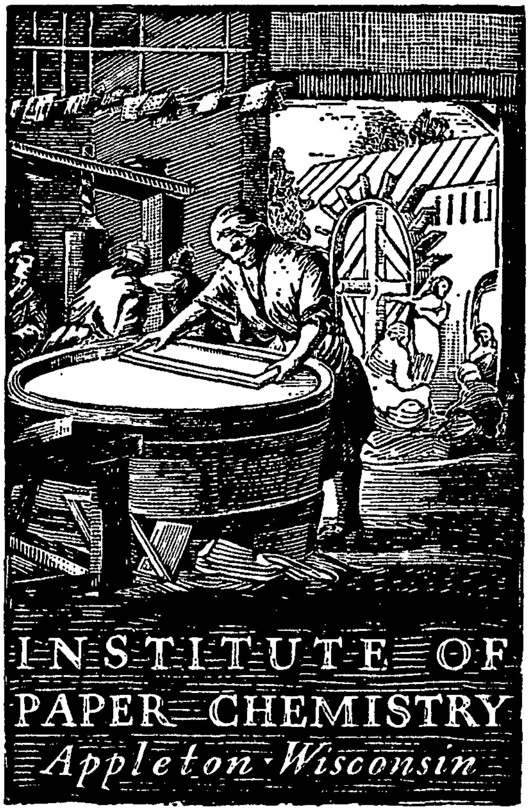

CHARACTERIZATION OF PULPS FOR PAPERMAKING

USE OF THE DRAINAGE RESISTANCE ANALYZER FOR ROUTINE TESTING

Project 2406

Report Six

A Progress Report

to

MEMBERS OF GROUP PROJECT 2406

March 8, 1967

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

CHARACTERIZATION OF PULPS FOR PAPERMAKING
USE OF THE DRAINAGE RESISTANCE ANALYZER FOR ROUTINE TESTING

SUMMARY

The A.I.L. Type 273 Drainage Resistance Analyzer has been designed and constructed for drainage resistance measurements on a routine basis. It was evaluated to this end with replicated tests on five beater runs of pulp in classified and unclassified form and compared with results of tests on the same pulps conducted with the Institute's research model constant rate filtration resistance apparatus. Drainage resistance was calculated as a function of pressure drop in increments of 10 cm. water. It was determined by multiple regression analysis that at consistencies and flow rates sufficient to result in 50-cm. water overall pressure drop after 300 seconds, the effect of the level of consistency, temperature, and flow rate could be minimized so that 95% of the change in drainage resistance could be attributed to the pressure drop. Apparently, under conditions not sufficient to approach a 50-cm. water pressure drop in 300 seconds, the precision of the test suffers. Comparison with the research model results showed good agreement for both the classified and unclassified samples providing consistencies in the D.R.A. unit were sufficiently high (0.01 to 0.04%) to obtain a nearly full-scale deflection (95 cm. water) on the strip chart recorder in 300 seconds. At lower consistencies, particularly under conditions that did not produce a 50-cm. water pressure drop, the D.R.A. measurements tended to be 20 to 33% high.

INTRODUCTION

Past research at the Institute (under academic, institutional, and cooperative programs) has contributed to a better understanding of pulp characteristics as related to paper machine drainage. Much of this work was conducted by constant-rate filtration techniques, using a "research model" built to provide versatile and precise operation. (See Progress Report 27 under Project 1513.) Consideration was given to this unit in the design and construction of a test instrument utilizing this approach but suitable for commercial production and use.

Further work concerned with the design of a test instrument suitable for manufacture was conducted in cooperation with the Airborne Instruments Laboratory Division of Cutler-Hammer Incorporated as a phase of Project 2211 and was presented in Progress Report Two. Since that time the A.I.L. Type 273 Drainage Resistance Analyzer (D.R.A.) has come into being on the basis of the original design concepts with some modifications in the pressure sensing system. The purpose of the work described in this report was to evaluate the application of this unit to a pulp after various degrees of beating in classified and unclassified forms in terms of reproducibility and comparison with the more precise research model constant rate filtration resistance apparatus originally constructed at the Institute by Ingmanson (1).

The determination of filtration resistance as a function of pressure drop permits a more complete evaluation of pulp relative to various machine conditions than is possible with a freeness test. By running wet mat compressibility (as a separate test) it is possible to analyze the specific filtration resistance into its components of compressibility, specific volume, and specific surface, thereby obtaining further useful information on the pulp and its behavior. No attempt was made to include this aspect in the present evaluation of the D.R.A.

FILTRATION RESISTANCE

The approach to the concept of constant rate filtration resistance is based upon Darcy's Law:

$$q = -B_1 A \frac{dP}{dx} \qquad (1)$$

where q is the flow rate, B_1 a proportionality constant, A the cross-sectional area available to flow, and dP/dx the pressure gradient. The concept of resistance based upon this relation has been discussed and demonstrated in Progress Report 27, Project 1513 and in Progress Report Two, Project 2211 it was used to derive an equation applicable to a constant rate filtration resistance apparatus:

$$R = \frac{A^2 \Delta P}{\mu q W} \qquad (2)$$

where R is an average drainage resistance, ΔP the overall frictional pressure drop, μ the viscosity, and W the basis weight of the fibrous bed. It was also demonstrated in the latter report that R depends solely on the overall pressure drop.

The form of Equation (2) used in calculations with data from both the research model filtration resistance apparatus and the A.I.L. Drainage Resistance Analyzer is:

$$R = B \frac{\Delta P/\rho g}{\theta} \qquad (3)$$

where: R = drainage resistance, cm./g.

ΔP = overall pressure drop, dynes/cm.^{2}

θ = time, sec.

ρ = density of the water, g./cc.

g = gravitational acceleration, 980.0 cm./sec.^{2}

B = the test constant

The test constant $\underline{B}$ is calculated from the equation

$$B = \frac{A^2 \rho g}{C \mu q^2} \qquad (4)$$

where $\underline{A}$ = area of the septum, cm.^{2}

$\underline{C}$ = fiber concentration of the fiber slurry, g./cc.

μ = viscosity of the water, poises (dyne-sec./cm.)

$\underline{q}$ = flow rate through the fiber mat, cc./sec.

THE DRAINAGE RESISTANCE ANALYZER

APPARATUS

The Drainage Resistance Analyzer Type 273 is manufactured by the A.I.L. Division of Cutler-Hammer Incorporated. It consists of a 20-liter Lucite deckle and a 3-inch septum with a 64 x 51-mesh nylon screen. Pressure sensing ports are located on either side of the septum to measure the pressure drop across the fiber mat as it forms. A centrifugal pump with a needle valve throttle on the output followed by a rotameter (1.44 g./m. maximum) is used to obtain a constant flow rate past the septum while transducers provide a measure of the pressure drop up to 100 cm. water presented as a function of time on a strip chart recorder. The water temperature during a test is indicated by a thermometer located downstream from the pump. The operation of the pump and valving is controlled through relays and solenoid valves so that the test can be started and stopped over a given interval; a digital timer indicates the actual test time. By means of potentiometers in the controlling circuitry the test can be halted upon reaching any of four preset pressure drops selected by a five position switch. Front and rear photographs of this unit are shown in Fig. 1 and 2, respectively. A schematic diagram of the hydraulic system is shown in Fig. 3.

