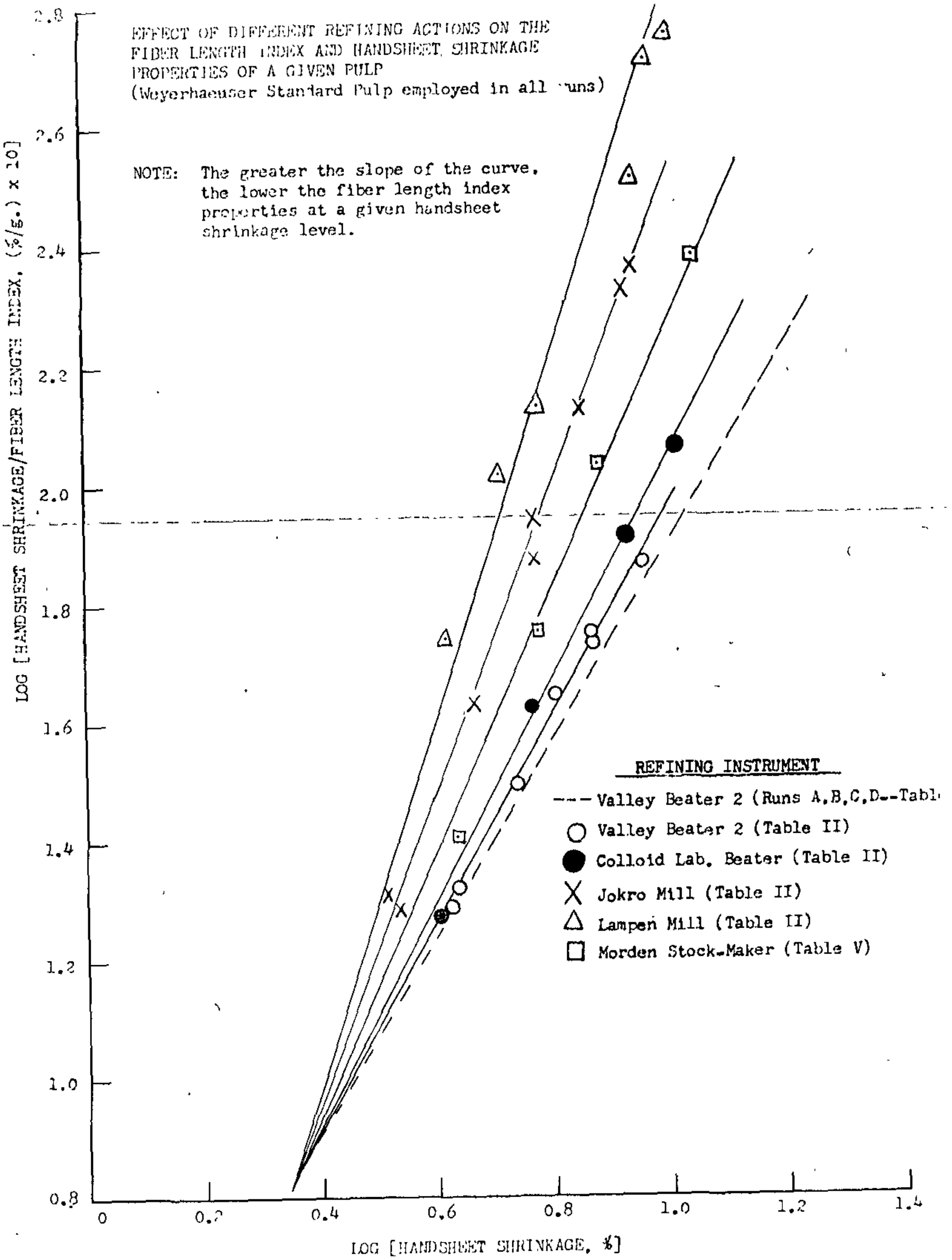


FIGURE 1-3


EFFECT OF DIFFERENT REFINING ACTIONS ON THE FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES OF A GIVEN PULP
(Weyerhaeuser Standard Pulp employed in all runs)
NOTE: The greater the slope of the curve, the lower the fiber length index properties at a given handsheet shrinkage level.
LOG [HANDSHEET SHRINKAGE/FIBER LENGTH INDEX, (%/g.) x 10]
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
LOG [HANDSHEET SHRINKAGE, %]
REFINING INSTRUMENT
--- Valley Beater 2 (Runs A,B,C,D--Tabl
Valley Beater 2 (Table II)
Colloid Lab. Beater (Table II)
Jokro Mill (Table II)
Lampen Mill (Table II)
Morden Stock-Maker (Table V)

fiber length index properties than the Valley beater. (General differences in the refining action of the various instruments may also be noted by the fact that at a given level of tensile strength, the Lampén mill produced the lowest tearing strength properties and the Valley beater produced the highest tearing strength properties.)

(4) The relationship of fiber length index to handsheet shrinkage varies depending upon the nature of the pulp refined. Again, however, for a given pulp and a given refining action, a fixed relationship exists over the entire refining cycle (see Figures 1-4 and 1-5). Thus, the general fiber length index and handsheet shrinkage relationships previously described hold for a wide variety of pulps and refining actions. In fact, the relationships held with all of the data presently available.

EXPERIMENTAL DETERMINATION OF FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The nature of the curves in Figures 1-2 through 1-5 indicate that the fiber length index and handsheet shrinkage relationship for any given pulp and any given refining action could be simply and rapidly established by merely determining the handsheet shrinkage and fiber length index properties of the unrefined pulp and the handsheet shrinkage and fiber length index properties of the pulp refined to any one given level. Also, the relationship for any additional refining actions could be established by refining the pulp, with the desired refining action, to any one given level and subsequently determining the fiber length index and handsheet shrinkage properties of the refined pulps. It should be noted, however, that investigations

FIGURE 1-4

EFFECT OF DIFFERENT REFINING ACTIONS ON THE FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

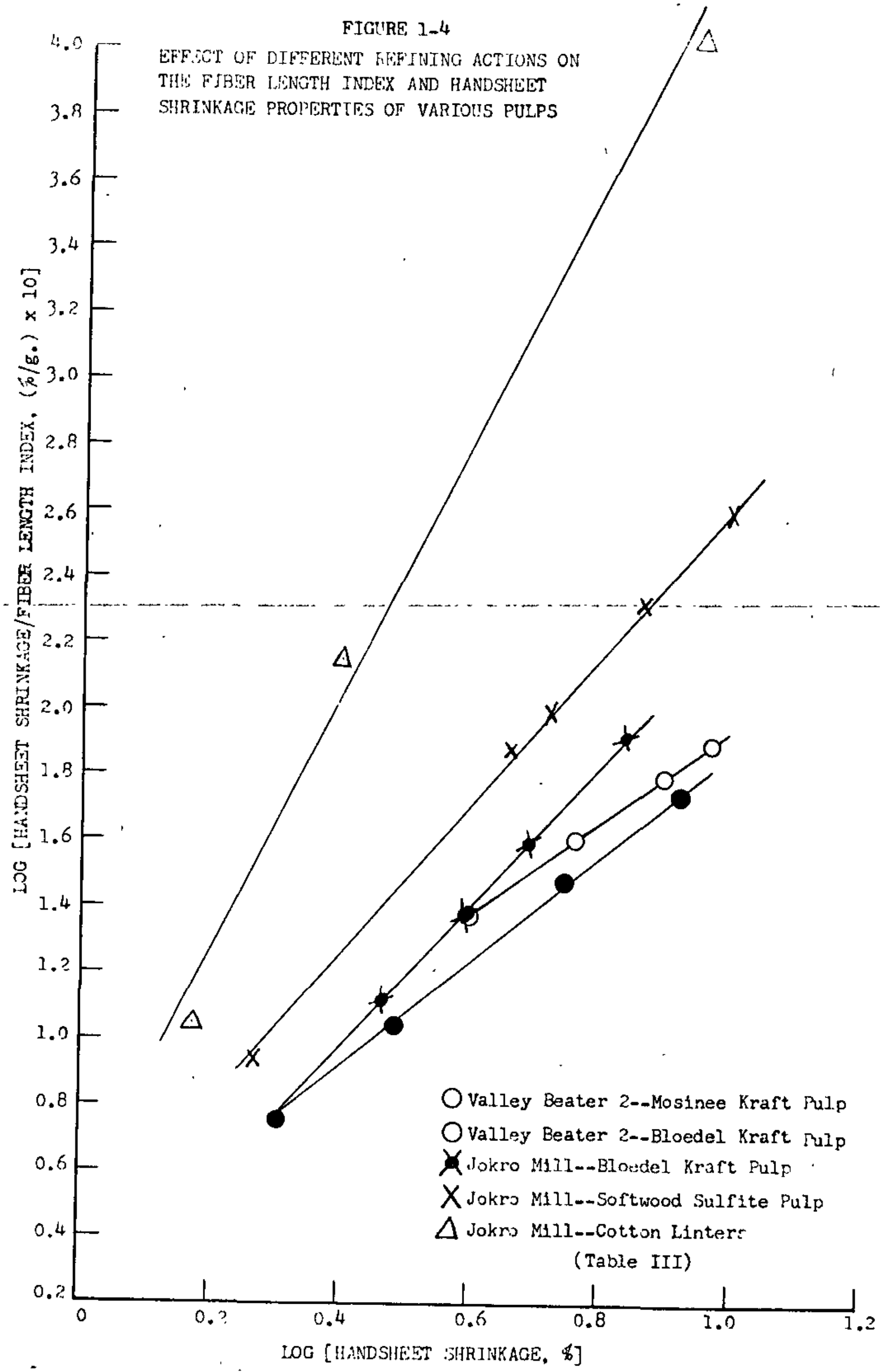
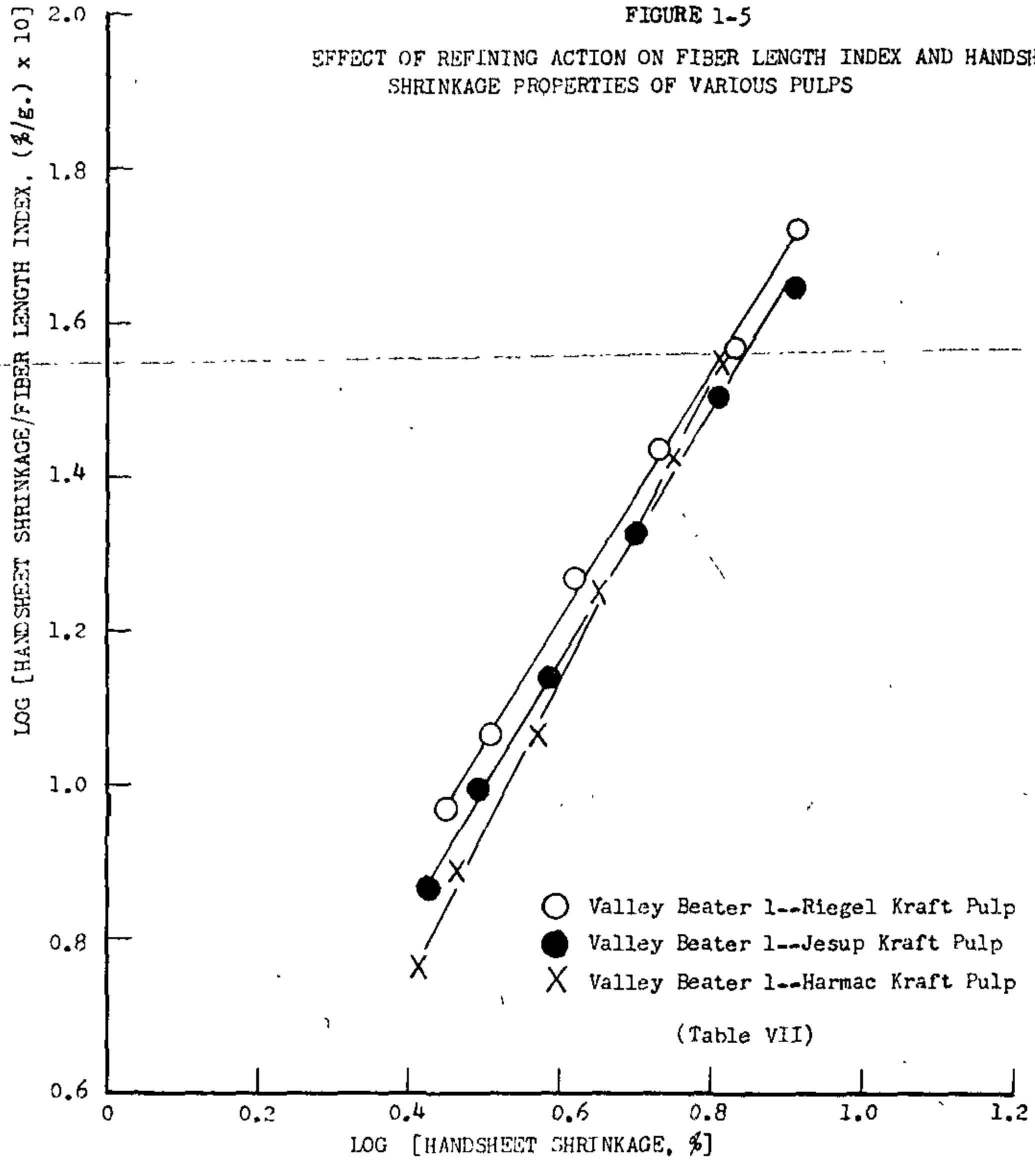


FIGURE 1-5

EFFECT OF REFINING ACTION ON FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS



at additional refining levels would improve the accuracy of the relationships determined by this method.

MATHEMATICAL EXPRESSION OF THE FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE RELATIONSHIP PRODUCED BY MECHANICAL REFINING

A mathematical expression of the fiber length index and handsheet shrinkage relationship produced by mechanical refining may be derived as follows:

(1) Refer to Figure 1-2 and let:

A = the slope of the curve (straight line)

FL_o = the fiber length index of the unrefined pulp

FL_x = the fiber lengthindex of the pulp after any given refining time of x minutes

S_o = the handsheet shrinkage of the unrefined pulp

S_x = the handsheet shrinkage of the pulp after any given refining time of x minutes

(2) Then, from Figure 1-2:

$$\log \frac{S_x}{FL_x} - \log \frac{S_o}{FL_o} = A\,(\log S_x - \log S_o), \quad \text{or}$$

$$\frac{\dfrac{S_x}{FL_x}}{\dfrac{S_o}{FL_o}} = \frac{S_x^{\,A}}{S_o^{\,A}}$$

(3) Then by algebraic manipulation: $\dfrac{S_x}{FL_x} = \dfrac{S_x^{\,A}\,S_o}{S_o^{\,A}\,FL_o}$,

$$FL_x = \frac{S_x\,(S_o^{\,A})\,(FL_o)}{S_x^{\,A}\,S_o}, \text{ and } FL_x = FL_o\left(\frac{S_o}{S_x}\right)^{A-1}$$

For the specific case represented in Figure 1-2:

"A" in the above expression would be a constant equivalent to the slope of the curve, or 1.66:

"S_o" would be a constant equivalent to the handsheet shrinkage of the unrefined pulp, or 2.23; and

"FL_o" would be a constant equivalent to the fiber length index of the unrefined pulp, or 3.373.

Thus, the expression would become:

$$FL_x \text{ (grams)} = 3.373 \left(\frac{2.23}{S_x}\right)^{0.66},$$

and it would be possible to calculate fiber length index properties of the pulp which correspond to the experimentally determined handsheet shrinkage values obtained at various levels of refining. (Such calculations were performed and are represented by the curve in Figure 1-1--i.e., the actual curve was based on fiber length index values calculated with the above expression, and the experimental points were superimposed on this curve.)

Likewise, the mathematical expression for curves presented in Figure 1-3 would be:

$F_x = 3.373 \left(\frac{2.23}{S_x}\right)^{2.09}$ for Weyerhaeuser pulp refined in the Lampén mill

$F_x = 3.373 \left(\frac{2.23}{S_x}\right)^{1.61}$ for Weyerhaeuser pulp refined in the Jokro mill

$F_x = 3.373 \left(\frac{2.23}{S_x}\right)^{1.22}$ for Weyerhaeuser pulp refined in the Morden Stock-Maker, etc.

SIGNIFICANCE AND UTILITY OF FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The experimental results indicate that fiber length index and handsheet drainage relationships may prove useful in a number of applications including:

(1) Characterization of a refining action. Fiber length index and handsheet shrinkage measurements could be employed to at least partially characterize a refining action. This could be accomplished by a method demonstrated in Figure 1-3--i.e., the slope of the curves obtained with a given pulp and different refining actions could be employed to characterize the refining action.

(2) Control of a refining process. Fiber length index and handsheet shrinkage measurements could be employed to control a given refining process. As an example, the [fiber length index-handsheet shrinkage] relationship for a desired refining process could be established and employed as a control. Thus, possible subsequent changes in this relationship would indicate that the process was out of control--i.e., either the refining action had changed or/and the pulp supplied to the process had changed.

(3) Laboratory evaluation of a pulp. Fiber length index measurements could be employed to indicate the relative degree to which refining shortens the fibers in a pulp. Also, the fiber length index properties of a pulp could be predicted over an entire refining cycle by means of handsheet shrinkage measurements and a limited number of fiber length index measurements. This would be particularly advantageous when small quantities of pulp are involved--i.e., about 3 to 5 grams of pulp are required for a handsheet shrinkage determination, whereas at least 20 g. of pulp are required for a fiber length index determination.

SECTION 2

EFFECT OF MECHANICAL REFINING ON THE FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

SECTION 2

EFFECT OF MECHANICAL REFINING ON THE FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

NATURE OF FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The changes which filtration resistance and handsheet shrinkage properties undergo as a result of mechanical refining have been presented in Figures 2-1 through 2-4. These figures indicate that:

(1) When a pulp is subjected to a Valley beater refining action, both the handsheet shrinkage and the filtration resistance properties of the pulp progressively increase (see Figure 2-1).

(2) For a given pulp and a given refining action, there is a fixed relationship between filtration resistance and handsheet shrinkage properties which apparently exists over the entire refining cycle. [This type of relationship is apparent with filtration resistance data obtained at any given pressure drop and with filtration resistance data obtained with either "whole" or "handsheet" stock (see Figures 2-1 and 2-2).]

(3) The relationships between filtration resistance and handsheet shrinkage properties vary depending upon the nature of the pulp refined. Again, however, for a given pulp and a given refining action, a fixed relationship exists throughout the refining cycle (see Figures 2-3 and 2-4).

EXPERIMENTAL DETERMINATION OF FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The nature of the curves in Figures 2-1 and 2-4 indicate that the filtration resistance and handsheet shrinkage relationship for any given pulp refined in the Valley beater (other types of refiners were not checked in the present work) could be simply and rapidly established by merely determining the handsheet shrinkage and filtration resistance properties of the unrefined pulp and the handsheet shrinkage and filtration resistance properties of the pulp refined to any one given level. It should be noted, however, that investigations at additional refining levels would improve the accuracy of the relationship.

MATHEMATICAL EXPRESSION OF THE FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

From any curve in Figures 2-1 to 2-4, it may be seen that a mathematical expression for the filtration resistance and handsheet shrinkage relationship produced by mechanical refining would be:

$$FR_x = \text{anti log}\,[A(S_x - S_o) + \log FR_o]$$

where:

A = the slope of the curve (straight line)

FR_o = the filtration resistance of the unrefined pulp at any given pressure drop ΔP.

FR_x = the filtration resistance of the pulp at any given pressure drop ΔP after any given refining time of x minutes.

S_o = the handsheet shrinkage of the pulp after any given refining time of x minutes.

