GENERAL

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

AN EVALUATION OF DRAINAGE AIDS IN CORRUGATING MEDIUM AND LINERBOARD FURNISHES

Project 2926

Report One

A Progress Report

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

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AN EVALUATION OF DRAINAGE AIDS IN CORRUGATING MEDIUM AND LINERBOARD FURNISHES

SUMMARY

The performance of selected drainage aids in liner secondary and primary pulps has been examined under dynamic conditions in a series of laboratory tests. Polyethylenimine (PEI), a cationic drainage aid, and an anionic polyacrylamide resin (PAM) were incorporated into a constant volume of 0.1% consistency stock at addition levels in the range of 0.005 to 2.0% based on fiber resulting in concentrations of 0.05 to 20 parts per million. Immediately after addition of the drainage aids the fiber suspensions were subjected to a controlled degree of agitation (either moderate or vigorous) for 10 or 100 seconds. The agitation cycle was then stopped and the drainage process started simultaneously. The time required for drainage was the primary measurement. Supplementary measurements included vacuum levels in drainage, water removal in wet pressing, solids in white water, and freeness.

Four series of drainage tests were conducted utilizing the following ionic environments:

1. tap water plus sulfuric acid to pH 5.5 (18-27 p.p.m. of $SO_4^=$),
2. deionized water plus sulfuric acid to pH 5.5 (3-4 p.p.m. of $SO_4^=$),
3. deionized water plus alum to pH 5.5 (18 p.p.m. of alum or 8 p.p.m. of $SO_4^=$), and
4. synthetic white water comprised of tap water with 1.0 lb. of fines per 1000 gal., 2% of alum (based on fiber), and sulfuric acid to pH 5.5 (approx. 40 p.p.m. of $SO_4^=$).

Supplementary tests to Series Three examined the effects of rosin-alum sizing and a higher alum concentration on drainage aid performance.

PEI was found to be an effective drainage aid for the liner secondary pulp under most ionic environments when used at approximately 5-10 p.p.m. under conditions of low agitation rate and short duration (10 seconds at 100 cycles/min.). PEI was not effective when the alum concentration was increased sevenfold as in the supplementary tests to Series Three. The effectiveness of PEI in the other environments was reduced or eliminated at higher concentrations and by agitating the fiber suspension at high speed for 100 seconds. The greatest increase in drainage rate ($\cong$ 140%) with PEI was accomplished in the synthetic white water system; the lowest increase ($\cong$ 46%) was obtained in the tap water plus alum system. Rosin-alum size had little or no effect on the performance of PEI when used under the optimum drainage conditions in Series Three. In the absence of added fines, i.e., excluding the synthetic white water system, PEI was more effective at low $SO_4^=$ content. However, PEI also proved effective in the presence of the added fines where the $SO_4^=$ content was approximately 40 p.p.m. Polyethylenimine generally had little effect on the drainage properties of the primary pulp although some advantage was indicated in the synthetic white water system. PEI also proved effective in reducing white water solids, particularly under those conditions which provided optimum or near optimum drainage rates. Some indication that PEI increases water retention slightly in wet pressing was noted but, since a constant volume of fiber suspension was used in all tests, the indicated increase may have resulted from increased fines retention and slightly higher basis weight.

In general, the polyacrylamide resin (PAM) proved ineffective as a drainage aid under the dynamic conditions utilized in these tests. This applied to all environments examined with the exception of the third series (deionized water plus

18 p.p.m. of alum) where a maximum increase in drainage rate of 20% was achieved. This advantage was obtained at about 5 p.p.m. of PAM under conditions of low agitation rate and short time. Addition of rosin size reduced the advantage indicated. In all other systems PAM either had no effect or decreased drainage rate. PAM decreased white water solids in several cases apparently by a dispersion and filtration mechanism.

Freeness values in the presence of PEI paralleled drainage rates to the extent that both reached a maximum at a PEI addition level of about 0.5% but it was also found that a sizable difference in drainage rate was obtained at the same nominal freeness depending upon the agitation rate and time. Hence, floc strength was demonstrated to be an important factor in the liner pulp system. Further evidence for the importance of floc strength was indicated in the case of the polyacrylamide resin. This material was found to produce sizable increases in freeness, particularly in the presence of alum, but generally poor dynamic drainage properties. Hence, it appears that PAM formed a weakly flocced system which was destroyed under the moderate agitation conditions employed in the drainage tests.

INTRODUCTION

This is Progress Report One on Project 2926 established in cooperation with the Fourdrinier Kraft Board Institute, Inc. for the purpose of studying the use of drainage aids in linerboard furnishes.

From the papermaking standpoint, the removal of water from the fiber matrix occurs at three major locations:

1) on the wire,
2) in the presses, and
3) on the driers.

The function of the drainage aid is one of promoting the ease of water removal at these locations and, in particular, on the wire. Supplementary benefits may include reduced white water solids and cleaner effluents. Theoretical aspects of flocculation and the performance of drainage aids in the fiber-water system are discussed in the following sections.

Most lyophilic colloidal systems are polymeric in nature and, if the polymer molecule possesses ionizable groups, the dispersed particles may be stabilized by the resulting double layer and, hence, pH, electrolyte concentration, valence, etc., should have a predictable influence on stability. However, it has been observed that electrolyte concentrations sufficient to completely collapse the double layer and bring the particles to their isoelectric point do not necessarily cause flocculation. This is attributed to the presence of a solvation barrier or, more correctly, to an entropy barrier which is difficult to disperse. The observation has been frequently made that addition of a lyophilic colloid to a lyophobic colloid may stabilize the lyophobic sol, an effect which is sometimes termed protective colloid action. In contrast, very low concentrations of lyophilic colloids may flocculate the lyophobic dispersion which could be stabilized at higher levels of addition. Such flocculated systems often filter and drain much faster, an effect which is important to the papermaker.

The mechanism by which drainage aids function in papermaking systems is generally attributed to the attachment of fines and particulate material to the larger fibers by some sort of bridging mechanism. One theory which has been rather successful in elucidating flocculation in some systems is that proposed by La Mer and coworkers (1-3). According to the theory, when a dilute polymer dispersion is added to a colloidal dispersion whose particles have a high surface area, single polymer molecules may be adsorbed on two or more particles simultaneously and form bridges. The resulting network leads to flocculation even against an opposing electrical double layer barrier. It is postulated that the probability of building flocs is proportional to the fraction of the surface covered by polymer, θ, and to the fraction of the surface that is uncovered, $(1-\theta)$. The rate of floc formation, $-dn_o/dt$, expressed as the decrease in the number of primary particles, n_o, will depend upon the product $\theta(1-\theta)$ and is given by

$$-dn_o/dt = k_1 n_o^2\ \theta(1-\theta) \qquad (1)$$

where the number of floc nuclei and the number of particles per unit volume available to add to the floc nuclei are both proportional to n_o^2. Hence, the bridging mechanism involves a bimolecular process where $n_o\theta$ represents the "concentration" of active species containing flocculant and $n_o(1-\theta)$ represents the "concentration" of species with open surface able to react with the first species. This leads to the formation of flocs whose envelope of volume denied to flow is less than that of the constituent particles. According to the Kozeny-Carman theory the flow rate through a bed of particles is inversely proportional to the hydrodynamic surface area so polymer flocculation should increase drainage rate and such has been found to be the case.

At higher polymer concentrations or under conditions of continued or intense agitation, polymer molecules tend to adsorb on single particles with little or no bridging. This leads to stabilization of the particle dispersion due to the large entropy barrier which develops as particles approach one another. Hubley and coworkers (4) observed that the same concentration of fiber flocculant will disperse long fibers and simultaneously coagulate the fines in a papermaking pulp. This observation may be explained by the LaMer theory since the much greater surface area of the fines favors bridging, whereas the lesser area of the whole fibers is more quickly covered and discourages bridging.

Several methods have been proposed for studying the retention of fines and the drainage properties of pulp systems. Some of these are simply based on freeness measurements while others are concerned with maximizing the electrokinetic conditions of the system. In general, however, these methods are not directly applicable to the practical papermaking system wherein dynamic polymer adsorption behavior makes time effects and floc strength important factors. The present program examines the effectiveness of selected commercial drainage aids under dynamic conditions in order to optimize their utilization in commercial linerboard furnishes.

EXPERIMENTAL

EXPLORATORY DRAINAGE TESTS

For purposes of studying drainage properties in the laboratory, consideration was given to the use of a Rapid-Köthen sheet mold equipped with vacuum drainage and vacuum gage such that drainage could be measured in terms of time and pressure after subjecting the fiber suspension to several degrees of agitation. A number of exploratory tests were conducted with a substitute softwood kraft pulp (425 cc. C.S.F.) in order to establish approximate conditions of basis weight, fiber consistency, and agitation suitable for drainage studies. Consistencies were explored over a range of 0.1 to 0.8% at several basis weights, including 42 and 52 lb./1000 sq.ft. While a fiber consistency in the range of 0.5 to 0.8% would be considered more desirable from the standpoint of commercial practice, the volume of material required in the 8-inch diameter mold to produce the equivalent of 42 or 52-lb. liner was inadequate for controlled agitation. Of equal importance was the probability that kraft pulp at these consistencies would contain material which was not deflocculated; a condition which was considered undesirable in a system designed to study floc formation and strength. It was finally decided to use 7.43 liters of 0.1% stock to provide the equivalent of 52-lb. liner. This fiber consistency is somewhat lower than that used in commercial practice but it is higher than that normally used in handsheet preparations.

Several types of agitation devices were considered in the preliminary drainage tests including rotational stirrers and circulating pumps. Uniform webs could not be formed with rotational agitation and circulating pumps were rejected on the basis of uncontrolled shear forces in the impeller and unreasonable fiber retention or hang-up. A variable speed reciprocating stirrer was subsequently constructed to fit the mold. The mold and stirrer are shown in Fig. 1. The stirrer, which consists of a vertical shaft with four planar fins, operates with a reciprocal motion through an arc of 60 degrees. The stirrer is powered through a Variac and voltage regulator so that agitation rate can be accurately controlled. The fins (3-1/8 x 4-1/8 in.) serve to dampen the motion of the fiber suspension as soon as the stirrer is stopped, thereby providing for more uniform formation. In operation, the stirrer is stopped and the drainage process started simultaneously without removing the stirrer from the mold.

PROCESSING OF LINER PULPS

Approximately 40 lb. of commercial primary and secondary liner pulps were procured for the drainage studies. The pulps were diluted to 4% consistency in tap water and then refined on the Institute's 36-inch Bauer disk refiner. The primary stock was refined to 710 cc. and the secondary to approximately 300 cc. C.S.F. The refined pulps were washed with deionized water, dewatered to 20-25% solids, and then stored at 40°F. with a small amount of preservative. The arithmetic average fiber length of the primary was 0.95 mm.; the weight average length was 2.05 mm. The corresponding lengths for the secondary pulp were 0.80 and 1.72 mm., respectively.

DRAINAGE TESTS

Series One

The first series of drainage tests was carried out in tap water to test the sensitivity of the method to changes in time and rate of agitation. For each set of sheets, 88 grams (O.D. basis) of dewatered pulp were redispersed at 1.5% consistency by subjecting the slurry to 400 counts in a British disintegrator.

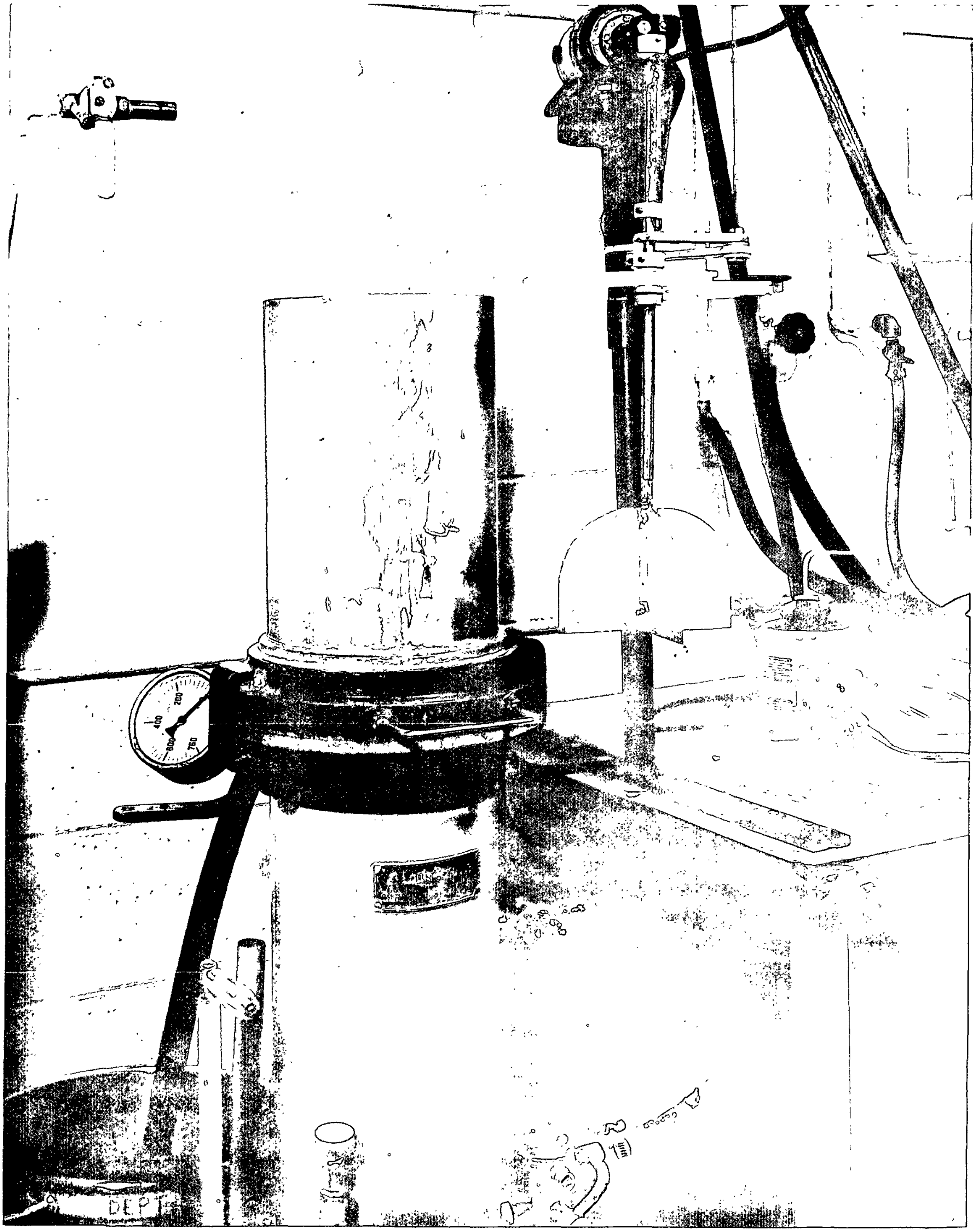

Figure 1. Drainage Tester

The resuspended pulp was then diluted to 0.1% consistency in a stainless steel container. In this series and all subsequent series the pH of the pulp suspension was adjusted to 5.5 and the temperature to 25°C. unless indicated otherwise. Sulfuric acid was used for pH adjustment in the first series. An aliquot of resuspended pulp (7.43 l.) was metered into the mold followed by a measured amount of polyethylenimine (PEI) or polyacrylamide (PAM). More specifically, the polyethylenimine product used was Tydex 12 (Dow Chemical Co.) and the polyacrylamide was Accurac 27 (American Cyanamid Co.). These materials are representative of the two major chemical classes of drainage aids and, further, PEI is cationic and Accurac 27 is anionic. The drainage aids were used as dilute solutions (0.1% or less) in distilled water and were added in amounts ranging from 0.005 to 2.0% based on fiber.

After stirring the fiber suspension for either 10 or 100 seconds at rates of 100 or 260 cycles/min., the stirrer was stopped and the drainage process started simultaneously. The maximum vacuum and the stabilized vacuum levels were recorded as well as the drainage time to the nearest 0.5 second. Two sheets were formed at each drainage condition. The sheets were couched lightly onto blotter stock and subsequently pressed between blotters at 50 p.s.i. The fiber solids content was determined after pressing for three and six minutes. The white water from each sheet was drained by gravity into a reservoir and the solids content was determined according to corrected TAPPI Method RC-95. Freeness measurements were made on the pulp alone and on samples containing the drainage aids. In general, drainage times in a set agreed to within 0.5 sec., vacuum levels to within 10 mm., and water solids to within 0.05 lb./1000 gal. Results are recorded in Tables I to III and some of the more pertinent information is shown graphically in Fig. 2-8. A slightly different

TABLE I

THE EFFECT OF PEI ON THE DRAINAGE PROPERTIES OF LINER PULP IN TAP WATER CONTAINING SULFURIC ACID (pH 5.5)

Set No.	Liner Stock	PEI Addition Level, %	PEI Concentration, p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Av. Drainage Time, sec.			Approx. Drainage Rate, ml/sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
						To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
1	Secondary	0.0	0.0	10	100	18	1	19.0	391	393	78	35.6	37.2	0.31
2	Secondary	0.05	0.5	10	100	16	1	17.0	437	345	60	34.2	38.2	0.19
3	Secondary	0.5	5.0	10	100	12	1	13.0	571	205	53	34.1	36.6	0.09
4	Secondary	2.0	20.0	10	100	14.5	1	15.5	479	240	55	35.1	37.4	0.15
5	Secondary	0.0	0.0	10	260	18	1	19.0	391	385	78	36.2	37.9	0.31
6	Secondary	0.05	0.5	10	260	18	1	19.0	391	345	65	34.8	37.4	0.17
7	Secondary	0.5	5.0	10	260	15	1	16.0	464	245	50	34.6	37.0	0.18
8	Secondary	2.0	20.0	10	260	18.5	1	19.5	381	325	60	36.4	37.9	0.21
9	Secondary	0.0	0.0	100	100	17	1	18.0	413	378	75	37.2	38.4	0.32
10	Secondary	0.05	0.5	100	100	17.5	1	18.5	402	325	65	35.5	38.1	0.14
11	Secondary	0.5	5.0	100	100	14	1	15.0	495	245	55	35.3	37.5	0.07
12	Secondary	2.0	20.0	100	100	18	1	19.0	391	385	83	36.3	38.8	0.19
13	Secondary	0.0	0.0	100	260	16.5	1	17.5	425	320	70	35.3	37.1	0.32
14	Secondary	0.05	0.5	100	260	17.5	1	18.5	402	340	68	35.4	37.7	0.21
15	Secondary	0.5	5.0	100	260	16.0	1	17.0	437	300	65	35.5	37.9	0.11
16	Secondary	2.0	20.0	100	260	19.5	1	20.5	362	395	78	37.0	38.0	0.27
17	Primary	0.0	0.0	10	100	9.0	<1	9.0	826	50	28	34.2	37.2	0.27
18	Primary	0.05	0.5	10	100	9.0	<1	9.0	826	50	28	32.7	36.8	0.18
19	Primary	0.5	5.0	10	100	8.0	<1	8.0	929	35	25	32.8	35.8	0.12
20	Primary	2.0	20.0	10	100	8.0	<1	8.0	929	43	33	33.7	36.1	0.11
21	Primary	0.0	0.0	100	260	8.5	<1	8.5	874	60	30	34.4	37.7	0.30
22	Primary	0.05	0.5	100	260	8.0	<1	8.0	929	60	33	33.6	36.9	0.19
23	Primary	0.5	5.0	100	260	8.0	<1	8.0	929	60	33	34.6	36.8	0.14
24	Primary	2.0	20.0	100	260	8.5	<1	8.5	874	65	35	35.2	38.1	0.32

Note: 18 p.p.m. $SO_4^{=}$ added.

TABLE II

THE EFFECT OF POLYACRYLAMIDE ON THE DRAINAGE PROPERTIES OF LINER PULP IN TAP WATER CONTAINING SULFURIC ACID (pH 5.5)

Set No.	Liner Stock	Polyacrylamide Addition Level, %	Polyacrylamide Concentration, p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/Min.	Av. Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb/1000 gal.
						To Start of Vacuum Drop	From start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
25	Secondary	0.0	0.0	10	100	19	1	20	372	410	78	35.1	38.1	0.25
26	Secondary	0.005	0.05	10	100	21	1	22	338	425	78	35.3	37.5	0.26
27	Secondary	0.05	0.5	10	100	25	1	26	286	465	85	34.6	36.8	0.25
28	Secondary	0.5	5.0	10	100	27.5	1	28.5	261	485	88	34.8	37.1	0.17
29	Secondary	0.0	0.0	10	260	19	1	20	372	400	78	37.5	38.3	0.28
30	Secondary	0.005	0.05	10	260	21	1	22	338	415	80	35.5	37.9	0.20
31	Secondary	0.05	0.5	10	260	21	1	22	338	410	78	35.4	37.7	0.23
32	Secondary	0.5	5.0	10	260	24.5	1	25.5	291	455	83	34.9	37.8	0.30
33	Secondary	0.0	0.0	100	100	18	1	19	391	370	73	35.2	37.5	0.25
34	Secondary	0.005	0.05	100	100	22.5	1	23.5	316	455	80	34.7	36.5	0.13
35	Secondary	0.05	0.5	100	100	25.5	1	26.5	280	465	83	34.5	37.0	0.23
36	Secondary	0.0	5.0	100	100	26	1	27	275	440	83	35.0	36.0	0.26
37	Secondary	0.0	0.0	100	260	16	1	17	437	320	63	34.4	37.2	0.29
38	Secondary	0.005	0.05	100	260	17	1	18	413	335	53	34.9	37.6	0.31
39	Secondary	0.05	0.5	100	260	17	1	18	413	325	60	35.4	37.5	0.24
40	Secondary	0.5	5.0	100	260	18	1	19	391	345	65	34.9	36.9	0.27
41	Primary	0.0	0.0	10	100	8.0	<1	8.0	929	55	35	33.0	38.0	0.28
42	Primary	0.005	0.05	10	100	8.0	<1	8.0	929	55	35	34.1	37.2	0.31
43	Primary	0.05	0.5	10	100	8.0	<1	8.0	929	65	35	33.5	37.1	0.24
44	Primary	0.5	5.0	10	100	9.5	<1	9.5	782	112	35	34.4	37.8	0.16
45	Primary	0.0	0.0	100	260	8.0	<1	8.0	929	50	35	34.0	37.6	0.25
46	Primary	0.005	0.05	100	260	8.0	<1	8.0	929	50	35	34.5	36.5	0.32
47	Primary	0.05	0.5	100	260	8.0	<1	8.0	929	50	35	34.0	37.2	0.27
48	Primary	0.5	5.0	100	260	8.3	<1	8.5	895	55	35	34.4	37.4	0.18

Note: 27 p.p.m. of $SO_4^{=}$ added.

range in addition level was utilized with the two drainage aids because of differing response. Also, since the fiber consistency in the drainage tests was lower than that used in practice, the drainage aid content is expressed in terms of both addition level and concentration as parts per million.