Previous to this work, difficulties had been experienced with the pressure limit switch operations and it was decided to operate in such a manner that pressure drop curves over a given time interval would be obtained. Consequently, an R. W. Cramer five-minute timer was connected to the unit so that the pump, the downstream solenoid valve, the recorder chart and pen drives, and time recorder could be shut down after a given interval of operation up to five minutes. A double pole switch was used to take the timer control out of the circuit; the

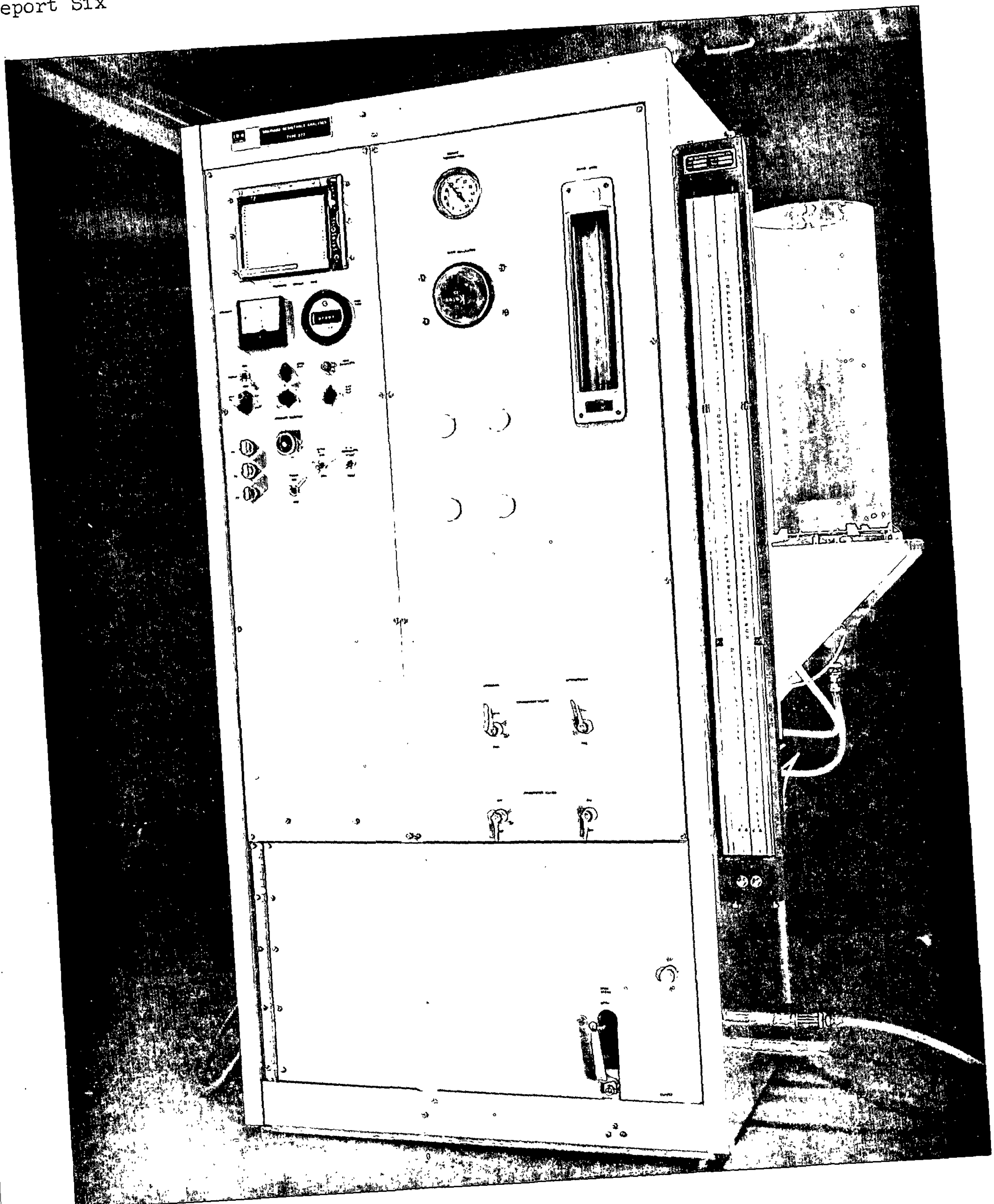

Figure 1. A.I.L. Type 273 Drainage Resistance Analyzer — Front View

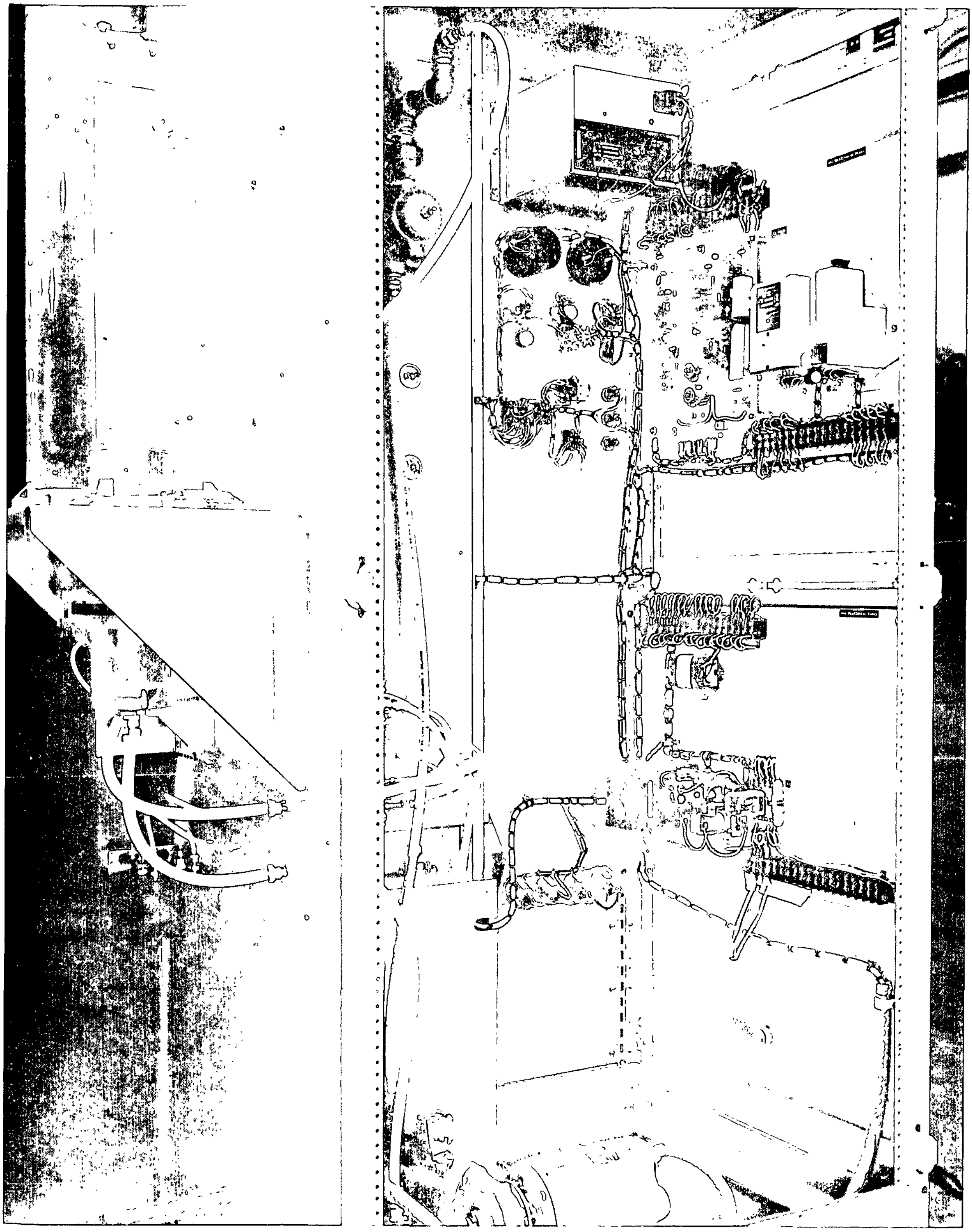

Figure 2. A.I.L. Type 273 Drainage Resistance Analyzer — Rear View, Cabinet Doors Removed