In the specific case of the "ΔP = 50 cm. H_2O" curve in Figure 2-2:

"A" in the above expression would be a constant equivalent to the slope of the curve, or 0.264;

"S_o" would be a constant equivalent to the handsheet shrinkage of the unrefined pulp, or 2.32; and

FIGURE 2-1

GENERAL EFFECT OF VALLEY BEATER REFINING ACTION ON FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE PROPERTIES

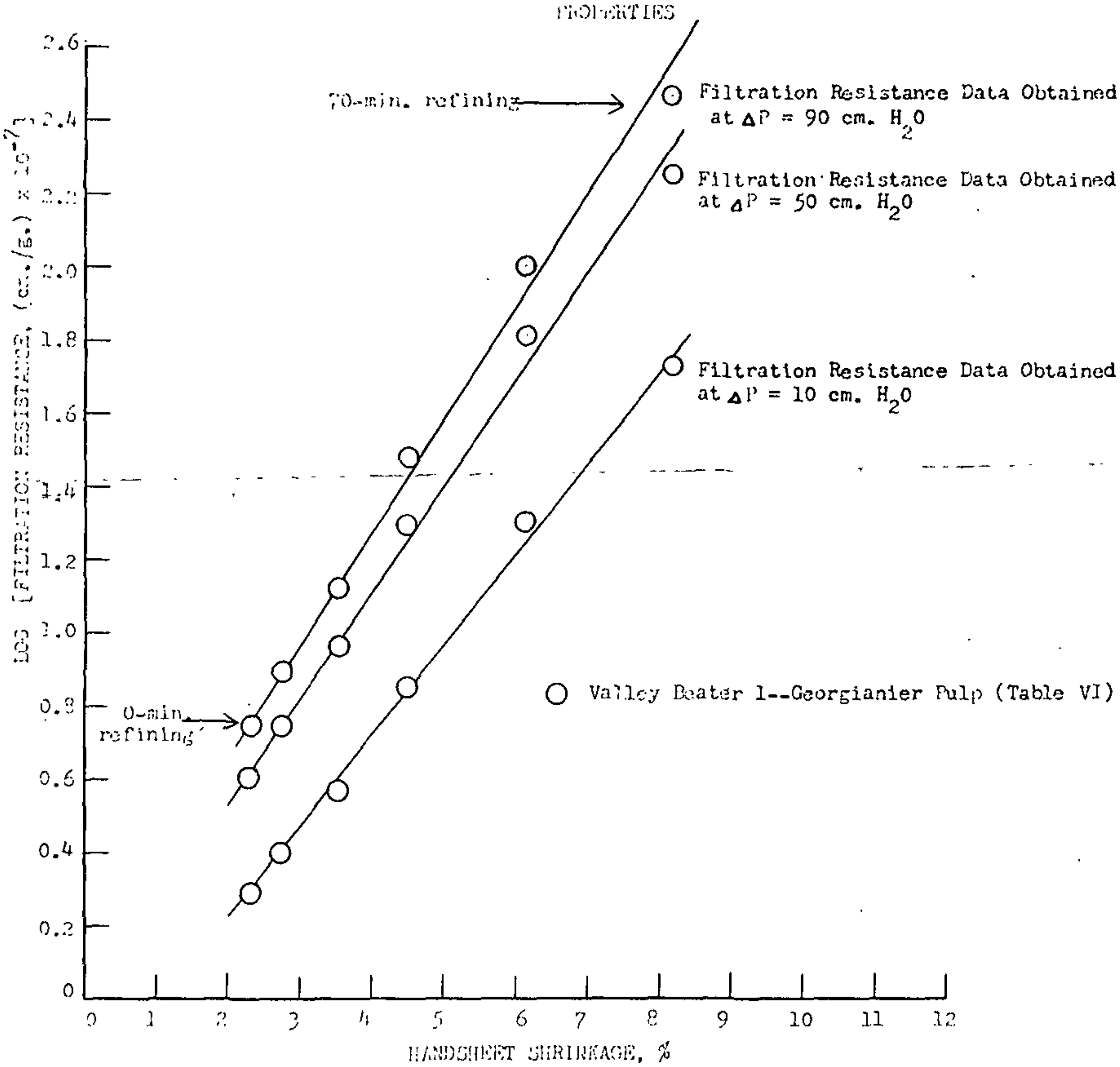


FIGURE 2-2

GENERAL EFFECT OF VALLEY BEATER REFINING ACTION ON FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE PROPERTIES

(Filtration Resistance Data Obtained on "Handsheet" Stock)

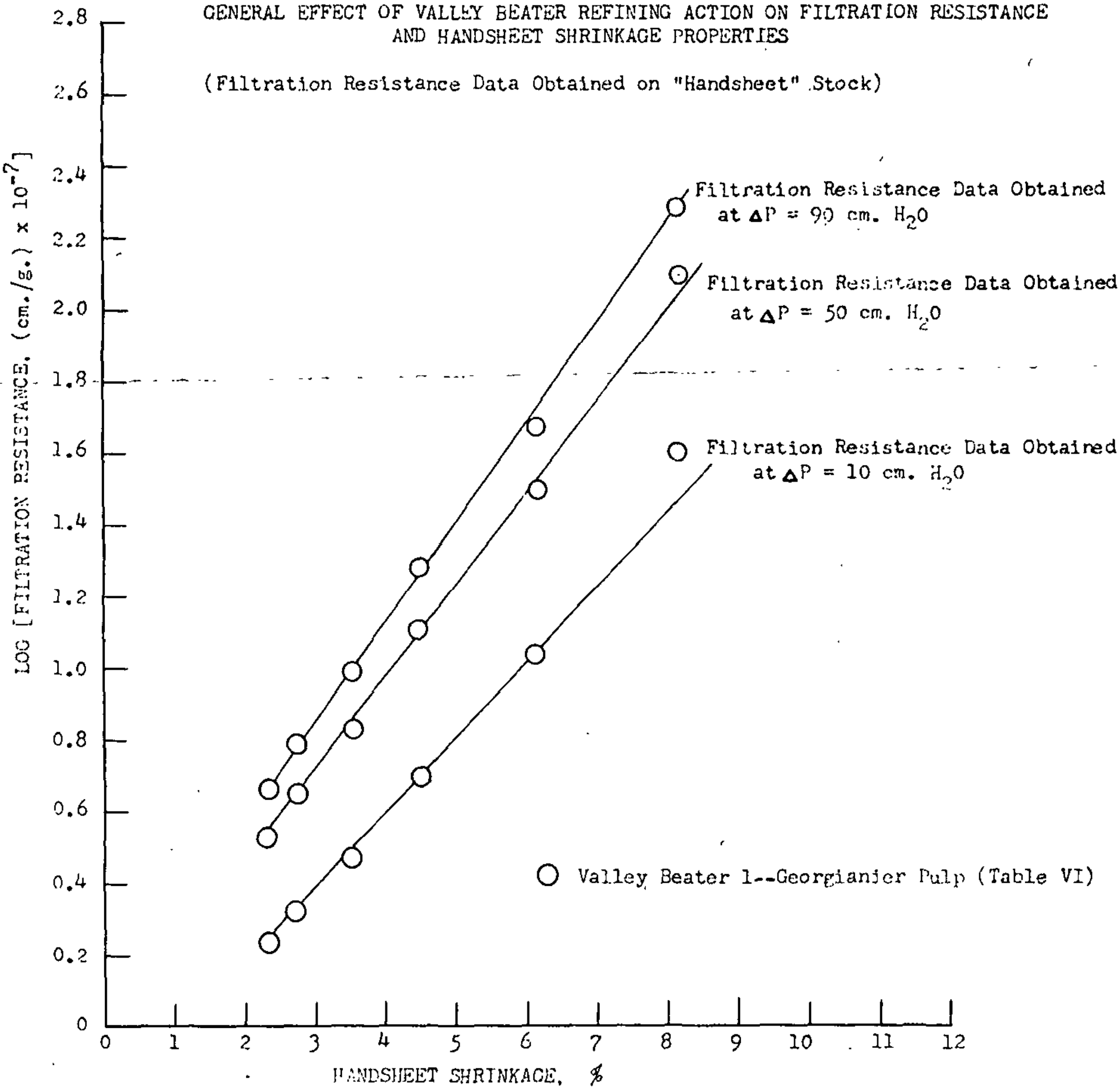


FIGURE 2-3

EFFECT OF VALLEY BEATER REFINING ACTION ON FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

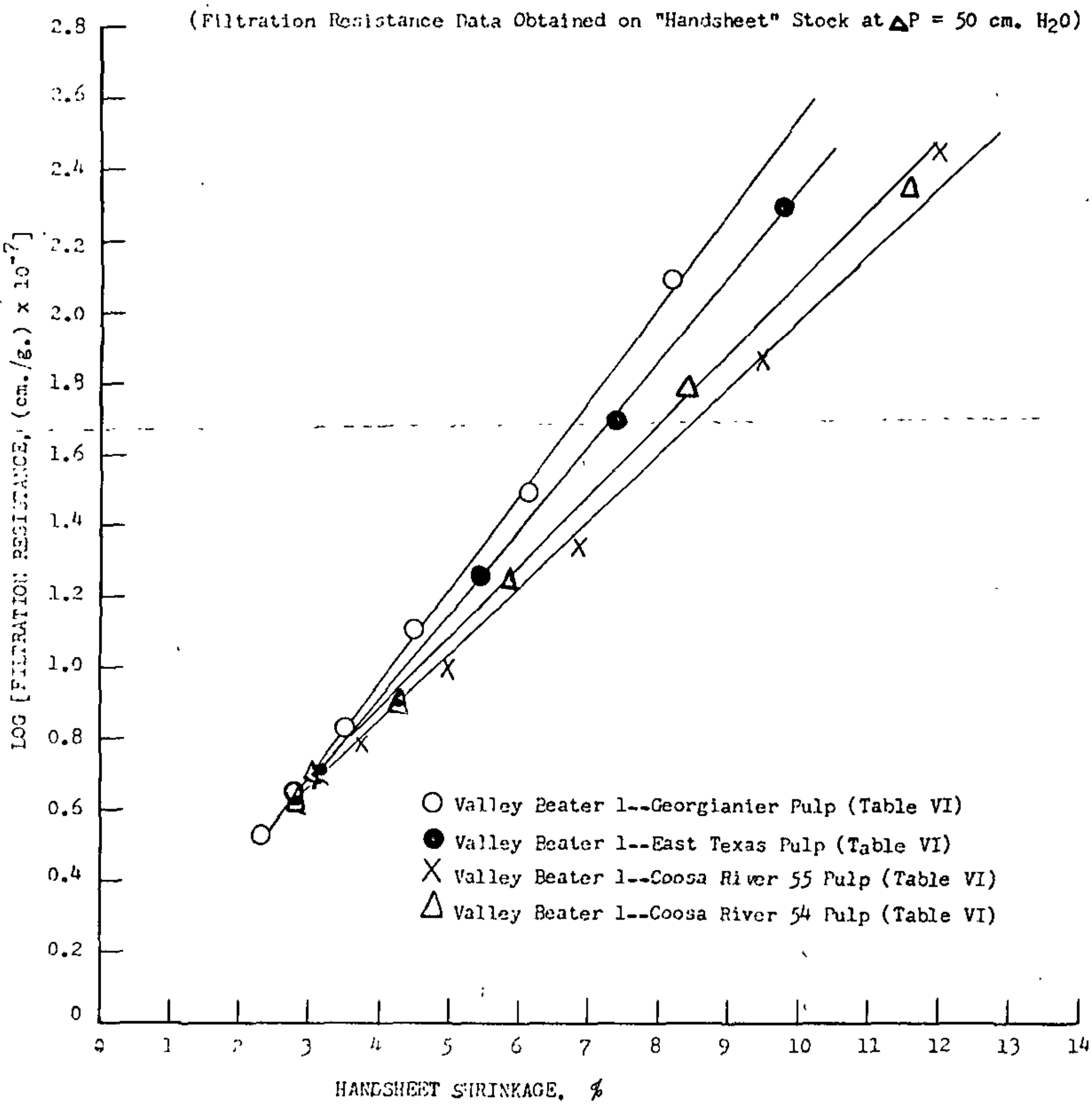
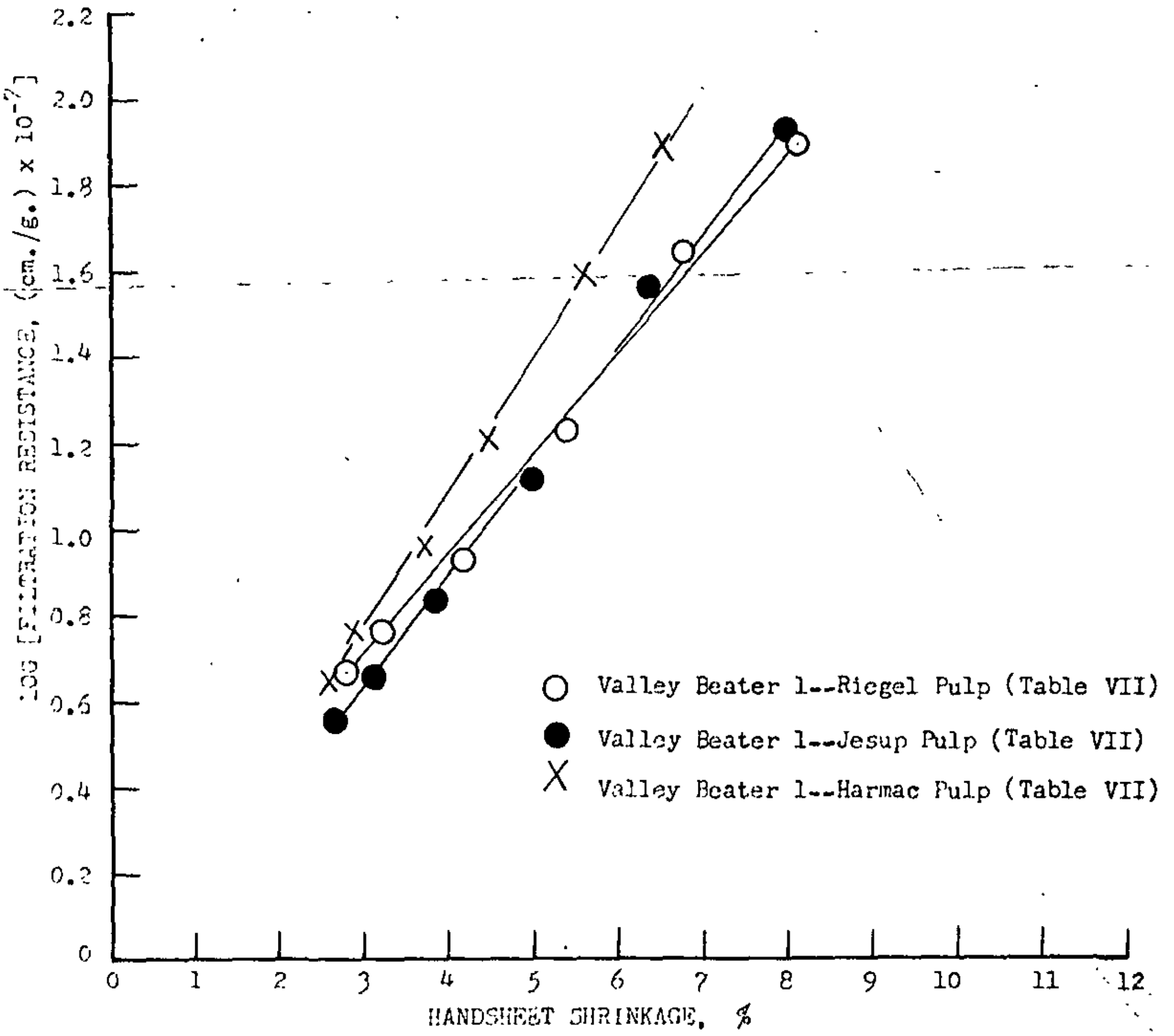


FIGURE 2-4

EFFECT OF VALLEY BEATER REFINING ACTION ON FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

(Filtration Resistance Data Obtained on "Handsheet" Stock at ΔP = 50 cm. H_2O)



"log FR_o" would be a constant equivalent to log [(filtration resistance of the unrefined "handsheet" stock obtained at a pressure drop of 50 cm. of water) x 10^{-7}], or 0.543.

Thus, the expression would become:

FR_x [(cm./g.) x 10^{-7}] = anti log [0.264 (S_x-2.32) + 0.543].

In the present work, both filtration resistance and handsheet shrinkage data were available only for pulps which had been refined in the Valley beater. Therefore, it cannot be definitely stated if the above type of relationship would also apply to pulps refined in other refining instruments. It appears quite likely, however, that such would be the case and further work would be desirable to substantiate this contention. If the same general type of relationships were found with other refining instruments, the [filtration resistance-handsheet shrinkage] relationship would perhaps provide a convenient method for at least partially characterizing a refining action. Thus, if a given pulp were refined in a variety of instruments, "A" in the above relationship would be the only constant which would change with different refining actions and consequently the value of A could be employed to define the refining action.

SIGNIFICANCE AND UTILITY OF FILTRATION RESISTANCE AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The experimental results indicate that filtration resistance and handsheet shrinkage relationships may prove useful in a number of applications including:

(1) Characterization of a refining action. Further work would be required to definitely establish the utility of filtration resistance and handsheet shrinkage relationships for characterizing a refining action. It appears likely, however, that such relationships would prove useful and could be employed in the manner previously described in this section of the report.

An obvious advantage in using [fiber length index-handsheet shrinkage] and [filtration resistance-handsheet shrinkage] relationships to characterize a refining action would be the fact that the relationships apparently apply over the entire refining cycle (further work should be done with the filtration resistance test) and they may readily be established with a small number of relatively simple and rapid tests. Also, fiber length index measurements are considered a measure of fiber length, handsheet shrinkage measurements are considered a measure of hydration, and filtration resistance measurements are considered a measure of the drainage behavior of stock in papermaking operations and a strong indication of the specific surface of the pulp. Thus, the use of the above two relationships for characterizing a refining action would tend to be indicative of the relative cutting, hydration, surface development, and drainage characteristics produced by the refining action.

(2) Control of a refining process. Filtration resistance values have been advocated for control purposes in certain refining operations. The relationship between filtration resistance and handsheet shrinkage measurements demonstrated in the present work, however, would indicate that--at least in certain applications--handsheet shrinkage measurements could be substituted for filtration resistance tests. Further, it would appear that

[filtration resistance-handsheet shrinkage] relationships might be employed for control purposes in the same manner as the [fiber length index-handsheet shrinkage] relationships described in Section 1 of this report (see page 21).

(3) <u>Laboratory evaluation of a pulp</u>. Apparently the filtration resistance properties of a pulp could be predicted over an entire refining cycle by means of handsheet shrinkage measurements and a limited number of filtration resistance measurements. This would be particularly advantageous because of a saving in work and time.

SECTION 3

EFFECT OF MECHANICAL REFINING ON THE TENSILE STRENGTH AND FIBER LENGTH INDEX PROPERTIES OF PULPS

SECTION 3

EFFECT OF MECHANICAL REFINING ON THE TENSILE STRENGTH AND FIBER LENGTH INDEX PROPERTIES OF PULPS

NATURE OF TENSILE STRENGTH AND FIBER LENGTH INDEX RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The changes which tensile strength and fiber length index properties undergo as a result of mechanical refining have been presented in Figures 3-1 through 3-5. These figures indicate that:

(1) When a pulp is subjected to a Valley beater refining action, the fiber length index properties of the pulp progressively decrease and the tensile strength properties progressively increase (see Figure 3-1 and note that the fiber length index scale has been reversed). Further, there is a straight line relationship between tensile strength and fiber length index properties which exists over most of the refining cycle.

(2) For a given pulp, the straight line relationship between tensile strength and fiber length index properties varies depending upon the type of refining action to which the pulp is subjected (see Figure 3-2).

(3) The straight line relationship between tensile strength and fiber length index properties varies depending upon the nature of the pulp refined (see Figures 3-3, 3-4, and 3-5).

(4) For a given pulp and a given refining action, a straight line relationship exists between the tensile strength and fiber length index properties of the pulp (see Figures 3-1 through 3-5). This relationship, however, exists only until the maximum attainable tensile strength of the pulp is approached--i.e., the relationship is no longer valid when the refining cycle is extended to the point where the tensile strength remains constant or actually decreases (see Figure 3-4).

FIGURE 3-1

GENERAL EFFECT OF VALLEY BEATER REFINING ACTION ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES

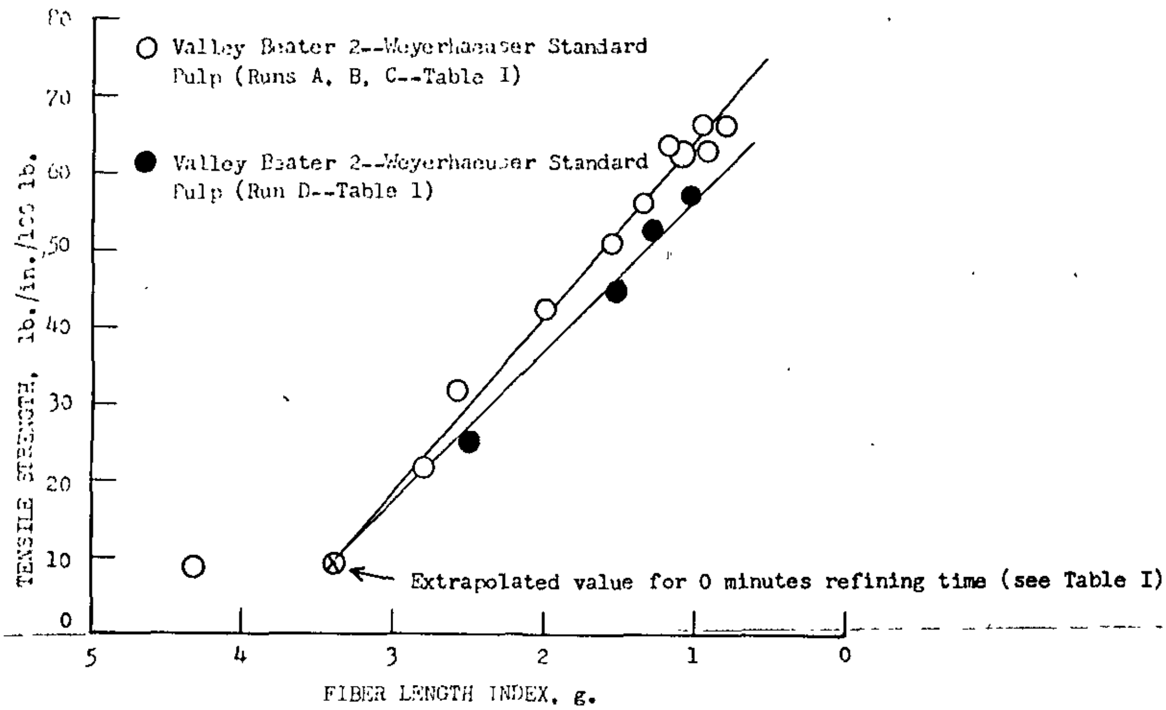
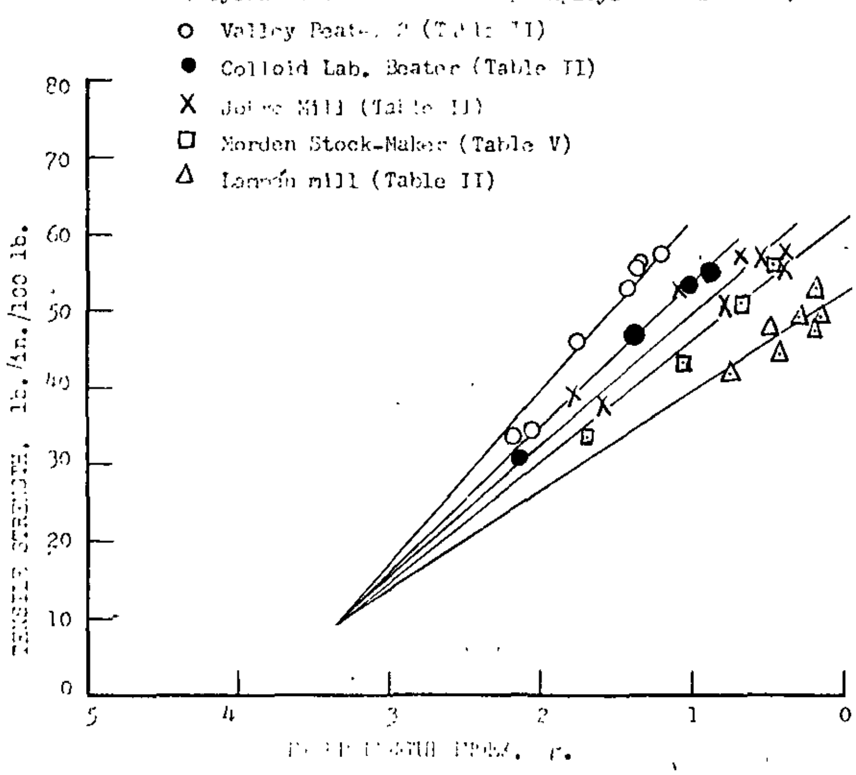