TABLE III

THE FREENESS OF LINER STOCKS AT pH 5.5
IN TAP WATER CONTAINING SULFURIC ACID

Liner Stock	Drainage Aid	Addition Level, %	Canadian Freeness, cc.
Secondary	None	--	300
	PEI	0.05	410
	PEI	0.5	600
	PEI	2.0	495
	PAM	0.005	335
	PAM	0.05	335
	PAM	0.5	360
Primary	None	--	710
	PEI	0.05	685
	PEI	0.5	710
	PEI	2.0	705
	PAM	0.005	695
	PAM	0.05	710
	PAM	0.5	695

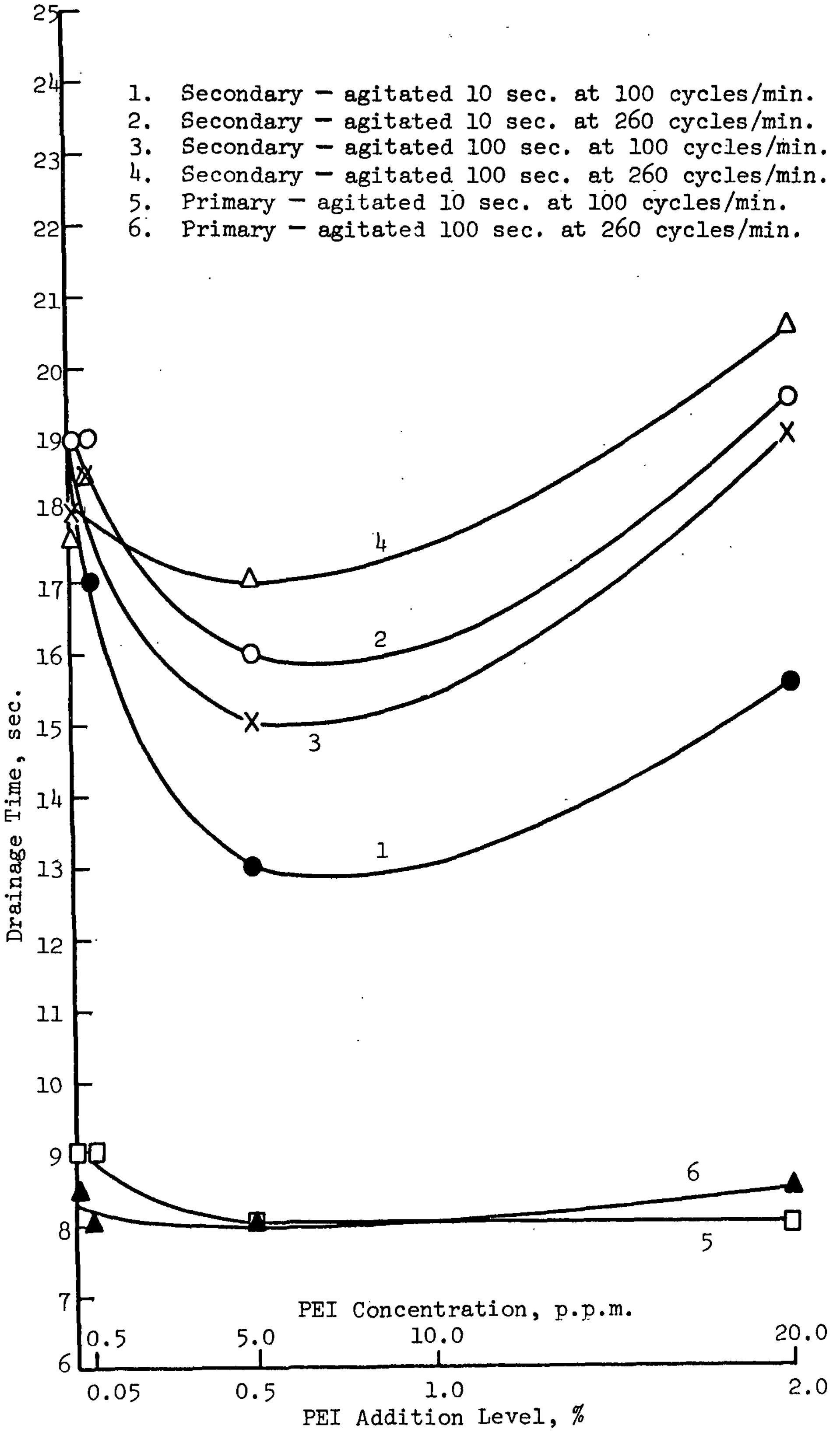

Figure 2. The Effect of PEI Concentration on Drainage Time
(Tap Water — pH 5.5 with Sulfuric Acid)

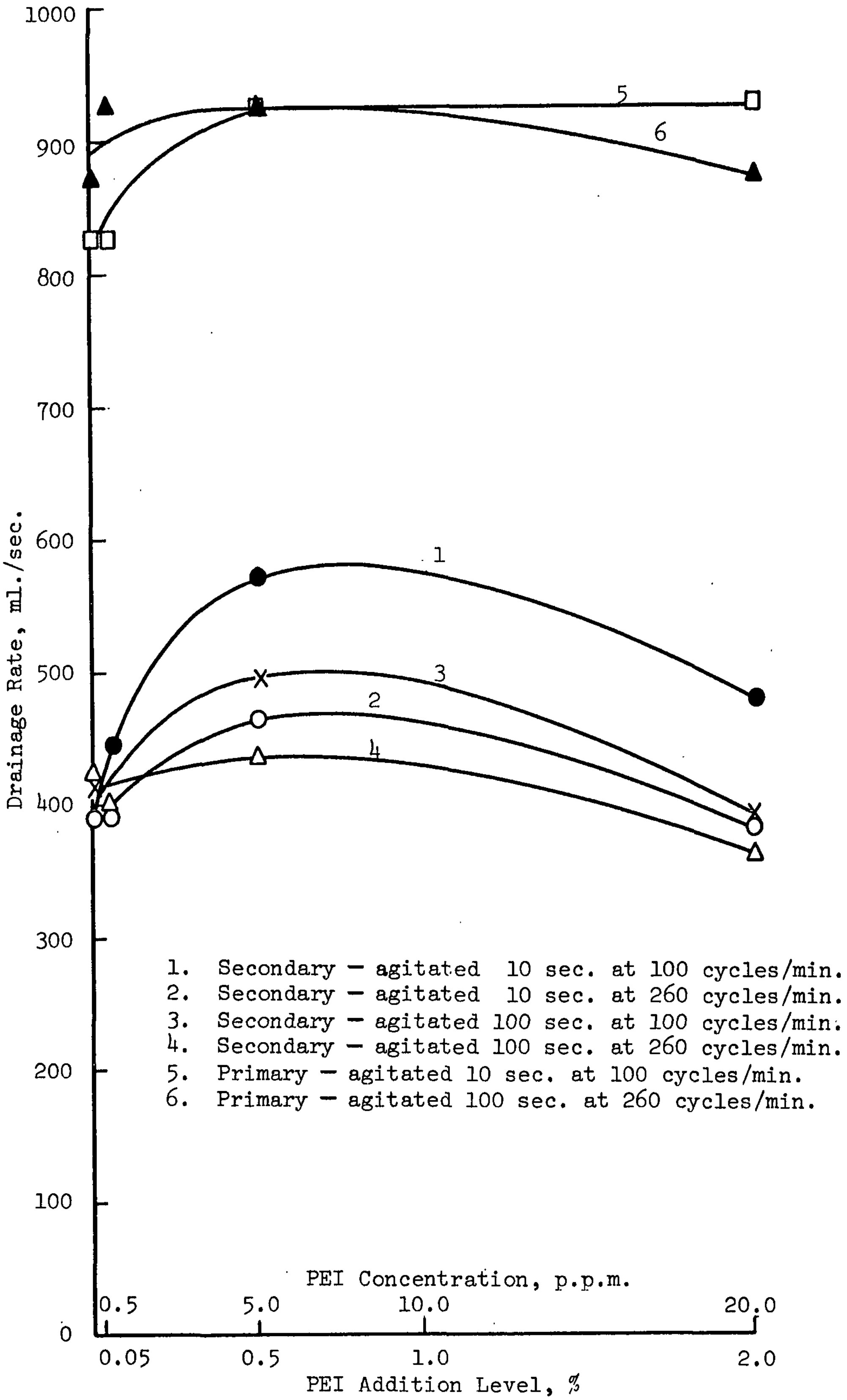

Figure 3. The Effect of PEI Concentration on Drainage Rate
(Tap Water — pH 5.5 with Sulfuric Acid)

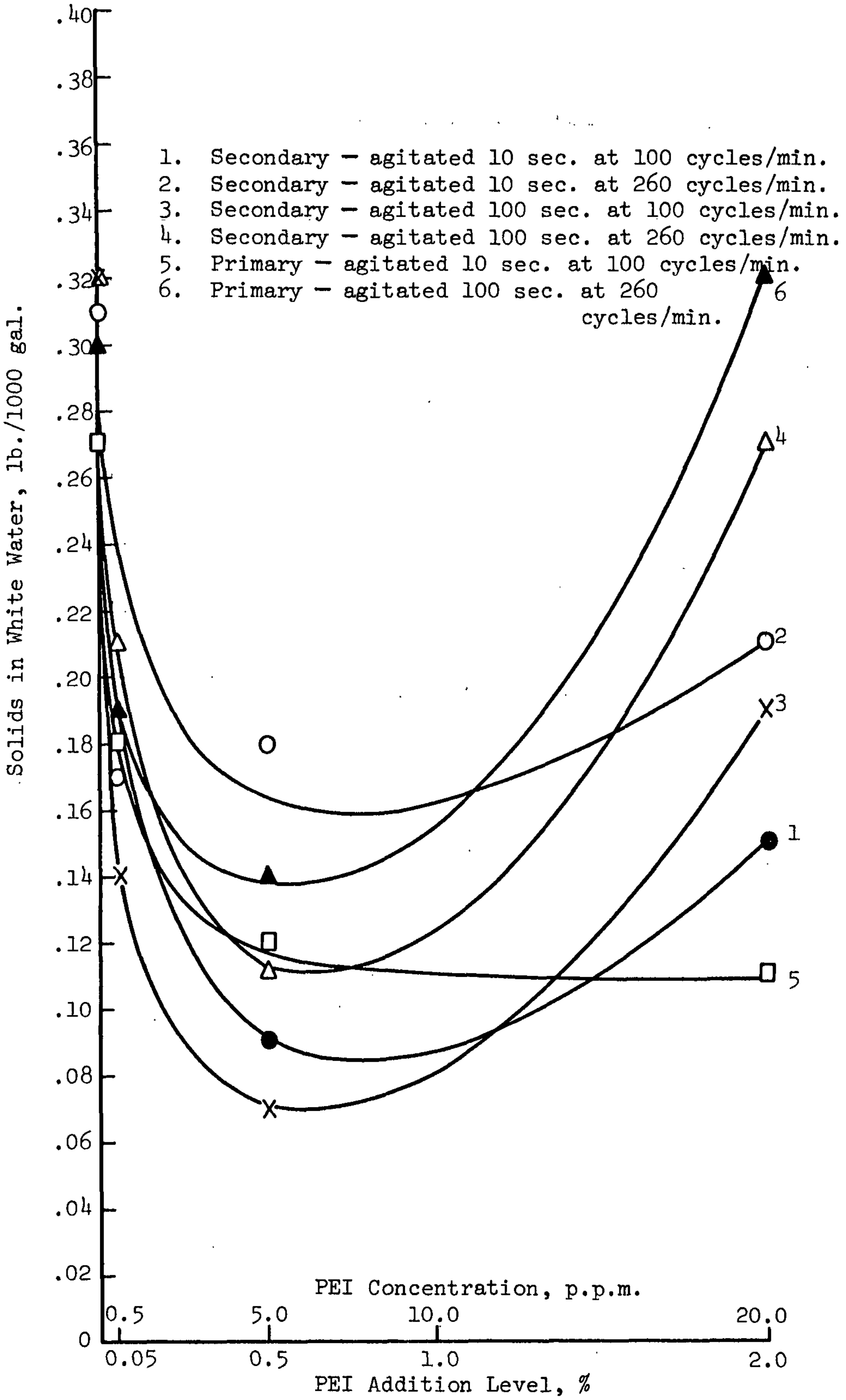

Figure 4. The Effect of Polyethylenimine Concentration on White Water Solids (Tap Water—pH 5.5 with Sulfuric Acid)

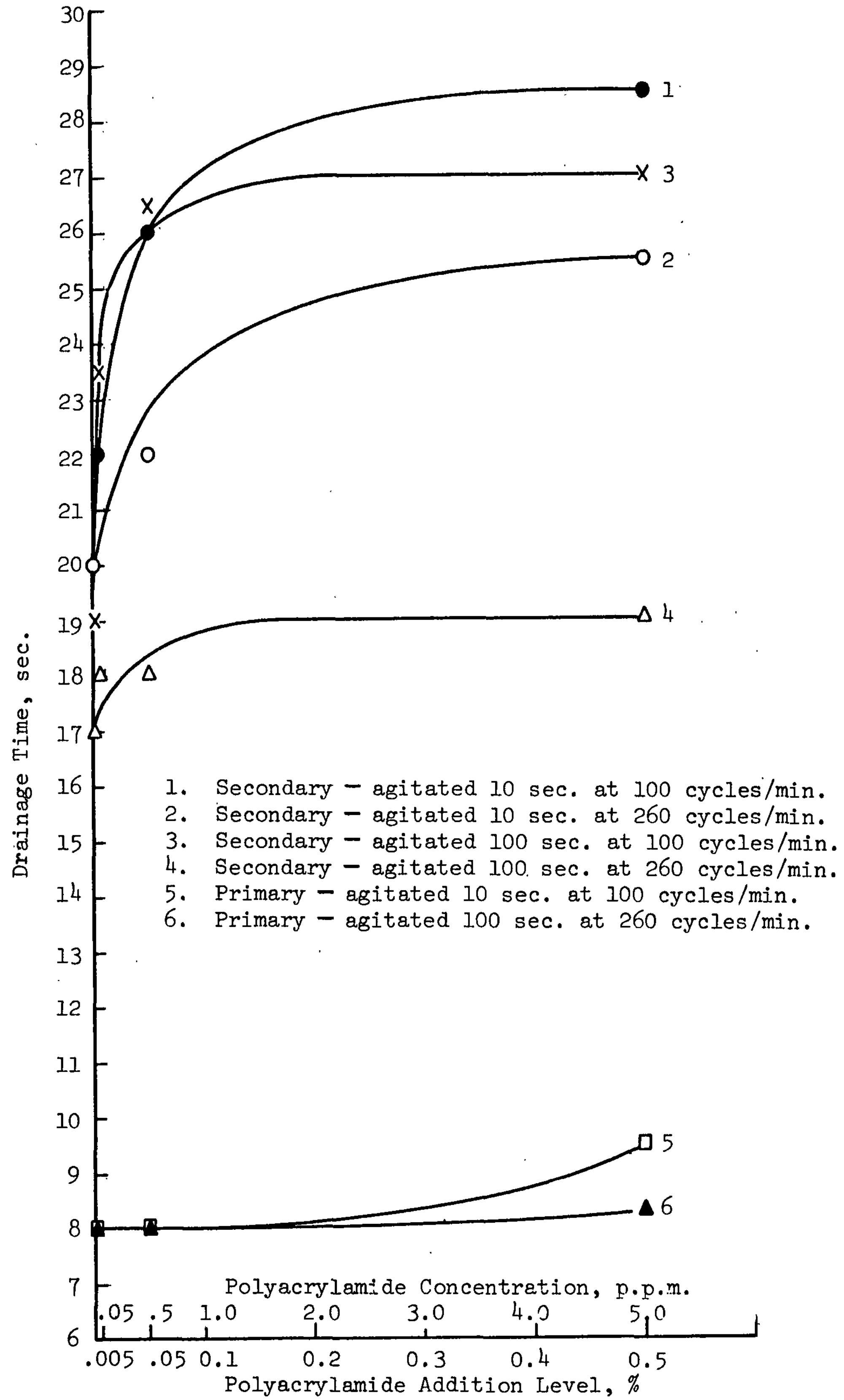

Figure 5. The Effect of Polyacrylamide Concentration on Drainage Time (Tap Water — pH 5.5 with Sulfuric Acid)

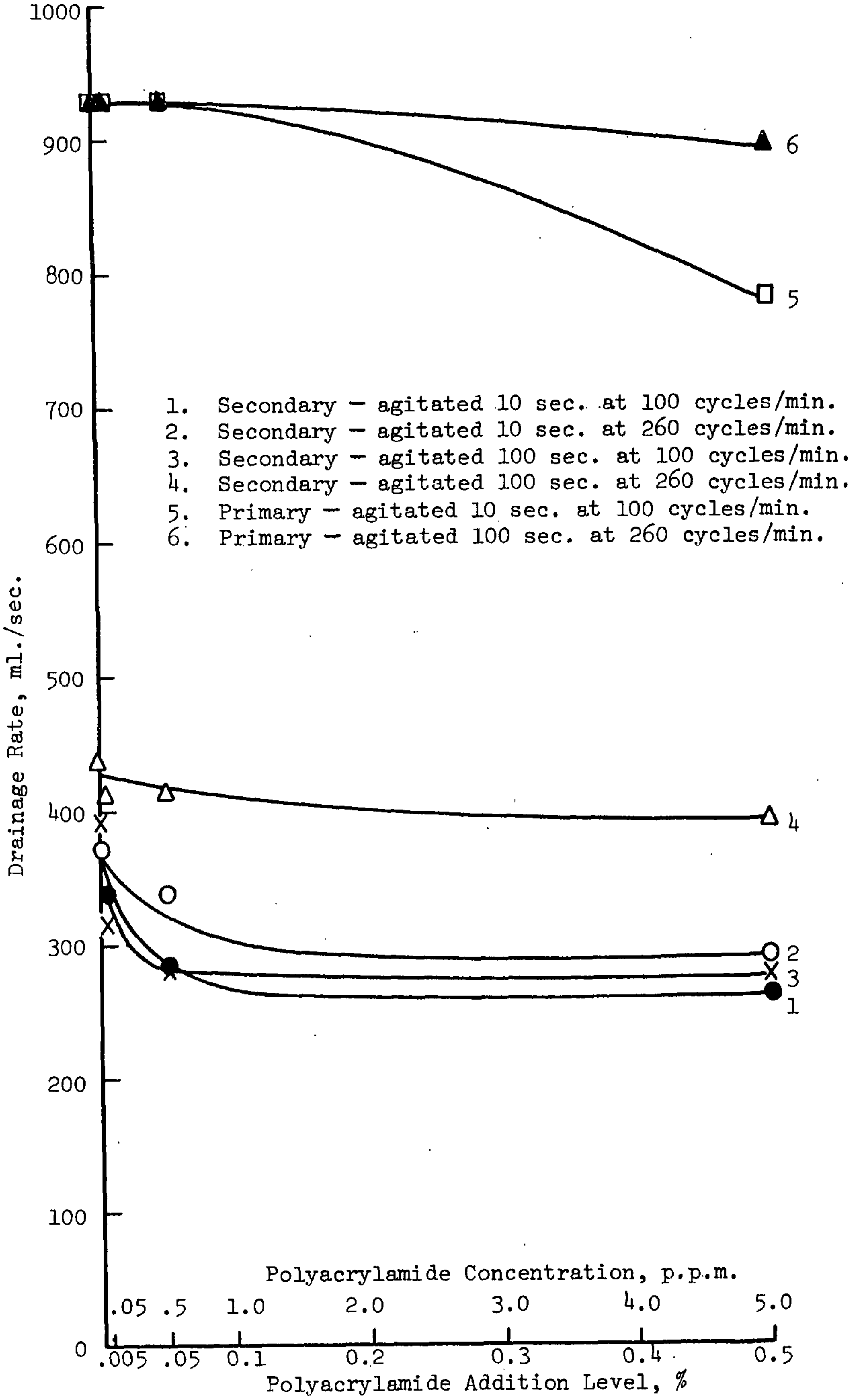

Figure 6. The Effect of Polyacrylamide Concentration on Drainage Rate (Tap Water — pH 5.5 with Sulfuric Acid)

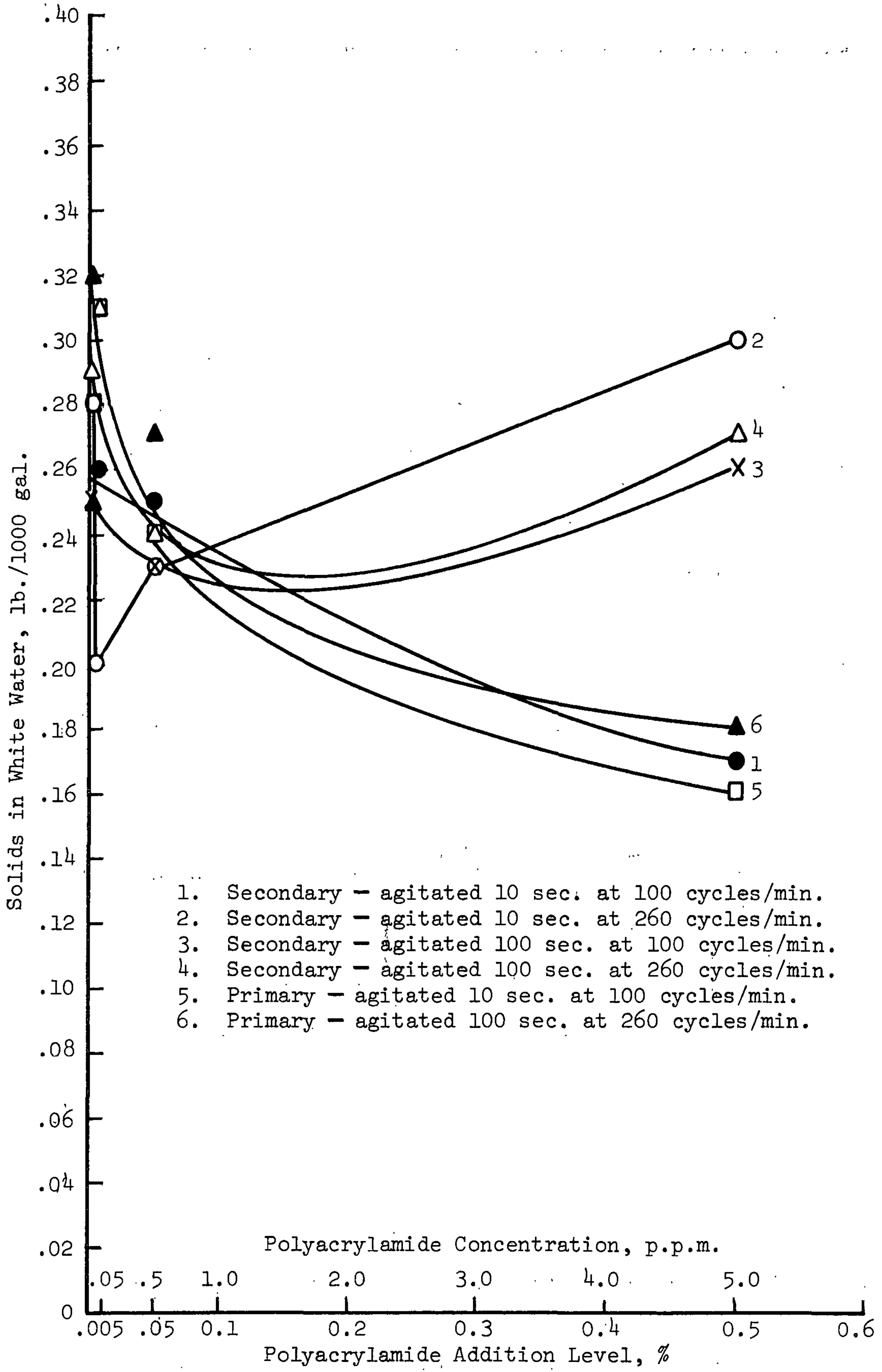

Figure 7. The Effect of Polyacrylamide Concentration on White Water Solids (Tap Water — pH 5.5 with Sulfuric Acid)

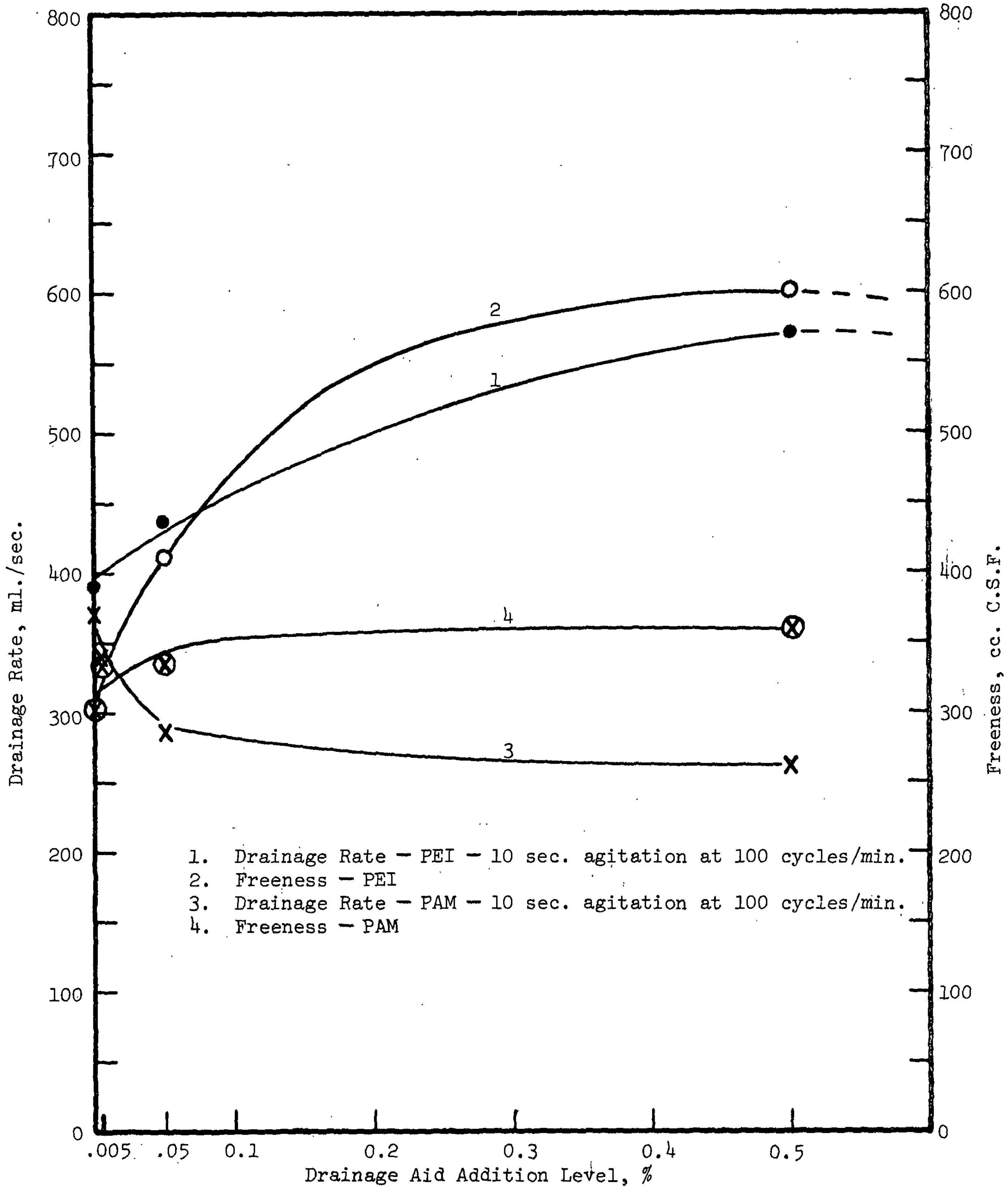

Figure 8. Drainage Rate and Freeness of Liner Secondary Pulp as a Function of Drainage Aid Addition Level (Tap Water — pH 5.5 with Sulfuric Acid)

Series Two

The sensitivity of the method shown in Series One was considered quite satisfactory and, hence, the decision was made to proceed to a second ionic environment, i.e., deionized water plus sufficient sulfuric acid to adjust the pH to 5.5. The amount of sulfuric acid required was equivalent to 3-4 p.p.m. The procedures followed in this series were identical to those utilized in Series One with the exception that drainage times were measured to the nearest 0.1 second. Temperature was again controlled to 25°C. Results are recorded in Tables IV-VI and are shown graphically in Fig. 9-15.