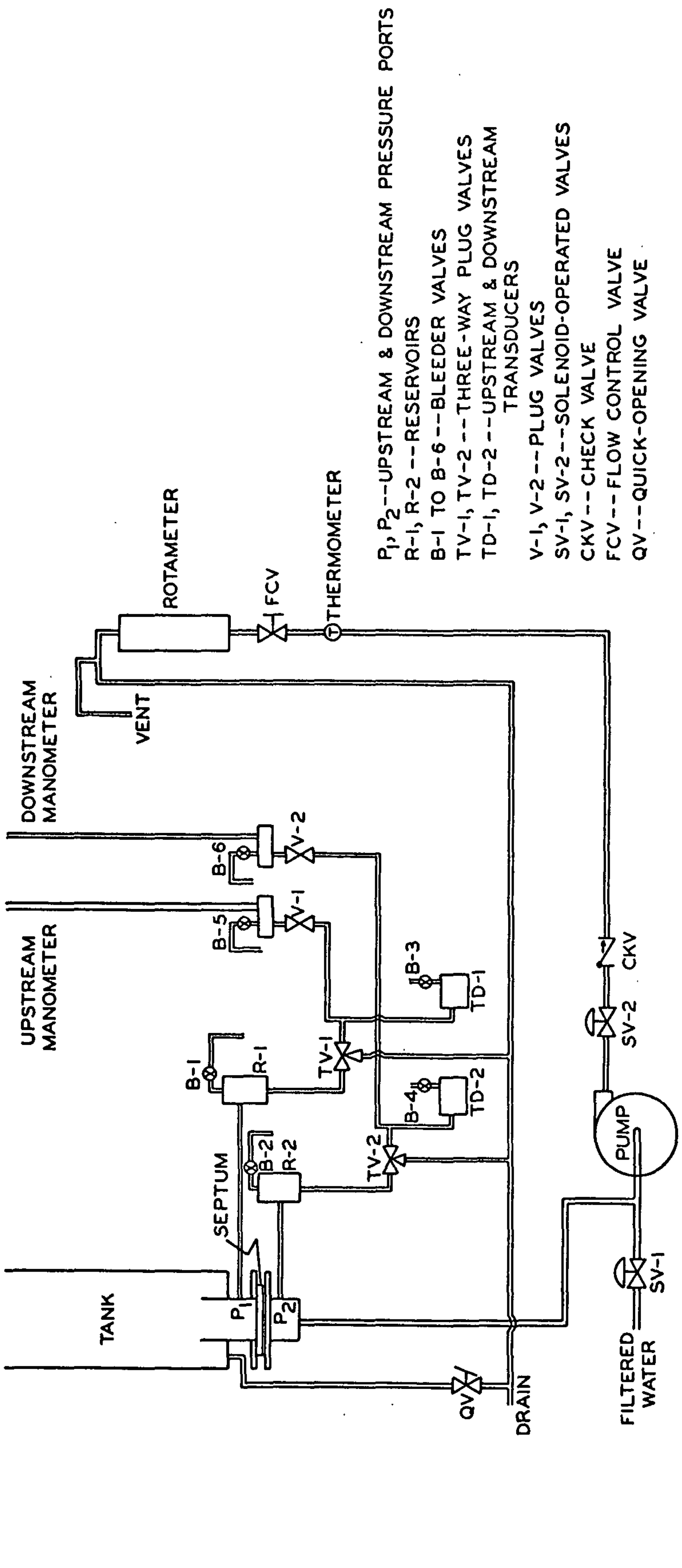

Figure 3. Schematic Diagram of Hydraulic System in A.I.L. Type 273 Drainage Resistance Analyzer

start-reset switch allowed the test to be halted should the pressure drop reach 100 cm. before the end of the set time interval.

Two conditions which were not desirable were noted prior to the tests; their effects were not entirely assessed. The first was a surge in flow rate lasting several seconds which occurred when the pump was started at the beginning of the test and resulted in a slight bump in the pressure trace. This was attributed to an inertial effect from the pump. An attempt was made to reduce this surge with a bypass line but this did not remedy the situation. The "bump" did not seem to alter the continuity of the trace and nothing more was done concerning this. The second condition was due to the downstream location of the thermometer. A slight temperature rise was noted in cases where the pump was operated without flow or at very low flow rates meaning that the water was gaining heat in the pump so that the temperature at the septum was not necessarily the same as the indicated temperature. Since the temperature changes were small, representing only slight viscosity changes, the temperatures indicated during the tests were accepted as the water temperatures at the septum.

Some agitation in the deckle box during a run was found necessary. A perforated three-inch diameter sheet mold stirrer connected to a laboratory stirrer motor by a crankshaft to provide reciprocal two-inch motion at a frequency of 100 strokes per minute proved satisfactory.

CALIBRATION

Calibration of the transducers was necessary at the beginning of the trials, and checks and adjustments were made during the course of the trials. This was accomplished through manometers connected to each of the transducers through valves in such a way that they could be filled via the pressure ports, and bled to give a differential pressure between the transducers. With a zero differential the transducers were adjusted to a zero voltage output as read on a null voltage meter. The strip chart recorder was then adjusted to read directly the differential pressure between the transducers.

OPERATION

An arbitrary fill level of 18,770 ml. was set and marked on the deckle box and sample dilutions were made to this volume; this corresponded to 100 cm. on the manometer tubes. A test was run by introducing the sample into the partially filled deckle and diluting to the fill level. The sample was dispersed and the septum checked visually for entrapped air. At this point a 500-ml. aliquot was taken, filtered onto a tared filter paper, dried on a hot plate, and weighed in a hot balance as a check on the deckle consistency. The flow rate was adjusted to the desired setting; the deckle refilled to the level mark and the sample redispersed. The timer was switched into the circuit and switched on to begin the test. In cases where replicate tests were desired on the same sample the deckle was refilled, the sample redispersed, and the test repeated.

EXPERIMENTAL WORK

An experimental program in three phases, identified as Trial I, Trial II, and Trial III, covering a range of beating conditions, was set up. Also, since the fine materials present in a pulp seem to play a role of their own, tests on whole pulp samples were duplicated on samples with fines removed by classification.