FIGURE 3-2

EFFECT OF DIFFERENT REFINING ACTIONS ON THE TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF A GIVEN PULP
(Weyerhaeuser Standard Pulp Employed in All Runs)



FIGURES 3-3 AND 3-4

EFFECT OF DIFFERENT REFINING ACTIONS ON THE TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

FIGURE 3-3

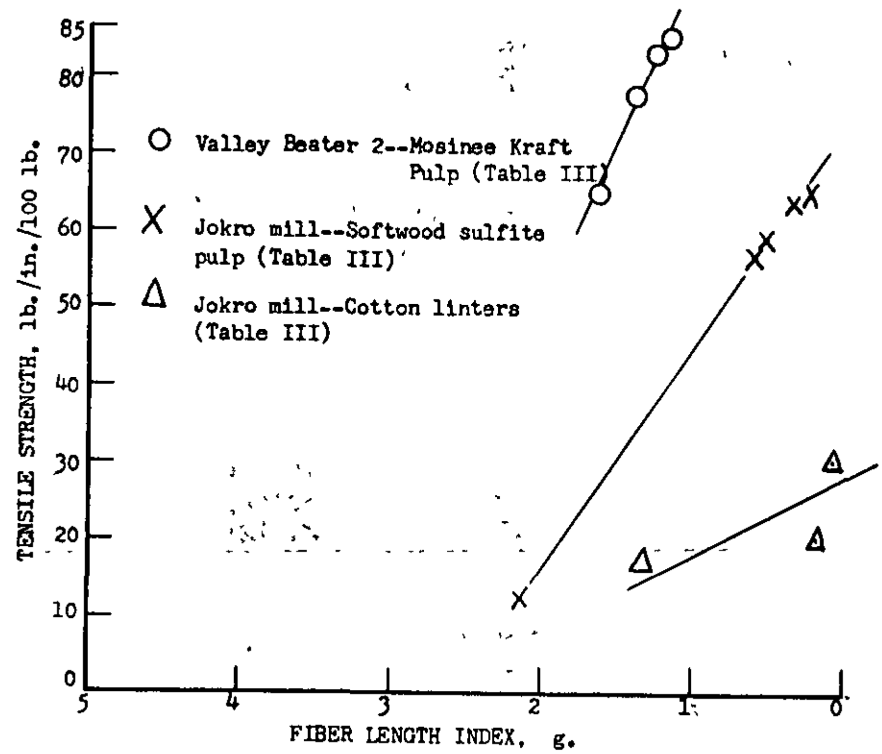


FIGURE 3-4

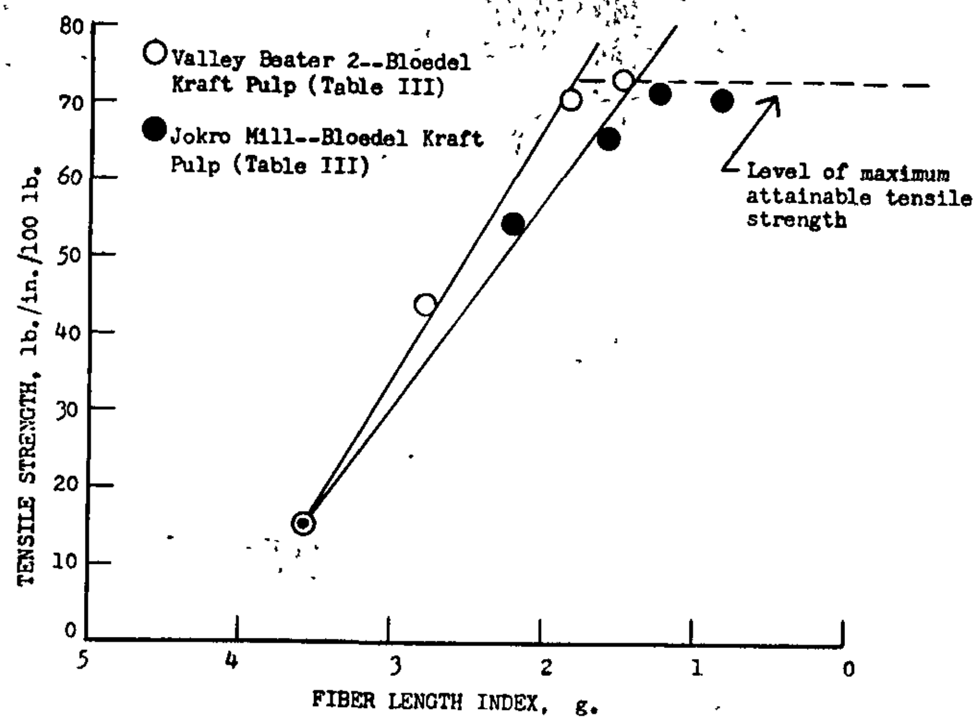
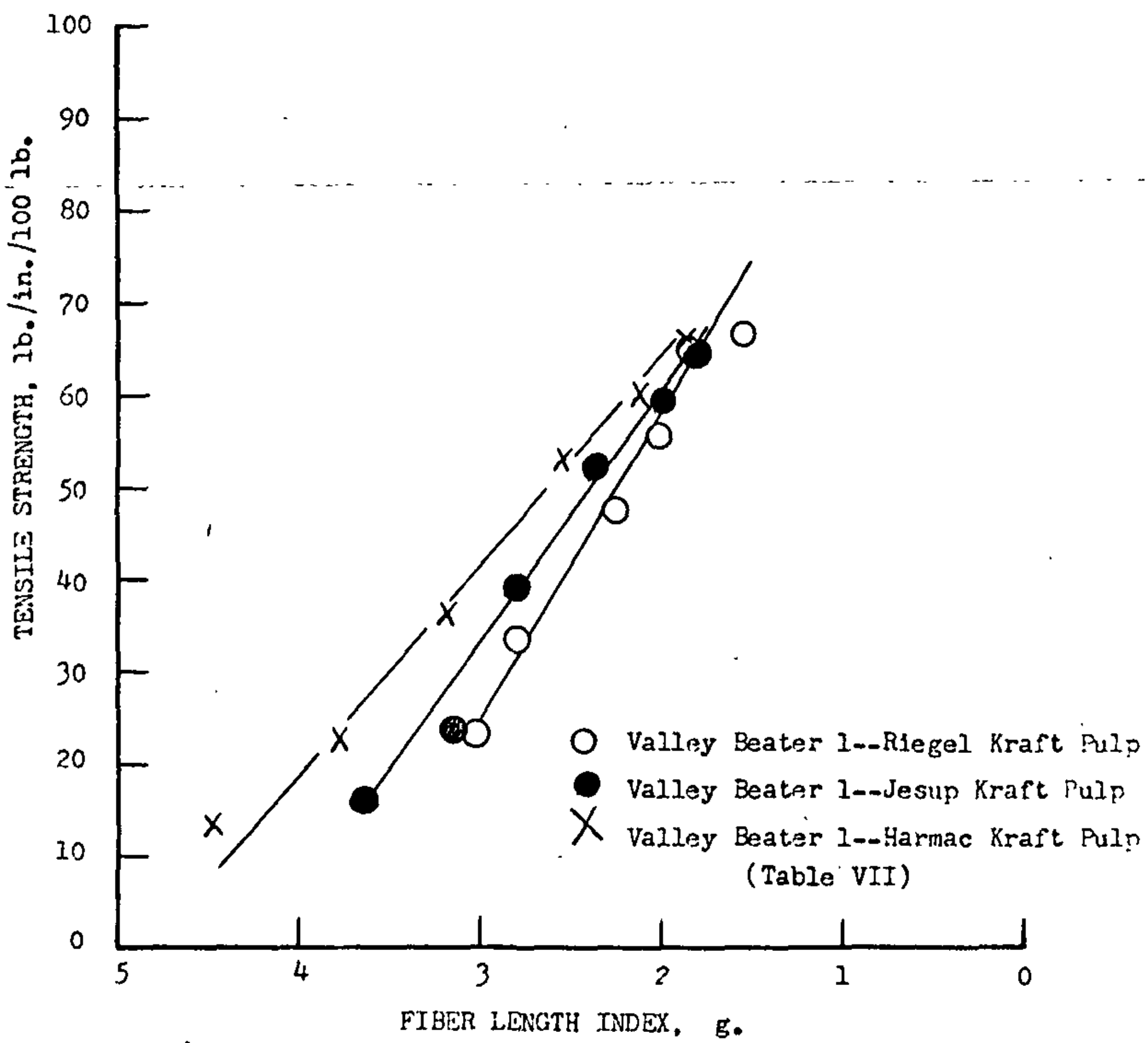


FIGURE 3-5

EFFECT OF REFINING ACTION ON TENSILE STRENGTH AND FIBER LENGTH INDEX PROPERTIES OF VARIOUS PULPS



EXPERIMENTAL DETERMINATION OF TENSILE STRENGTH AND FIBER LENGTH INDEX RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The nature of the curves in Figures 3-1 through 3-5 indicates that the tensile strength and fiber length index relationship for any given pulp and any given refining action could be simply and rapidly established by merely determining the tensile strength and fiber length index properties of the unrefined pulp and the tensile strength and fiber length index properties of the pulp refined to any one given level below the maximum attainable tensile strength of the pulp. Also, the relationship for any additional refining actions could be established by refining the pulp, with the desired refining action, to any one given level, below the maximum attainable tensile strength, and subsequently determining the fiber length index and tensile strength properties of the refined pulp. It should be noted, however, that investigations at additional refining levels would improve the accuracy of the relationship determined by this method.

MATHEMATICAL EXPRESSION OF THE TENSILE STRENGTH AND FIBER LENGTH INDEX RELATIONSHIP PRODUCED BY MECHANICAL REFINING

From any curve in Figures 3-1 to 3-5, it may be seen that a mathematical expression for the tensile strength and fiber length index relationship produced by mechanical refining would be:

$$T_x = A(FL_o - FL_x) + T_o$$

where:

A = the slope of the curve (straight line)

FL_o = the fiber length index of the unrefined pulp

FL_x = the fiber length index of the pulp after any given refining time of x minutes

T_o = the tensile strength of the unrefined pulp

T_x = the tensile strength of the pulp after any given refining time of x minutes

For the specific case of the Valley beater No. 2 refined pulp in Figure 3-2:

"A" in the above relationship would be a constant equivalent to the slope of the curve, or 22.3;

"FL_o" would be a constant equivalent to the fiber length index of the unrefined pulp, or 3.373; and

"T_o" would be a constant equivalent to the tensile strength of the unrefined pulp, or 9.1.

Thus, the expression would become:

$$T_x \text{ (lb./in./100 lb.)} = 22.3\ (3.373 - FL_x) + 9.1$$

Likewise, the mathematical expression for other curves presented in Figure 3-2 would be:

$T_x = 15.6\ (3.373 - FL_x) + 9.1$ for Weyerhaeuser pulp refined in the Morden Stock-Maker.

$T_x = 12.9\ (3.373 - FL_x) + 9.1$ for Weyerhaeuser pulp refined in the Lampen mill, etc.

SIGNIFICANCE AND UTILITY OF TENSILE STRENGTH AND FIBER LENGTH INDEX RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The experimental results indicate that tensile strength and fiber length index relationships may prove useful in a number of applications including:

(1) Characterization of a refining action. With a standard pulp, the tensile strength-fiber length index relationship could serve as a method for partially characterizing and checking the refining action of a refining instrument.

(2) Control of a refining process. The nature of the [tensile strength-fiber length index] relationships suggests that fiber length index measurements would prove desirable for controlling a given refining process.

SECTION 4

EFFECT OF MECHANICAL REFINING ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

SECTION 4

EFFECT OF MECHANICAL REFINING ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

NATURE OF TENSILE STRENGTH AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The changes which tensile strength and handsheet shrinkage properties undergo as a result of mechanical refining have been presented in Figures 4-1 through 4-9. These figures indicate that:

(1) When a pulp is subjected to a Valley beater refining action, both the handsheet shrinkage and the tensile strength properties of the pulp progressively increase (see Figure 4-1).

(2) When the [tensile strength x handsheet shrinkage] properties of a pulp are plotted against the handsheet shrinkage properties of the pulp, a straight line relationship results which exists over most of the refining cycle (see Figure 4-2). Thus, for a given pulp and a given refining action, there is a fixed relationship between tensile strength and handsheet shrinkage properties which exists over most of the refining cycle.

(3) The relationship of tensile strength to handsheet shrinkage varies depending upon the nature of the pulp refined. Again, however, for a given pulp and a given refining action, a fixed relationship exists over most of the refining cycle (see Figures 4-2 through 4-8).

(4) For a given pulp, the relationship of tensile strength to handsheet shrinkage properties varies depending upon the type of refining action to which the pulp is subjected. Again, however, for any given type of refining action, a fixed relationship exists over most of the refining

FIGURES 4-2 and 4-2

GENERAL EFFECT OF VALLEY BEATER REFINING ACTION ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES

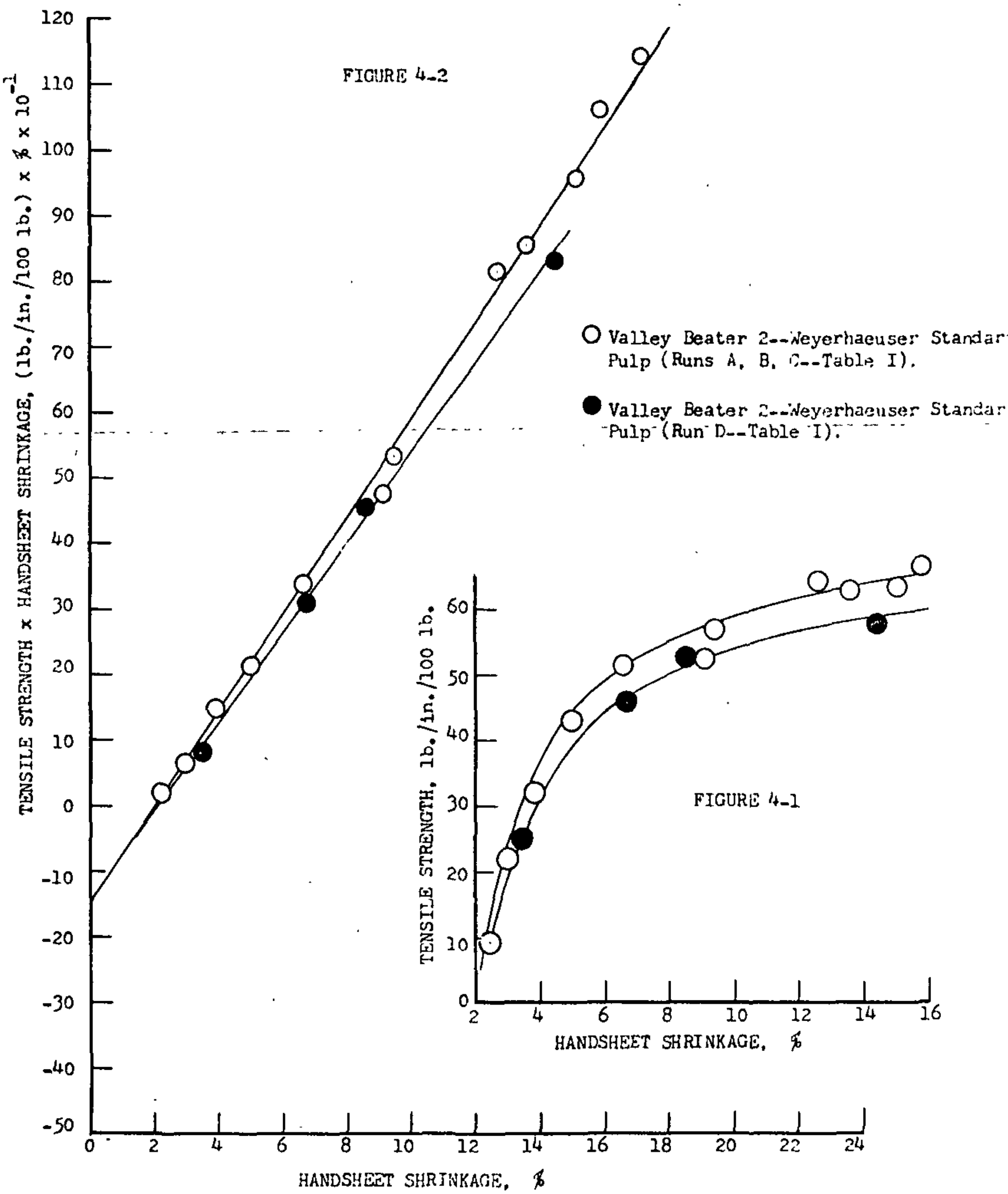


FIGURE 4-3

EFFECT OF VALLEY BEATER REFINING ACTION ON THE TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

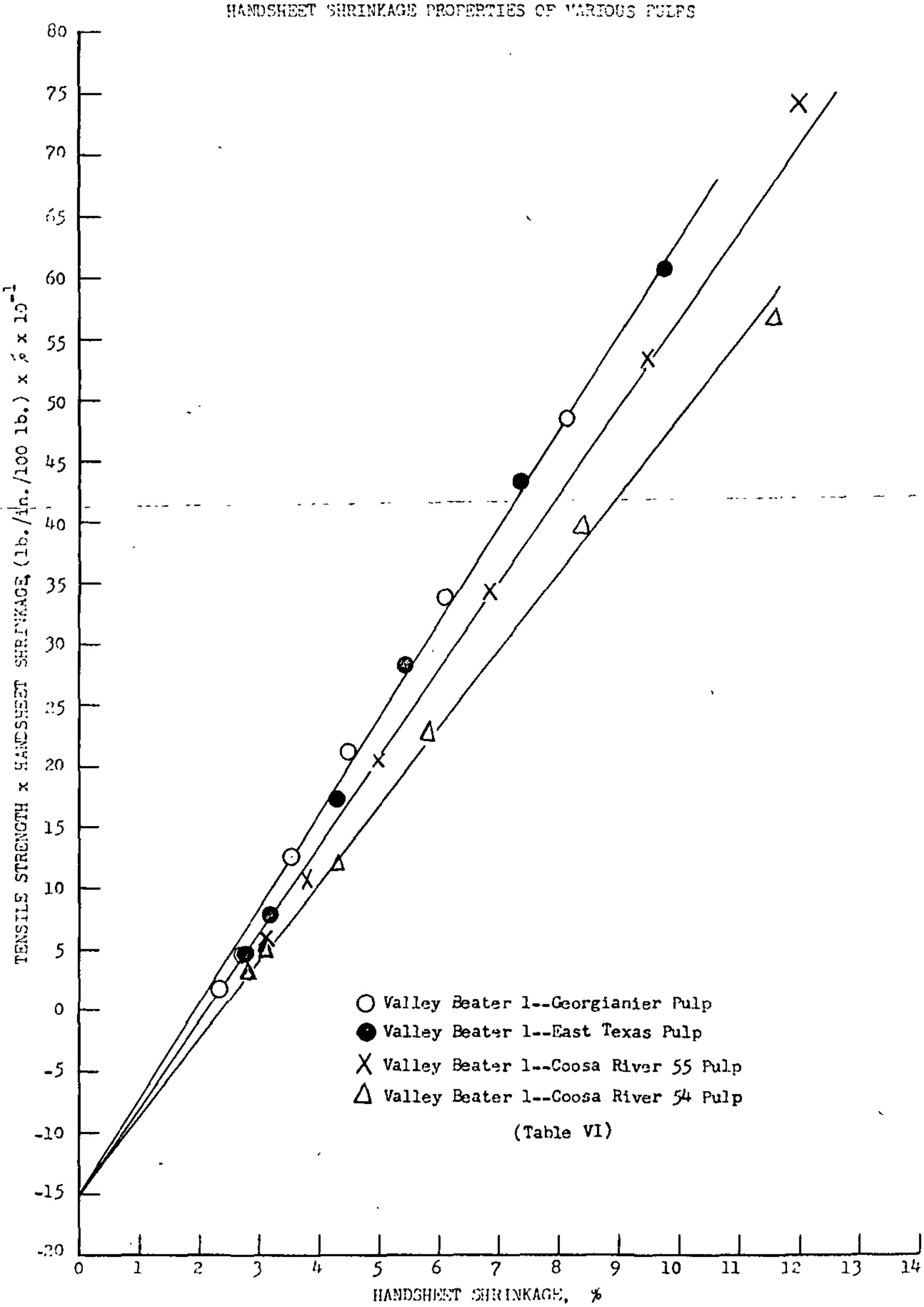


FIGURE 4-4

[illegible] OF VALLEY [illegible] ACTION ON THE TENSILE STRENGTH AND [illegible] PROPERTIES OF VARIOUS PULPS