Series Three

The third series examined the effectiveness of PEI and PAM in deionized water plus alum at pH 5.5. This required 1.8% of alum based on fiber or a concentration of 18 p.p.m. (equivalent to 8 p.p.m. of $SO_4^=$). Results are recorded in Tables VII-IX and are presented graphically in Fig. 16-22. In addition to these tests, separate short-time drainage studies examined the effects of high alum concentration and rosin size under the agitation conditions which provided the best drainage in the current series, i.e., 10 seconds at 100 cycles/min. The alum concentration in the first set was increased to a level equivalent to that which would nominally exist at a practical forming consistency of 0.7%, i.e., seven times as concentrated as that existing at 0.1% fiber consistency. The resulting pH was 4.5. Drainage results are recorded in Table X and Fig. 23-25. Freeness data are given in Table XI. The second set utilized 0.5% of fortified rosin size and 1.8% of alum based on fiber weight. The rosin size was stirred into the 0.1% stock for five minutes followed by the alum and an additional five-minute stirring. The pH was finally adjusted to 5.5 through addition of approximately 1 p.p.m. of sulfuric acid. The drainage test and freeness results for this set are presented in Tables XII and XIII and in Fig. 26 and 27.

TABLE IV

THE EFFECT OF PEI ON THE DRAINAGE PROPERTIES OF LINER PULP
IN DEIONIZED WATER CONTAINING SULFURIC ACID (pH 5.5)

Set No.	Liner Stock	PEI Addition Level, %	PEI Concentration, p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Av. Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
						To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
49	Secondary	0.0	0.0	10	100	18.2	1	19.2	387	318	80	34.4	36.8	0.39
50	Secondary	0.05	0.5	10	100	14.9	1	15.9	467	175	45	33.4	36.1	0.12
51	Secondary	0.5	5.0	10	100	10.1	1	11.1	669	95	40	31.9	34.7	0.12
52	Secondary	2.0	20.0	10	100	13.3	1	14.3	520	170	48	32.3	34.7	0.11
53	Secondary	0.0	0.0	10	260	19.5	1	20.5	362	295	78	33.9	36.2	0.40
54	Secondary	0.05	0.5	10	260	19.1	1	20.1	370	295	65	34.4	34.0	0.17
55	Secondary	0.5	5.0	10	260	12.5	1	13.5	550	180	60	33.8	36.6	0.11
56	Secondary	2.0	20.0	10	260	15.8	1	16.8	442	235	65	32.5	34.7	0.13
57	Secondary	0.0	0.0	100	100	18.1	1	19.1	389	265	75	32.0	36.3	0.25
58	Secondary	0.05	0.5	100	100	20.0	1	21.0	354	265	73	33.7	36.8	0.13
59	Secondary	0.5	5.0	100	100	13.5	1	14.5	512	170	45	33.8	35.5	0.05
60	Secondary	2.0	20.0	100	100	18.0	1	19.0	391	235	55	34.2	35.9	0.07
61	Secondary	0.0	0.0	100	260	17.2	1	18.2	408	260	60	34.2	37.0	0.38
62	Secondary	0.05	0.5	100	260	17.5	1	18.5	400	275	60	33.3	37.3	0.24
63	Secondary	0.5	5.0	100	260	14.0	1	15.0	495	215	55	33.7	36.5	0.20
64	Secondary	2.0	20.0	100	260	17.5	1	18.5	400	265	63	34.5	36.8	0.15
65	Primary	0.0	0.0	10	100	7.6	<1	7.6	978	50	30	33.8	36.9	0.34
66	Primary	0.05	0.5	10	100	7.9	<1	7.9	941	40	30	32.5	36.0	0.09
67	Primary	0.5	5.0	10	100	7.9	<1	7.9	941	40	30	32.2	35.4	0.03
68	Primary	2.0	20.0	10	100	8.1	<1	8.1	917	45	30	32.7	34.9	0.06
69	Primary	0.0	0.0	100	260	7.9	<1	7.9	941	53	30	33.7	36.8	0.39
70	Primary	0.05	0.5	100	260	7.3	<1	7.3	1017	53	30	32.5	37.7	0.19
71	Primary	0.5	5.0	100	260	7.6	<1	7.6	978	55	30	32.3	36.6	0.09
72	Primary	2.0	20.0	100	260	7.9	<1	7.9	941	63	35	33.0	36.5	0.18

Note: 3-4 p.p.m. $SO_4^=$ added.

TABLE V

THE EFFECT OF POLYACRYLAMIDE ON THE DRAINAGE PROPERTIES OF LINER PULP IN DEIONIZED WATER CONTAINING SULFURIC ACID (pH 5.5)

Set No.	Liner Stock	Polyacrylamide Addition Level, %	Polyacrylamide Concentration, p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Av. Drainage Time, sec. To Start of Vacuum Drop	Av. Drainage Time, sec. From Start of Vacuum Drop to Stable Vacuum	Av. Drainage Time, sec. Total	Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., % 3 min.	Solids in Web After Wet Pressing at 50 p.s.i., % 6 min.	Solids in White Water, lb./1000 gal.
73	Secondary	0.0	0.0	10	100	18.2	1	19.2	387	350	80	34.2	36.4	0.33
74	Secondary	0.005	0.05	10	100	18.3	1	19.3	385	345	78	34.1	36.1	0.36
75	Secondary	0.05	0.5	10	100	20.4	1	21.4	347	357	83	34.2	36.3	0.40
76	Secondary	0.5	5.0	10	100	24.4	1	25.4	293	390	85	33.1	36.0	0.32
77	Secondary	0.0	0.0	10	260	18.3	1	19.3	385	345	80	35.0	36.9	0.35
78	Secondary	0.005	0.05	10	260	18.2	1	19.2	387	327	78	33.7	35.3	0.35
79	Secondary	0.05	0.5	10	260	18.3	1	19.3	385	330	75	34.1	36.3	0.36
80	Secondary	0.5	5.0	10	260	22.7	1	23.7	314	385	83	34.8	35.0	0.38
81	Secondary	0.0	0.0	100	100	17.2	1	18.2	408	330	75	34.4	36.4	0.30
82	Secondary	0.005	0.05	100	100	16.5	1	17.5	425	310	75	33.8	35.7	0.32
83	Secondary	0.05	0.5	100	100	18.2	1	19.2	387	325	75	33.9	36.3	0.31
84	Secondary	0.5	5.0	100	100	21.0	1	22.0	338	350	80	34.2	36.1	0.27
85	Secondary	0.0	0.0	100	260	16.5	1	17.5	425	295	68	34.2	36.7	0.38
86	Secondary	0.005	0.05	100	260	16.4	1	17.4	427	280	68	34.8	35.7	0.38
87	Secondary	0.05	0.5	100	260	16.8	1	17.8	417	270	68	33.7	36.2	0.41
88	Secondary	0.5	5.0	100	260	16.4	1	17.4	427	300	65	33.7	36.1	0.39
89	Primary	0.0	0.0	10	100	7.6	<1	7.6	978	50	30	33.5	37.2	0.39
90	Primary	0.005	0.05	10	100	8.1	<1	8.1	917	50	30	33.8	36.5	0.38
91	Primary	0.05	0.5	10	100	8.0	<1	8.0	929	70	30	33.7	37.2	0.36
92	Primary	0.5	5.0	10	100	10.3	<1	10.3	721	100	30	33.7	37.4	0.40
93	Primary	0.0	0.0	100	260	7.6	<1	7.6	978	55	30	33.9	37.2	0.45
94	Primary	0.005	0.05	100	260	7.6	<1	7.6	978	50	30	34.1	37.0	0.40
95	Primary	0.05	0.5	100	260	7.4	<1	7.4	1000	45	30	33.4	37.0	0.40
96	Primary	0.5	5.0	100	260	8.5	<1	8.5	874	60	35	33.7	36.9	0.43

Note: 3-4 p.p.m. of $SO_4^=$ added.

TABLE VI

THE FREENESS OF LINER STOCKS AT pH 5.5 IN DEIONIZED WATER CONTAINING SULFURIC ACID

Liner Stock	Drainage Aid	Addition Level, %	Canadian Freeness, cc.
Secondary	None	--	190
	PEI	0.05	560
	PEI	0.5	730
	PEI	2.0	670
	PAM	0.005	220
	PAM	0.05	275
	PAM	0.5	320
Primary	None	--	670
	PEI	0.05	720
	PEI	0.5	745
	PEI	2.0	720
	PAM	0.005	670
	PAM	0.05	680
	PAM	0.5	630

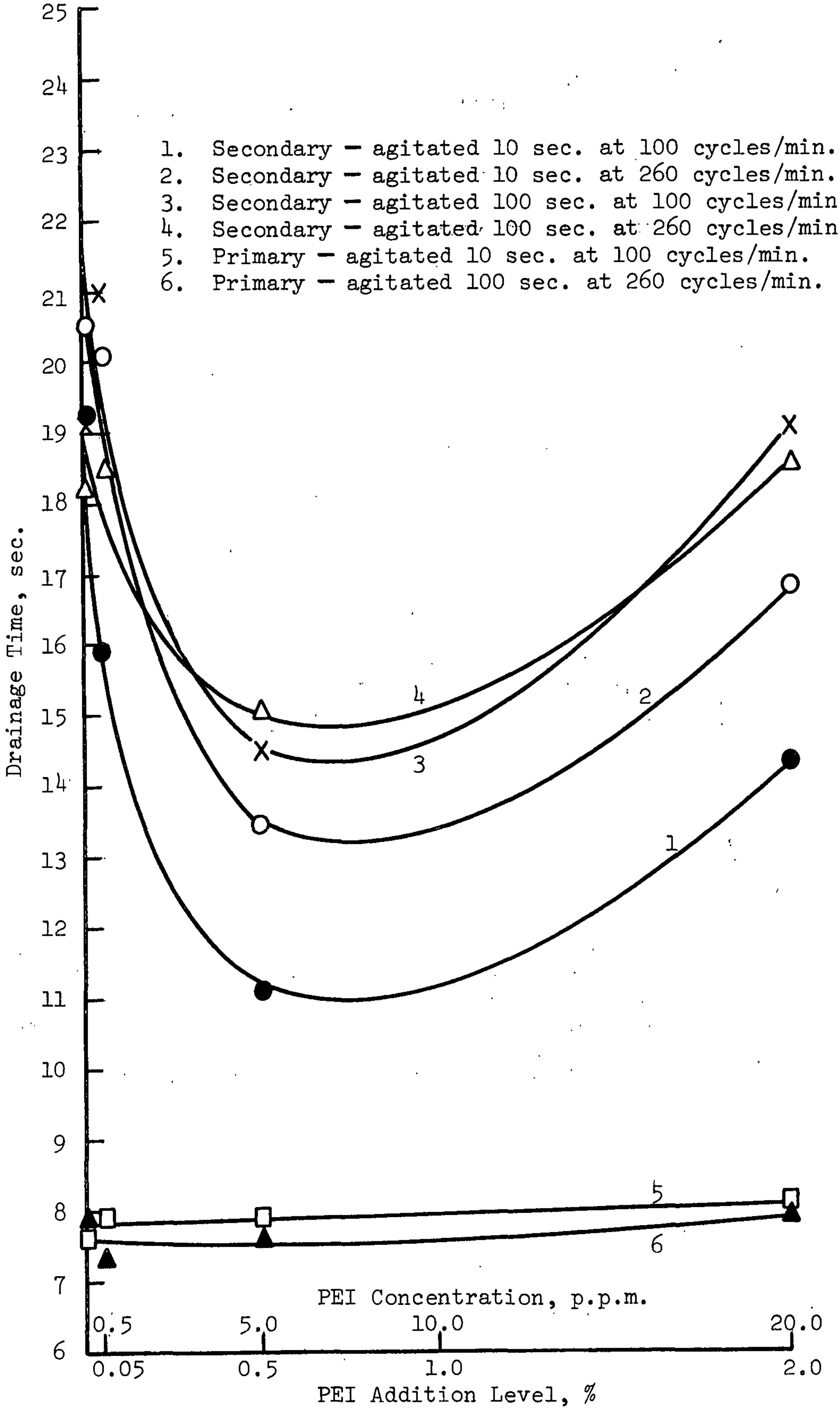

Figure 9. The Effect of PEI Concentration on Drainage Time (Deionized Water — pH 5.5 with Sulfuric Acid)

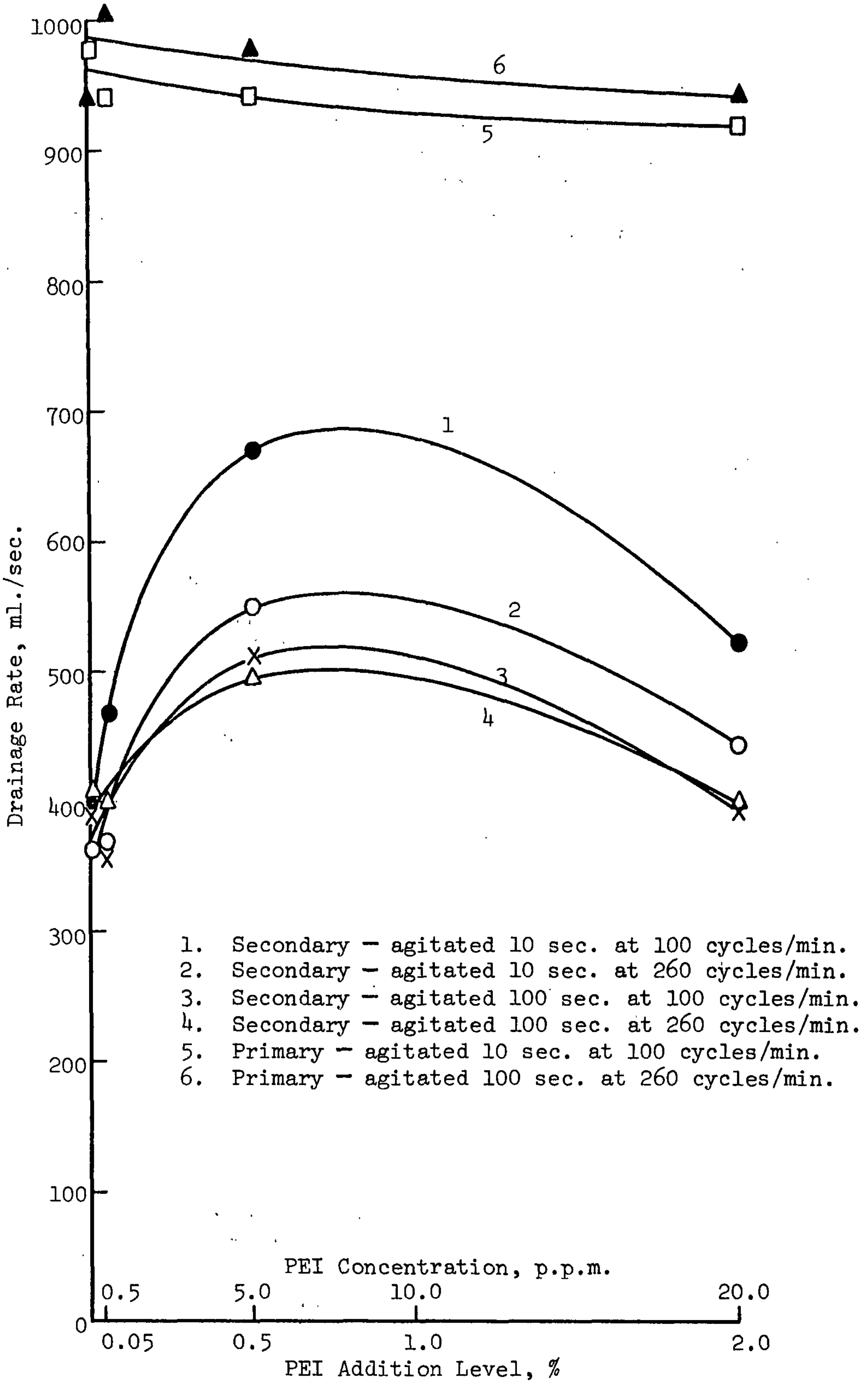

Figure 10. The Effect of PEI Concentration on Drainage Rate (Deionized Water — pH 5.5 with Sulfuric Acid)

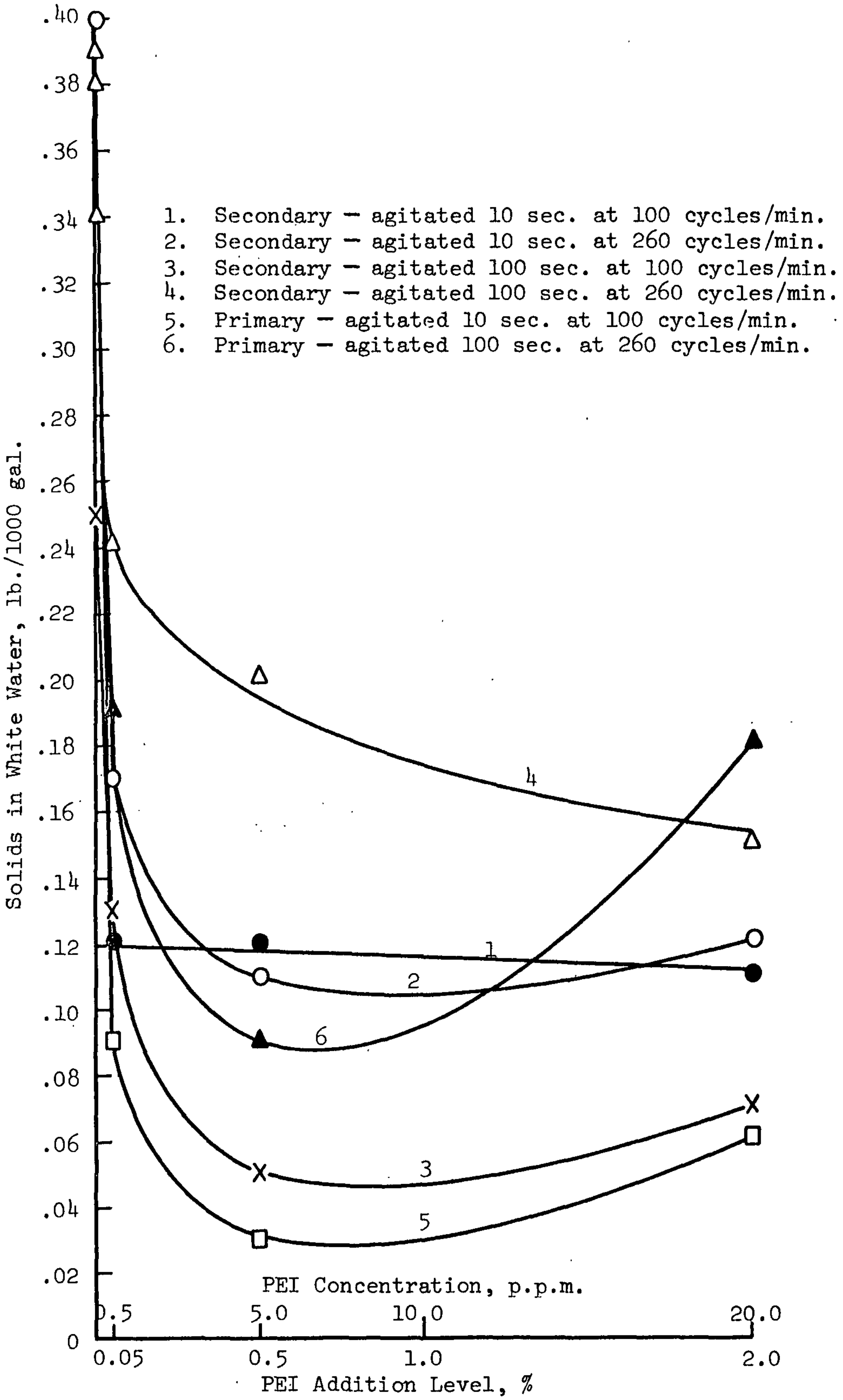

Figure 11. The Effect of Polyethylenimine Concentration on White Water Solids (Deionized Water – pH 5.5 with Sulfuric Acid)