Ideally, drainage resistance as applied to this analysis is a function of pressure drop and is unaffected by consistency and drainage rate. However, consistency can be a factor if it is sufficient that interactions between fibers occur to the extent that flocculation takes place somewhat before deposition on the fiber mat (0.01% is generally considered a level at which negligible fiber interactions occur). Also, drainage rate and consistency affect the rate of mat formation on the septum, in turn affecting the rate of change in pressure drop. The sensitivity and response characteristics of the pressure sensing and indicating elements in the unit then becomes involved. The theory of the drainage resistance measurement is based upon the condition of viscous flow; while extreme conditions can produce deviations from this condition, the maximum attainable drainage rate with the A.I.L. unit is within the laminar flow regime.

The first phase, Trial I, was carried out with varied consistencies and flow rates to determine the influence of these conditions through multiple regression techniques. Trial II was conducted under conditions selected from the work in Trial I in order to obtain data that could be compared with resistance values determined on the Institute's research model constant rate filtration resistance apparatus. Phase III was carried out to determine the resistance changes resulting from replicated tests on a single specimen which would be indicative of fiber losses and/or changes in fiber properties and dispersion as the result of repeated mat formation and redispersion.

PULP

Five beater runs (Valley beater) of 2406 stockpile pulp "A", a bleached sulfite, were prepared at beating intervals ranging from zero minutes to 50 minutes. Portions of these beater runs were classified in a Bauer-McNett classifier throwing out everything passing through a 150-mesh screen and combining the rest. The resulting samples tested are listed in Table I.

TABLE I

BEATEN AND CLASSIFIED SAMPLES PREPARED FROM WEYERHAEUSER BLEACHED SULFITE

Sample Code 2406-2387-	Beating Interval	Canadian Standard Freeness, cc.
119-1	0 min.	740
119-1C	0 min. – classified	
119-2	5 min.	700
119-2C	5 min. – classified	
119-3	20 min.	535
119-3C	20 min. – classified	
119-4	35 min.	355
119-4C	35 min. – classified	
119-5	50 min.	200
119-5C	50 min. – classified	

TRIALS AND RESULTS

Duplicate runs were made on one specimen from each sample at nominal consistencies of 0.02, 0.01, and 0.005% and rotameter scale readings of 25, 50, and 100%. The runs on each specimen were begun at 0.02% consistency; runs were made at each flow rate and the dispersed specimen diluted to the next lower consistency by draining 50% of the dispersion in the deckle box and rediluting. At filtration flow rates greater than a rotameter reading of 57% the deckle was emptied before the five-minute test interval. Therefore, at greater flow rates the test was halted when the level of the dispersion reached the top of the septum cell and the time interval was noted on the strip chart record. These runs were termed Trial I.

From these runs conditions were selected for each sample that would result, if possible, in a pressure drop of 50 to 60 cm. water after an interval of 300 seconds. Duplicate runs were made on each specimen. These runs were termed Trial II.

In Trial III a sample of classified pulp and a sample of unclassified pulp was selected that would give a 50-cm. pressure drop at 300 seconds and ten replications were run on a single specimen of each sample. The purpose of these runs was to observe any changes in filtration resistance that might occur in repeated testing due to fines loss or changes in fiber properties resulting from repeated mat formation and redispersion.

The results of these trials shown in terms of the pressure drop across the mat at the end of a run are presented in Tables II, III, and IV.

TABLE II

AVERAGED RESULTS OF TRIAL I

			Nominal Consistency					
			0.02%		0.01%		0.005%	
Sample	Beating Interval	Flow Rate,%[a]	ΔP, cm. H_2O	Time, sec.	ΔP, cm. H_2O	Time, sec.	ΔP, cm. H_2O	Time, sec.
119-1	0 min.	25	7	300	4	300	4	300
		50	38	300	14	300	8	300
		100	100	136	45	172	16	171
119-1C	0 min.--classified	25	4	300	4	300	3	300
		50	15	300	9	300	7	300
		100	42	173	17	172	11	172
119-2	5 min.	25	10	300	5	300	4	300
		50	100	292	21	300	10	300
		100	100	71	80	173	24	173
119-2C	5 min.--classified	25	5	300	4	300	4	300
		50	18	300	10	300	8	300
		100	67	171	23	173	12	175
119-3	20 min.	25	48	300	12	300	4	300
		50	100	122	100	285	16	300
		100	100	30	100	84	85	173
119-3C	20 min.--classified	25	7	300	4	300	4	300
		50	42	300	15	300	9	300
		100	100	115	52	173	17	173
119-4	35 min.	25	100	162	88	300	8	300
		50	100	47	100	114	92	299
		100	100	14	100	39	100	81
119-4C	35 min.-classified	25	8	300	5	300		
		50	61	300	19	300		
		100	100	87	85	172		
119-5	50 min.	10	100	300	8	300		
		25	100	89	100	208	22	300
		50	100	30	100	78	100	202
		100	100	9	100	26	100	73
119-5C	50 min.--classified	25	11	300	6	300	12	300
		50	100	247	32	300	100	247
		100	100	59	100	125	100	59

[a]Rotameter scale reading--flow at full scale (100%) is 1.44 g./m.

TABLE III

AVERAGED RESULTS OF TRIAL II

Sample	Beating Interval	Measured Consistency, %	Flow Rate,[a] %	ΔP, cm. H_2O	Time, sec.
119-1	0 min.	0.0190	60	63	297
			50	40	299
119-1C	0 min.--classified	0.0184	100	44	174
			50	16	301
			25	4	302
119-2	5 min.	0.0182	45	55	302
			40	36	295
119-2C	5 min.--classified	0.0177	85	49	202
			80	42	215
119-3	20 min.	0.0185	27	54	300
			26	45	301
			30	100	294
119-3C	20 min.--classified	0.0180	56	53	301
			55	46	301
119-4	35 min.	0.0079	23	43	298
			25	59	298
			20	30	297
			10	4	298
119-4C	35 min.--classified	0.0184	47	53	298
			48	50	301
			49	60	314
			50	58	299
			45	37	298
			40	26	298
119-5	50 min.	0.0090	14	53	298
			13	45	298
			12	39	301
			10	20	305
			15	82	300
			20	100	224
119-5C	50 min.--classified	0.0186	37	49	298
			35	35	301

[a]Rotameter scale reading--flow at full scale (100%) is 1.44 g./m.

TABLE IV

RUN BY RUN RESULTS OF TRIAL III

Sample	Beating Interval	Measured Consistency, %	Flow Rate,[a] %	Run	ΔP, cm. H_2O	Time, sec.
119-3C	20 min.--classified	0.0175	56	1	48	301
				2	52	301
				3	50	301
				4	52	298
				5	50	298
				6	50	300
				7	47	298
				8	56	301
				9	52	298
				10	55	301
119-3	20 min.	0.0186	26	1	40	302
				2	42	301
				3	40	302
				4	43	299
				5	40	299
				6	52	299
				7	50	299
				8	56	298
				9	55	298
				10	60	298

[a]Rotameter scale reading--flow at full scale (100%) is 1.44 g./m.