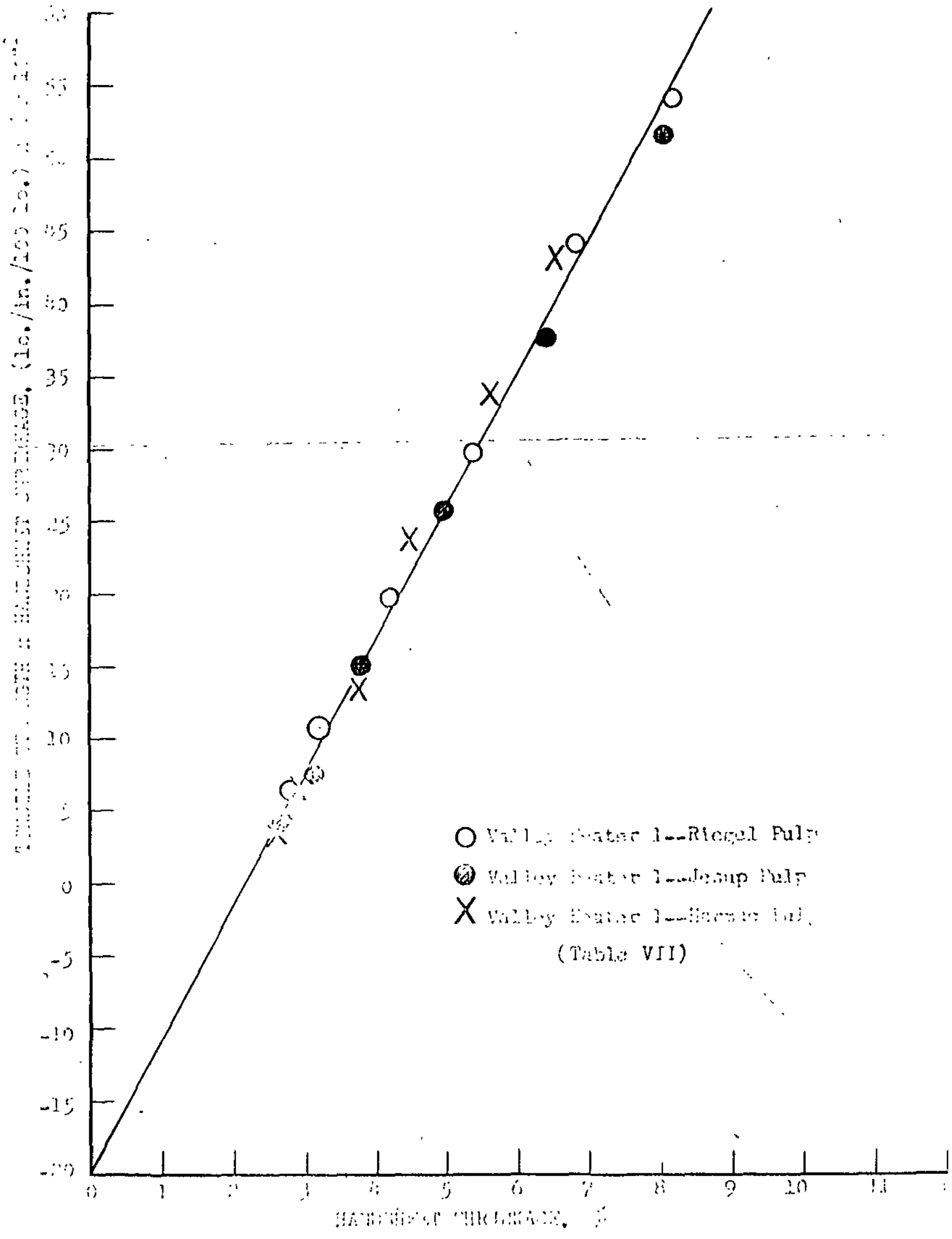


FIGURE 4-5
EFFECT OF VALLEY BEATER REFINING ACTION ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

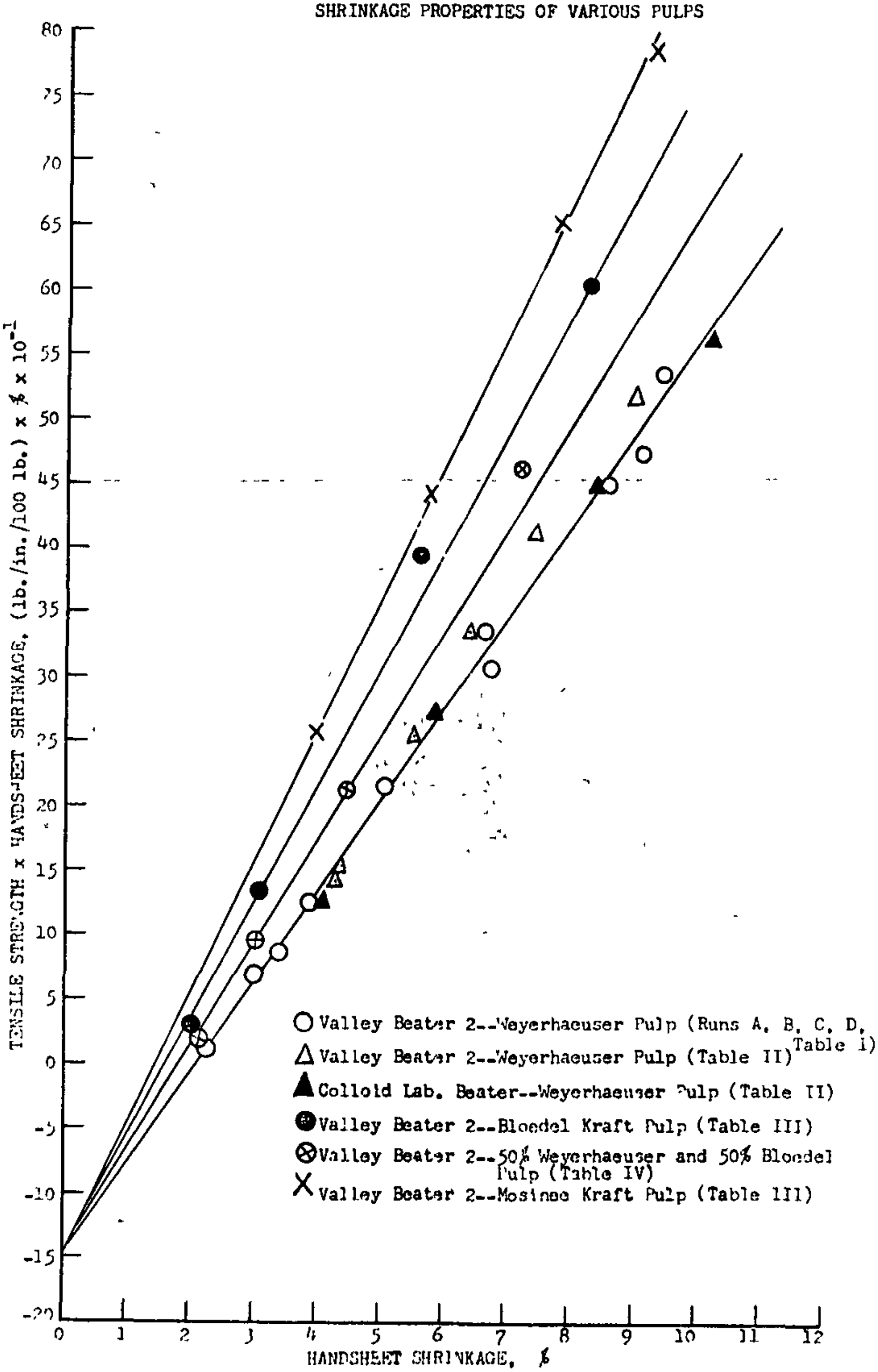


FIGURE 4-6

EFFECT OF JOKRO MILL BEATING ACTION ON THE TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

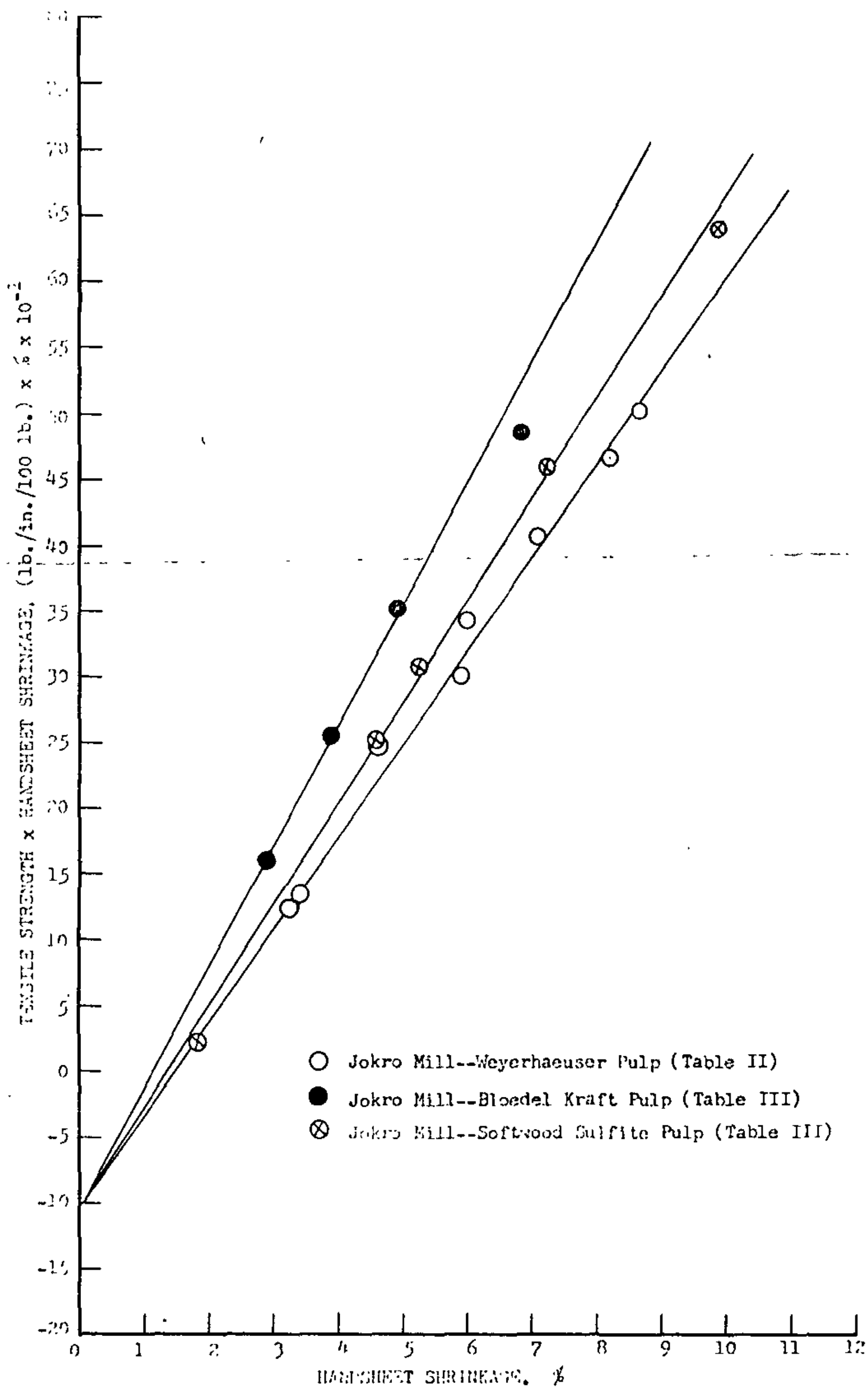


FIGURE 4-7

EFFECT OF MORDEN STOCK-MAKER REFINING ACTION ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER STANDARD PULP

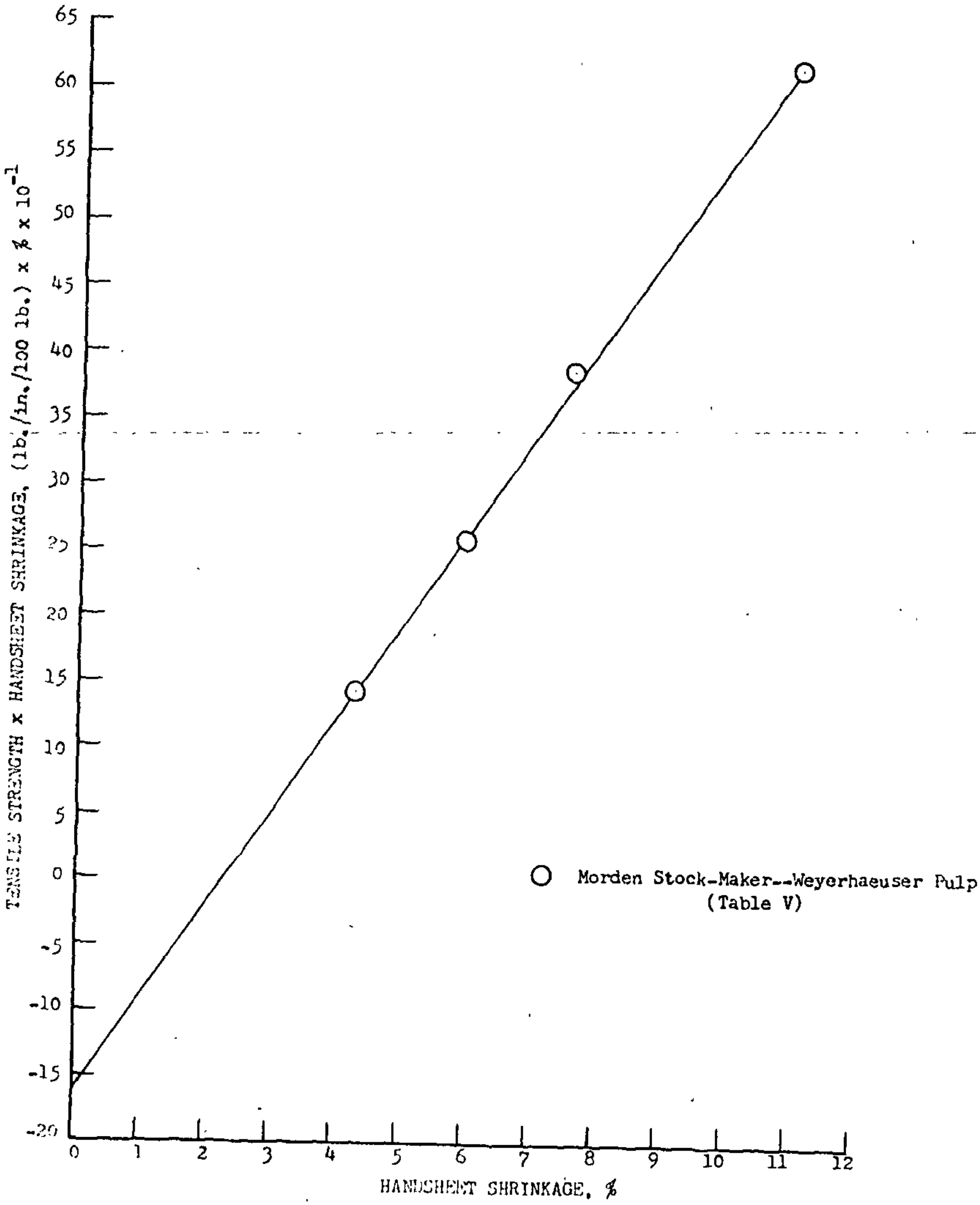


FIGURE 4-8

EFFECT OF LAMPEN MILL REFINING ACTION ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER STANDARD PULP

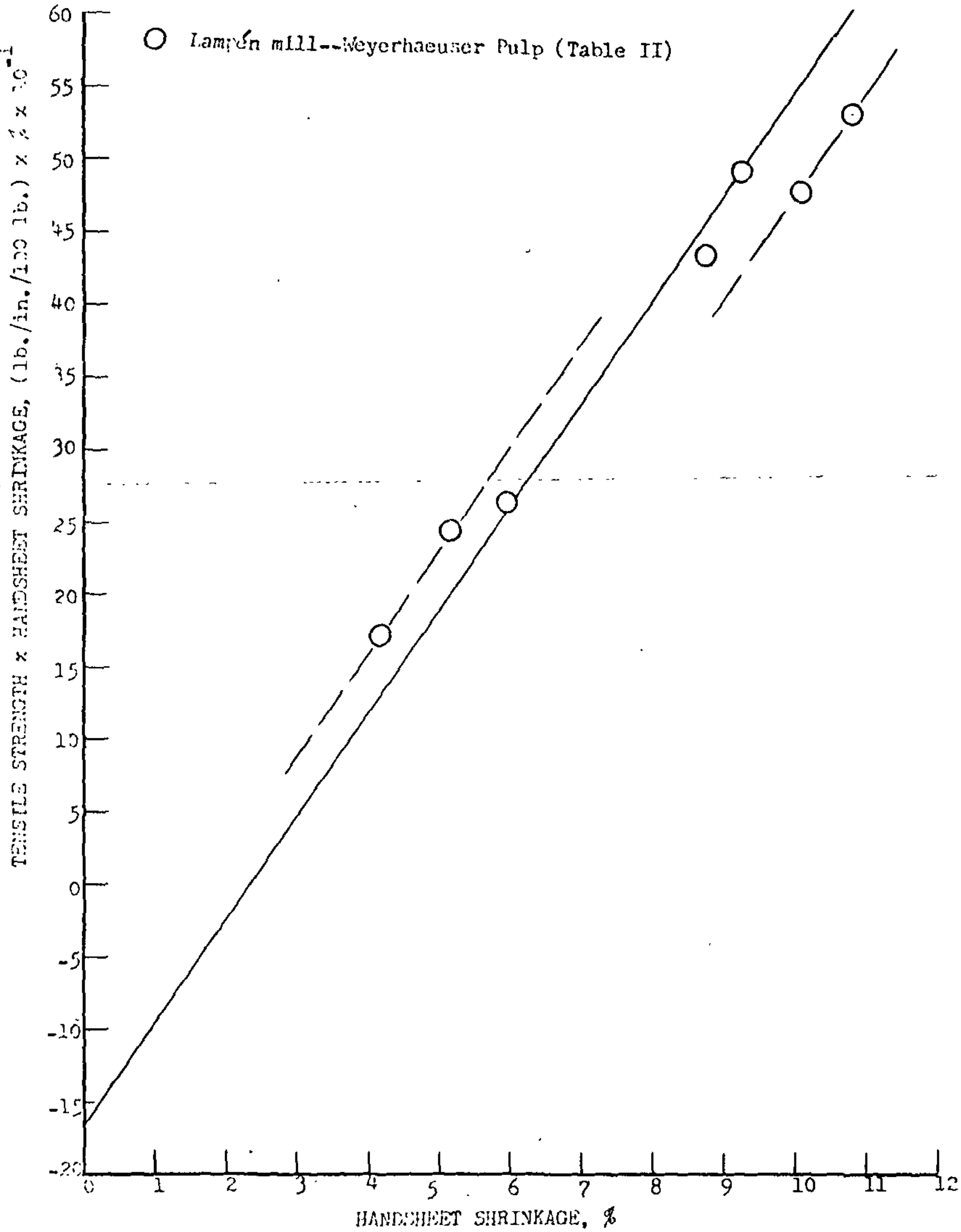
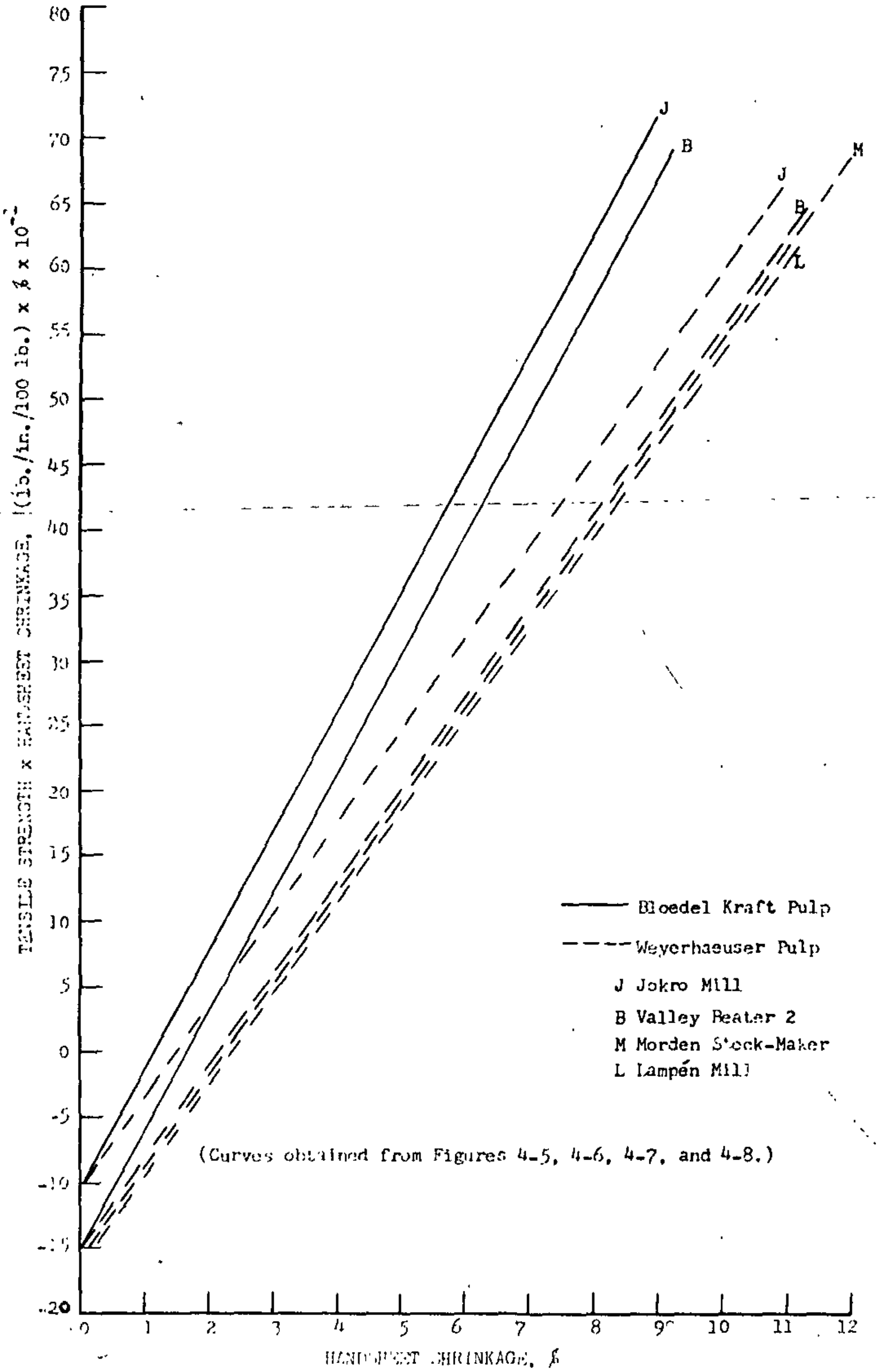


FIGURE 4-9

EFFECT OF VARIOUS REFINING ACTIONS ON TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS



cycle (see Figures 4-5 through 4-8, and particularly Figure 4-9).