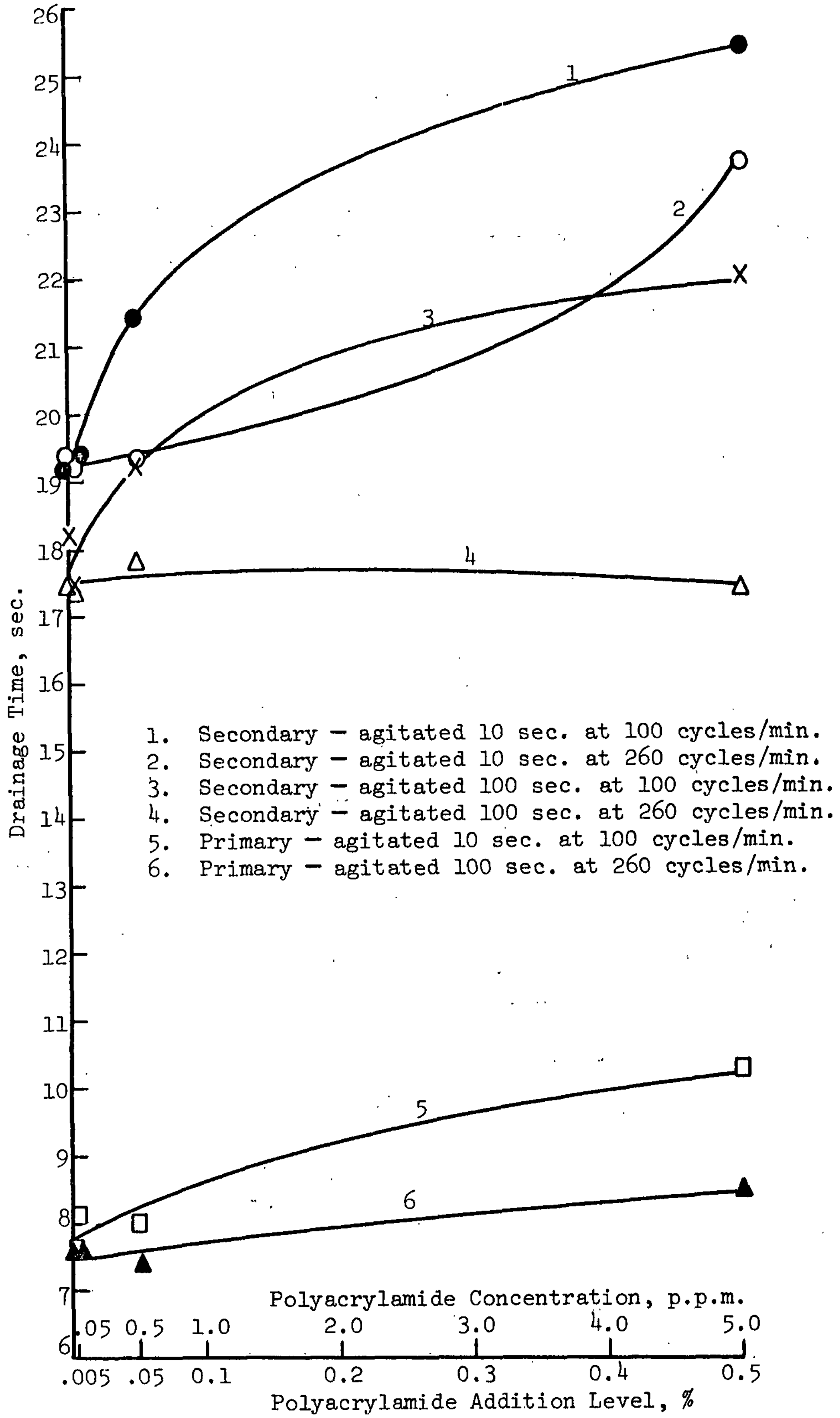

Figure 12. The Effect of Polyacrylamide Concentration on Drainage Time (Deionized Water — pH 5.5 with Sulfuric Acid)

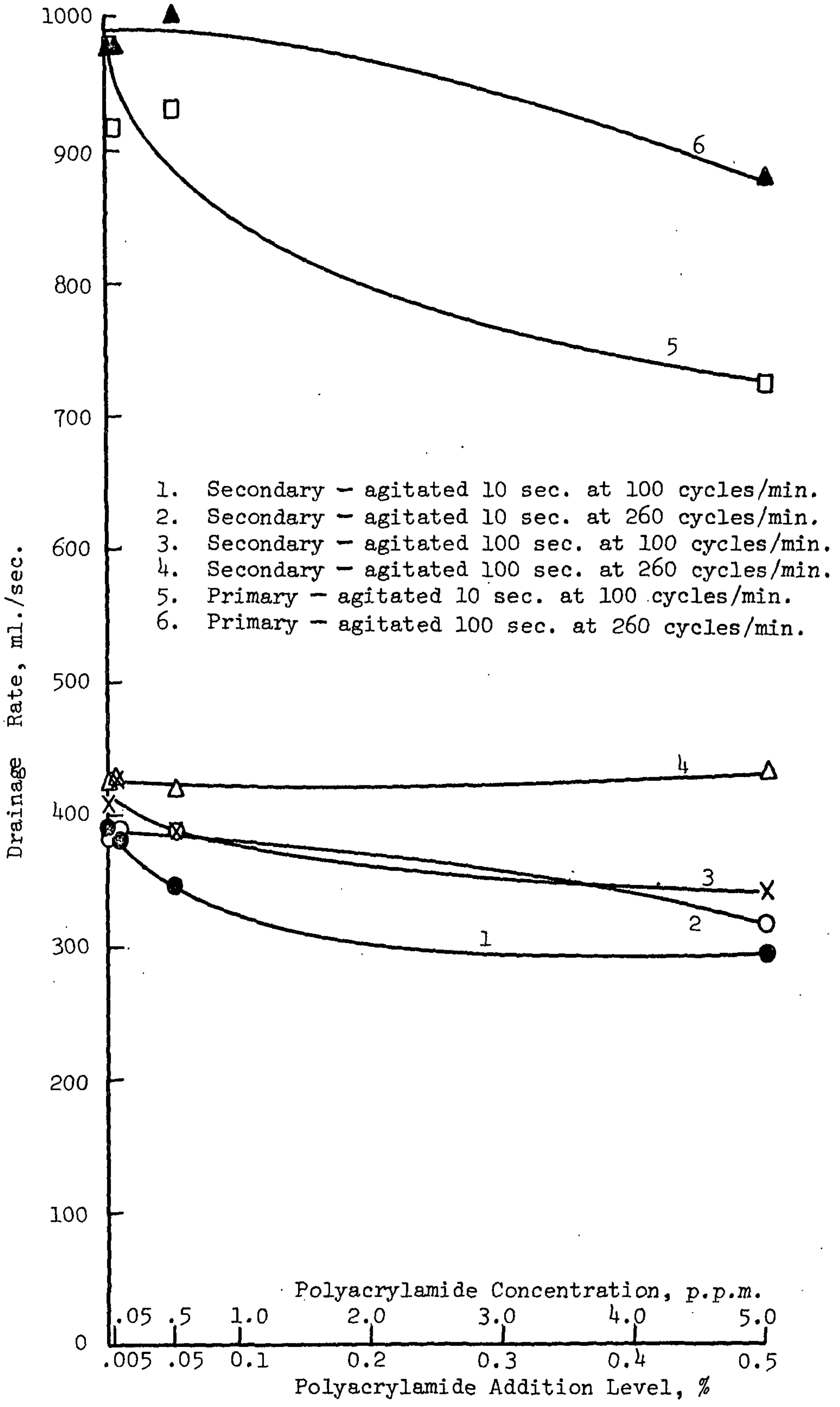

Figure 13. The Effect of Polyacrylamide Concentration on Drainage Rate (Deionized Water — pH 5.5 with Sulfuric Acid)

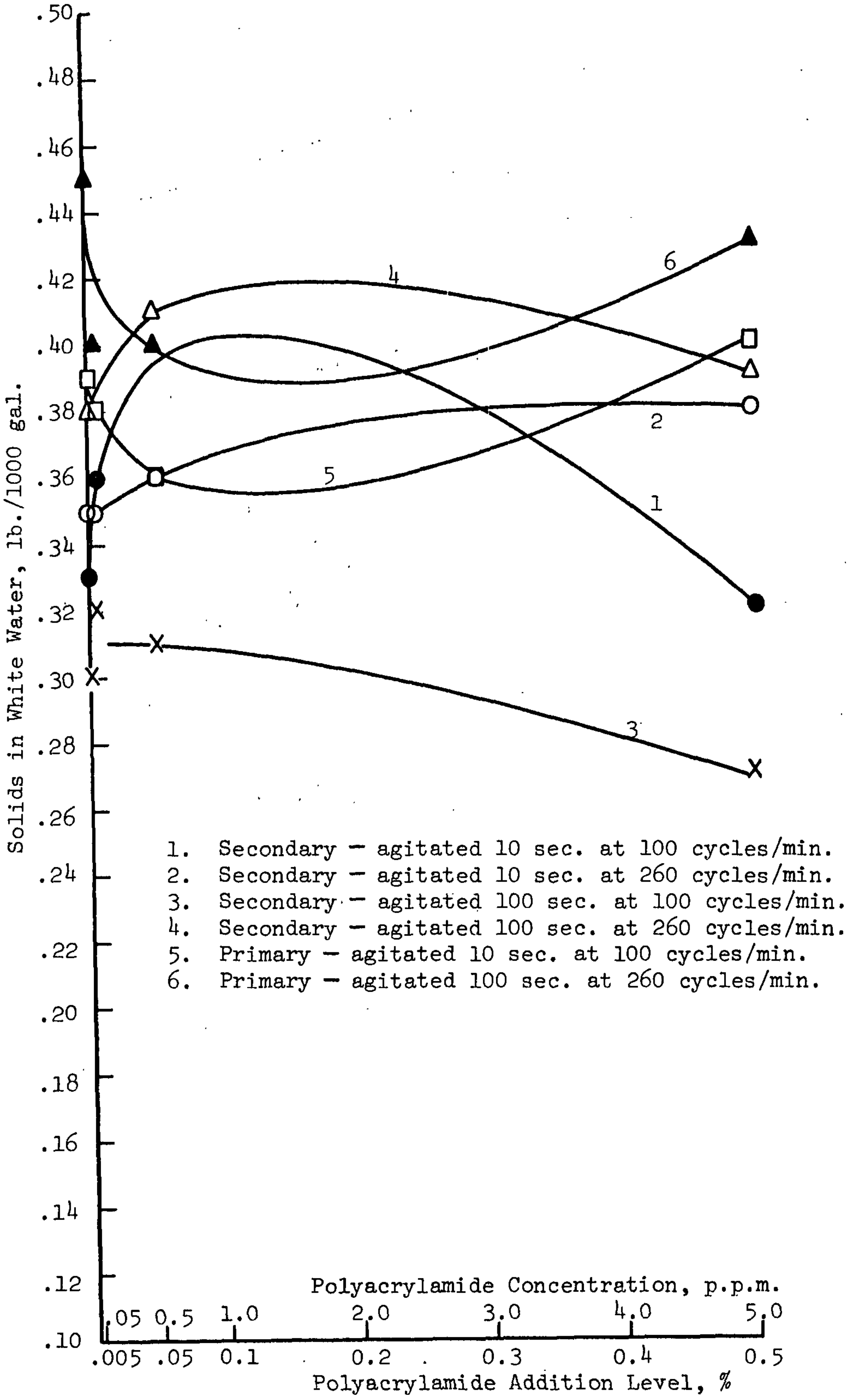

Figure 14. The Effect of Polyacrylamide Concentration on White Water Solids (Deionized Water – pH 5.5 with Sulfuric Acid)

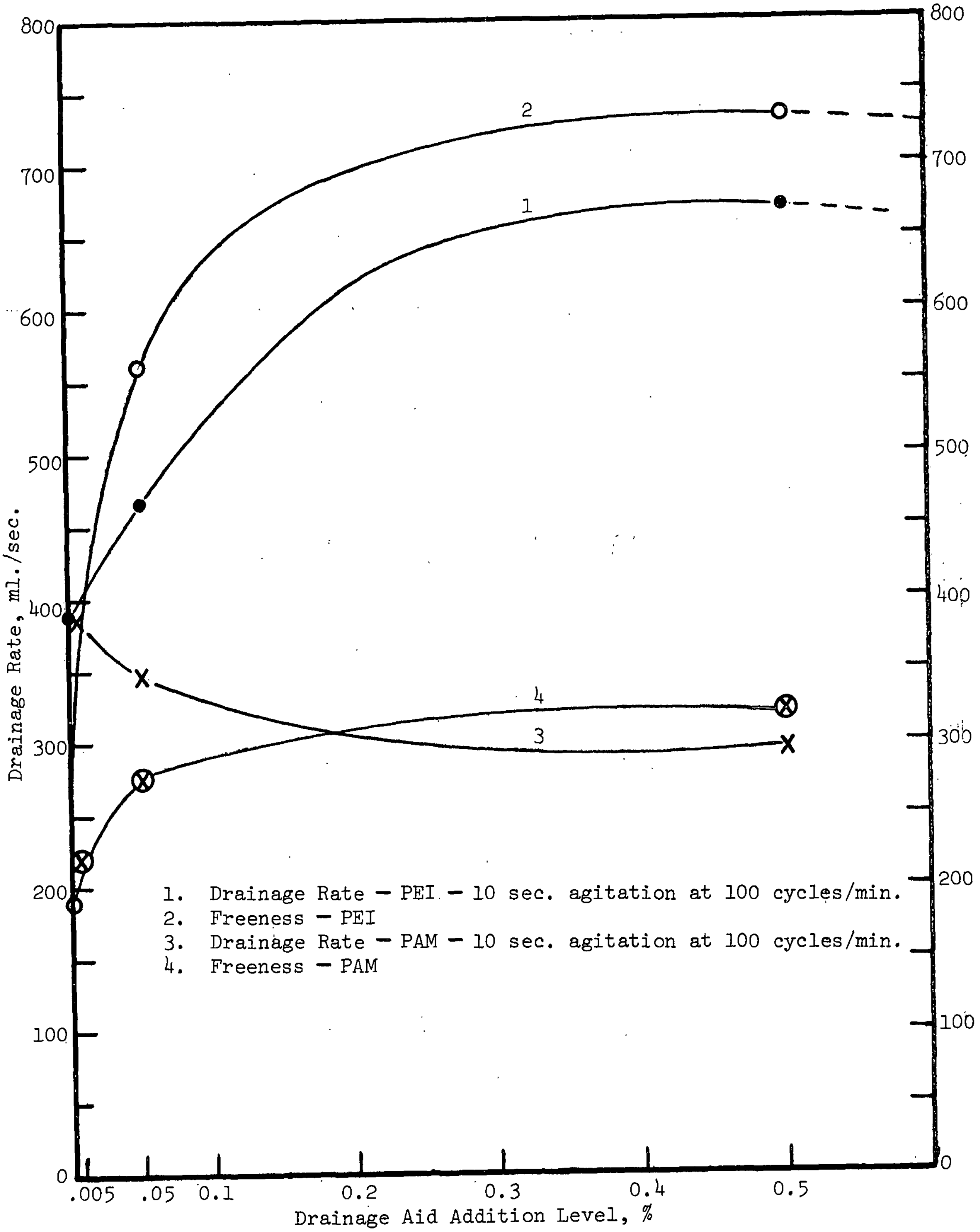

Figure 15. Drainage Rate and Freeness as a Function of Drainage Aid Addition Level (Deionized Water — pH 5.5 with Sulfuric Acid)

TABLE VII

THE EFFECT OF PEI ON THE DRAINAGE PROPERTIES OF LINER PULP IN DEIONIZED WATER CONTAINING ALUM (pH 5.5)

Set No.	Liner Stock	PEI Addition Level, %	PEI Concn., p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Average Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
						To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
97	Secondary	0.0	0.0	10	100	20.7	1	21.7	342	400	90	34.2	37.1	0.26
98	"	0.05	0.5	10	100	14.8	1	15.8	470	255	60	31.9	35.6	0.10
99	"	0.5	5.0	10	100	11.8	1	12.8	580	185	55	32.2	34.7	0.09
100	"	2.0	20.0	10	100	12.7	1	13.7	542	195	55	32.5	34.6	0.12
101	"	0.0	0.0	10	260	18.1	1	19.1	389	385	80	33.7	36.3	0.25
102	"	0.05	0.5	10	260	15.4	1	16.4	453	300	63	33.6	35.5	0.10
103	"	0.5	5.0	10	260	14.1	1	15.1	492	250	58	33.6	35.4	0.12
104	"	2.0	20.0	10	260	14.6	1	15.6	476	255	60	33.5	34.9	0.08
105	"	0.0	0.0	100	100	19.3	1	20.3	366	355	80	34.0	36.5	0.30
106	"	0.05	0.5	100	100	15.6	1	16.6	448	295	63	33.2	37.1	0.18
107	"	0.5	5.0	100	100	14.9	1	15.9	467	250	65	34.3	35.9	0.21
108	"	2.0	20.0	100	100	17.0	1	18.0	413	285	65	34.7	36.1	0.23
109	"	0.0	0.0	100	260	16.9	1	17.9	415	315	75	33.7	36.4	0.37
110	"	0.05	0.5	100	260	16.4	1	17.4	427	285	70	33.8	36.8	0.32
111	"	0.5	5.0	100	260	15.6	1	16.6	448	275	68	34.6	36.8	0.25
112	"	2.0	20.0	100	260	18.0	1	19.0	391	295	73	34.7	36.4	0.34
113	Primary	0.0	0.0	10	100	8.5	<1	8.5	874	70	38	33.1	36.6	0.14
114	"	0.05	0.5	10	100	8.2	<1	8.2	906	53	35	32.7	35.5	0.05
115	"	0.5	5.0	10	100	8.0	<1	8.0	929	40	30	32.6	34.5	0.05
116	"	2.0	20.0	10	100	8.3	<1	8.3	895	43	30	32.3	34.7	0.07
117	"	0.0	0.0	100	260	7.4	<1	7.4	1004	55	33	33.5	36.8	0.31
118	"	0.05	0.5	100	260	7.7	<1	7.7	965	53	33	32.8	36.0	0.17
119	"	0.5	5.0	100	260	8.2	<1	8.2	906	55	35	33.3	35.6	0.20
120	"	2.0	20.0	100	260	8.2	<1	8.2	906	53	33	33.4	35.6	0.29

Note: Approximately 18 p.p.m. of alum added equivalent to 8 p.p.m. of $SO_4^=$.

TABLE VIII

THE EFFECT OF POLYACRYLAMIDE ON THE DRAINAGE PROPERTIES OF LINER PULP IN DEIONIZED WATER CONTAINING ALUM (pH 5.5)

Set No.	Liner Stock	PAM Addition Level, %	PAM Concn., p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Average Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
						To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
121	Secondary	0.0	0.0	10	100	20.3	1	21.3	349	380	83	34.8	36.8	0.21
122	"	0.05	0.5	10	100	17.0	1	18.0	413	310	53	32.1	34.2	0.06
123	"	0.5	5.0	10	100	16.4	1	17.4	427	285	65	30.0	32.4	0.09
124	"	2.0	20.0	10	100	22.3	1	23.3	319	375	85	30.8	33.5	0.28
125	"	0.0	0.0	10	260	21.2	1	22.2	335	310	80	33.9	36.6	0.23
126	"	0.05	0.5	10	260	20.8	1	21.8	341	307	63	32.4	34.3	0.21
127	"	0.5	5.0	10	260	17.5	1	18.5	402	285	65	30.3	33.1	0.14
128	"	2.0	20.0	10	260	24.1	1	25.1	296	358	70	30.0	33.3	0.24
129	"	0.0	0.0	100	100	19.5	1	20.5	362	365	80	32.6	36.6	0.26
130	"	0.05	0.5	100	100	20.0	1	21.0	354	370	75	34.0	35.4	0.16
131	"	0.5	5.0	100	100	21.9	1	22.9	324	393	70	31.5	33.7	0.08
132	"	2.0	20.0	100	100	19.5	1	20.5	362	330	58	30.2	33.2	0.03
133	"	0.0	0.0	100	260	17.4	1	18.4	404	345	75	33.6	36.2	0.33
134	"	0.05	0.5	100	260	17.1	1	18.1	410	310	70	34.2	35.3	0.21
135	"	0.5	5.0	100	260	27.7	1	28.7	259	445	85	32.4	35.0	0.16
136	"	2.0	20.0	100	260	29.5	1	30.5	244	440	75	30.8	33.0	0.04
137	Primary	0.0	0.0	10	100	8.6	<1	8.6	864	63	33	33.3	37.0	0.19
138	"	0.05	0.5	10	100	8.5	<1	8.5	874	55	30	32.2	35.4	0.07
139	"	0.5	5.0	10	100	9.0	<1	9.0	826	60	33	32.7	34.6	0.01
140	"	2.0	20.0	10	100	11.0	<1	11.0	675	120	35	31.6	34.3	0.04
141	"	0.0	0.0	100	260	8.1	<1	8.1	917	55	38	33.9	36.9	0.30
142	"	0.05	0.5	100	260	8.1	<1	8.1	917	55	35	33.3	36.0	0.18
143	"	0.5	5.0	100	260	9.0	<1	9.0	826	85	35	34.0	37.8	0.18
144	"	2.0	20.0	100	260	12.3	<1	12.3	604	170	35	33.2	33.7	0.04

Note: Approximately 18 p.p.m. of alum added equivalent to 8 p.p.m. of $SO_4^{=}$.

TABLE IX

THE FREENESS OF LINER STOCK AT pH 5.5 IN DEIONIZED WATER CONTAINING ALUM

Liner Stock	Drainage Aid	Addition Level, %	Canadian Freeness, cc.
Secondary	None	--	390
	PEI	0.05	510
	PEI	0.5	580
	PEI	2.0	545
	PAM	0.05	545
	PAM	0.5	650
	PAM	2.0	590
Primary	None	--	685
	PEI	0.05	695
	PEI	0.5	695
	PEI	2.0	675
	PAM	0.05	735
	PAM	0.5	735
	PAM	2.0	710

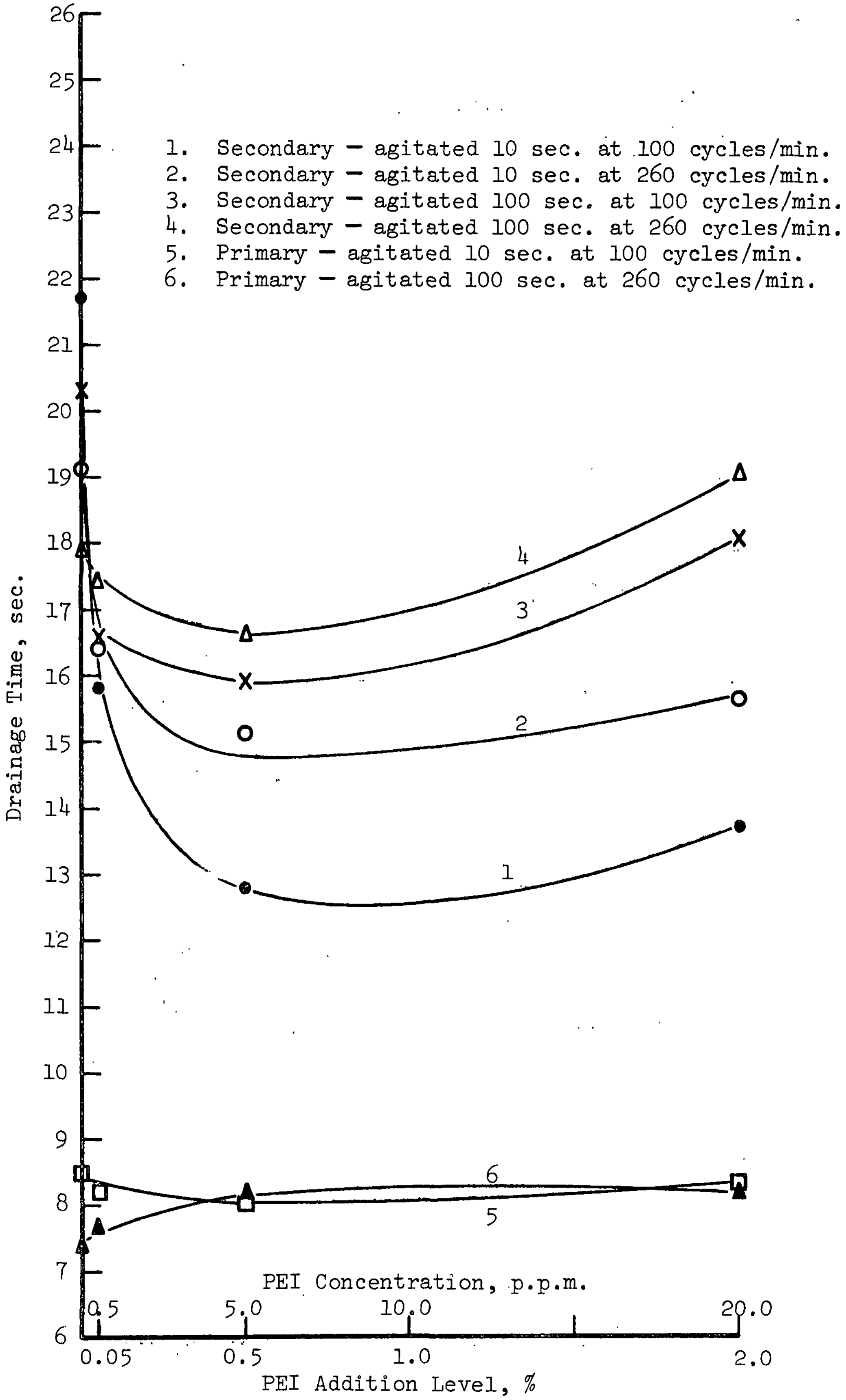

Figure 16. The Effect of PEI Concentration on Drainage Time (Deionized Water — pH 5.5 with Alum)