CALCULATIONS

The drainage resistance was calculated at intervals of 10-cm. water pressure drop from Equations (3) and (4). These calculations were carried out by means of a computer program and a multiple regression analysis was run on the calculated resistance as a function of fiber concentration (consistency), temperature, flow rate, and pressure drop. This analysis shows the dependency of the resistance on the levels of these four variables. Ideally the dependency should be zero for the various levels of consistency, temperature, and flow rate and 100% less a small amount attributable to random test variations for the pressure drop. Measurement errors and variations in the levels of these variables would be included in their accounted influence on resistance so that an influence attributable to one of the variables other than pressure drop does not necessarily indicate a true dependence. The regressions are summarized for all three trials in Table V. In most cases, nearly all of the changes in resistance are accounted for by changes in pressure drop. In those cases, particularly Trial I, where other factors seem to contribute greatly to the resistance variations the overall pressure drop was small, i.e., less than 10 cm. This, more than anything, indicates a lack of precision under conditions where the overall pressure drop is low.

Drainage resistances calculated from Trial II data are plotted as functions of pressure drop in Fig. 4 and 5 (the resistances are plotted on different scales in the two figures due to the substantial differences in the classified and unclassified pulps). Resistances are plotted for the series of runs in Trial III with constant pressure drop parameters in Fig. 6 and 7. The resistance remained essentially constant with the classified pulp while the resistance of the unclassified pulp, contrary to expectations, tended to increase.

TABLE V

SUMMARY OF MULTIPLE REGRESSION DATA

TRIALS I, II & III

TRIAL I

Sample	Beating Interval	Consist.	Variation Accounted, % Temp.	FR	P	All	Runs
119-5C	50 min.--classified	10.2025	0.4466	0.0382	84.8012	95.4885	1-19
119-5	50 min.--unclassified	7.3138	0.0106	19.3584	63.9659	90.6487	20-42
119-4	35 min.--unclassified	0.4998	0.0544	1.3815	72.3373	74.2730	43-61
119-4C	35 min.--classified	14.2921	0.0883	0.0113	82.6604	97.0521	175-186
119-3	20 min.--unclassified	3.5284	0.4355	0.2416	81.1782	85.3837	80-99
119-3C	20 min.--classified	18.7638	0.2662	16.0103	22.3658	57.4061	62-79
119-2	5 min.--unclassified	3.2936	0.6264	2.0475	74.1938	80.1613	118-135
119-2C	5 min.--classified	43.7219	0.3380	6.9947	11.6443	62.6989	100-117
119-1	0 min.--unclassified	29.4348	0.8557	6.4586	34.4277	71.1768	155-174
119-1C	0 min.--classified	16.9198	67.9421	0.4333	4.2345	89.5297	136-154

TRIAL II

Sample	Beating Interval	Consist.	Variation Accounted, % Temp.	FR	P	All	Runs
119-1	0 min.--unclassified	0.0000	0.1841	5.5237	83.5482	89.2560	187-192
119-1C	0 min.--classified	0.0000	0.8146	41.1018	34.0027	75.9191	193-198
119-2	5 min.--unclassified	0.0000	0.4321	0.0000	98.5093	98.9414	199-202
119-2C	5 min.--classified	0.0000	0.0920	0.0034	99.4425	99.5379	203-205
119-3	20 min.--unclassified	0.0000	0.0792	0.3052	99.1113	99.4957	206-210
119-3C	20 min.--classified	0.0000	0.0555	0.3037	98.8469	99.2061	211-214
119-4	35 min.--unclassified	0.0000	0.7661	0.1865	97.7853	98.7379	215-220
119-4C	35 min.--classified	0.0000	0.0141	0.0127	96.9502	96.9770	221-228
119-5	50 min.--unclassified	0.0000	0.4643	2.5222	89.1766	92.1631	229-236
119-5C	50 min.--classified	0.0000	0.0609	0.1007	99.2386	99.4002	237-240

TRIAL III

Sample	Beating Interval	Consist.	Variation Accounted, % Temp.	FR	P	All	Runs
119-3C	20 min.--classified	0.0000	1.0446	0.0000	89.5679	90.6125	241-250
119-3	20 min.--unclassified	0.0000	0.9817	0.0000	97.5964	98.5781	251-260