(5) When a given pulp is refined with a variety of refining actions, the slope of the [tensile strength x handsheet shrinkage] vs. [handsheet shrinkage] relationship remains essentially constant (see Figures 4-2, 4-5, through 4-8, and particularly Figure 4-9). As an example:

Figure 4-2 (Weyerhaeuser pulp, Valley beater) - slope = 6.90 to 74.0 (av. = 71.5).

Figure 4-5 (Weyerhaeuser pulp, Valley beater runs) - slope = 71.2.

Figure 4-6 (Weyerhaeuser pulp, Jokro mill) - slope = 70.7.

Figure 4-7 (Weyerhaeuser pulp, Morden Stock-Maker) - slope = 70.8.

Figure 4-8 (Weyerhaeuser pulp, Lampen mill) - slope = 71.0.

Figure 4-5 (Bloedel kraft pulp, Valley beater) - slope = 91.6.

Figure 4-6 (Bloedel kraft pulp, Jokro mill) - slope = 91.6.

(6) When a given pulp is refined with a variety of refining actions, the intercept of the [tensile strength x handsheet shrinkage] vs. [handsheet shrinkage] relationship may vary, although the slope of the relationship remains essentially constant (see Figure 4-9). Thus, it may be seen that the relationship does not hold at extremely low degrees of refining (does not apply until the specific characteristics of the refining action have been exerted on the pulp--i.e., until the Schopper-Riegler freeness of the unrefined pulp has been reduced by about 30 ml.). Also, from the nature of the relationship, it can be seen that it would not be expected to apply when the refining cycle has been extended to the point where tensile strength actually begins to decrease.

EXPERIMENTAL DETERMINATION OF TENSILE STRENGTH AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The nature of the curves in Figures 4-2 to 4-9 indicates that the tensile strength and handsheet shrinkage relationship for any given pulp and any given refining action could be easily established by determining the handsheet shrinkage and tensile strength properties of the pulp at any two given levels of refining midway in the refining cycle. Also, since the slope of the straight line relationship (see figures) apparently remains the same for a given pulp, the relationship for any additional refining actions could be established by refining the pulp, with the desired refining action, to any one given level midway in the refining cycle and subsequently determining the tensile strength and handsheet shrinkage properties of the refined pulp. It should be noted, however, that investigations at additional refining levels would improve the accuracy of the relationships determined by this method.

MATHEMATICAL EXPRESSION OF THE TENSILE STRENGTH AND HANDSHEET SHRINKAGE RELATIONSHIP PRODUCED BY MECHANICAL REFINING

From the curves in Figure 4-2 it may be seen that a mathematical expression for the tensile strength and handsheet shrinkage relationship produced by mechanical refining would be:

$$T_x \times S_x = AS_x - C, \quad \text{or} \quad T_x = A - \frac{C}{S_x},$$

where: A = the slope of the curve (straight line)

C = the intercept of the curve (straight line), expressed as a positive number

S_x = the handsheet shrinkage of the pulp after any given refining time of x minutes

T_x = the tensile strength of the pulp after any given refining time of x minutes.

For the specific case of Valley beater No. 2, Runs A, B, and C (Figure 4-2):

"A" in the above relationship would be a constant equivalent to the slope of the curve, or 74.0;

"C" would be a constant equivalent to the intercept of the curve, or 150. Thus, the expression would become:

$$T_x \text{ (lb./in./100 lb.)} = 74.0 - \frac{150}{S_x} .$$

Likewise, the expression would become:

$$T_x \text{ (lb./in./100 lb.)} = 69.0 - \frac{150}{x}$$ for Valley beater No. 2, Run D.

From these two expressions, it would be possible to calculate tensile strength properties which correspond to the handsheet shrinkage values experimentally determined at various levels of refining. Such calculations were performed and are represented by the curves in Figure 4-1--i.e., the actual curves were based on tensile strength values calculated with the above expressions and the experimental points were superimposed on these curves.

SIGNIFICANCE AND UTILITY OF TENSILE STRENGTH AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The experimental results indicate that tensile strength and handsheet shrinkage relationships may prove useful in a number of applications including:

(1) <u>Control of a refining process</u>. The nature of the [tensile strength-handsheet shrinkage] relationships suggests that handsheet shrinkage measurements would prove desirable for controlling a given refining process.

(2) <u>Laboratory evaluation of a pulp</u>. The nature of the [tensile strength x handsheet shrinkage] vs. [handsheet shrinkage] relationships suggests a number of applications for pulp evaluation purposes, i.e.:

(a) With complete handsheet shrinkage data and only limited tensile strength data (two experimental points), it would be possible to estimate the tensile strength properties of a pulp over the range of a refining cycle which is generally of most interest in papermaking operations.

(b) When a pulp is subjected to different refining actions, it appears that "C" in the "$T_x = A - \frac{C}{S_x}$" relationship is the only constant which would vary (see Figure 4-9). Thus, an estimation of the tensile strength characteristics produced in a pulp when refined by a different refining action could be readily approximated by determining the handsheet shrinkage properties of the pulp over the entire refining cycle and the actual tensile strength properties of the pulp at only one level of refining.

(c) In the "$T_x = A - \frac{C}{S_x}$" relationship, the value for "A" is dependent upon the nature of the pulp, and relatively independent of the type of refining action (see Figure 4-9). Thus, it would appear that the value of "A" obtained with a given pulp would serve as a convenient constant for characterizing the maximum tensile strength development potential of the pulp. As an example, consider the pulps represented in Figure 4-5, where:

For the Weyerhaeuser pulp: $T_x = 71.2 - \frac{C}{150}$; $A = 71.2$

For the 50% Weyerhaeuser pulp: $T_x = 81.0 - \frac{C}{150}$; $A = 81.0$

For the Bloedel pulp: $T_x = 91.6 - \frac{C}{150}$; $A = 91.6$

For the Mosinee pulp: $T_x = 102.2 - \frac{C}{150}$; $A = 102.2$

With these pulps it may be seen that the maximum tensile strength development potential of the pulps increases as the "A" values for the pulps increase. As an example, "A" for the Weyerhaeuser pulp = 71.2 and "A" for the 50% Weyerhaeuser pulp = 81.0. Also, the maximum tensile strength development potential of the 50% Weyerhaeuser pulp is greater than for the Weyerhaeuser pulp, etc.

An obvious advantage to this method of pulp characterization would be the fact that only a limited quantity of data would be required (only two experimental points) and the levels of refining at which the data were obtained would not be very critical. Furthermore, the refining cycle would not necessarily have to be extended to the point of maximum tensile strength development and apparently the type of refining action would not be critical.

SECTION 5

EFFECT OF MECHANICAL REFINING ON TENSILE STRENGTH AND FILTRATION RESISTANCE PROPERTIES OF PULPS

SECTION 5

EFFECT OF MECHANICAL REFINING ON TENSILE STRENGTH AND FILTRATION RESISTANCE PROPERTIES OF PULPS

NATURE OF TENSILE STRENGTH AND FILTRATION RESISTANCE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

Previous relationships [filtration resistance-handsheet shrinkage] and [tensile strength-handsheet shrinkage] suggested that a straight line relationship would result when the [tensile strength x log (filtration resistance)] properties of refined pulps were plotted against the [log (filtration resistance)] properties of the pulp. This, in fact, proved to be the case and the changes which tensile strength and filtration resistance properties undergo as a result of mechanical refining have been presented in Figures 5-1 through 5-3. These figures indicate that:

(1) When a pulp is subjected to either a Valley beater refining action or a ball mill refining action, both the filtration resistance and the tensile strength properties of the pulp progressively increase (see Figures 5-1 through 5-3).

(2) When the [tensile strength x log (filtration resistance)] properties of a pulp are plotted against the [log (filtration resistance)] properties of the pulp, a straight line relationship results which exists over most of the refining cycle (see Figures 5-1 through 5-3). Thus, for a given pulp and a given refining action, there is a fixed relationship between tensile strength and filtration resistance properties which exists over most of the refining cycle. (From the nature of the relationship, it can be seen that it would not be expected to apply when the refining cycle has been

FIGURE 5-1

EFFECT OF VALLEY BEATER BEATING ACTION ON THE TENSILE STRENGTH AND FILTRATION RESISTANCE PROPERTIES OF VARIOUS PULPS

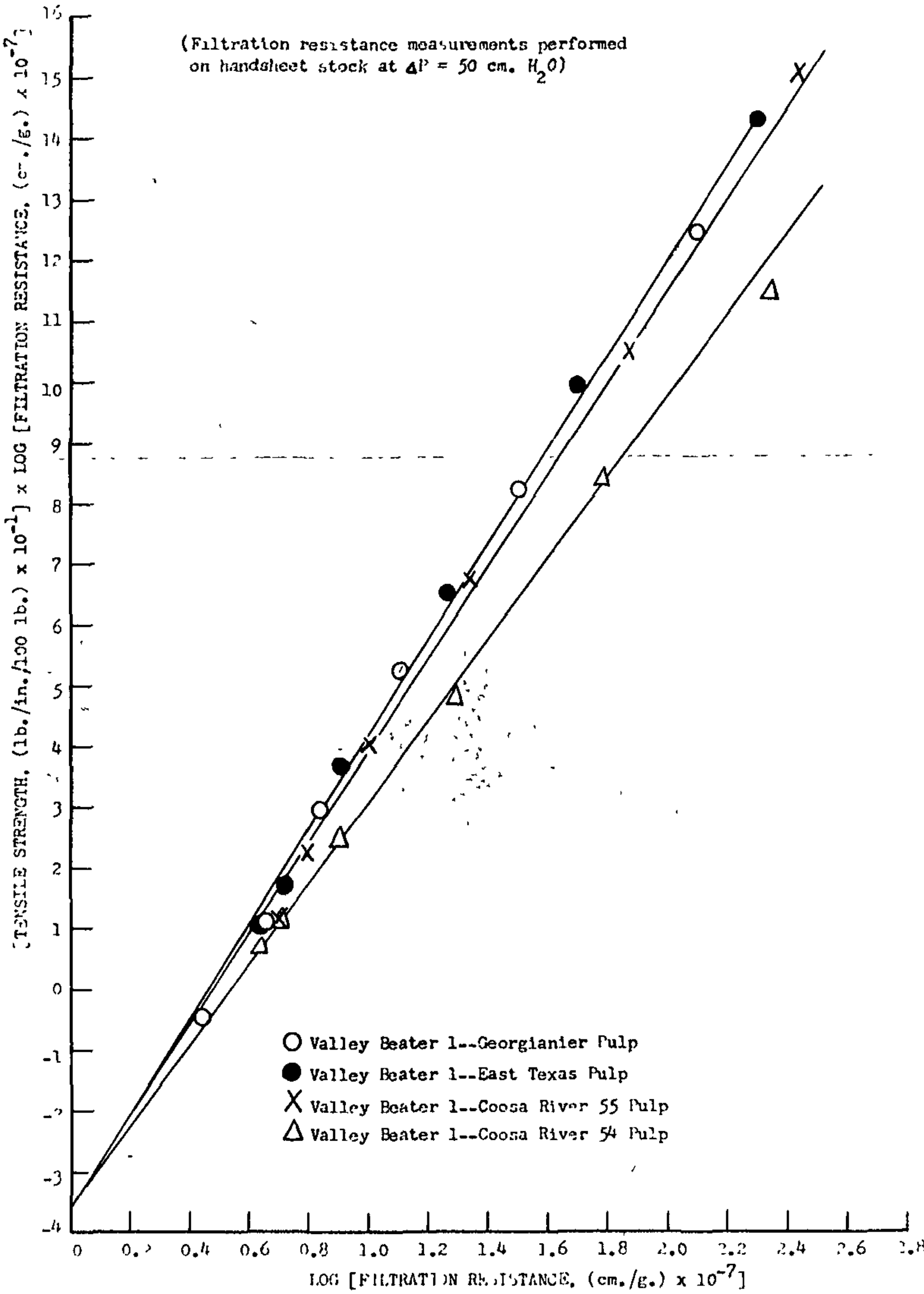


FIGURE 5-2

EFFECT OF VALLEY BEATER REFINING ACTION ON THE TENSILE STRENGTH AND FILTRATION RESISTANCE PROPERTIES OF VARIOUS PULPS

(Filtration resistance measurements performed on handsheet stock at ΔP = 50 cm. H_2O)

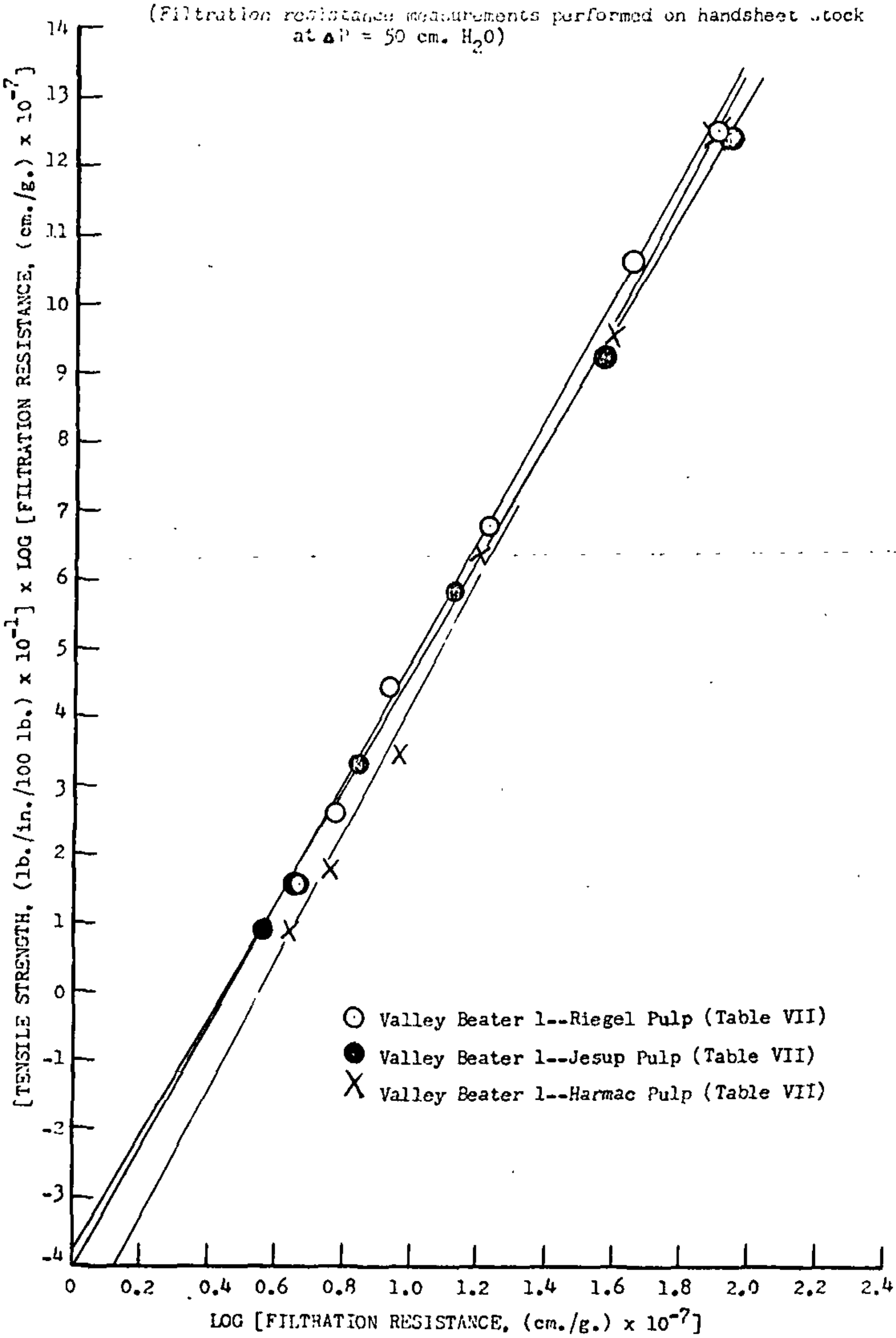
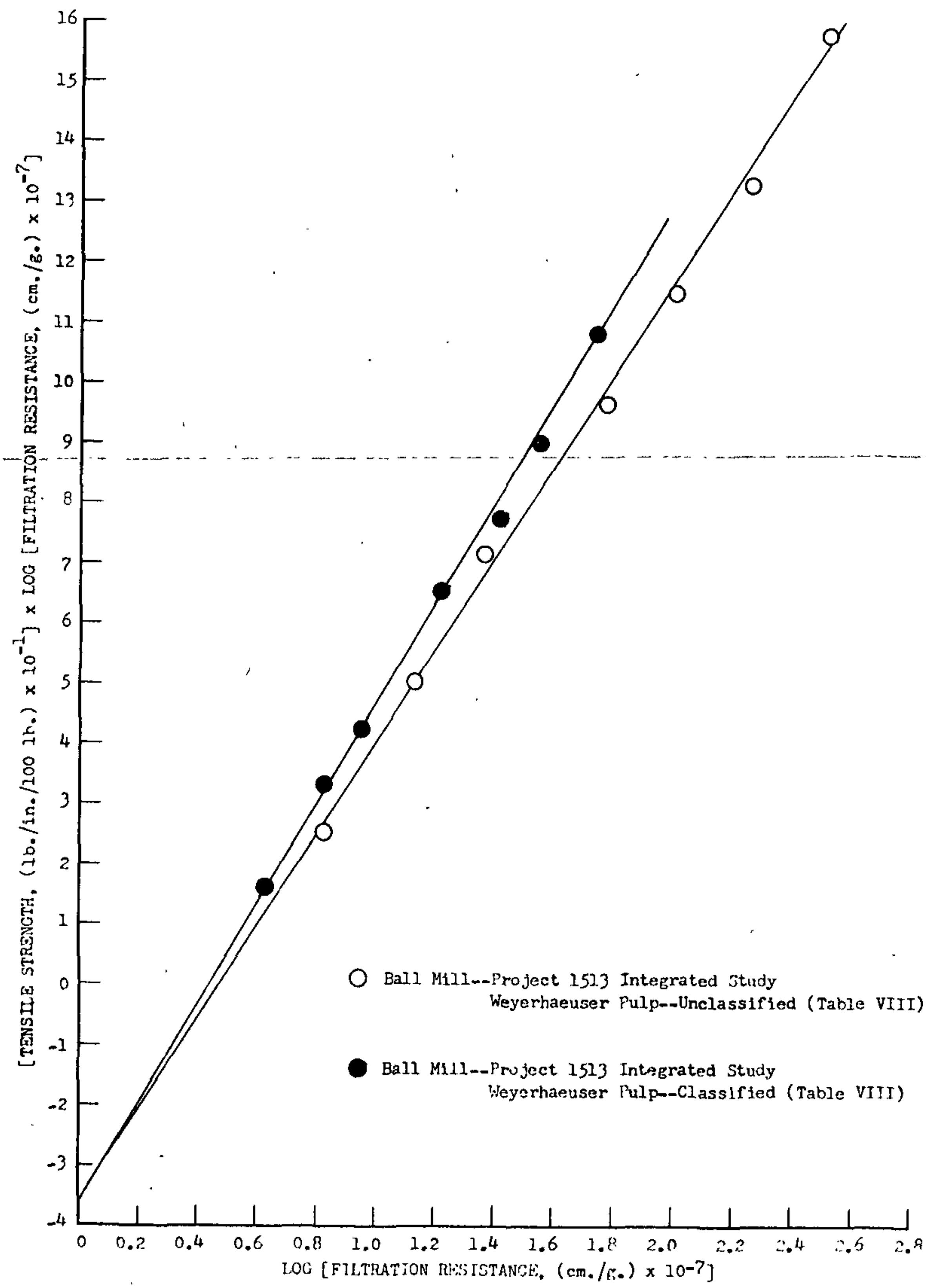


FIGURE 5-3

EFFECT OF BALL MILL REFINING ACTION OF THE TENSILE STRENGTH AND FILTRATION RESISTANCE PROPERTIES OF PROJECT 1513--INTEGRATED STUDY WEYERHAEUSER SULFITE PULP (Filtration Resistance Measurements Performed on Handsheet Stock at $\Delta P = 50$ cm. H_2O)



extended to the point where tensile strength actually begins to decrease.)