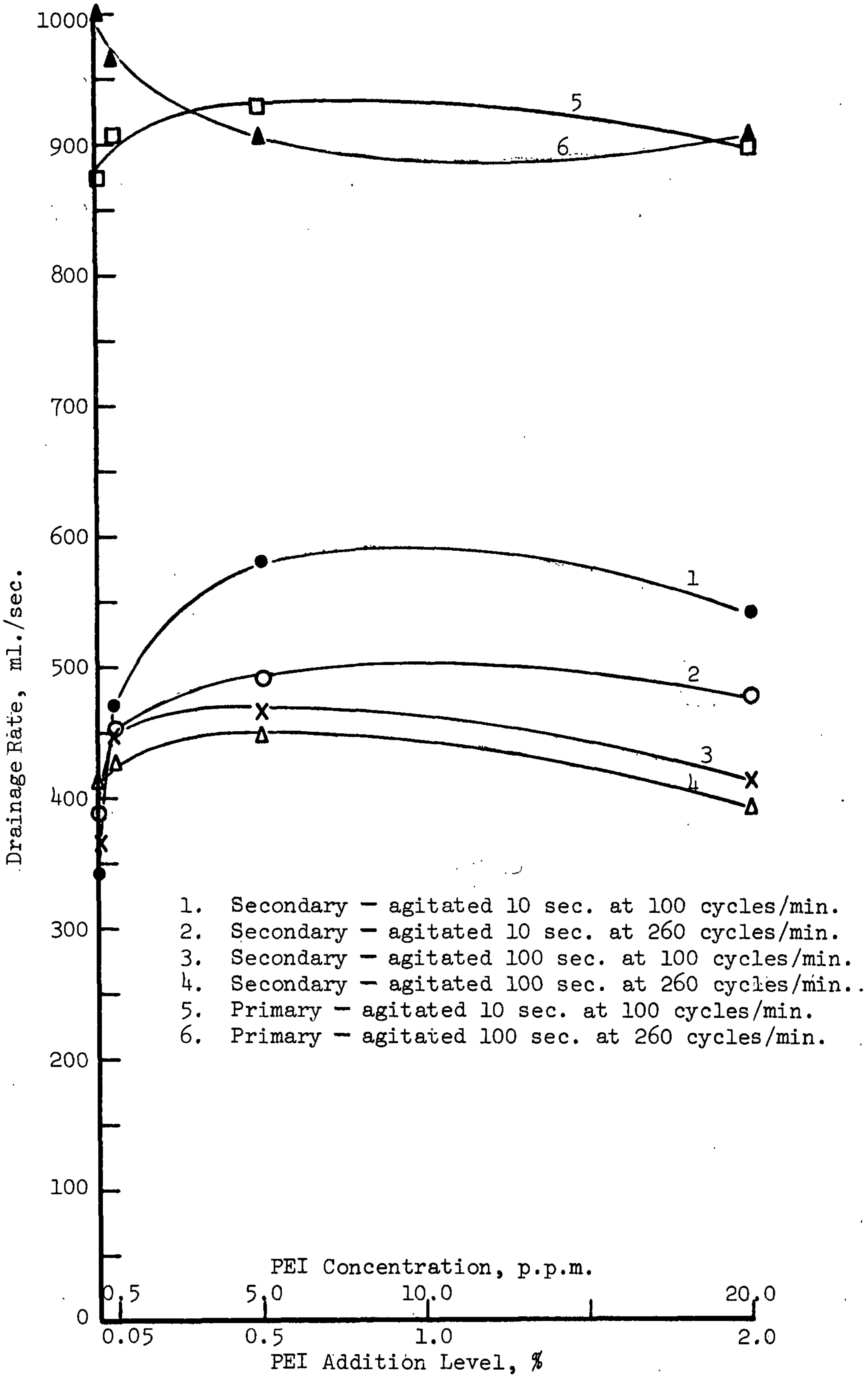

Figure 17. The Effect of PEI Concentration on Drainage Rate (Deionized Water — pH 5.5 with Alum)

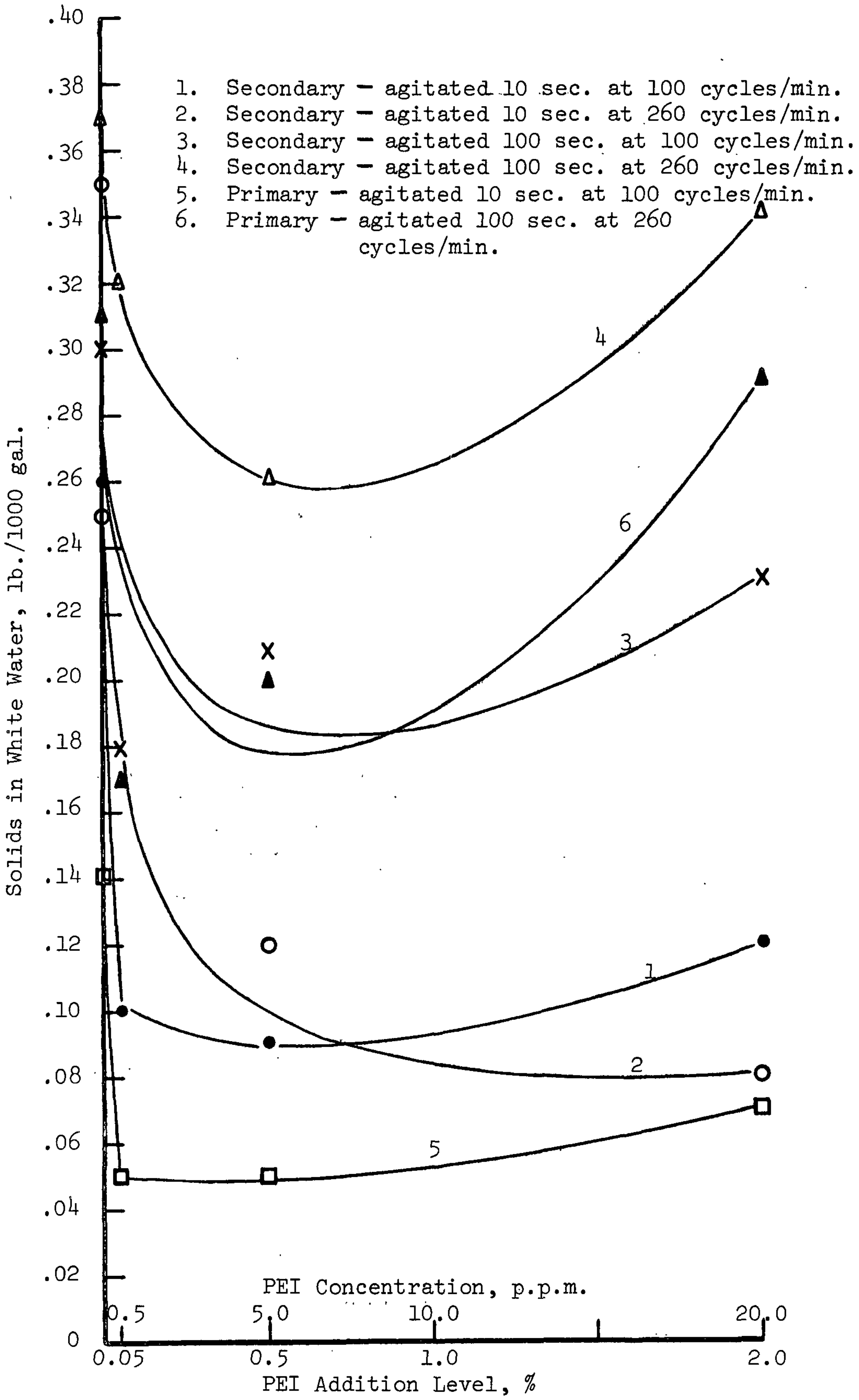

Figure 18. The Effect of PEI Concentration on White Water Solids (Deionized Water — pH 5.5 with Alum)

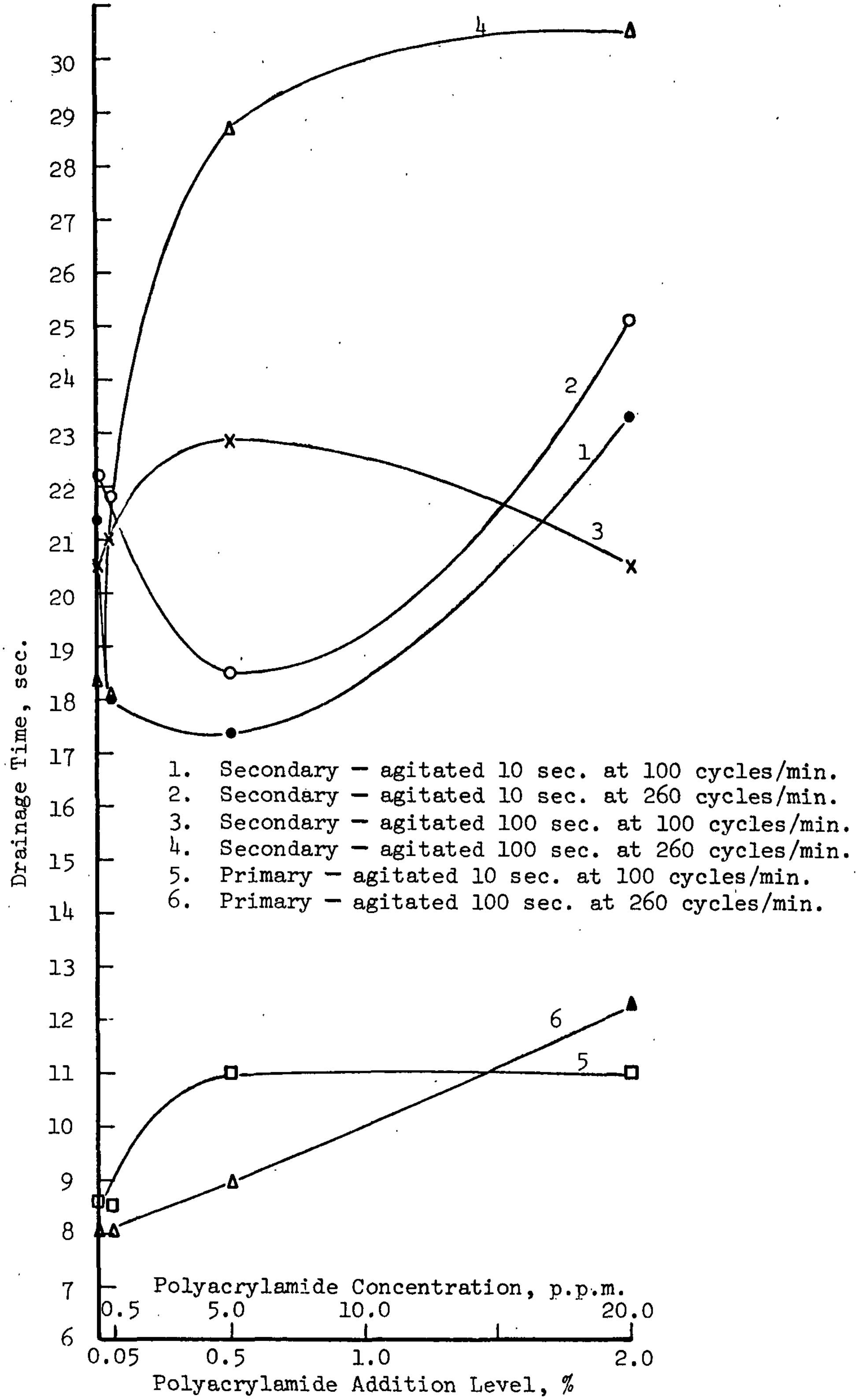

Figure 19. The Effect of Polyacrylamide Concentration on Drainage Time (Deionized Water — pH 5.5 with Alum)

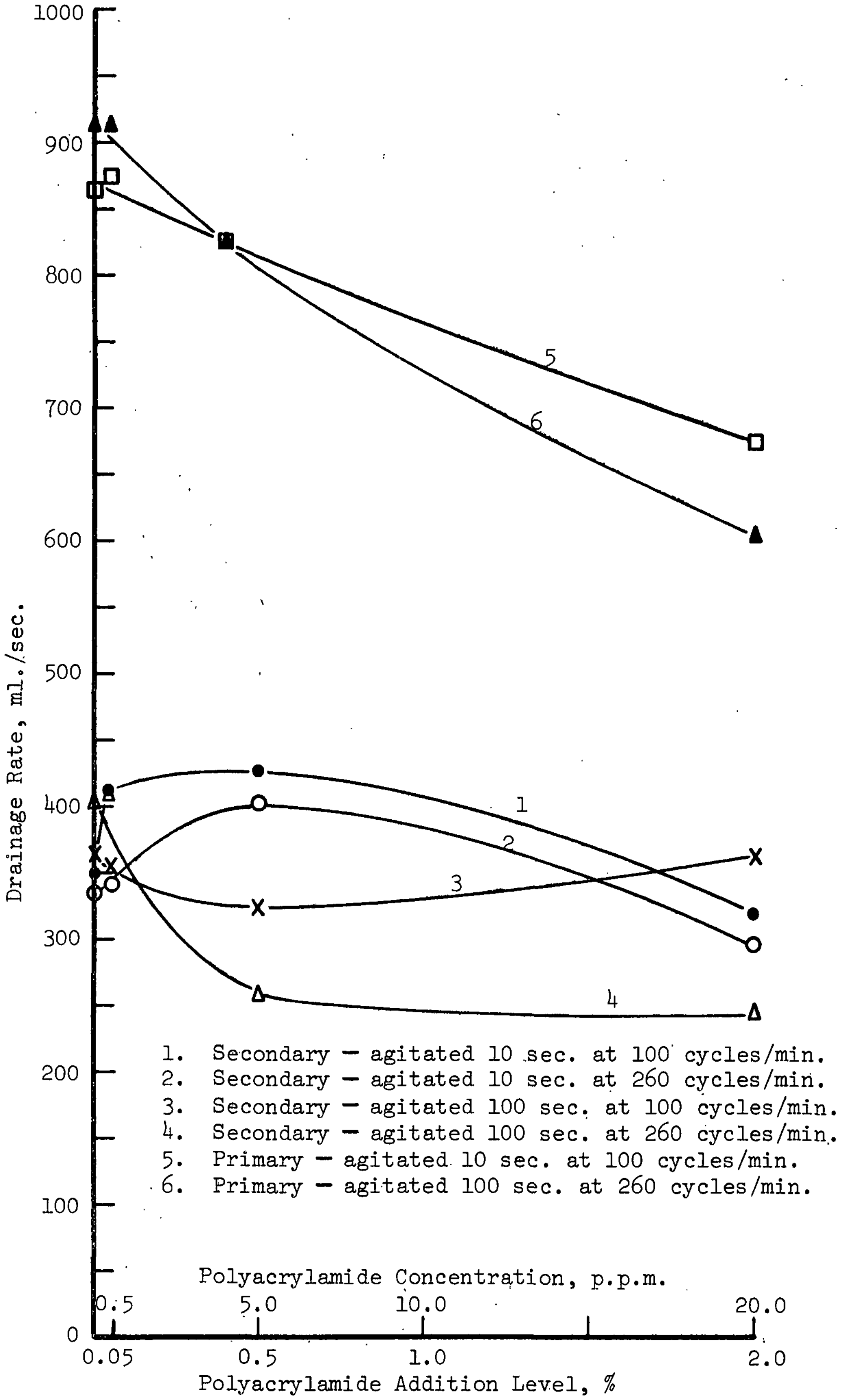

Figure 20. The Effect of Polyacrylamide Concentration on Drainage Rate (Deionized Water — pH 5.5 with Alum)

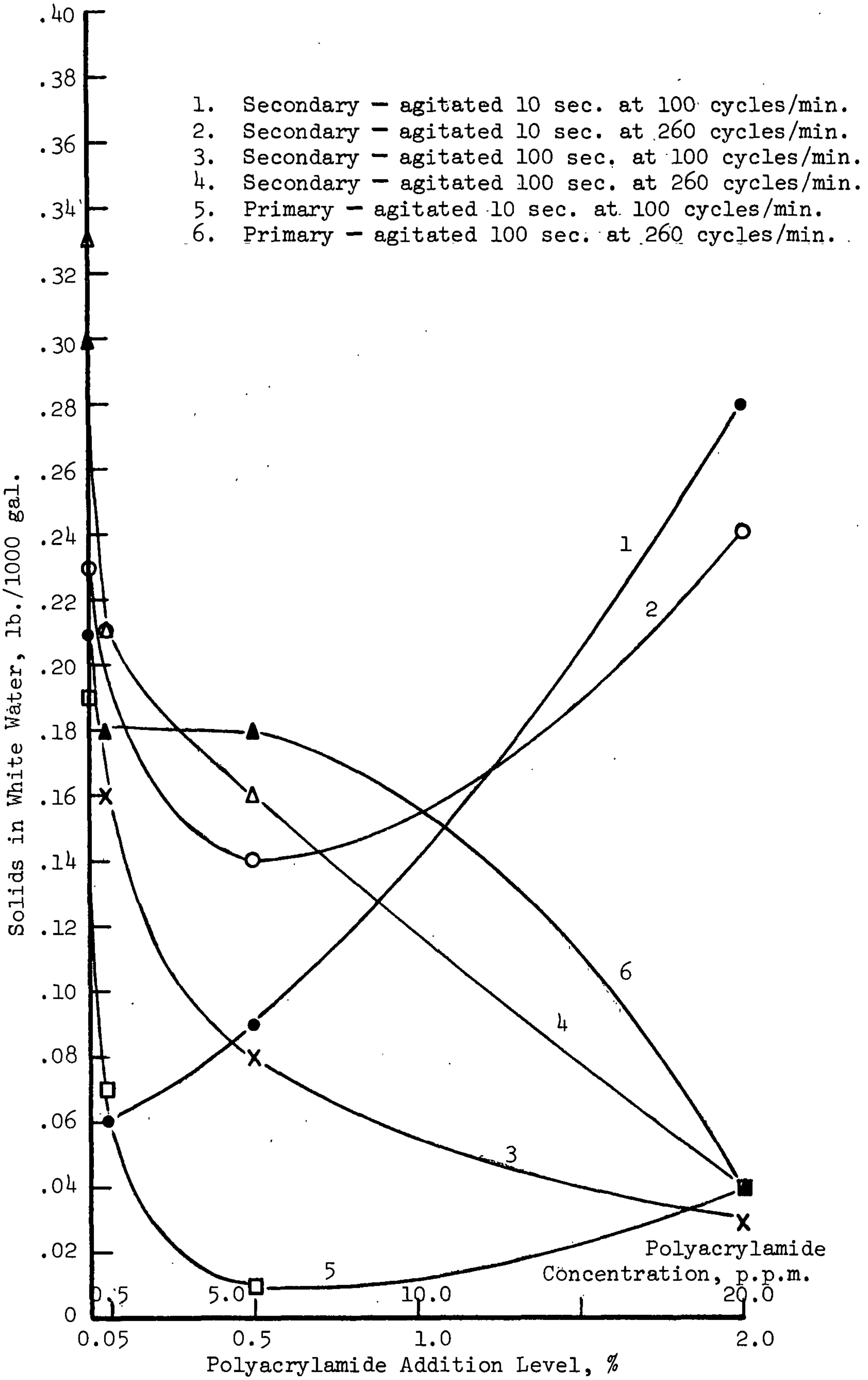

Figure 21. The Effect of Polyacrylamide Concentration on White Water Solids (Deionized Water — pH 5.5 with Alum)

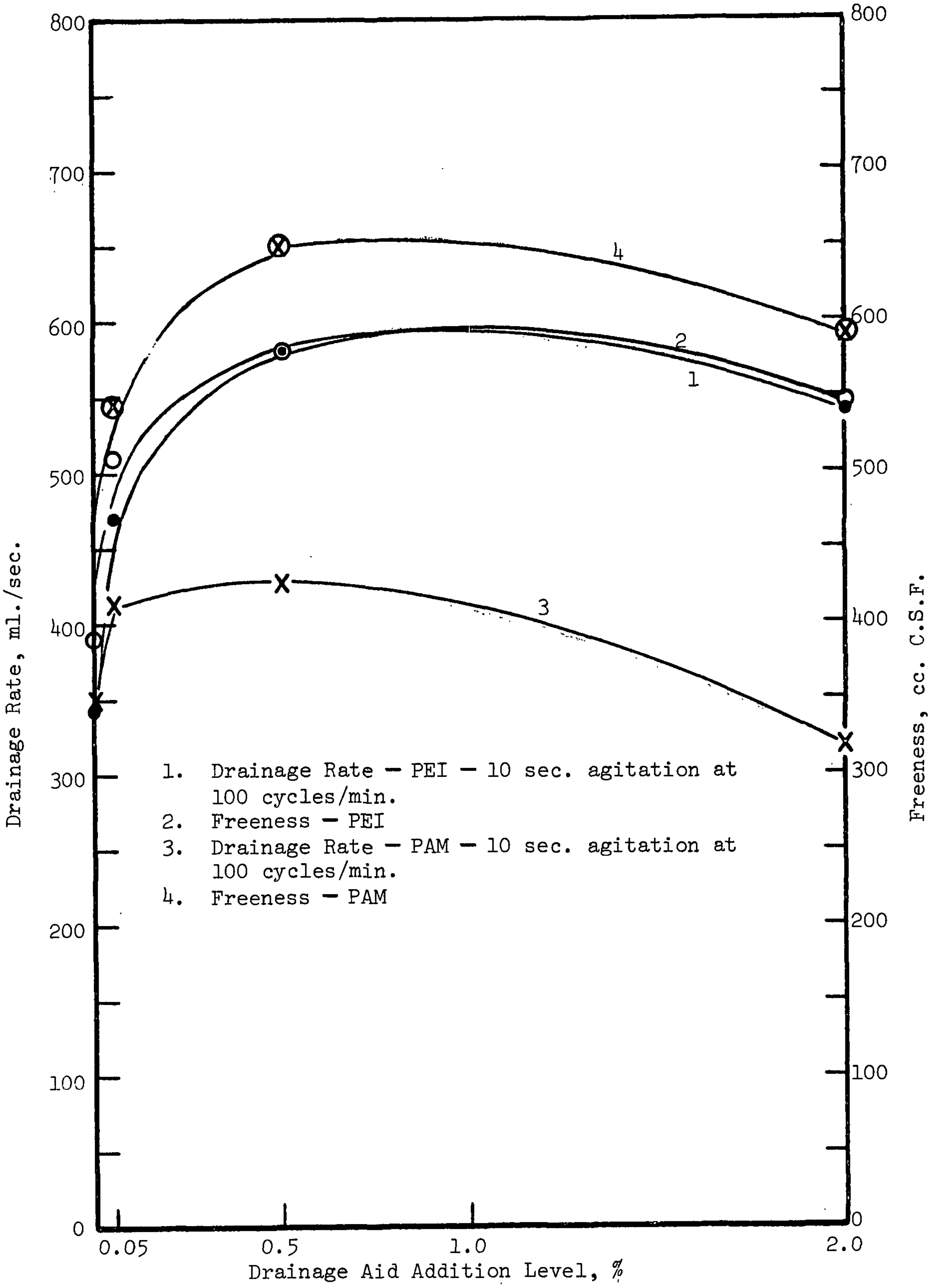

Figure 22. Drainage Rate and Freeness as a Function of Drainage Aid Addition Level (Deionized Water — pH 5.5 with Alum)

TABLE X

THE EFFECT OF HIGH ALUM CONTENT[a] ON THE PERFORMANCE OF PEI AND PAM DRAINAGE AIDS (SECONDARY LINER PULP – DEIONIZED WATER – pH 4.5)

Set No.	Drainage Aid Addition Level, %	Drainage Aid Concn., p.p.m.	Stirring Time, sec.	Stirring Rate cycles/min.	Average Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Level Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
					To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
145	None	--	10	100	19.5	1	20.5	362	405	80	34.3	36.6	0.29
146	PEI, 0.05	0.5	10	100	19.5	1	20.5	362	365	78	33.4	36.0	0.25
147	PEI, 0.5	5.0	10	100	18.3	1	19.3	385	305	65	34.0	35.4	0.27
148	PAM, 0.005	0.05	10	100	21.4	1	22.4	332	395	78	34.7	36.1	0.13
149	PAM, 0.05	0.5	10	100	28.9	2	30.9	240	440	78	35.1	32.2	0.09
150	PAM, 0.5	5.0	10	100	29.8	2	31.8	234	440	75	32.9	29.9	0.07

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[a] The alum concentration for these tests was equivalent to that which would nominally exist at 0.7% fiber consistency if added at 1.8% based on fiber, i.e., seven times as concentrated as that used in the previous set of tests. Hence, the alum concn. was 126 p.p.m. or 56 p.p.m. of $SO_4^=$.