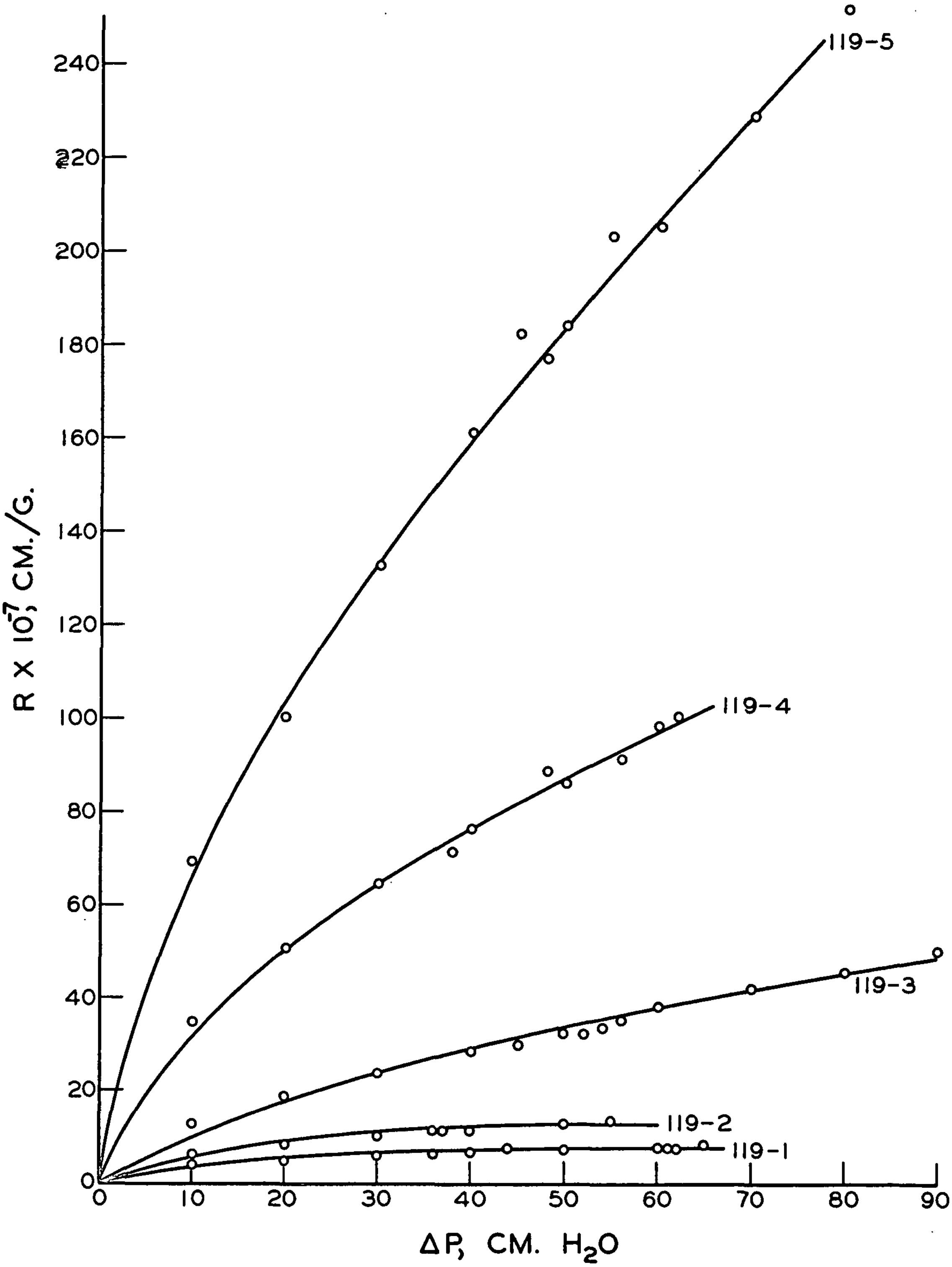

Figure 4. D.R.A. Trial II — Unclassified

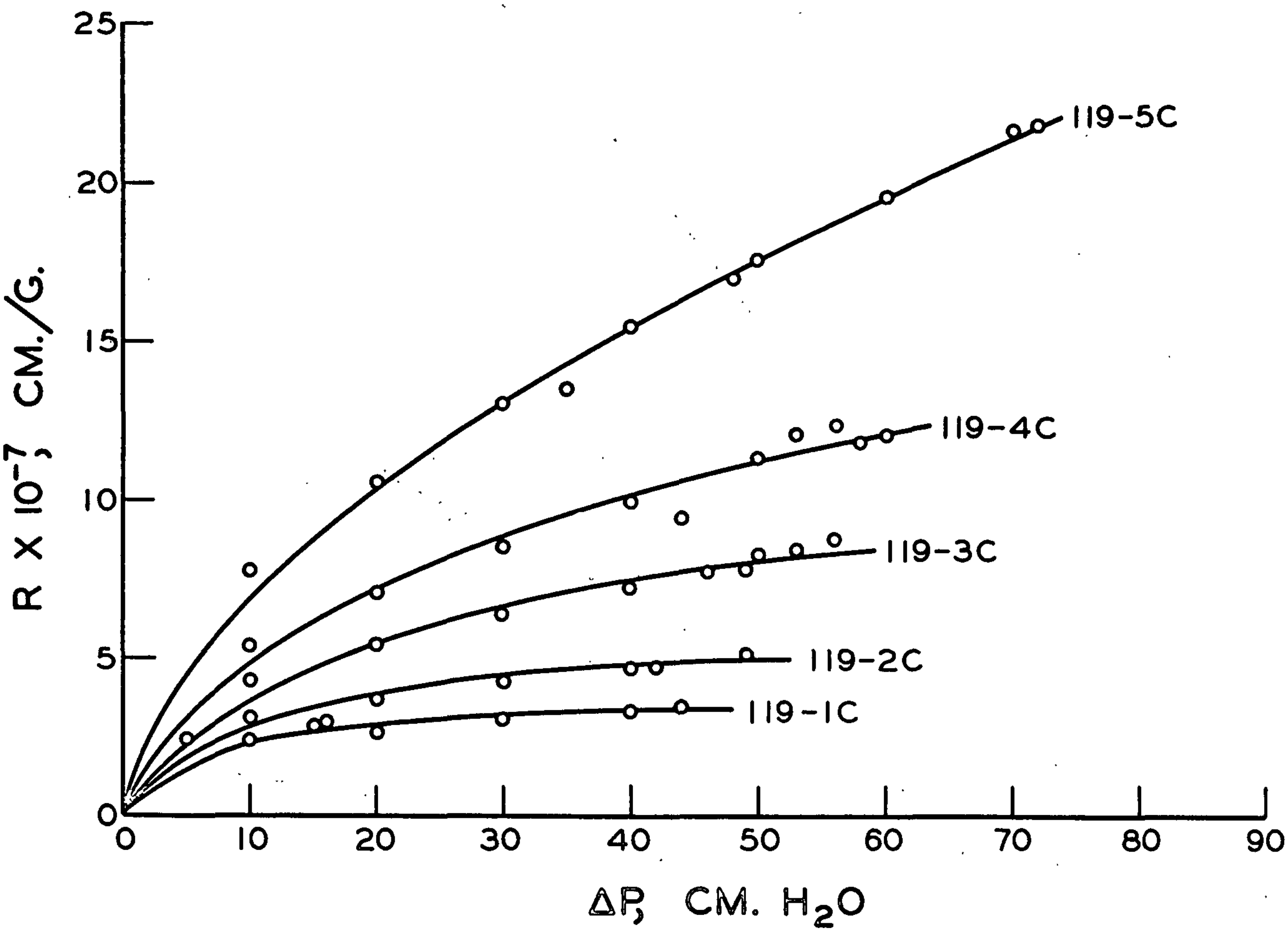

Figure 5. D.R.A. Trial II – Classified

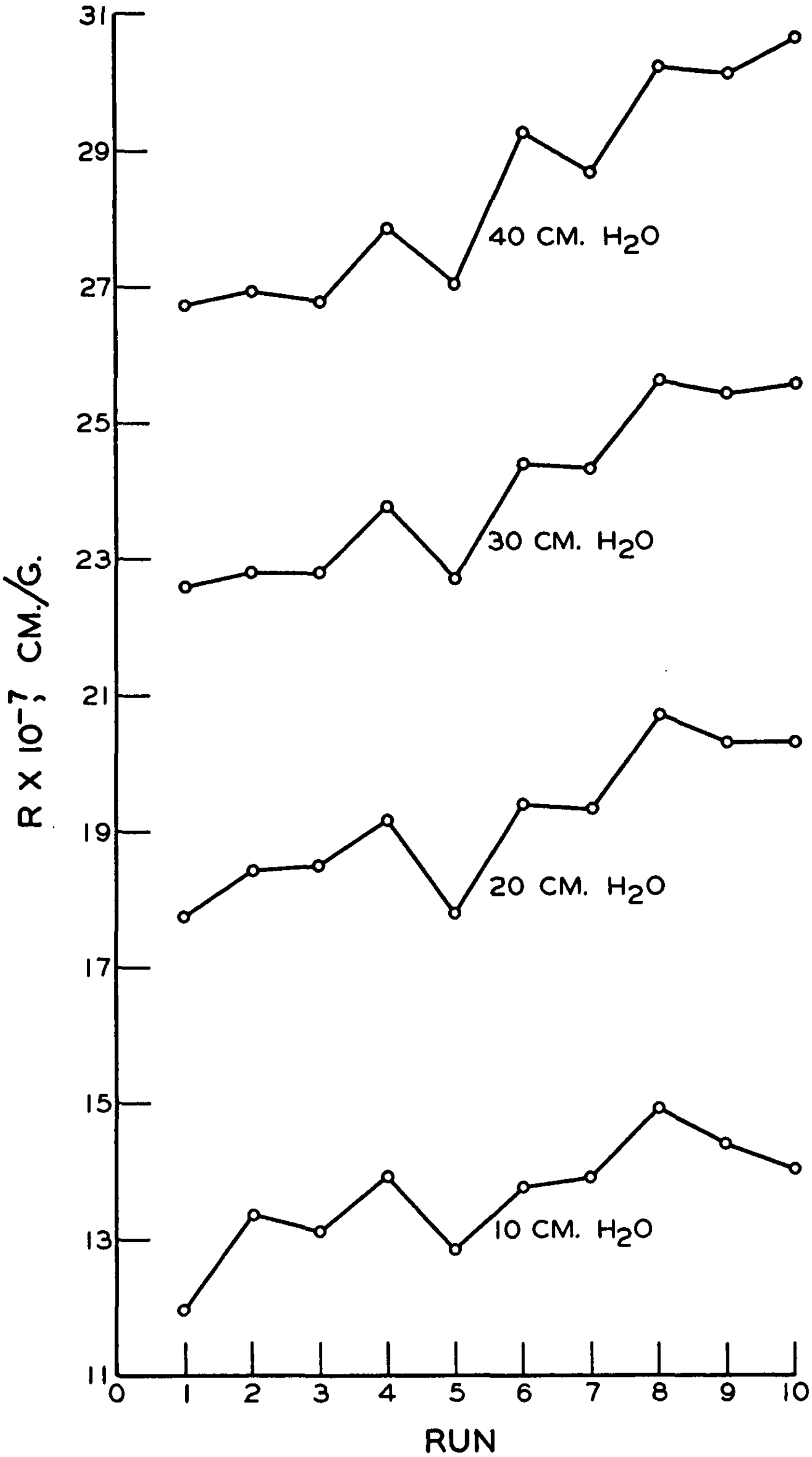

Figure 6. Trial III – Sample 119-3 Unclassified

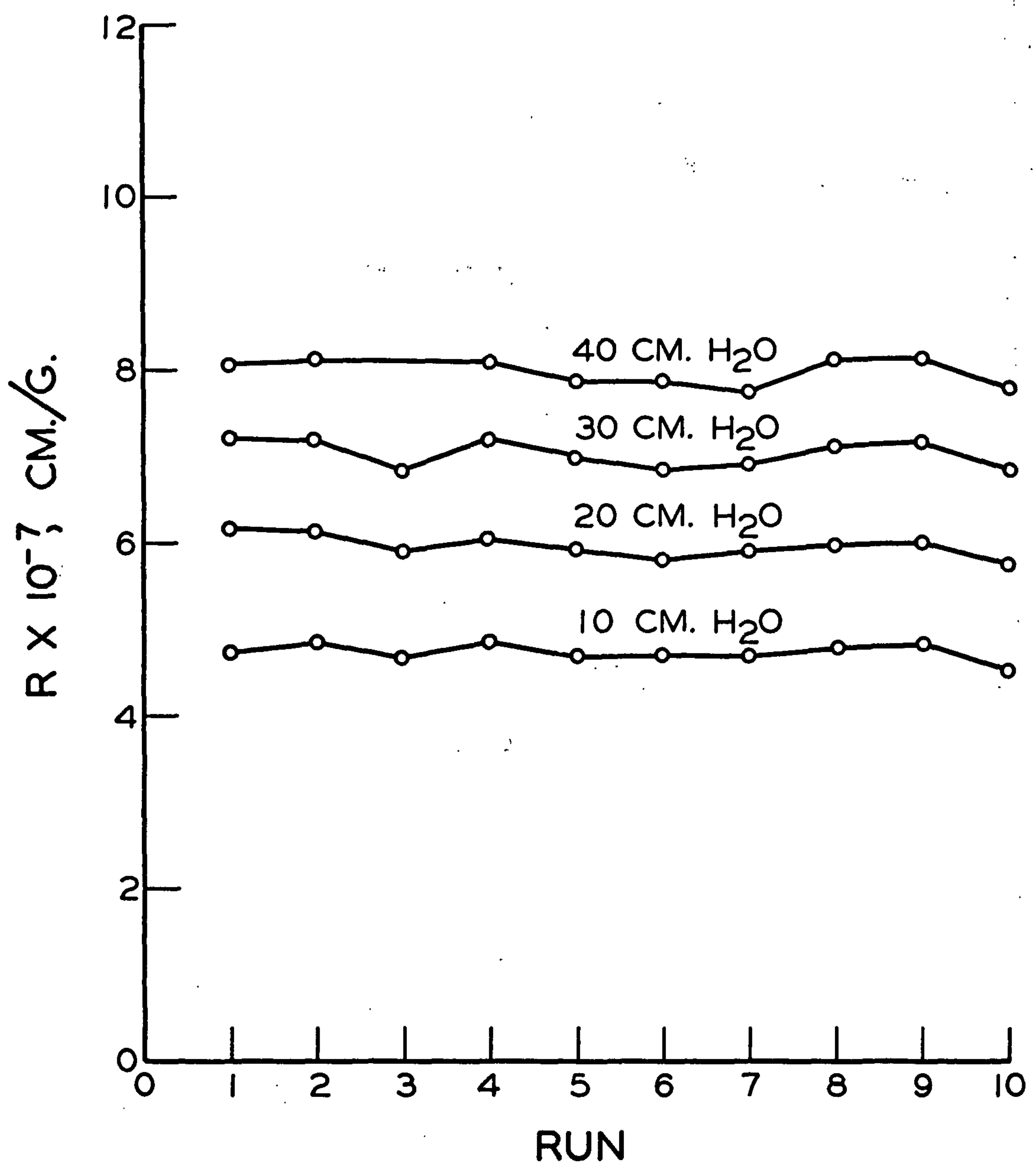

Figure 7. Trial III – Sample 119-3C – Classified

The loss of fines during the mat-forming process would be accompanied by a decrease in drainage resistance with recycling of the tests. Apparently, this did not occur, at least to the extent that the drainage resistance was affected. It has been suggested (2) that the observed increase may be due to fines retention by the larger fibers thereby causing a change in distribution through the mat and an increase in the specific surface of these fibers.

COMPARISON WITH RESEARCH MODEL CONSTANT RATE FILTRATION RESISTANCE APPARATUS

The research model filtration resistance apparatus was constructed at the Institute and used as a basis for the design of the A.I.L. instrument. The research model, shown schematically in Fig. 8, differs from the D.R.A. in that the pressure downstream from the septum is related to a constant head in order to obtain the pressure drop across the mat while the D.R.A., it will be recalled, utilizes a falling head and pressure ports on either side of the septum. The constant head in the research model is maintained by an inflow of fiber slurry over a weir equal to the flow rate. Essentially, there should be no difference in the resistances determined with either unit other than a greater precision with the research model due to a larger strip chart recorder and a more elaborate pumping system; differences do, however, exist. Samples of the same beater runs of pulp were tested on this unit to obtain a comparison between the two units. The results of the runs on the research model are plotted on Fig. 9 and 10 in comparison with the resistance curves obtained with the A.I.L. unit.

The agreement of the test results for the unclassified pulp is good; i.e., within about 10%. The tests on the A.I.L. model tended to show higher resistances at lower pressure drops merging as the pressure drop increased. This might be attributed to the flow surge experienced with the A.I.L. model at the beginning of the run. The test results for the classified pulp samples were not in good agreement – the A.I.L. resistances running 20 to 33% higher at a 40-cm. pressure drop.

The agreement with the unclassified pulp and the lack of agreement with the classified samples was found to be contrary to previous experience (3).