(3) The relationship of tensile strength to filtration resistance varies depending upon the nature of the pulp refined. Again, however, for a given pulp and a given refining action, a fixed relationship exists over most of the refining cycle (see Figures 5-1 through 5-3).

(4) Data regarding the refining of a given pulp with a number of different refining actions are not presently available. Therefore, the effect of different refining actions on the tensile strength-filtration resistance relationships cannot be properly assessed at this time.

EXPERIMENTAL DETERMINATION OF TENSILE STRENGTH AND FILTRATION RESISTANCE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The nature of the curves in Figures 5-1 through 5-3 indicates that the tensile strength and filtration resistance relationship for any given pulp and any given refining action could be easily established by determining the filtration resistance and tensile strength properties of a pulp refined to two different levels below the maximum attainable tensile strength of the pulp. It should be noted, however, that investigations at additional refining levels would improve the accuracy of the relationships determined by this method.

MATHEMATICAL EXPRESSION OF THE TENSILE STRENGTH AND FILTRATION RESISTANCE RELATIONSHIP PRODUCED BY MECHANICAL REFINING

From the curves in Figure 5-1, it may be seen that a mathematical expression for the tensile strength and filtration resistance relationship produced by refining would be:

$$T_x \times \log FR_x = A \log FR_x - C, \text{ or } T_x = A - \frac{C}{\log FR_x},$$

where:

A = the slope of the curve (straight line)

C = the intercept of the curve (straight line), expressed as a positive number

FR_x = the filtration resistance of the pulp at any given pressure drop ΔP after any given refining time of x minutes.

T_x = the tensile strength of the pulp after any given refining time of x minutes

For the specific case of the Coosa River 54 pulp in Figure 5-1:

"A" in the above relationship would be a constant equivalent to the slope of the curve, or 66.8;

"C" would be a constant equivalent to the intercept of the curve, or 36.0. Thus, the expression would become:

$$T_x \text{ (lb./in./100 lb.)} = 66.8 - \frac{36.0}{\log FR_x} .$$

SIGNIFICANCE AND UTILITY OF TENSILE STRENGTH AND FILTRATION RESISTANCE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The experimental results indicate that tensile strength and filtration resistance relationships may prove useful in a number of applications including:

(1) Control of a refining process. The nature of the [tensile strength-filtration resistance] relationships suggests that filtration resistance measurements would prove desirable for controlling a given refining process. (Due to the similarity of these relationships with tensile strength-handsheet shrinkage relationships, however, it would appear that in many cases, handsheet shrinkage measurements could be substituted for filtration resistance measurements.)

(2) Laboratory evaluation of a pulp. The nature of the [tensile strength x log (filtration resistance)] vs. [log (filtration resistance)] relationships suggests a number of applications for pulp evaluation purposes--i.e.:

(a) With complete filtration resistance data and only limited tensile strength data (two experimental points), it would be possible to estimate the tensile strength properties of a pulp over the range of a refining cycle which is generally of most interest in papermaking operations. Conversely, the changes in the filtration resistance or drainage properties of a pulp could be estimated with complete tensile strength data and limited filtration-resistance data.

(b) The values of "A" in the "$T_x = A - \frac{C}{FR_x}$" relationship might possibly serve as a convenient constant for characterizing the maximum tensile strength development potential of a pulp. Such a characterization method would be similar to that previously described with the [tensile strength-handsheet shrinkage] relationship (see Section 4 of this report, page 50). It should be noted, however, that additional work with a variety of refining actions would be required to fully investigate the use of the [tensile strength-filtration resistance] relationship in this manner.

It is interesting to note the values of "A" obtained for several pulps from both the [tensile strength-handsheet shrinkage] relationship and the [tensile strength-filtration resistance] relationships--i.e.:

Pulp	"A" from "$T_x = A - \frac{C}{S_x}$" (Figures 4-3 and 4-4)	"A" from "$T_x = A - \frac{C}{FR_x}$" (Fig. 5-1 and 5-2)
Georgianier--Valley beater	78.3	78.2
East Texas--Valley beater	78.3	78.2
Coosa River 55--Valley beater	71.5	75.4
Coosa River 54--Valley beater	63.5	66.8
Riegel--Valley beater	91.5)	88.9)
Jesup--Valley beater	91.5) Av.= 91.5	93.3) Av.= 88.8
Harmac--Valley beater	91.5)	84.2)

SECTION 6

EFFECT OF MECHANICAL REFINING ON THE PROPERTIES OF PULP MIXTURES

SECTION 6

EFFECT OF MECHANICAL REFINING ON THE PROPERTIES OF PULP MIXTURES

In previous sections of this report (Sections 1-5), the effect of refining on various relationships between pulp properties have been presented and discussed. The primary purpose of this section of the report is to examine the effect of pulp mixtures on these relationships. This has been done with the aid of Figures 6-1 through 6-3 which indicate the following effects:

(1) Characteristics of the [fiber length index-handsheet shrinkage] relationships produced with pulp mixtures (see Figure 6-1, and refer to Section 1 of this report for background information).

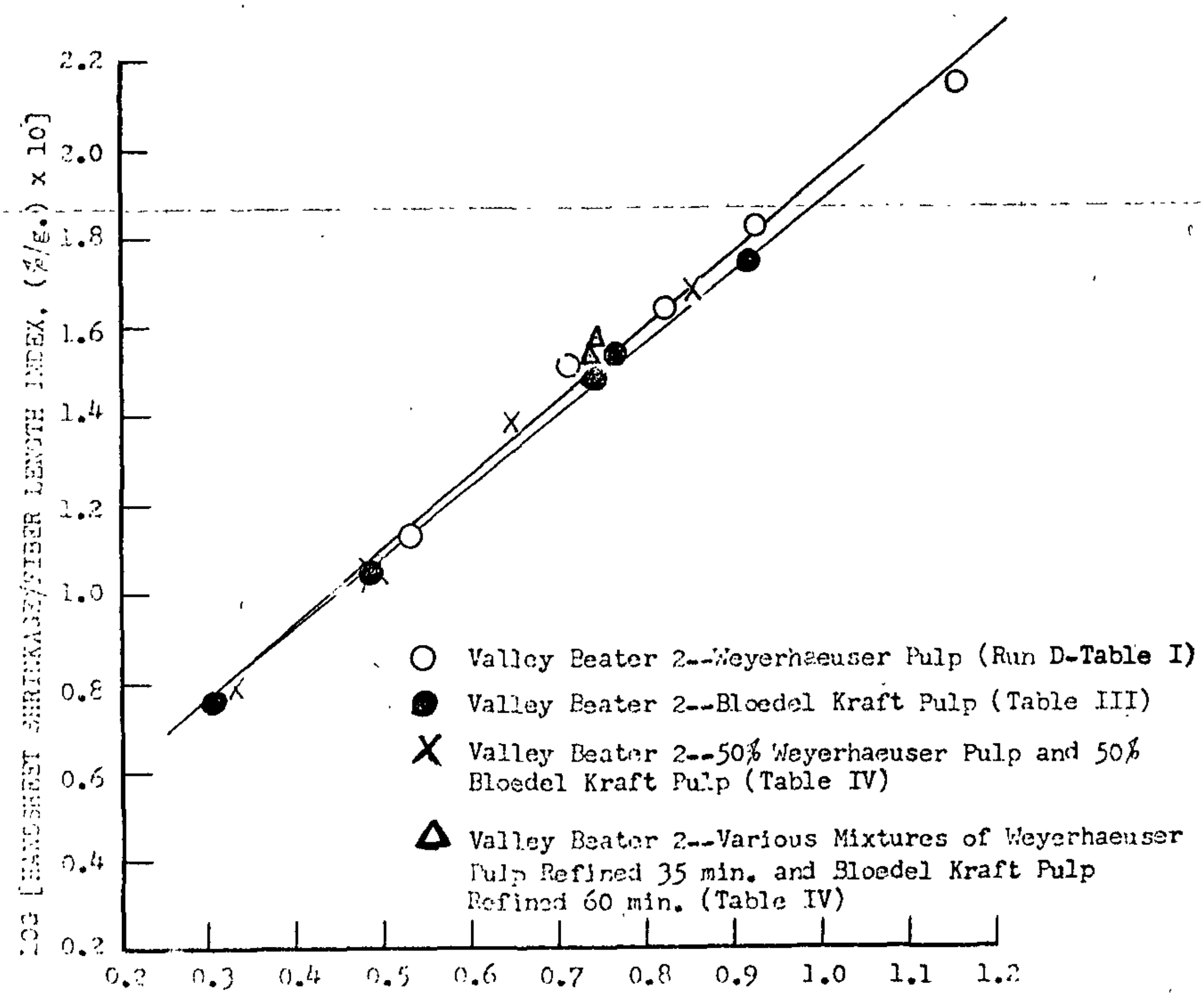
(a) Figure 6-1 indicates that a Valley beater refining action produced essentially the same relationship between the fiber length index and handsheet shrinkage properties of the Weyerhaeuser pulp and the fiber length index and handsheet shrinkage properties of the Bloedel kraft pulp.

(b) As would be expected, essentially the same relationship between fiber length index and handsheet shrinkage properties also resulted when a 50% mixture of the Weyerhaeuser pulp and the Bloedel kraft pulp was refined by the same Valley beater refining action (see Figure 6-1).

(c) Also, as would be expected, essentially the same relationship between fiber length index and handsheet shrinkage properties also results when various mixtures are prepared from a Valley beater refined Weyerhaeuser pulp and a Valley beater refined Bloedel kraft pulp (see Figure 6-1).

FIGURE 6-1

EFFECT OF VALLEY BEATER REFINING ACTION ON THE FIBER LENGTH INDEX AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER PULP, BLOEDEL KRAFT PULP, AND MIXTURES OF WEYERHAEUSER AND BLOEDEL PULPS



LOG [HANDSHEET SHRINKAGE, %]

FIGURE 6-2

[illegible] OF VALLEY BEATER [illegible] ACTION ON THE TENSILE STRENGTH AND FIBER LENGTH [illegible] OF [illegible] KRAFT PULP, AND MIXTURES OF [illegible] AND BLOEDEL PULPS

○ [illegible] 2--[illegible] Pulp (Run D, Table I)

● [illegible] 2--[illegible] Kraft Pulp (Table III)

X [illegible] 2--50% [illegible] Pulp and 50% Bloedel Kraft Pulp (Table IV)

△ [illegible] 2--Various Mixtures of [illegible] Pulp Refined 35 min. and [illegible] Kraft Pulp [illegible] min. ([illegible])

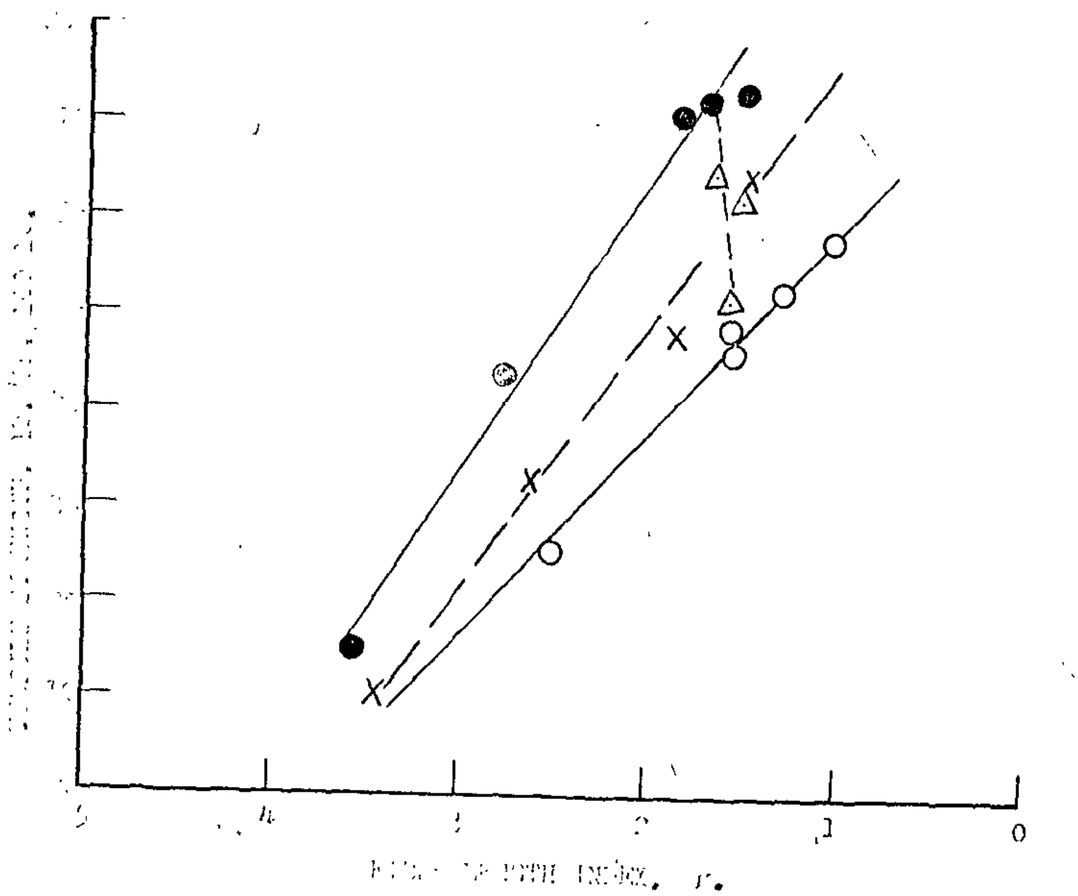
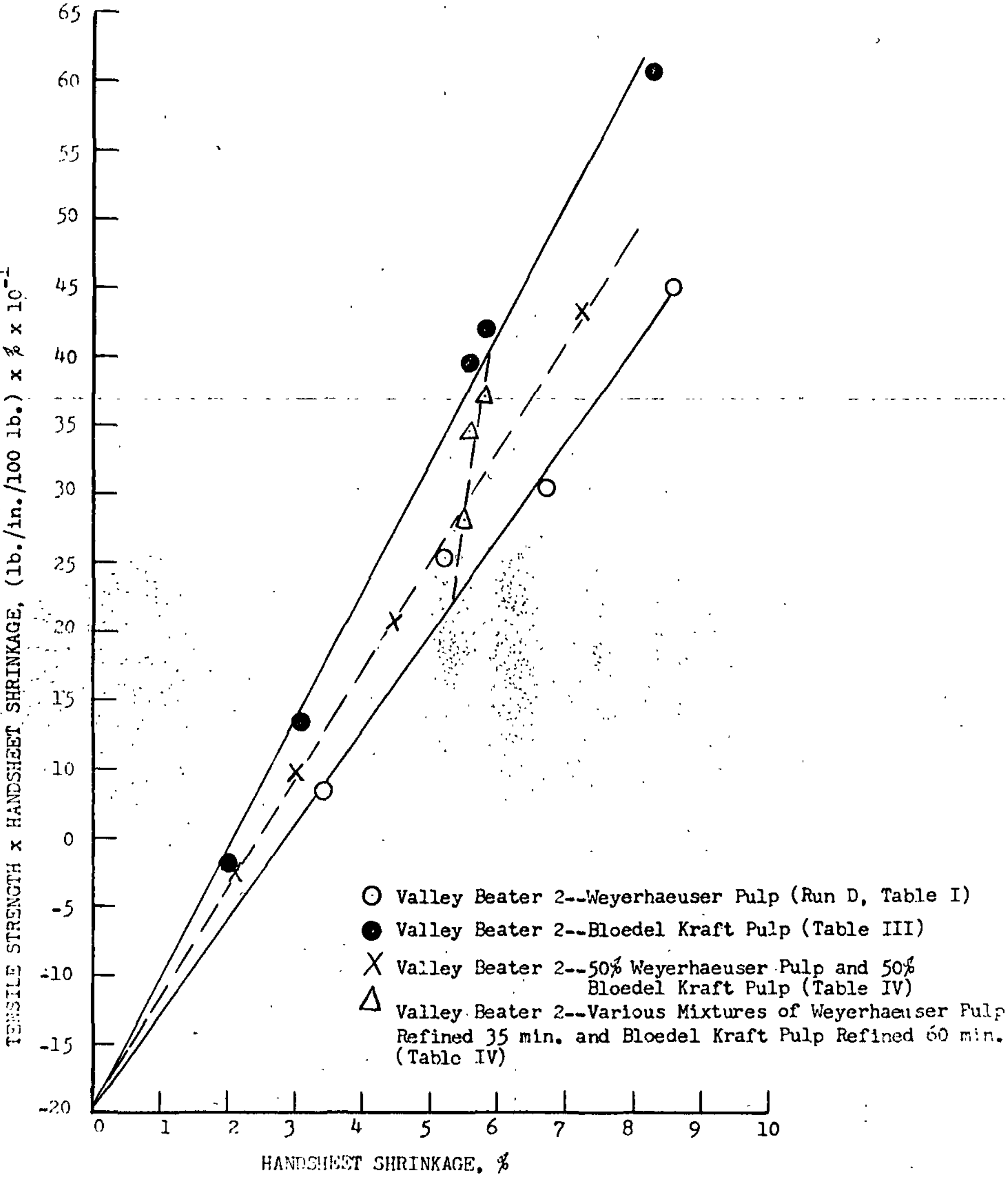


FIGURE 6-3

EFFECT OF VALLEY BEATER REFINING ACTION ON THE TENSILE STRENGTH AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER PULP, BLOEDEL KRAFT PULP, AND MIXTURES OF WEYERHAEUSER AND BLOEDEL PULPS



(d) Thus, it may be seen that the same [fiber length index-handsheet shrinkage] relationship applies when either the Weyerhaeuser pulp is refined in the Valley beater, the Bloedel kraft pulp is refined in the Valley beater, mixtures of the Weyerhaeuser and Bloedel pulps are refined in the Valley beater, or Valley beater refined Weyerhaeuser and Valley beater refined Bloedel pulps are mixed.

(e) In the present work, both the Weyerhaeuser and the Bloedel pulps fortuitously produced the same [fiber length index-handsheet shrinkage] relationship and it should be noted that other combinations of dissimilar pulps would not necessarily produce the same relationship for both pulps. From the present work, however, it may be noted that the [fiber length index-handsheet shrinkage] relationships produced with pulp mixtures indicate the additive nature of the [fiber length index-handsheet shrinkage] relationships produced with individual pulps. (It is felt that this additive nature would also be demonstrated if two dissimilar pulps producing different [fiber length index-handsheet shrinkage] relationships had been used in the work.)

(2) Characteristics of the [tensile strength-fiber length index] relationships produced with pulp mixtures (see Figure 6-2, and refer to Section 3 of this report for background information).

(a) Figure 6-2 indicates that the [tensile strength-fiber length index] relationship produced when the Weyerhaeuser pulp is refined in the Valley beater differs from the [tensile strength-fiber length index] relationship produced when the Bloedel kraft pulp is refined in the Valley beater.

(b) As would be expected, the [tensile strength-fiber length index] relationship produced when a 50% mixture of Weyerhaeuser and Bloedel pulps is refined in the Valley beater is midway between the [tensile strength-fiber length index] relationship produced when the Weyerhaeuser pulp is refined in the Valley beater and the [tensile strength-fiber length index] relationship produced when the Bloedel pulp is refined in the Valley beater (see Figure 6-2).

(c) Also, as would be expected, various mixtures of a Weyerhaeuser pulp refined in the Valley beater and a Bloedel kraft refined in the Valley beater produce a straight line [tensile strength-fiber length index] relationship extending from a point representing the [tensile strength vs. fiber length index] properties of the refined Weyerhaeuser pulp to a point representing the [tensile strength vs. fiber length index] properties of the refined Bloedel kraft pulp (see Figure 6-2).

(d) In the present work, the [tensile strength-fiber length index] relationships produced with pulp mixtures indicate the additive nature of the [tensile strength-fiber length index] relationships produced with individual pulps.

(e) The additive nature of the [tensile strength-fiber length index] relationships suggest that fiber length index measurements might advantageously be employed for such purposes as predicting the tensile strength properties of pulp mixtures, etc. As an example, the tensile strength properties of various pulp mixtures could be predicted from fiber length index measurements and the tensile strength and fiber length index properties of the two pulp components in the mixture.

(3) Characteristics of the [tensile strength-handsheet shrinkage] relationships produced with pulp mixtures (see Figure 6-3, and refer to Section 4 of this report for background information).

(a) The data presented in Figure 6-3 may be considered in essentially the same manner as the data previously presented and discussed in Figure 6-2. Thus, in the present work, the [tensile strength x handsheet shrinkage] vs. [handsheet shrinkage] relationships produced with pulp mixtures indicate the additive nature of the [tensile strength x handsheet shrinkage] vs. [handsheet shrinkage] relationships produced with individual pulps. Also, the additive nature of these relationships suggests handsheet shrinkage measurements might be advantageously employed for such purposes as predicting the tensile strength properties of pulp mixtures, etc. Such prediction methods would be essentially similar to those previously discussed when considering tensile strength and fiber length index relationships.