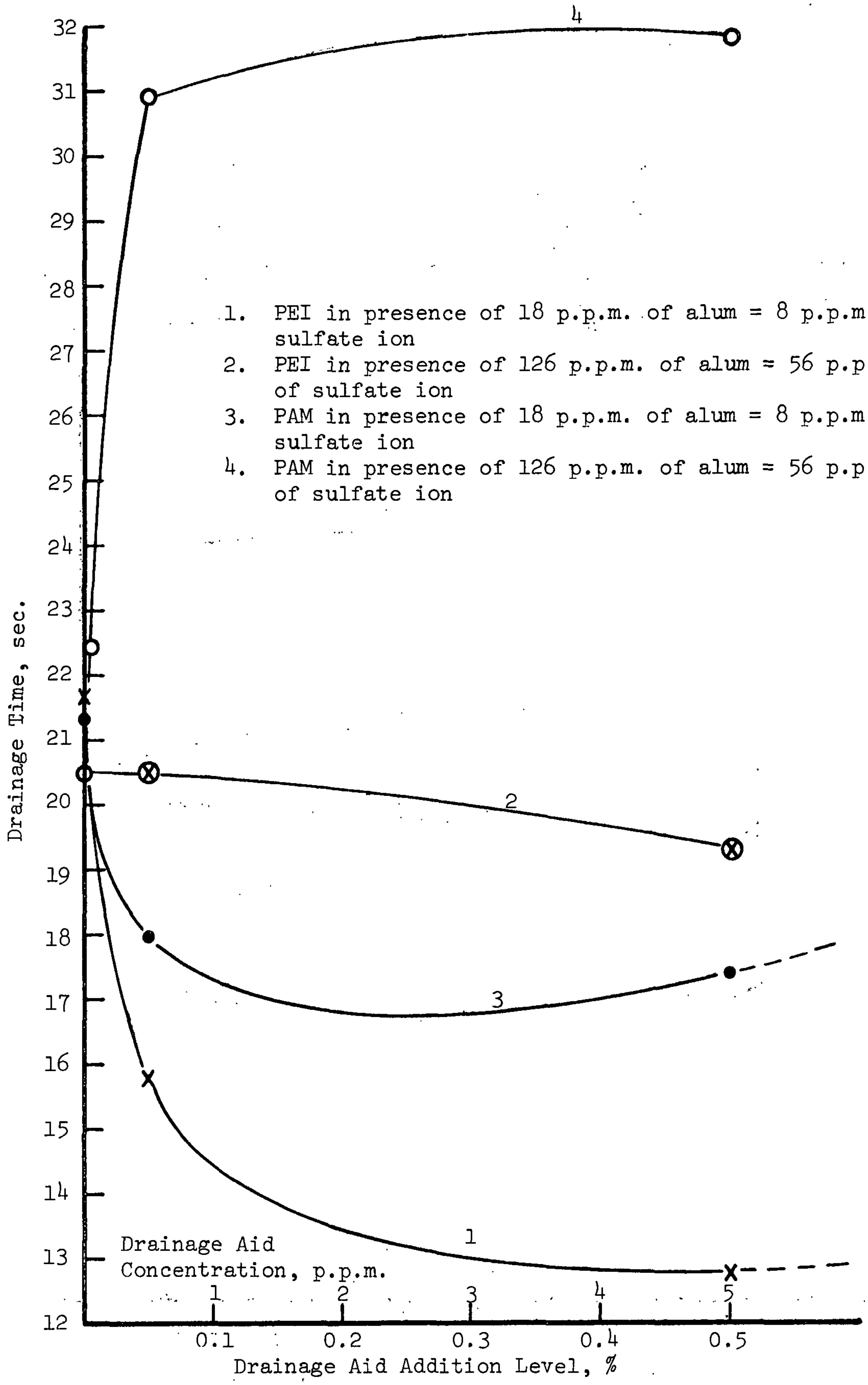

Figure 23. The Effect of Alum Content on Drainage Time (Deionized Water)

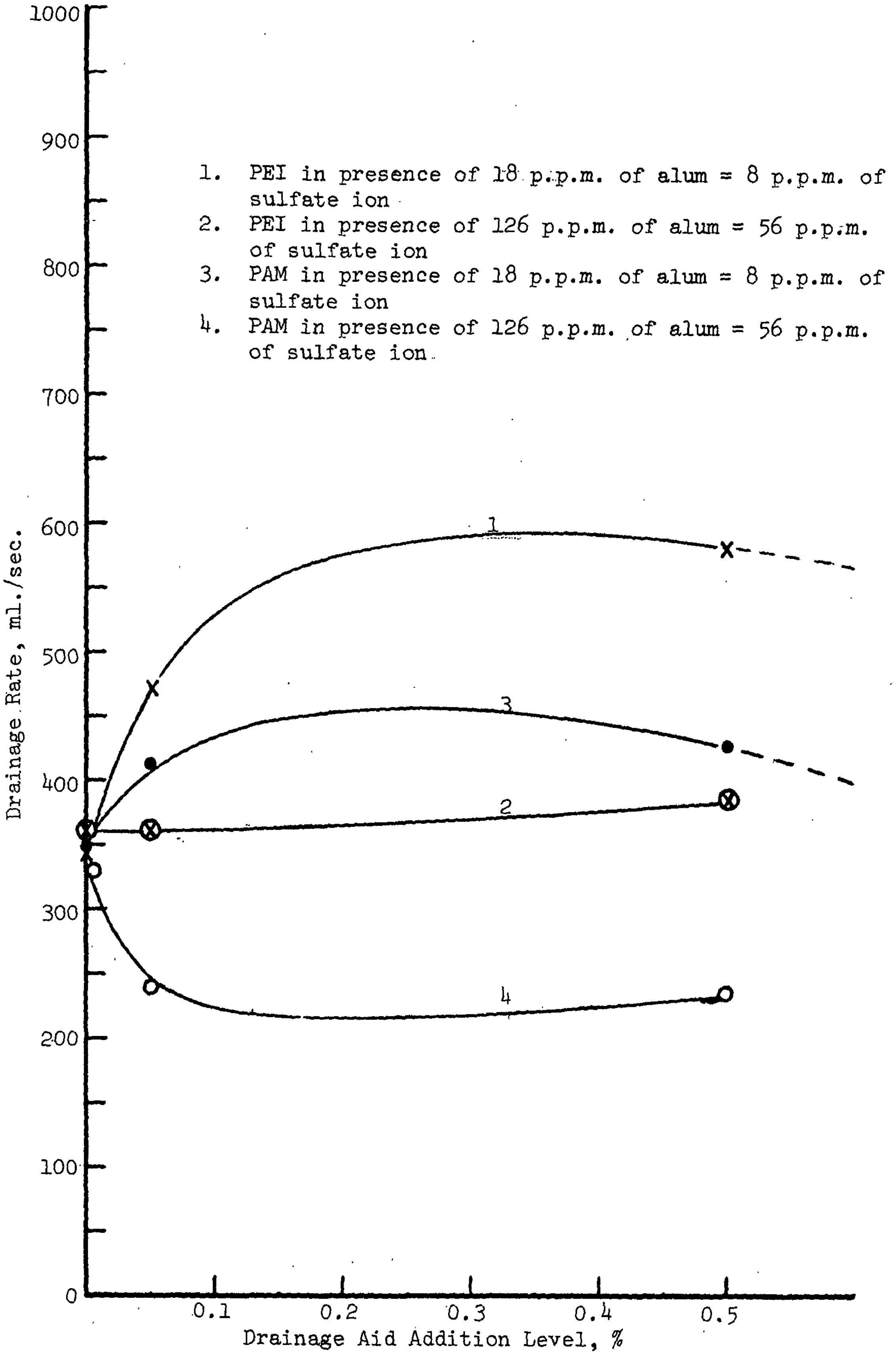

Figure 24. The Effect of Alum Content on Drainage Rate (Deionized Water)

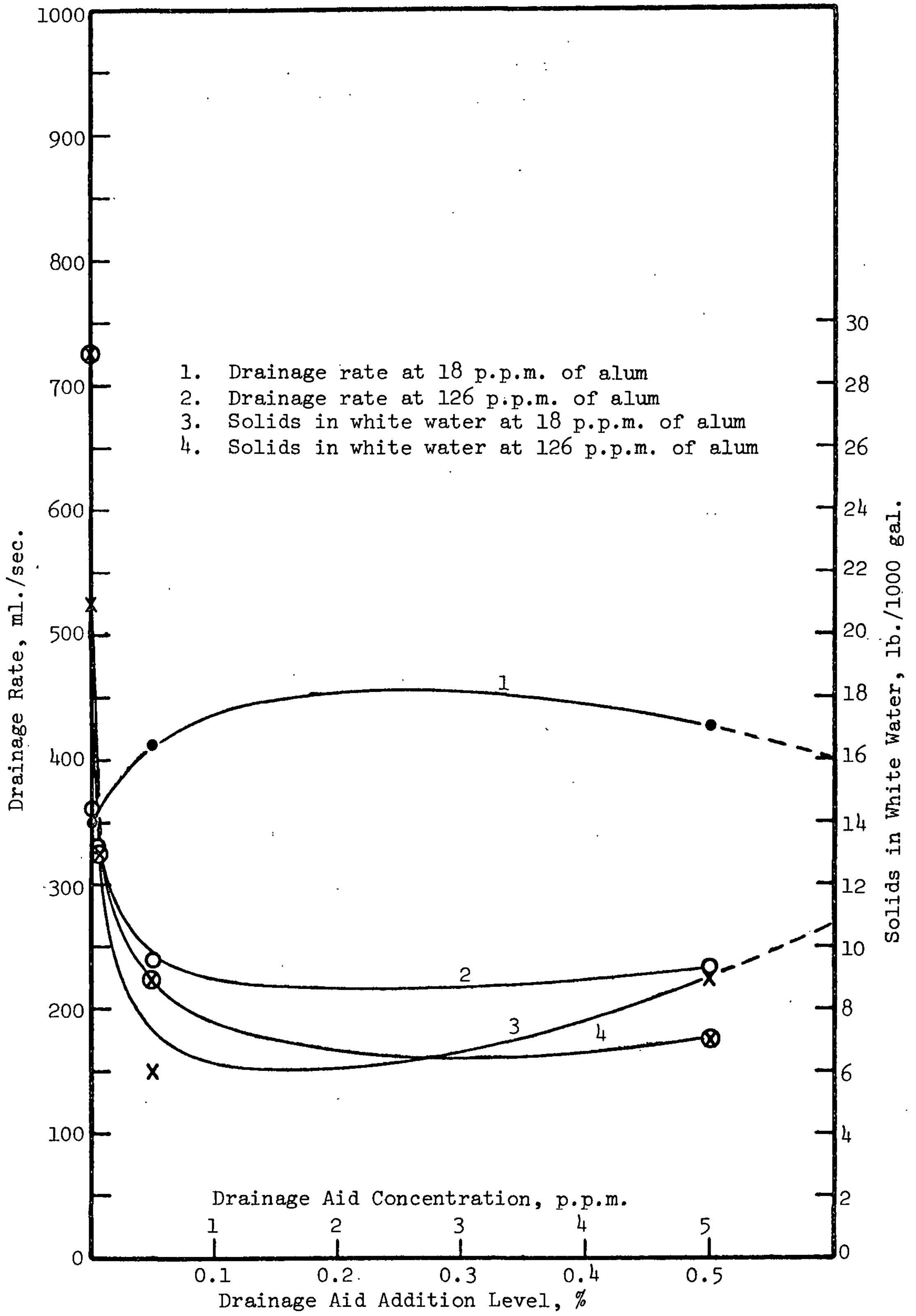

Figure 25. The Effect of PAM on Drainage Rate and White Water Solids at Low Agitation Rate and Time (10 sec.; 100 Cycles/Min., Deionized Water)

TABLE XI

THE FREENESS OF SECONDARY LINER STOCK AT pH 4.5 IN DEIONIZED WATER CONTAINING EXCESS ALUM

Drainage Aid	Addition Level, %	Canadian Freeness, cc.
None	--	385
PEI	0.05	400
PEI	0.5	400
PAM	0.005	385
PAM	0.05	415
PAM	0.5	580

Series Four

The fourth and final series of drainage tests utilized synthetic white water comprised of fiber fines, alum, and sulfuric acid in tap water. The fines were separated from the whole fibers on a Bauer-McNett classifier. Well-beaten southern pine unbleached kraft pulp was passed through the classifier in 30-gram batches comprised of three increments of 10 grams each at two minute intervals. Screens numbered 8, 20, 35, and 100 were used and that fraction of the pulp passing through the 100-mesh screen was considered to be fines. The fines were concentrated to some extent by settling in 55-gallon drums and finally by filtering on muslin-covered washboxes. A total of five pounds of pulp was passed through the classifier in this manner.

The fines were subsequently added to tap water at a rate of 1 lb./1000 gal. along with 2% of alum (based on fiber) and sufficient 2% sulfuric acid to adjust the pH to 5.5. The combination of alum and sulfuric acid resulted in a sulfate ion concentration of approximately 40 p.p.m.

TABLE XII

THE EFFECT OF ROSIN-ALUM SIZING[a] ON THE PERFORMANCE OF PEI AND PAM DRAINAGE AIDS (SECONDARY LINER PULP - DEIONIZED WATER - pH 5.5)

Set No.	Drainage Aid Addition Level, %	Drainage Aid Concn., p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Average Drainage Time, sec. To Start of Vacuum Drop	Average Drainage Time, sec. From Start of Vacuum Drop to Stable Vacuum	Average Drainage Time, sec. Total	Approx. Drainage Rate, ml./sec.	Maximum Vacuum Level Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., % 3 min.	Solids in Web After Wet Pressing at 50 p.s.i., % 6 min.	Solids in White Water, lb./1000 gal.
151	None	--	10	100	21.1	1	22.1	336	410	85	33.3	35.7	0.29
152	PEI, 0.05	0.5	10	100	15.6	1	16.6	448	260	58	32.2	35.2	0.15
153	PEI, 0.5	5.0	10	100	11.9	1	12.9	576	165	48	31.5	34.0	0.05
154	PEI, 2.0	20.0	10	100	11.8	1	12.8	581	180	50	32.8	34.1	0.09
155	PAM, 0.005	0.05	10	100	21.4	1	22.4	332	395	73	33.2	35.7	0.19
156	PAM, 0.05	0.5	10	100	18.3	1	19.3	385	300	63	31.7	34.0	0.12
157	PAM, 0.5	5.0	10	100	18.4	2	20.4	364	340	73	30.1	33.0	0.13

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[a] The furnish contained 0.5% of rosin size and 1.8% of alum based on fiber.

TABLE XIII

THE FREENESS OF SECONDARY LINER STOCK AT pH 5.5 IN DEIONIZED WATER CONTAINING ROSIN AND ALUM

Drainage Aid	Addition Level, %	Canadian Freeness, cc.
None	--	295
PEI	0.005	340
PEI	0.05	450
PEI	0.5	495
PEI	2.0	480
PAM	0.005	405
PAM	0.05	560
PAM	0.5	615

Results are recorded in Tables XIV-XVI.and are presented graphically in Fig. 28-33. A comparison of drainage and freeness behavior is shown in Fig. 34.

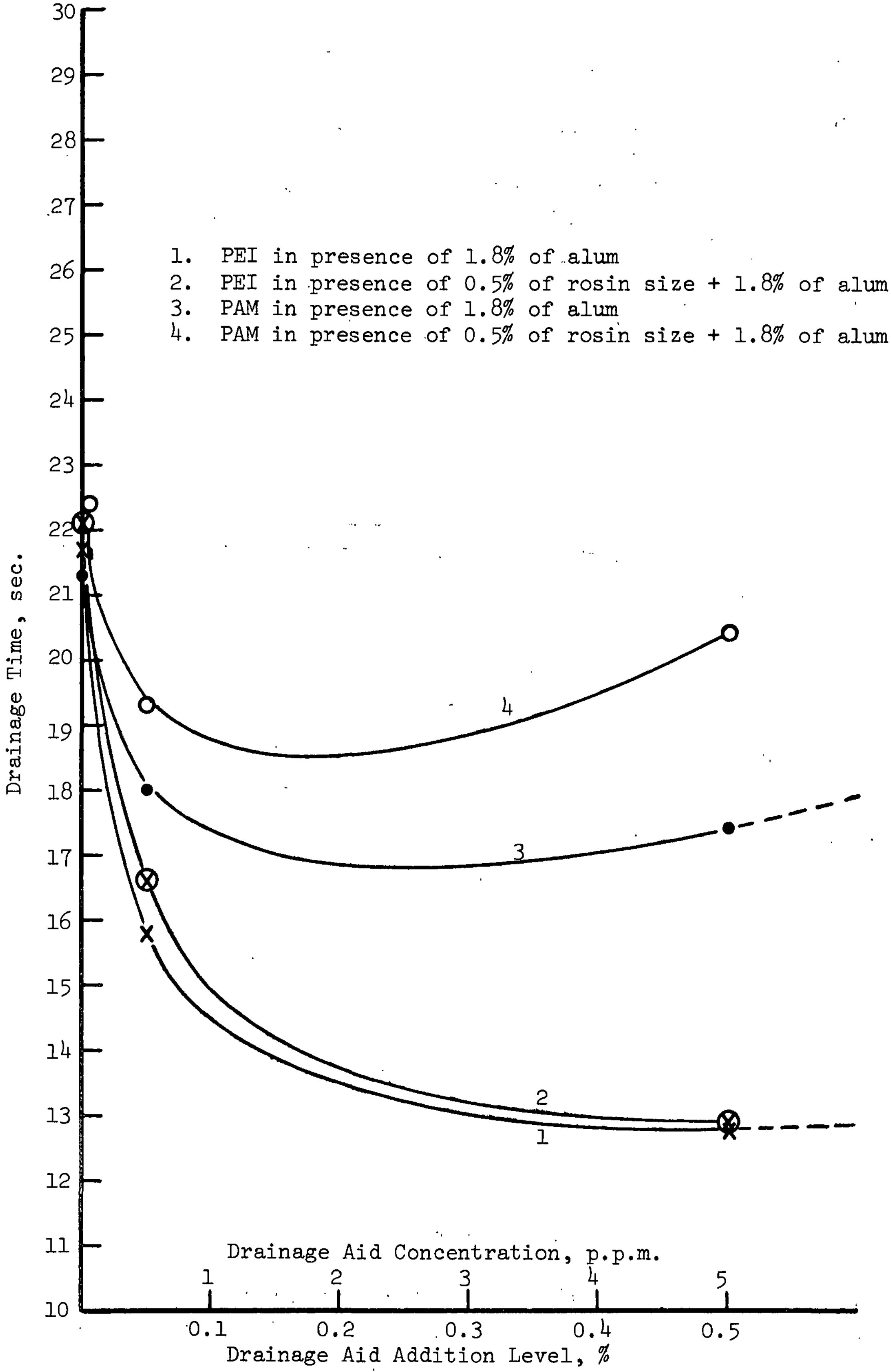

Figure 26. The Effect of Rosin-Alum Size on Drainage Time
(Deionized Water — pH 5.5)

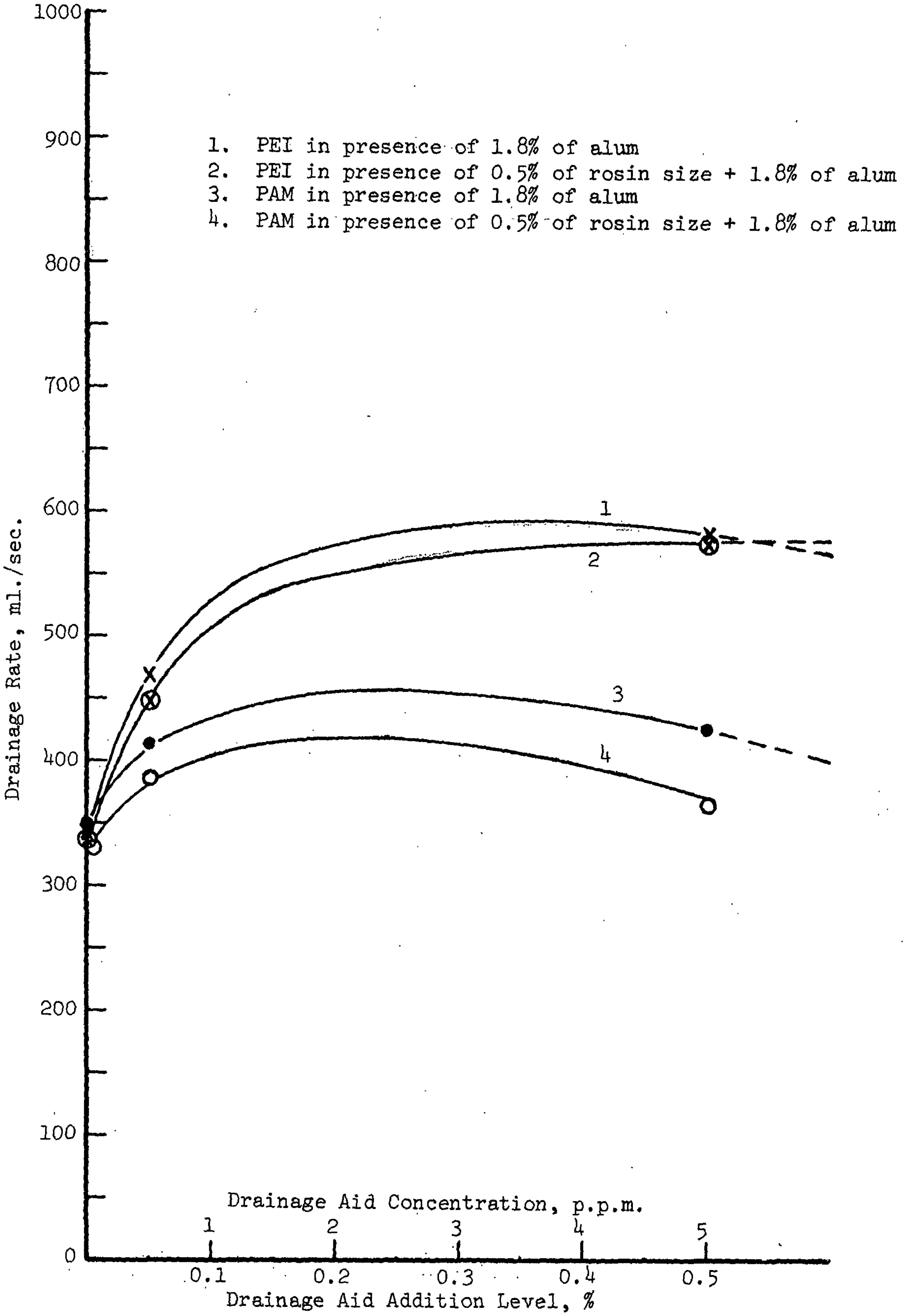

Figure 27. The Effect of Rosin-Alum Size on Drainage Rate
(Deionized Water — pH 5.5)

TABLE XIV

THE EFFECT OF PEI ON THE DRAINAGE PROPERTIES OF LINER PULP IN SYNTHETIC WHITE WATER[a] - pH 5.5

Set No.	Liner Stock	PEI Addition Level, %	PEI Concn., p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Average Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
						To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
158	Secondary	0.0	0.0	10	100	56.6	5	61.6	121	565	180	34.4	36.6	0.37
159	"	0.05	0.5	10	100	42.1	3	45.3	164	530	135	33.1	35.2	0.17
160	"	0.5	5.0	10	100	23.3	2	25.3	294	403	90	32,1	35.4	0.14
161	"	2.0	20.0	10	100	27.1	2	29.1	255	425	98	32.2	34.3	0.20
162	"	0.0	0.0	10	260	52.0	5	57.0	130	575	170	33.9	35.7	0.40
163	"	0.05	0.5	10	260	43.6	4	47.6	156	555	150	33.6	36.6	0.34
164	"	0.5	5.0	10	260	27.8	2	29.8	249	485	110	34.4	35.6	0.25
165	"	2.0	20.0	10	260	38.0	3	41.0	181	530	135	34.1	36.7	0.32
166	"	0.0	0.0	100	100	55.3	5	60.3	123	540	175	33.8	36.7	0.25
167	"	0.05	0.5	100	100	55.3	4	59.3	125	530	170	34.0	36.5	0.20
168	"	0.5	5.0	100	100	25.3	2	27.3	272	410	103	32.8	33.8	0.16
169	"	2.0	20.0	100	100	43.4	2	45.4	164	515	145	34.4	36.1	0.24
170	"	0.0	0.0	100	260	46.9	5	51.9	143	520	155	34.2	36.0	0.44
171	"	0.05	0.5	100	260	49.8	5	54.8	136	525	160	33.8	35.1	0.42
172	"	0.5	5.0	100	260	31.6	3	33.6	221	475	130	34.5	36.5	0.32
173	"	2.0	20.0	100	260	45.8	3	48.8	152	515	150	35.5	37.7	0.36
174	Primary	0.0	0.0	10	100	16.4	<1	16.4	453	350	70	34.2	36.0	0.36
175	"	0.05	0.5	10	100	15.6	<1	15.6	476	305	55	32.4	33.5	0.19
176	"	0.5	5.0	10	100	12.0	<1	12.0	619	200	48	31.4	35.6	0.14
177	"	2.0	20.0	10	100	13.8	<1	13.8	538	235	53	32.3	35.0	0.13
178	"	0.0	0.0	100	260	14.8	<1	14.8	502	285	55	33.7	35.8	0.46
179	"	0.05	0.5	100	260	15.9	<1	15.9	467	315	63	33.2	35.4	0.36
180	"	0.5	5.0	100	260	15.3	<1	15.3	486	275	60	34.0	36.0	0.27
181	"	2.0	20.0	100	260	16.9	<1	16.9	440	325	65	34.5	36.6	0.38

---

[a] Tap water containing 1 lb./1000 gal. of fines plus 2% of alum and sufficient sulfuric acid to adjust pH to 5.5.
2% of alum = 20 p.p.m. or 8.6 p.p.m. of $SO_4^=$.