SECTION 7

EFFECT OF MECHANICAL REFINING ON THE SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

SECTION 7

EFFECT OF MECHANICAL REFINING ON THE SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

NATURE OF SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The changes which Schopper-Riegler freeness and handsheet shrinkage properties undergo as a result of mechanical refining have been presented in Figures 7-1 through 7-3. These figures indicate that:

(1) When a pulp is subjected to a mechanical refining action, the handsheet shrinkage properties of a pulp progressively increase and the Schopper-Riegler freeness properties of the pulp progressively decrease (see Figures 7-1 through 7-3).

(2) When the [log (handsheet shrinkage/Schopper-Riegler freeness)] properties of a pulp are plotted against the handsheet shrinkage properties of the pulp, a straight line relationship results. Also, this straight line relationship varies, depending upon the nature of the pulp and the nature of the refining action (see Figure 7-1).

(3) In the present work, the [log (handsheet shrinkage/Schopper-Riegler freeness)] vs. [handsheet shrinkage] relationships produced with pulp mixtures indicate the additive nature of the [log (handsheet shrinkage/Schopper-Riegler freeness)] vs. [handsheet shrinkage] relationships produced with individual pulps (see Figure 7-2 which is similar in nature to the figures previously presented and discussed in Section 6 of this report).

(4) The straight line relationship produced when [log (handsheet shrinkage/Schopper-Riegler freeness)] properties are plotted against handsheet

shrinkage properties does not exist over the entire refining cycle, but generally applies only to refining levels above a pulp freeness of about 300-400 ml. Schopper-Riegler (see Figure 7-3).

EXPERIMENTAL DETERMINATION OF SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The straight line nature of the relationships presented in Figures 7-1 through 7-3 indicate the ease with which Schopper-Riegler freeness and handsheet shrinkage relationships could be established for a given pulp and a given refining action--i.e., only two experimental points, in the suitable refining range, would be required.

MATHEMATICAL EXPRESSION OF THE SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE RELATIONSHIP PRODUCED BY MECHANICAL REFINING

From the curves in Figure 7-1, it may be seen that a mathematical expression for the Schopper-Riegler freeness - handsheet shrinkage relationships produced by mechanical refining would be:

$$(SRF)_x = \frac{S_x}{\text{anti log }[A(S_x - S_o) + \log \frac{S_o}{(SRF)_o}]}$$

where:

A = the slope of the curve (straight line)

S_o = the handsheet shrinkage of the unrefined pulp

S_x = the handsheet shrinkage of the pulp after any given refining time of x minutes

$(SRF)_o$ = the Schopper-Riegler freeness of the unrefined pulp

$(SRF)_x$ = the Schopper-Riegler freeness of the pulp after any given refining time of x minutes.

For the specific case of the Valley beater refined Bloedel kraft pulp in Figure 7-1:

"A" in the above expression would be a constant equivalent to the slope of the curve, or 0.177;

"S_o" would be a constant equivalent to the handsheet shrinkage of the unrefined pulp, or 2.02;

"SRF_o" would be a constant equivalent to the Schopper-Riegler freeness of the unrefined pulp, or 865.

Thus, the expression would become:

$$(SRF)_x \text{ (ml.)} = \frac{S_x}{\text{anti log } [0.177\ (S_x - 2.02) + 0.369]}$$

From this expression, it would be possible to calculate Schopper-Riegler freeness properties which correspond to the handsheet shrinkage values experimentally determined at various levels of refining. Such calculations were performed and are summarized below:

Refining Time, min.	Calculated Schopper-Riegler Freeness, ml.	Experimentally Determined Schopper-Riegler Freeness, ml.
0	865	865
20	857	830
50	561	590
70	278	270

SIGNIFICANCE AND UTILITY OF SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The ease with which both the Schopper-Riegler freeness and the handsheet shrinkage properties of a pulp may be determined reduces the desirability of utilizing Schopper-Riegler freeness and handsheet shrinkage relationships for predicting either the freeness or handsheet shrinkage properties of a pulp. The relationships presented in this section of the report, however, might find certain limited application in characterizing a refining action and/or controlling a given refining process.

SECTION 8

EFFECT OF MECHANICAL REFINING ON THE TENSILE STRENGTH, SCHOPPER-RIEGLER FREENESS, AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

SECTION 8

EFFECT OF MECHANICAL REFINING ON THE TENSILE STRENGTH, SCHOPPER-RIEGLER FREENESS, AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

NATURE OF TENSILE STRENGTH, HANDSHEET SHRINKAGE, AND SCHOPPER-RIEGLER FREENESS RELATIONSHIPS PRODUCED BY MECHANICAL REFINING (BASED ON PREVIOUS PROJECT 1513 WORK)

In previous Project 1513 work (see Project 1513, Project Report 24), the changes which tensile strength, handsheet shrinkage, and Schopper-Riegler freeness properties undergo as a result of mechanical refining were investigated. Briefly, these investigations, undertaken in the moderate refining range, indicated the following:

(1) When a given pulp is refined by a variety of refining actions, a single straight line relationship appears to result when the [tensile strength x handsheet shrinkage] properties of the refined pulps are plotted against the [log (handsheet shrinkage/Schopper-Riegler freeness)] properties of the pulps (see the solid line portion of the curve in Figure 8-1).

(2) On the basis of the above straight line relationship, the tensile strength properties of the Weyerhaeuser standard pulp, refined by a variety of refining actions, may be predicted from the following expression:

$$\text{Tensile strength (lb./in./100 lb.)} = \frac{494\ [\log\ (\frac{S}{F} \times 10^3)}{S} - \frac{176}{S}$$

where:

S = handsheet shrinkage, %

F = Schopper-Riegler freeness, ml.

FIGURE 7-1

EFFECT OF DIFFERENT REFINING ACTIONS ON THE SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE PROPERTIES OF VARIOUS PULPS

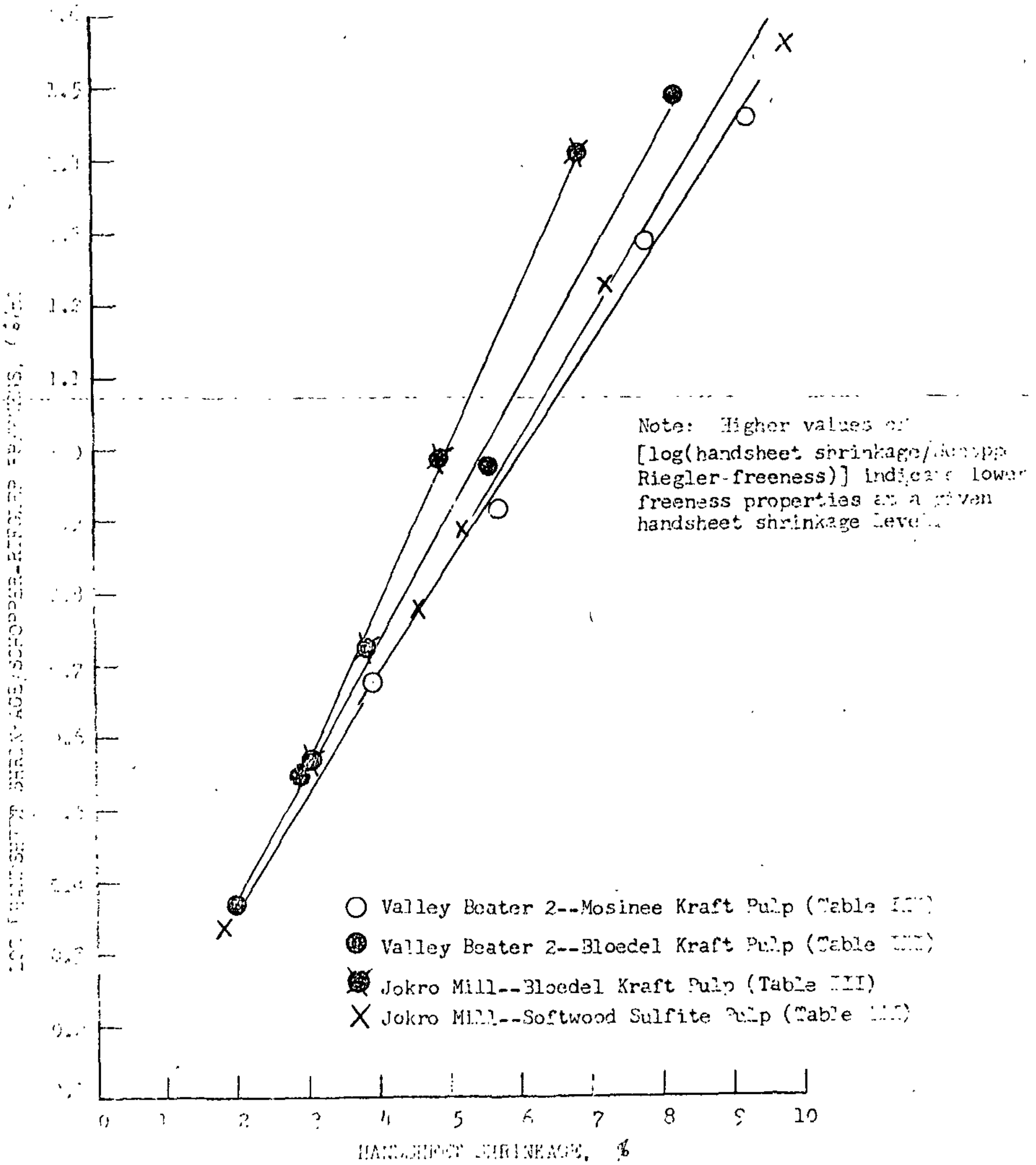
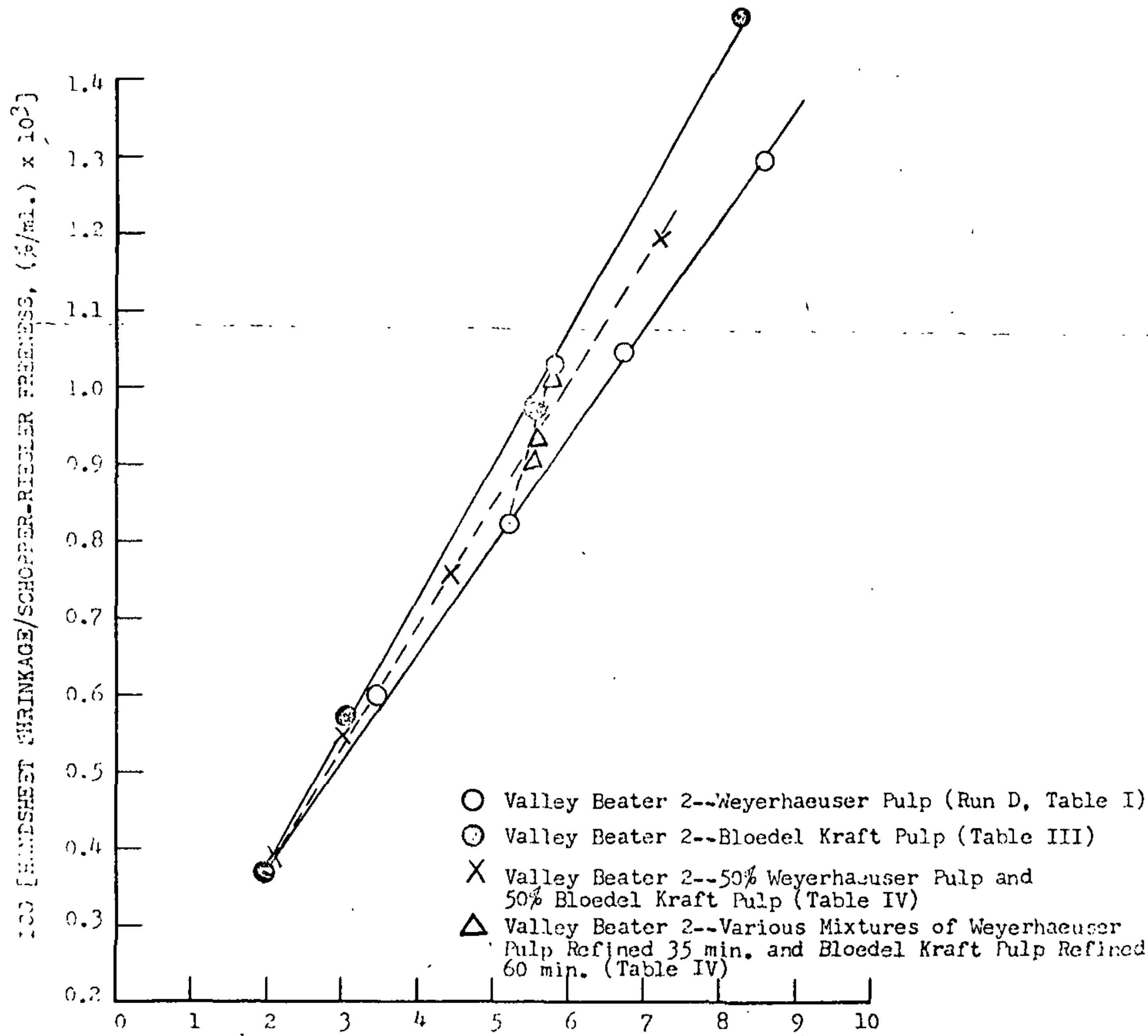


FIGURE 7-2

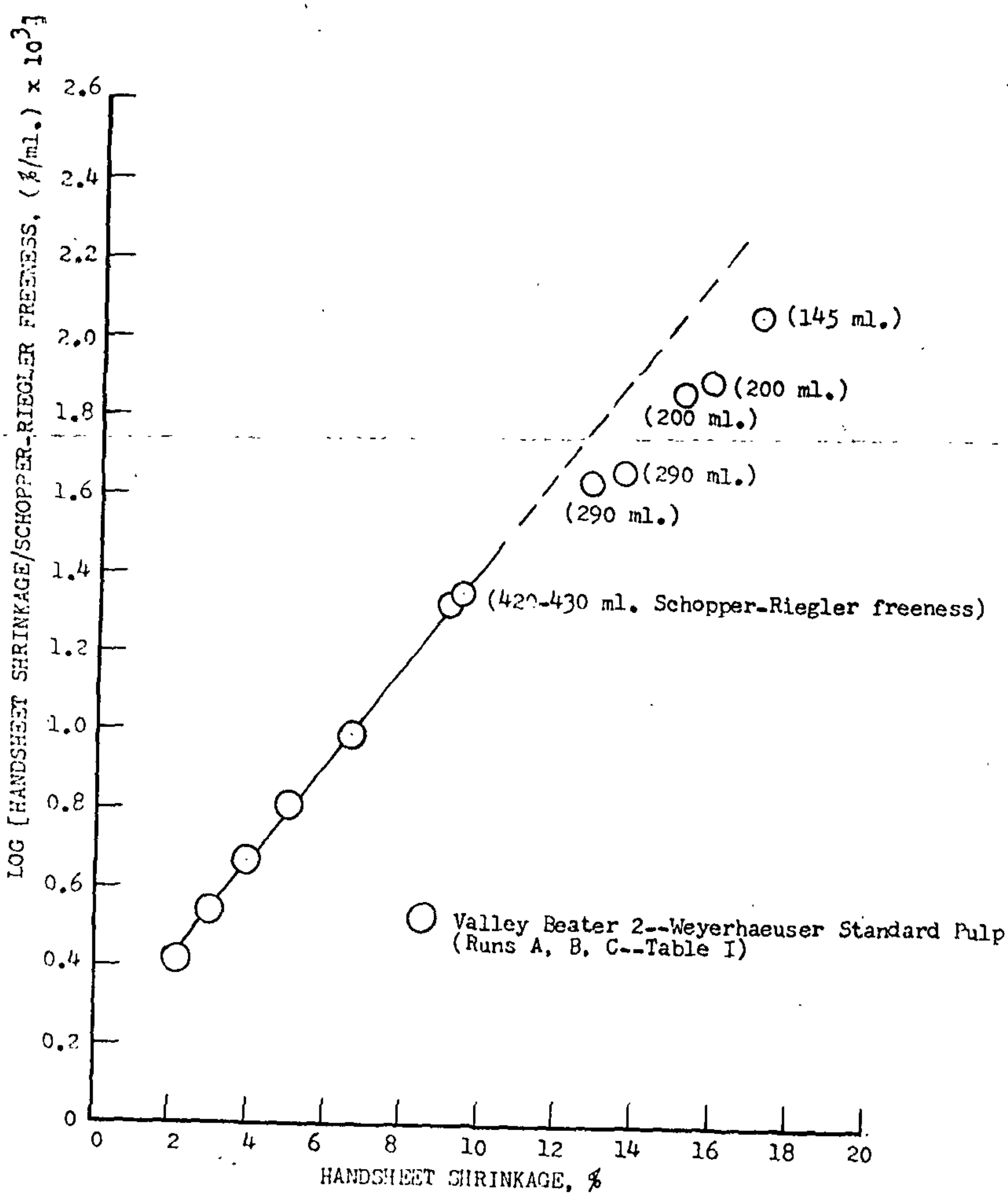
EFFECT OF VALLEY BEATER REFINING ACTION ON THE SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER PULP, BLOEDEL KRAFT PULP, AND MIXTURES OF WEYERHAEUSER AND BLOEDEL PULPS



HANDSHEET SHRINKAGE, %

FIGURE 7-3

EFFECT OF VALLEY BEATER REFINING ACTION ON THE SCHOPPER-RIEGLER FREENESS AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER STANDARD PULP



NATURE OF TENSILE STRENGTH, HANDSHEET SHRINKAGE, AND SCHOPPER-RIEGLER FREENESS RELATIONSHIPS PRODUCED BY MECHANICAL REFINING (BASED ON PRESENT WORK)

Previous Project 1513 work was limited to investigations in the moderate refining range. In the present work, however, these investigations were extended to include studies in both the extremely high and the extremely low refining range. On the basis of these studies, it appeared that:

(1) In the moderate refining range, the specific [tensile strength x handsheet shrinkage] vs. [log (handsheet shrinkage/Schopper-Riegler freeness)] relationship previously determined for the Weyerhaeuser standard pulp (Project 1513) also applied in present investigations (see the solid line portion of the curve in Figure 8-1).

(2) In the moderate refining range, a straight line [tensile strength x handsheet shrinkage] vs. [log (handsheet shrinkage/Schopper-Riegler freeness)] relationship resulted for the Bloedel kraft pulp. This relationship, however, was different than the one determined for the Weyerhaeuser standard pulp and apparently the relationship is influenced by the nature of the pulp (see Figure 8-2).

(3) Figure 8-1 indicates that the [tensile strength x handsheet shrinkage] vs. [log (handsheet shrinkage/Schopper-Riegler freeness)] straight line relationship deviates considerably when the refining cycle of the Weyerhaeuser standard pulp is extended beyond the moderate refining range. This failure of the relationship to be a straight line over the complete refining cycle may be attributed to the nature of the Schopper-Riegler freeness measurements--i.e., down to moderate freeness levels, the [log (handsheet shrinkage/Schopper-Riegler freeness)] properties of a pulp are directly proportional to the handsheet shrinkage properties of the pulp (see Section

FIGURE 8-1

EFFECT OF VARIOUS REFINING ACTIONS ON THE TENSILE STRENGTH, HANDSHEET SHRINKAGE, AND SCHOPPER-RIEGLER FREENESS PROPERTIES OF WEYERHAEUSER STANDARD PULP

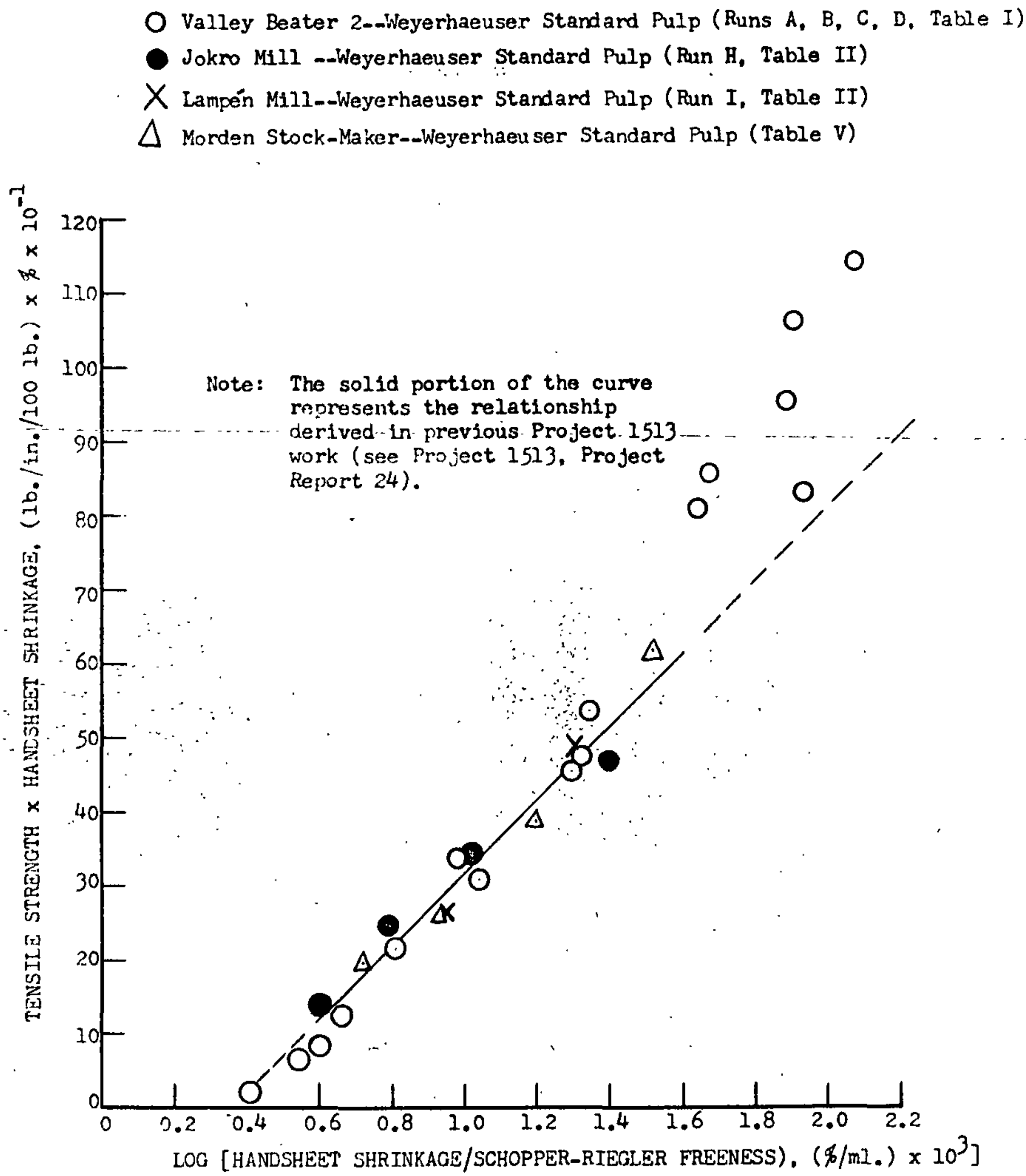
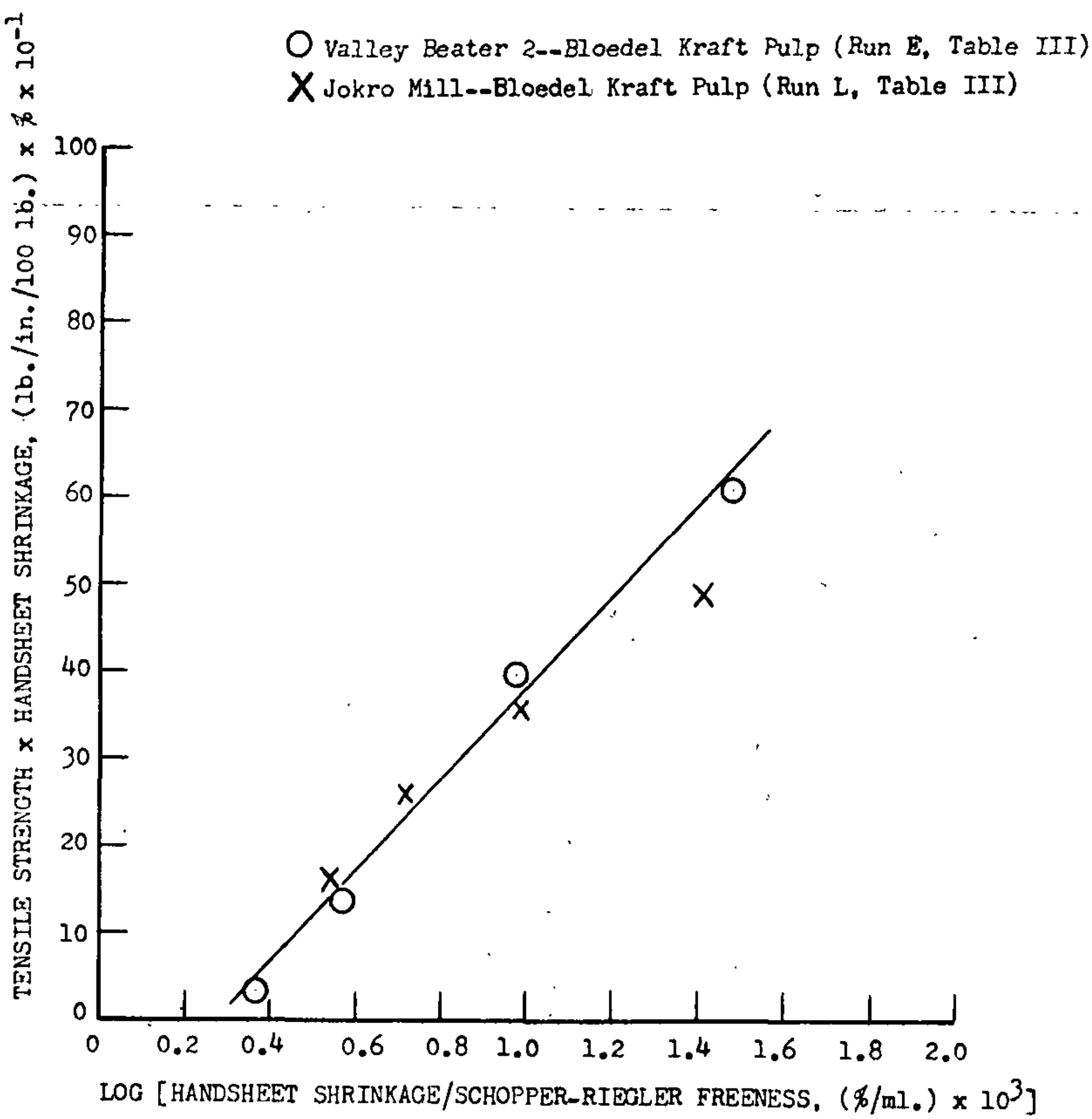


FIGURE 8-2

EFFECT OF VALLEY BEATER AND JOKRO MILL REFINING ACTIONS ON THE TENSILE STRENGTH, HANDSHEET SHRINKAGE, AND SCHOPPER-RIEGLER FREENESS PROPERTIES OF BLOEDEL KRAFT PULP



7 of this report). Beyond the moderate freeness level, however, this straight line relationship (see Figure 7-3, Section 7 of this report) no longer holds, because in the low freeness range, the freeness properties of the pulp change only slightly with increased refining. Thus, in the lower freeness range, the freeness values do not decrease rapidly enough with mechanical refining to maintain the same [tensile strength x handsheet shrinkage] vs. [log (handsheet shrinkage/Schopper-Riegler freeness)] relationship experienced at the more moderate levels of refining.

(4) From the previous discussion it may be seen that the "tensile strength = $\frac{494\ [\log (\frac{S}{F} \times 10^3)]}{S} - \frac{176}{S}$" expression derived for the Weyerhaeuser standard pulp in the moderate refining range would not be expected to accurately predict tensile strength properties in the lower freeness range. (This limitation of the prediction method has been represented in Figure 8-3 where both experimentally determined and predicted values of tensile strength have been presented for comparison purposes.)

(5) Figure 8-3 indicates that the utility of the tensile strength prediction method would be quite limited in the relatively high and the relatively low freeness range.

UTILITY OF TENSILE STRENGTH x HANDSHEET SHRINKAGE VS. LOG OF [HANDSHEET SHRINKAGE/FREENESS] RELATIONSHIPS PRODUCED BY MECHANICAL REFINING

The nature of the [tensile strength x handsheet shrinkage] vs. [log (handsheet shrinkage/Schopper-Riegler freeness)] relationship suggests that it would have certain, although limited, utility for control or pulp evaluation purposes.

FIGURE 8-3

EFFECT OF REFINING LEVEL ON RELATIONSHIPS BETWEEN THE TENSILE STRENGTH, HANDSHEET SHRINKAGE, AND SCHOPPER-RIEGLER FREENESS PROPERTIES OF VALLEY BEATER REFINED WEYERHAEUSER STANDARD PULP

● Experimentally determined points (Runs A, B, C, D--Table I)

○ Calculated points which fell in the range of previous Project 1513 work

X Calculated points which fell beyond the range of previous Project 1513 work

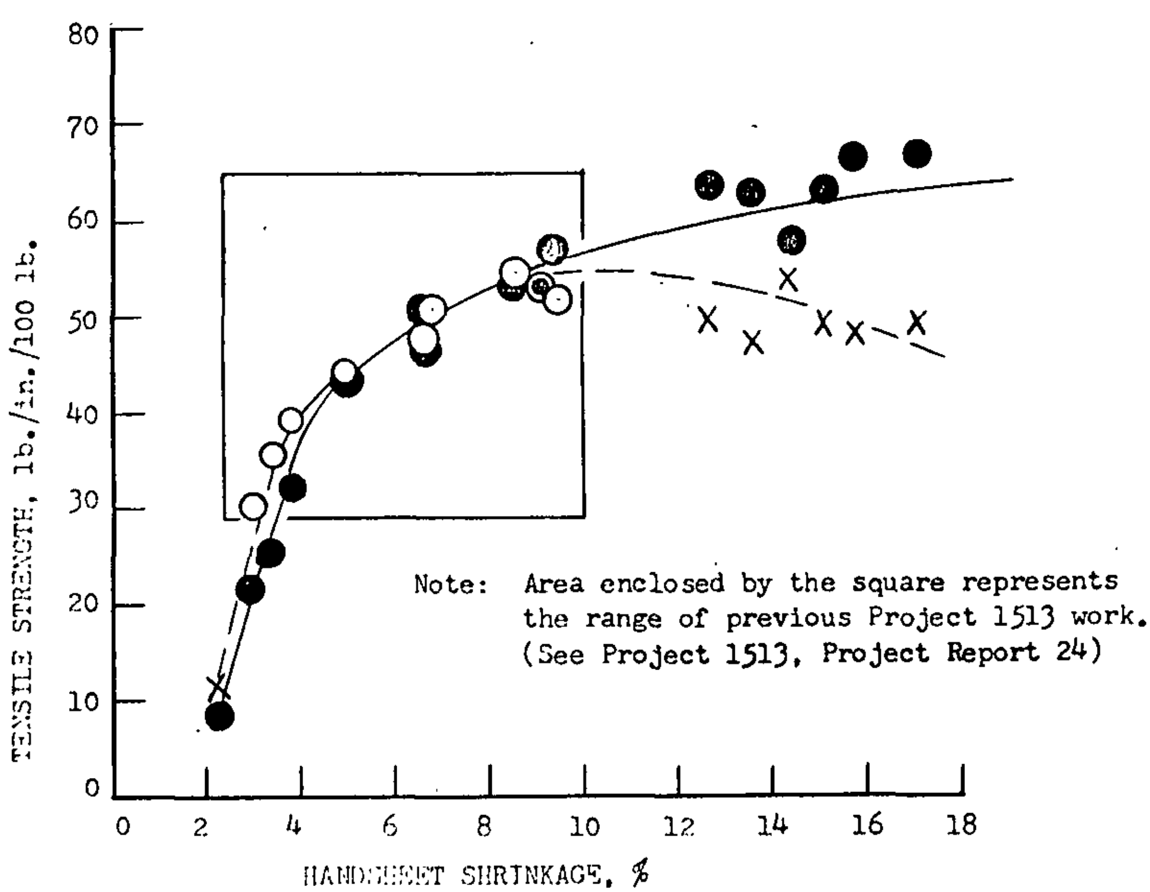
NOTE: Calculation of tensile strength properties were based on the relationship previously derived in Project 1513 work, i.e.:

$$\text{Tensile strength} = \frac{494\,[\log(\frac{S}{F} \times 10^3)]}{S} - \frac{176}{S},$$

where:

S = handsheet shrinkage, %

F = Schopper-Riegler freeness, ml.



SECTION 9

EFFECT OF MECHANICAL REFINING ON THE TEARING STRENGTH, FIBER LENGTH INDEX, AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

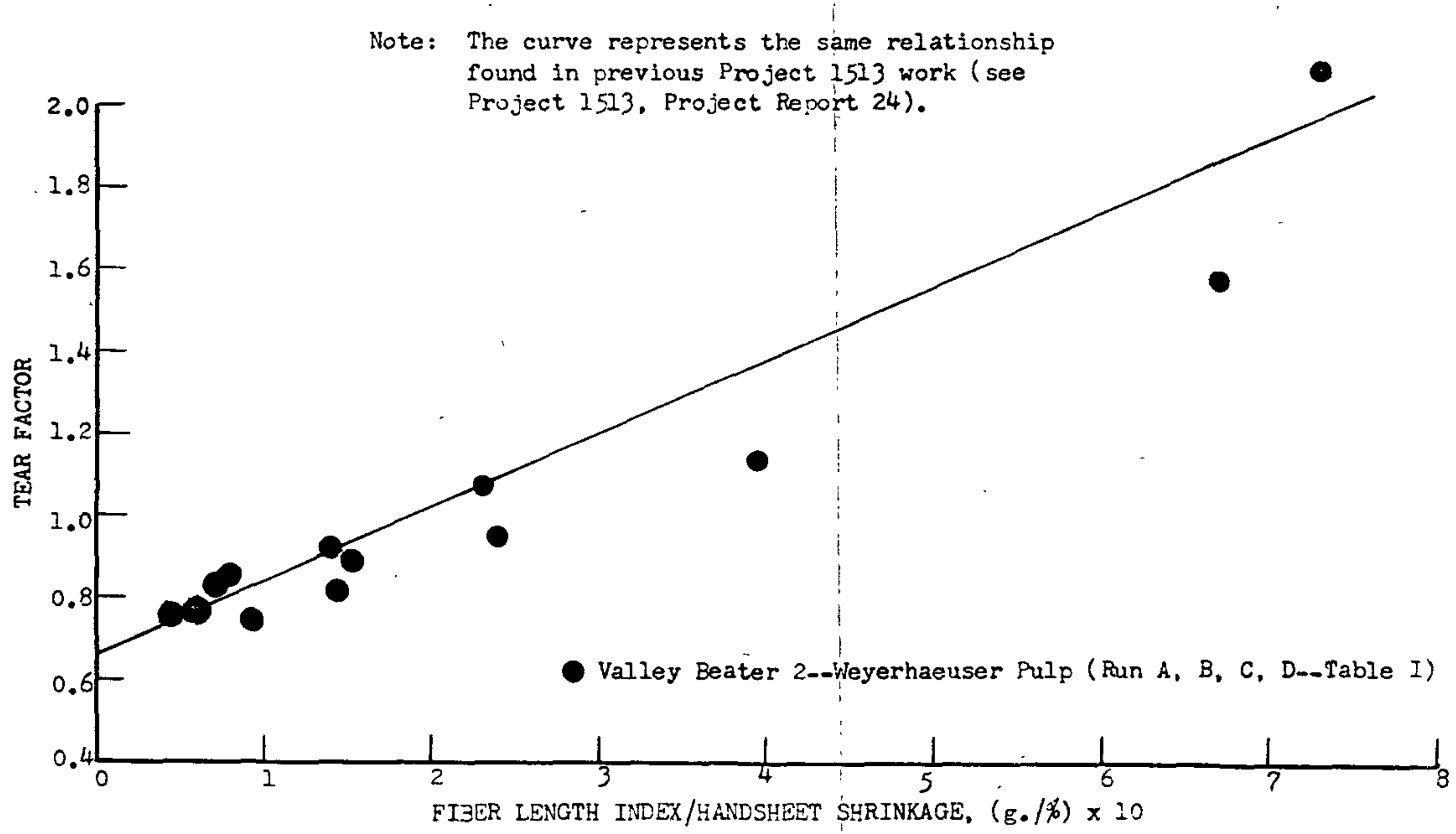
SECTION 9

EFFECT OF MECHANICAL REFINING ON THE TEARING STRENGTH, FIBER LENGTH INDEX, AND HANDSHEET SHRINKAGE PROPERTIES OF PULPS

In previous Project 1513 work (see Project 1513, Project Report 24), it was found that when Weyerhaeuser Standard pulp was refined by a variety of refining actions, a single straight line relationship appeared to exist when the tearing strength properties of the refined pulps were plotted against the [fiber length index/handsheet shrinkage] properties of the pulps (see Figure 9-1). The present work, however, indicated that a single straight line relationship does not necessarily always result when the tearing strength, fiber length index, and handsheet shrinkage properties of refined Weyerhaeuser pulps are plotted in this manner. Consequently, the utility of such relationships appear somewhat limited and the noted relationships are apparently quite general and more of a qualitative rather than a strictly quantitative nature.

FIGURE 9-1

EFFECT OF VALLEY BEATER REFINING ACTION ON THE TEARING STRENGTH, FIBER LENGTH INDEX, AND HANDSHEET SHRINKAGE PROPERTIES OF WEYERHAEUSER STANDARD PULP



SUMMARY AND CONCLUSIONS

The varied aspects of the experimental data makes it rather difficult to completely summarize all of the conclusions which may be obtained from the experimental work. Consequently, reference should be made to the "Experimental Results and Conclusions" section of this report for a complete understanding of all of the ramifications of the project. It appears, however, that a number of the more noteworthy conclusions from the work could be briefly summarized as follows:

I. The determination of both the handsheet shrinkage and the fiber length index properties of pulps requires very little equipment, time, or skill. Thus, these measurements would be well suited for control purposes and rapid techniques of pulp evaluation.

II. The handsheet shrinkage and the fiber length index properties of pulps, both by themselves and in conjunction with other pulp properties, could prove useful for evaluating pulps, characterizing mechanical refining actions, and controlling mechanical refining processes.

III. A number of experimental relationships were found which might prove useful in mechanical refining and pulp evaluation investigations. Certain of these relationships, their characteristics, and their utility may be briefly summarized as follows:

(1) Handsheet shrinkage and fiber length index relationships produced by mechanical refining (see Section 1 under "Experimental Results and Conclusions").

(a) When a pulp is subjected to a mechanical refining action, a plot of the [log (handsheet shrinkage/fiber length index)] vs. [log (handsheet shrinkage)] properties of the pulp results in a straight line relationship.

(b) Since the relationship is a straight line, it can be established with a minimum of experimental points.

(c) The relationship exists over the complete refining cycle and varies with the type of refining action and the nature of the pulp refined.

(d) This type of relationship could find application for characterizing a mechanical refining action, controlling a refining process, evaluating pulps, and reducing the experimental data required to define the refining characteristics of a pulp (refer to "Experimental Results and Conclusions").

(2) Filtration resistance and handsheet shrinkage relationships produced by mechanical refining (see Section 2, under "Experimental Results and Conclusions").

(a) When a pulp is subjected to a mechanical refining action, a plot of the [log (filtration resistance)] vs. [handsheet shrinkage] properties of the pulp results in a straight line relationship.

(b) Since the relationship is a straight line, it can be established with a minimum of experimental points.

(c) The relationship varies with the nature of the pulp refined.

(d) Further work, with a variety of refining actions, is required to more completely establish the characteristics of this type of relationship (see "Experimental Results and Conclusions"). It would appear, however, that this type of relationship could find application for characterizing a mechanical refining action, controlling a refining process, evaluating pulps, and reducing the experimental data required to define the refining characteristics of a pulp.

(3) Tensile strength and fiber length index relationships produced by mechanical refining (see Section 3 under "Experimental Results and Conclusions").

(a) When a pulp is subjected to a mechanical refining action, a plot of the [tensile strength] vs. [fiber length index] properties of the pulp results in a straight line relationship.

(b) Since the relationship is a straight line, it can be established with a minimum of experimental points.

(c) The relationship varies with the type of refining action and the nature of the pulp refined.

(d) The straight line relationship exists only until the maximum attainable tensile strength of the pulp is approached.

(e) This type of relationship could find application for characterizing a mechanical refining action, controlling a refining process, evaluating pulps, and reducing the experimental data required to define the refining characteristics of a pulp (refer to "Experimental Results and Conclusions").

(4) Tensile strength and handsheet shrinkage relationships produced by mechanical refining (see Section 4 under "Experimental Results and Conclusions").

(a) When a pulp is subjected to a mechanical refining action, a plot of the [tensile strength x handsheet shrinkage] vs. [handsheet shrinkage] properties of the pulp results in a straight line relationship.

(b) Since the relationship is a straight line, it can be established with a minimum of experimental points.

(c) The relationship varies with the type of refining action and the nature of the pulp refined.

(d) The straight line relationship exists only until the maximum attainable tensile strength of the pulp is approached.

(e) This type of relationship could find application for controlling a refining process, evaluating pulps, and reducing the experimental data required to define the refining characteristics of a pulp (refer to "Experimental Results and Conclusions").

(5) Tensile strength and filtration resistance relationships produced by mechanical refining (see Section 5 under "Experimental Results and Conclusions").

(a) When a pulp is subjected to a mechanical refining action, a plot of the [tensile strength x log (filtration resistance)] vs. [log (filtration resistance)] properties of the pulp result in a straight line relationship.

(b) Since the relationship is a straight line, it can be established with a minimum of experimental points.

(c) The relationship varies with the nature of the pulp refined.

(d) The straight line relationship exists only until the maximum attainable tensile strength of the pulp is approached.

(e) Further work, with a variety of refining actions, is required to more completely establish the characteristics of this type of relationship (see "Experimental Results and Conclusions"). It would appear, however, that this type of relationship could find application for controlling a refining process, evaluating pulps, and reducing the experimental data required to define the refining characteristics of a pulp.

IV. The experimental handsheet shrinkage, fiber length index, and strength relationships discussed in (III) above appeared to be of an additive nature--i.e., relationships for pulp mixtures appeared to follow patterns which could be predicted from the relationships of the individual pulp components in the mixtures (see Section 6 under "Experimental Results and Conclusions"). Thus, it would appear that the above relationships would have unique application in situations where the refining and evaluation of pulp mixtures are concerned. (It would appear that relationships involving handsheet shrinkage, filtration resistance, and strength properties would also be of an additive nature, but further work with filtration resistance measurements would have to be performed to definitely establish this contention.)