H_2SO_4 added equivalent to 31 p.p.m. of $SO_4^=$.

TABLE XV

THE EFFECT OF POLYACRYLAMIDE ON THE DRAINAGE PROPERTIES OF LINER PULP IN SYNTHETIC WHITE WATER[a] - pH 5.5

Set No.	Liner Stock	PAM Addition Level, %	PAM Concn., p.p.m.	Stirring Time, sec.	Stirring Rate, cycles/min.	Average Drainage Time, sec.			Approx. Drainage Rate, ml./sec.	Maximum Vacuum Attained, mm.	Stabilized Vacuum Level, mm.	Solids in Web After Wet Pressing at 50 p.s.i., %		Solids in White Water, lb./1000 gal.
						To Start of Vacuum Drop	From Start of Vacuum Drop to Stable Vacuum	Total				3 min.	6 min.	
182	Secondary	0.0	0.0	10	100	57.0	6	63.0	118	590	180	34.2	36.1	0.36
183	"	0.005	0.05	10	100	65.2	6	71.2	104	598	170	33.6	36.0	0.30
184	"	0.05	0.5	10	100	52.1	8	60.1	124	570	143	31.1	32.4	0.19
185	"	0.5	5.0	10	100	51.7	14	65.7	113	568	165	30.2	31.3	0.16
186	"	0.0	0.0	10	260	53.6	5	58.6	127	610	170	33.7	37.3	0.39
187	"	0.005	0.05	10	260	57.0	6	63.0	118	610	160	34.2	36.8	0.33
188	"	0.05	0.5	10	260	64.9	7	71.9	103	620	155	33.4	34.9	0.26
189	"	0.5	5.0	10	260	51.8	6	57.8	129	610	150	30.5	32.7	0.15
190	"	0.0	0.0	100	100	50.6	6	56.6	131	605	165	34.2	36.8	0.31
191	"	0.005	0.05	100	100	59.5	6	65.5	113	615	170	34.0	37.0	0.22
192	"	0.05	0.5	100	100	78.6	8	86.6	86	620	155	33.2	34.8	0.19
193	"	0.5	5.0	100	100	85.9	11	96.9	77	620	160	32.8	33.9	0.11
194	"	0.0	0.0	100	260	48.2	7	55.9	133	620	160	36.6	37.2	0.41
195	"	0.005	0.05	100	260	55.4	8	63.4	117	610	160	34.0	36.3	0.38
196	"	0.05	0.5	100	260	61.9	8	69.9	106	600	160	34.7	36.1	0.38
197	"	0.5	5.0	100	260	84.0	10	94.0	79	600	170	33.3	35.3	0.35
198	Primary	0.0	0.0	10	100	15.5	<1	15.5	479	345	70	33.9	35.8	0.35
199	"	0.005	0.05	10	100	15.9	<1	15.9	467	330	70	32.1	33.2	0.27
200	"	0.05	0.5	10	100	14.1	<1	14.1	527	285	55	29.9	33.5	0.19
201	"	0.5	5.0	10	100	13.0	<1	13.0	572	255	55	28.6	32.5	0.19
202	"	0.0	0.0	100	260	14.3	<1	14.3	520	300	68	33.5	36.1	0.34
203	"	0.005	0.05	100	260	15.0	<1	15.0	495	305	65	33.8	34.8	0.43
204	"	0.05	0.5	100	260	16.7	<1	16.7	444	325	65	32.9	34.3	0.29
205	"	0.5	5.0	100	260	18.7	<1	18.7	397	365	68	33.1	34.7	0.24

---

[a] Tap water containing 1 lb./1000 gal. of fines plus 2% of alum and sufficient sulfuric acid to adjust pH to 5.5.

2% of alum = 20 p.p.m. or 8.6 p.p.m. of $SO_4^{=}$.

H_2SO_4 added equivalent to 31 p.p.m. of $SO_4^{=}$.

TABLE XVI

THE FREENESS OF LINER STOCKS AT pH 5.5 IN SYNTHETIC WHITE WATER

Liner Stock	Drainage Aid	Addition Level, %	Canadian Freeness, cc.
Secondary	None	--	200
	PEI	0.05	370
	PEI	0.5	415
	PEI	2.0	400
	PAM	0.005	240
	PAM	0.05	490
	PAM	0.5	545
Primary	None	--	565
	PEI	0.05	630
	PEI	0.5	635
	PEI	2.0	570
	PAM	0.005	615
	PAM	0.05	665
	PAM	0.5	670

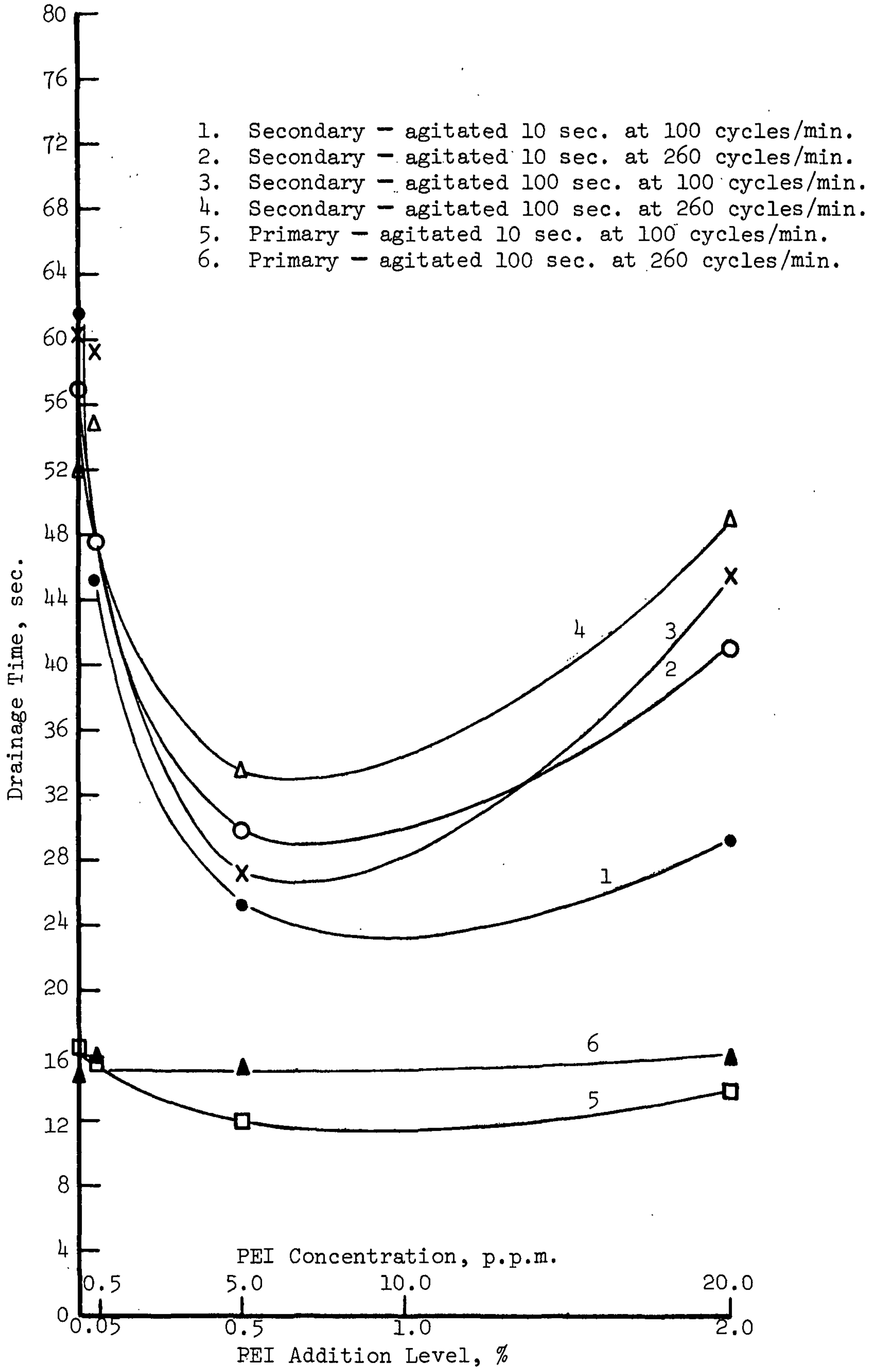

Figure 28. The Effect of PEI Concentration on Drainage Time (Synthetic White Water — pH 5.5)

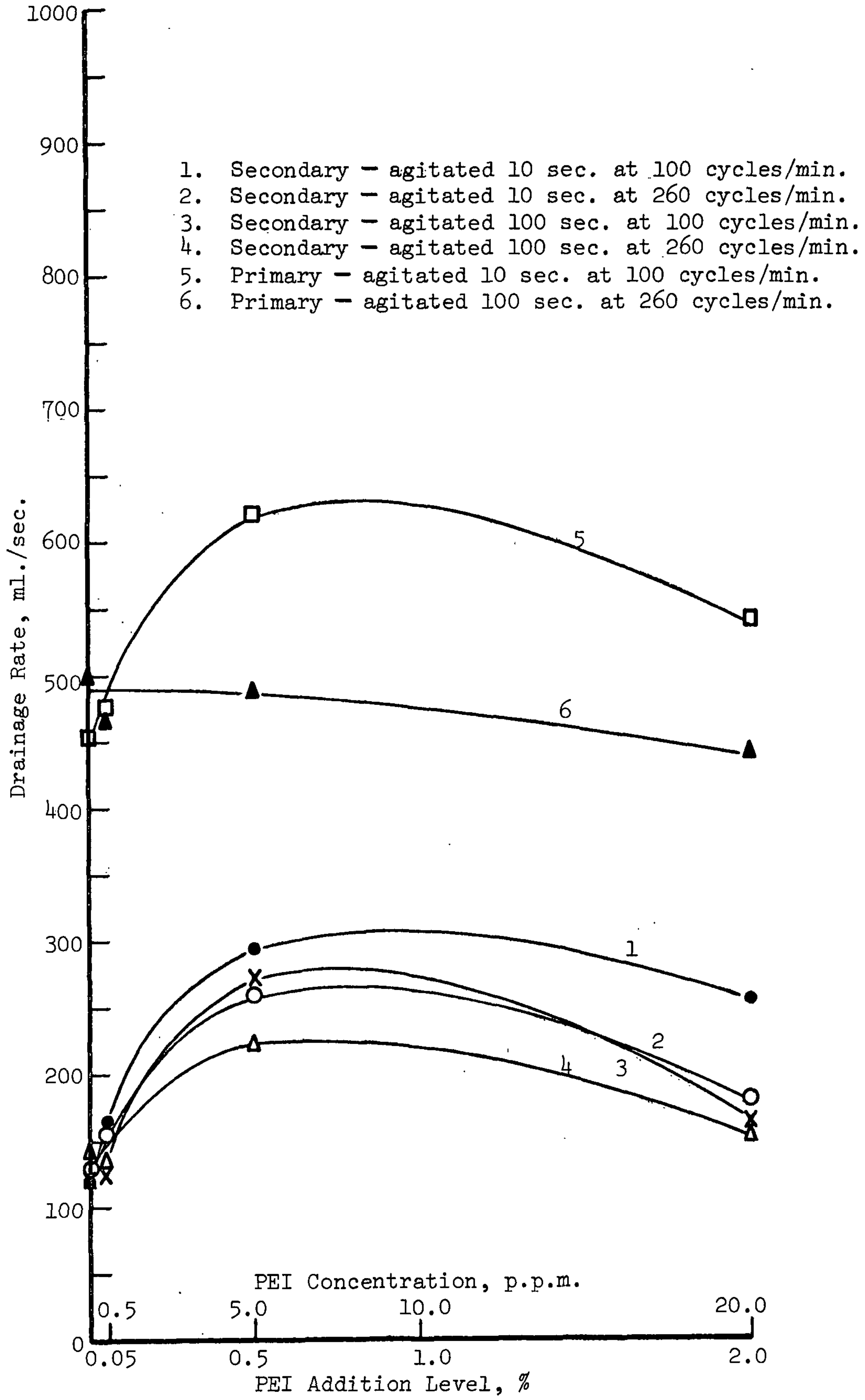

Figure 29. The Effect of PEI Concentration on Drainage Rate (Synthetic White Water — pH 5.5)

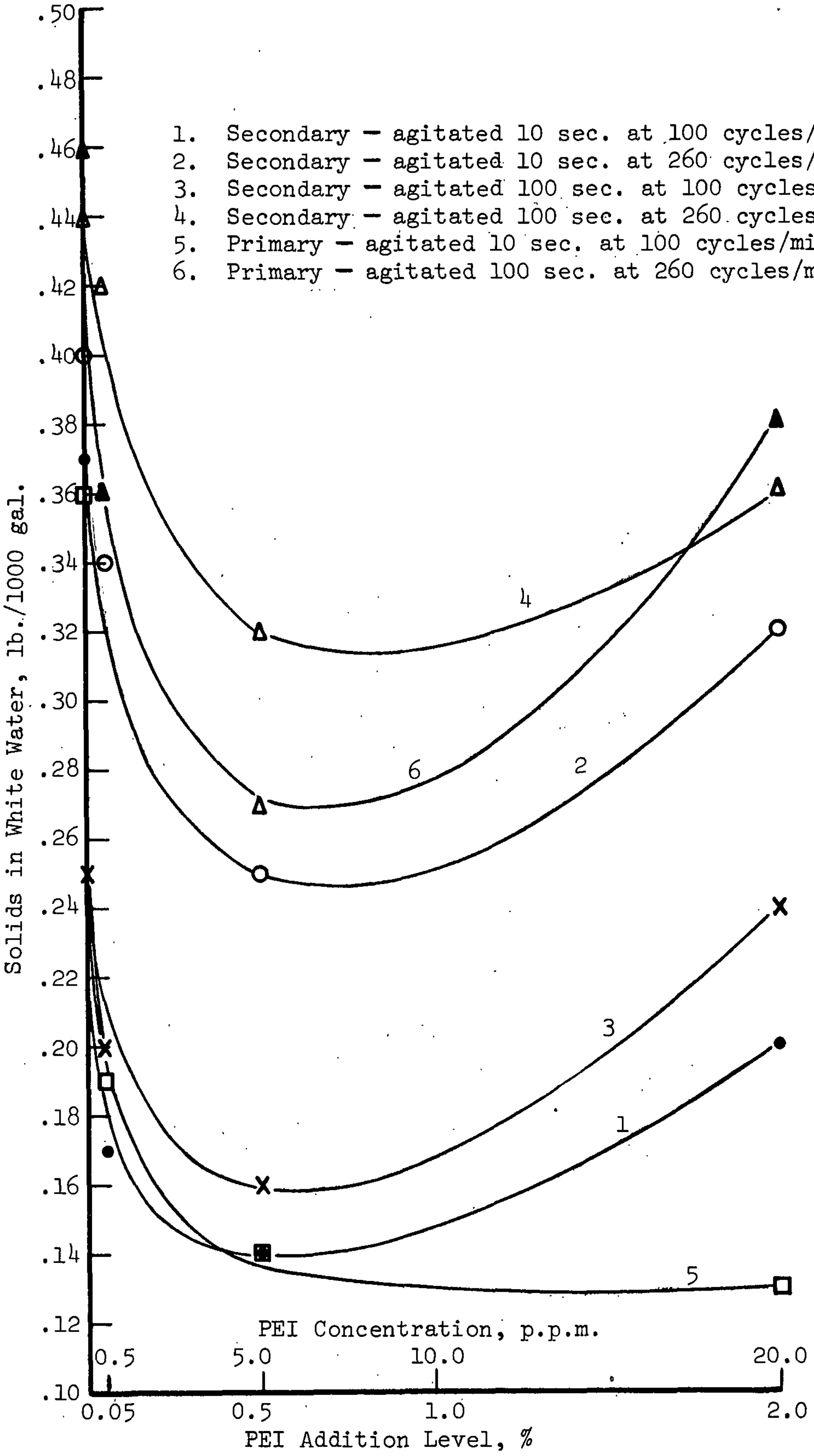

Figure 30. The Effect of PEI Concentration on White Water Solids (Synthetic White Water — pH 5.5)

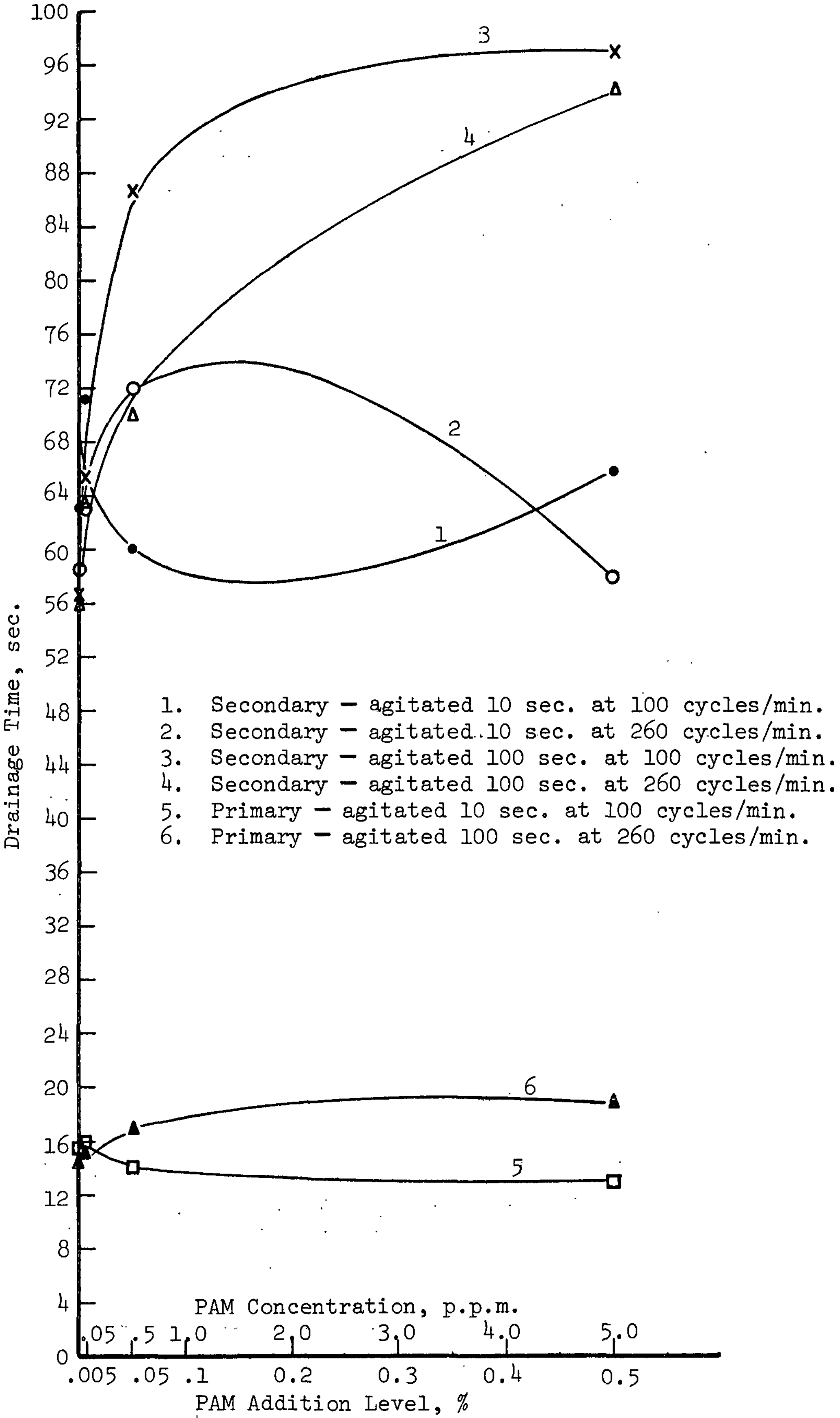

Figure 31. The Effect of PAM Concentration on Drainage Time (Synthetic White Water — pH 5.5)

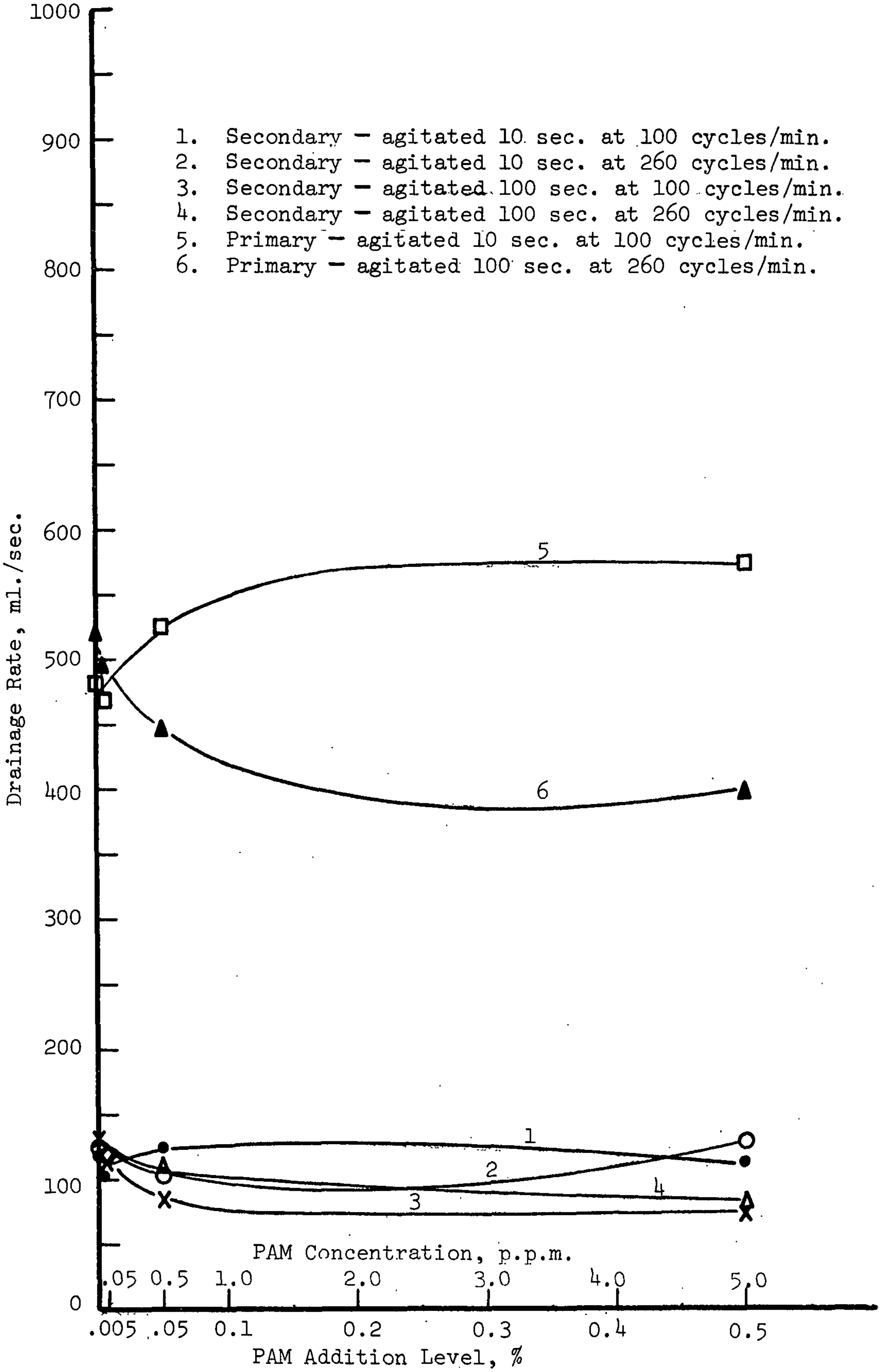

Figure 32. The Effect of PAM Concentration on Drainage Rate (Synthetic White Water — pH 5.5)

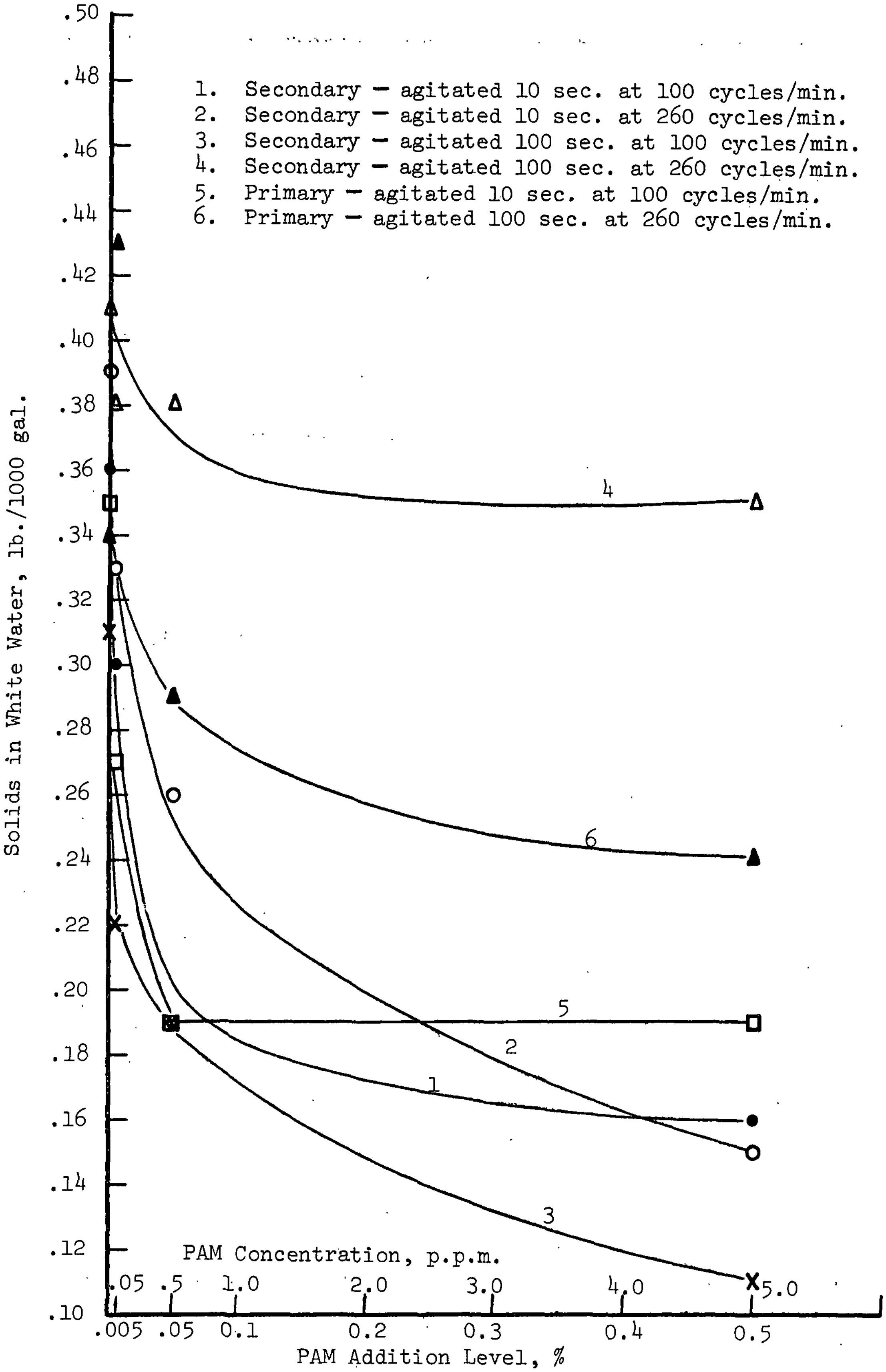

Figure 33. The Effect of PAM Concentration on White Water Solids (Synthetic White Water — pH 5.5)

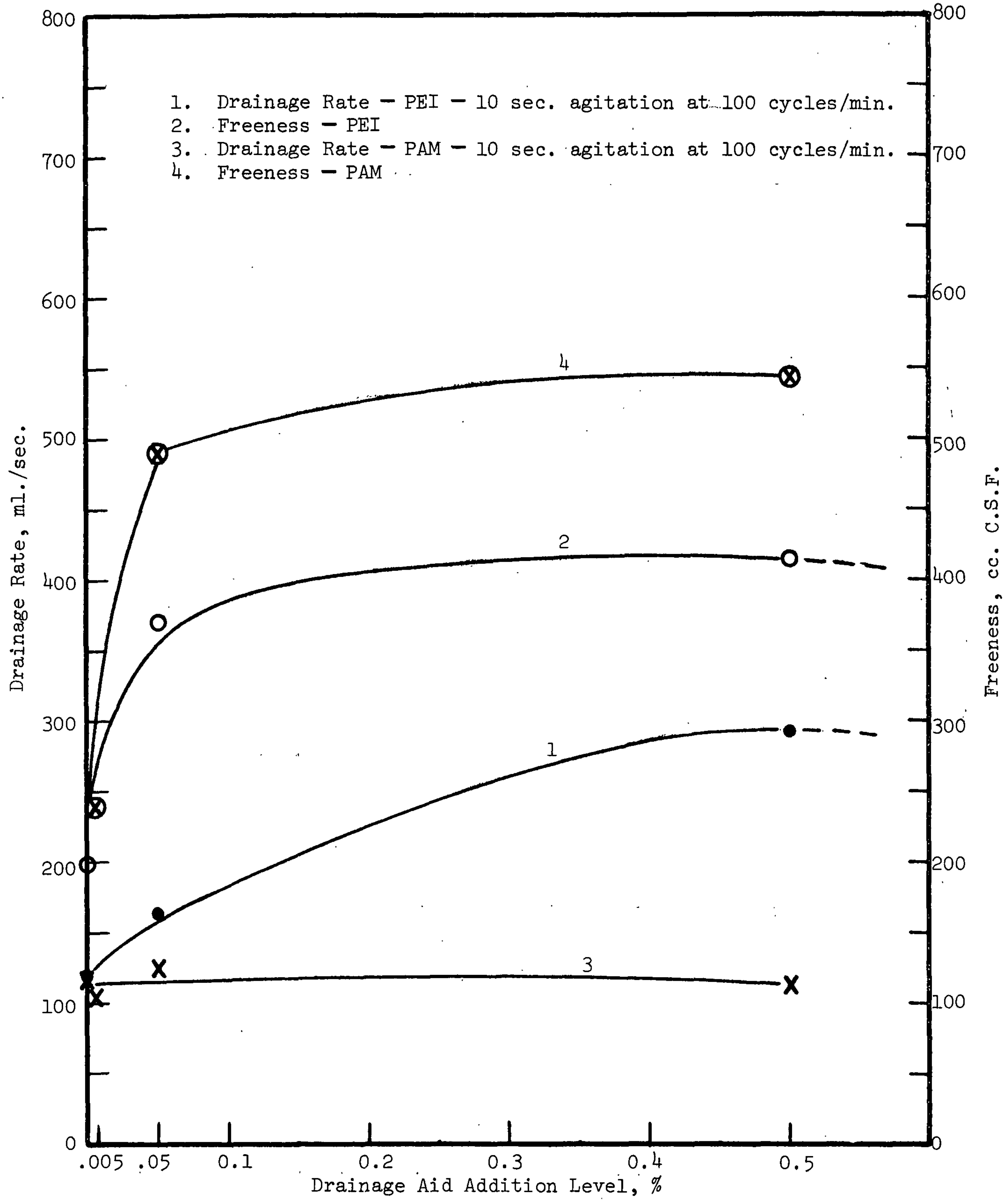

Figure 34. Drainage Rate and Freeness as a Function of Drainage Aid Addition Level (Synthetic White Water — pH 5.5)

DISCUSSION OF RESULTS

The results obtained in the first series of tests (Tables I to III; Fig. 2-8) reflect the sensitivity of the method to changes in rate and extent of agitation as well as drainage aid type and concentration. Considering first the results in Table I and Fig. 2 and 3, it is apparent that the drainage properties of the liner secondary pulp were markedly improved by PEI, whereas the higher freeness primary pulp was relatively unaffected. Optimum drainage with the secondary was obtained at a PEI concentration of 5-10 p.p.m., whereas redispersion and reduced drainage occurred at higher concentrations. These concentrations correspond to addition levels of 0.5 to 1.0% based on fiber for optimum drainage and 1.0 to 2.0% for redispersion, bearing in mind that the fiber consistency utilized in the drainage tests was considerably lower than that used in commercial linerboard production. While some improvement in drainage was obtained at about 5 p.p.m. under all agitation conditions, the most promising results were obtained under conditions of low agitation rate and short duration, i.e., 10 seconds at 100 cycles/min. The least advantage in drainage was obtained under conditions of high agitation rate and longer time, i.e., 100 seconds at 260 cycles/min.

The vacuum levels attained with the secondary pulp (Table I) more or less reflect the drainage properties to the extent that the optimum PEI concentration for drainage produced the lowest vacuum levels. PEI tended to increase water retention slightly in wet pressing, particularly under conditions providing optimum drainage but this may be caused by marginally higher basis weight resulting from increased retention of fines which hold proportionately more water. In commercial practice, an adjustment in basis weight would be made which may offset the increase in fines retention. In any case, no advantage in water removal is indicated when drainage properties were optimum. Further evidence of increased fines retention is indicated in the white water solids data (Table I, Fig. 4) with the maximum effect occurring under conditions of low agitation rate. The mechanism in this case is assumed to be one of flocculation or coflocculation rather than a filtering-out effect.

As previously noted, the primary liner pulp (Table I) shows little response to PEI in so far as drainage is concerned but some advantage in reduced white water solids is indicated. Apparently, increased fines retention in this lightly beaten, relatively coarse furnish does not alter drainage properties substantially.

A very different response was obtained with the polyacrylamide resin as shown by the results in Table II and Fig. 5-7. PAM is shown to produce a dispersion effect in the secondary furnish at all concentrations, i.e., drainage time increased and drainage rate decreased. The maximum dispersion effect was found under conditions of low agitation rate and short duration. In other words, those agitation conditions which produced maximum flocculation with PEI produced maximum dispersion with polyacrylamide. The vacuum levels attained and the water holding properties of the webs tend to parallel the drainage results. No consistent trends in white water solids removal are indicated.

The primary stock shows little response to the presence of PAM (Table II) and, if anything, a slight dispersion effect. There is some indication in Fig. 7 of reduced white water solids at 5 p.p.m. of PAM but the effect was not as dramatic as that indicated for PEI.

The effects of PEI and PAM on freeness are given in Table III and Fig. 8. In the case of PEI, the freeness values tend to parallel the drainage rate observed in the mold but it is important to note from these results and those in Table I that a significant difference in drainage time and rate can be attained at the same nominal freeness depending upon the shear rate and time. Hence, floc strength is demonstrated to be an important consideration in this system. Further evidence of the importance of floc strength is shown by the results obtained with the polyacrylamide resin (Fig. 8). The freeness results suggest a modest degree of flocculation but the dynamic conditions utilized in the drainage test were apparently adequate to destroy the weakly flocced system resulting in a slight dispersion effect.

Hence, in tap water containing sulfuric acid (18-27 p.p.m. $SO_4^=$) PEI produced substantial improvements in drainage rate (up to 46%) and in white water clarification in the secondary liner furnish particularly when used at 5-10 p.p.m. under conditions of low agitation rate and time. The same conditions also produced a reduction in white solids from the primary liner pulp but had little effect on drainage. In contrast, the polyacrylamide resin produced a dispersion effect in the secondary pulp at concentrations in the range of 0.05 to 5 p.p.m. under the same agitation conditions.

Results obtained in deionized water plus sulfuric acid (Series Two) show the same general trends found in tap water but to a somewhat different degree. For example, PEI in the secondary furnish (Table IV, Fig. 9 and 10) is shown to effect increases in drainage rate up to 70%. These greater increases are possibly due to the lower sulfate ion content in the deionized water series since PEI is known to be sensitive to the anion. Once again the optimum drainage results occurred at about 5-10 p.p.m. of PEI at low agitation rate and time. Redispersion is again indicated at higher PEI concentrations. As in the previous series, high agitation rate for 100 seconds reduced the effectiveness of PEI but it will be noted that a greater improvement in drainage was attained under these conditions in deionized water than in tap water. The vacuum levels in Table IV tend to parallel the drainage properties. Web solids after wet pressing varied considerably although a tendency for higher water retention is indicated at the maximum drainage rate (Set 51). Substantial reductions in white water solids (Fig. 11) were produced in both the primary and secondary furnishes and, while the condition which provided the optimum drainage in the secondary did not necessarily produce the lowest solids content, the least effective condition was again that produced by high agitation rate and long time. Other than reducing white water solids, PEI had little effect on the drainage properties of the primary liner pulp.

With respect to the polyacrylamide resin (Table V, Fig. 12-14) the same trend in drainage properties and water removal are indicated in deionized water as were found in tap water, i.e., PAM tended to reduce drainage rate over the range of concentrations and drainage conditions examined.

The effects of PEI and PAM on freeness in this series (Table VI, Fig. 15) were similar to those found in Series One, although the magnitude of the values differed somewhat. Once again, freeness and drainage rate showed roughly parallel response in the case of PEI but diverged in the case of PAM. However, very substantial differences in drainage rate were again obtained with PEI at the same nominal freeness. For example, the drainage rates in Sets 51, 55, 59, and 63 (Table IV) varied from 495 to 669 ml./sec. at the same freeness (730 cc.). Considered in other terms, the very substantial increase in freeness obtained with 0.05% of PEI did not reflect any increase in drainage rate when the fiber suspension was agitated for 100 seconds. Hence, freeness cannot be considered a satisfactory indicator of drainage response in this system.

The major part of the third series of drainage tests (Tables VII-IX; Fig. 16-22) was carried out in deionized water plus sufficient alum to adjust the pH to 5.5. This amounted to 18 p.p.m. of alum or 8 p.p.m. of $SO_4^=$. Under these ionic conditions, 5 p.p.m. of the polyacrylamide resin produced a modest increase in the drainage rate of the secondary pulp when agitated for 10 seconds (Sets 123 and 127; Table VIII). However, PEI provided a substantially greater effect under the same conditions. Generally speaking, the vacuum levels attained in the presence of PEI and PAM again parallel the drainage properties. Both PEI and PAM are shown to reduce white water solids over a rather broad range of concentration and agitation conditions. PEI shows its greatest advantage in this respect under those conditions which produced optimum drainage, whereas PAM produced substantial reductions in solids under conditions of both flocculation (Sets 122, 123, and 127) and dispersion (Set 136). Apparently, PAM behaves in a similar manner to PEI in this series when agitated for a short time but then passes into a dispersion effect at longer times. It is apparent, however, that simple flocculation or dispersion mechanisms cannot explain all observed behavior. For example, Sets 129-132 show little effect with respect to drainage but white water solids were drastically reduced at higher PAM additions. Conceivably, a combination of flocculation and dispersion effects occur in this system under the conditions employed. A given concentration of PAM may be a flocculant for fines and a dispersant for whole fibers owing to the large difference in surface area. The combination of these effects could conceivably result in little change in overall drainage rate but a significant reduction in white water solids.

As was found previously, the primary liner pulp shows little favorable response to the presence of PEI and PAM in so far as drainage properties are concerned although both show beneficial effects on white water solids. The drainage rate and freeness values for this series (Fig. 22) show parallel trends for the first time although it is apparent that the magnitude in response to PAM differed widely.

The supplementary test results (Table X-XIII, Fig. 23-27) show several interesting effects. First of all, the higher alum concentration eliminated the beneficial effects of PEI and reversed the effect shown by PAM at low alum content; i.e., PAM became a dispersant at high alum concentration. Secondly, 0.5% of rosin size in combination with 1.8% of alum (based on fiber) had essentially no effect on the performance of PEI but tended to reduce the effectiveness of PAM under the same ionic conditions. The varying effect of PAM on drainage properties and white water solids is made apparent in Fig. 25 where drainage rate improved at low alum concentration but declined at the higher alum concentration while white water solids declined under both conditions.

As would be expected, incorporation of 1 lb./1000 gal. of fines into tap water along with alum and sulfuric acid, as in Series Four, had a very marked effect on drainage time and rate (Tables XIV-XVI; Fig. 28-34). The drainage rates were approximately one-third the values obtained in the previous three series. Under the conditions of these tests PEI is shown to effect increases in drainage rate up to 144% at low agitation rate and short duration (Set 160). This compares with a maximum increase of 73% in Series Three. As was previously found, the advantage diminishes at higher agitation rate and longer time. However, in contrast to the earlier series, PEI begins to show an advantage in the primary stock at low agitation rate (Sets 174-177). Once again, the vacuum levels tend to parallel the drainage properties. Considerable variation in web solids content was obtained in this series and the overall values after pressing six minutes were not substantially different than those measured in the previous series in the absence of added fines. As before, PEI reduced white water solids, particularly under conditions of improved drainage.

As shown in Table XV and Fig. 31-32, PAM did not function as a drainage aid in the synthetic white water system under the conditions of these tests and, in fact, PAM tended to reduce drainage rate, particularly at high agitation rate and long time. The presence of PAM again tended to reduce white water solids, presumably by a filtration mechanism. Comparison of drainage rates and freeness values (Fig. 34) shows similar trends in the case of PEI although the response in these properties differed more than in the previous three series. PAM is shown to have little or no effect on drainage but a pronounced advantage on freeness again suggesting a weakly flocculated system.

In review, PEI has been found to be an effective drainage aid for liner secondary pulp under all environments examined with the exception of one containing 126 p.p.m. of alum equivalent to 56 p.p.m. of $SO_4^{=}$. This concentration of alum would be reasonable in a commercial linerboard furnish at 0.7% fiber consistency but it represents a large excess based on fiber in the present case since the drainage tests were carried out at 0.1% consistency. The improvements in drainage rate afforded by PEI ranged from 46% in tap water containing sulfuric acid to 144% in synthetic white water. Optimum drainage was obtained at 5-10 p.p.m. of PEI under conditions of low agitation rate and short time (10 seconds at 100 cycles/min.). Increasing the agitation rate and time generally reduced the effectiveness of PEI, indicating that floc strength is an important factor to this system. PEI had little effect on the liner primary pulp although some advantage was indicated in the synthetic white water system. In addition to improving drainage properties in the secondary, PEI reduced white water solids from both the primary and secondary pulps with the optimum result generally obtained under conditions of low agitation rate. Some indication of slightly higher water retention after pressing was indicated among webs formed under the optimum drainage conditions but this was possibly due to marginally higher sheet weight resulting from increased retention of fines which have a high water holding capacity. In general, freeness values paralleled drainage properties to the extent that the highest freeness was obtained at about 0.5% addition of PEI; however, it was also made evident that a significant difference in drainage time and rate can be attained at the same nominal freeness depending upon the shear condition. This again points to the importance of floc strength.

PAM, in contrast to PEI, proved to be ineffective as a drainage aid under all environmental conditions studied with the exception of the third series which utilized deionized water containing approximately 18 p.p.m. of alum or 8 p.p.m. of $SO_4^=$. Under these conditions PAM afforded a maximum increase in drainage rate of about 20%. The positive performance of PAM in this system would be expected since the anionic polyacrylamide resin is known to require some alum for maximum efficiency; however, increasing the alum concentration sevenfold caused a reversal in drainage properties, i.e., PAM reduced drainage rate. PAM was found to reduce white water solids in many cases, presumably as a result of a filtering process. PAM was also found to effect rather substantial increases in freeness, particularly in those systems containing alum. In most instances this was in contrast to the measured drainage behavior and, hence, it is assumed that PAM induced floc formation in this system but the strength of the flocs formed was too low to withstand the most moderate agitation conditions used in the drainage tests. Once again, floc strength emerges as a critical factor in the performance of the drainage aid and PEI apparently forms a stronger flocced network. The current results also reflect the inadequacy of the freeness test in predicting drainage properties under practical dynamic conditions.

From the standpoint of practical linerboard production, the available results suggest that drainage aids and, in particular, PEI will provide advantages in drainage rate and fines retention in liner pulp when added at the wet end of the board machine in the absence of major shear forces. The optimum concentration will depend somewhat upon the product used and the ionic environment. PEI was found to be most effective at 5-10 p.p.m. but this may vary somewhat from the practical mill condition where the fiber consistency is substantially higher and other complicating materials may be present. PAM improved drainage rate only in the presence of a moderate percentage of alum and this may be further complicated by other additives as indicated in the Series Three supplementary studies. The apparent trend for higher water retention under optimum drainage conditions would bear further attention since this effect would offset at least part of the advantage shown by the drainage aid. Hence, a need for further examination of drainage aids in practical linerboard furnishes is indicated.

FUTURE WORK

The dynamic drainage test utilized in the present study has proved useful in defining conditions for the effective use of drainage aids in fairly well-defined idealized systems. In order to apply the information obtained thus far to practical linerboard forming conditions it will be necessary to examine the effects of additives and other potentially complicating materials on the performance of the drainage aids. Future work would be concerned with these effects, with water removal in wet pressing, and with the strength properties of webs containing the drainage aids. Additives would include starch, galactomannan gum, and synthetic resin. Retained cooking liquor would be considered a potentially complicating material.

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