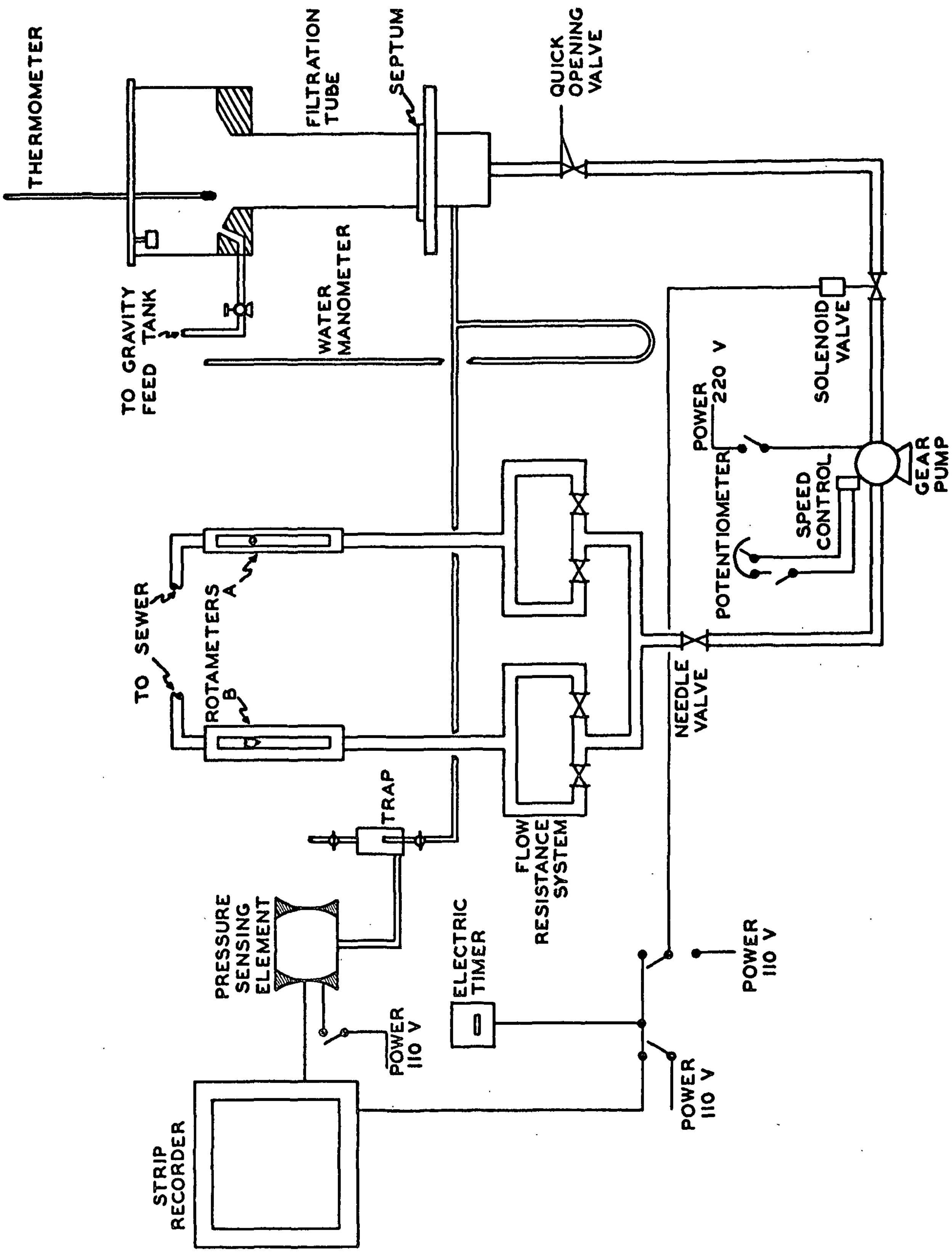

Figure 8. Schematic Flow Diagram of Research Model Constant Rate Filtration Resistance Apparatus Hydraulic System

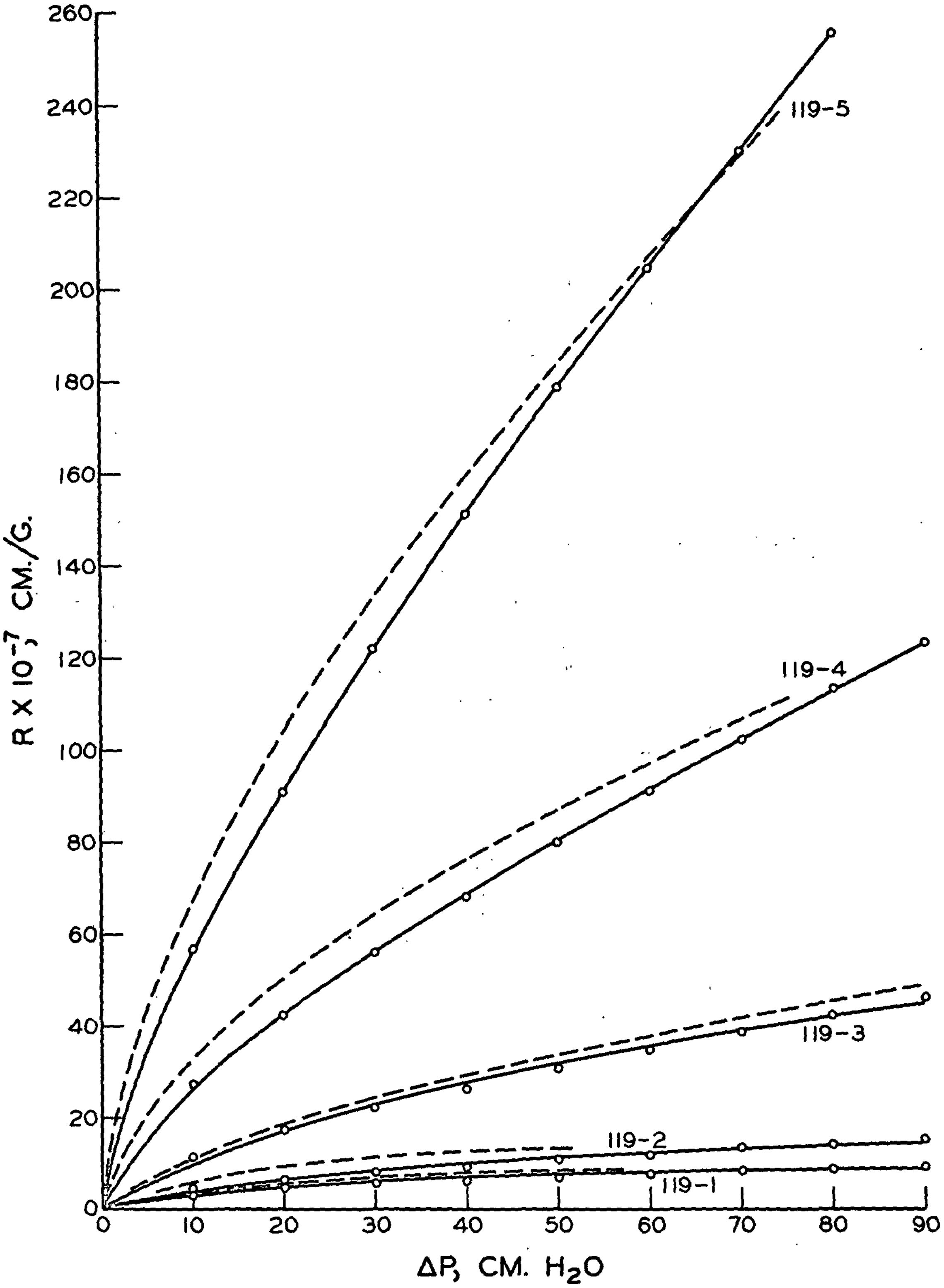

Figure 9. Filtration Resistance Data Obtained with the Research Model Apparatus Plotted in Comparison with Curves Obtained with the A.I.L. Unit (Dashed Lines) - Unclassified Pulp

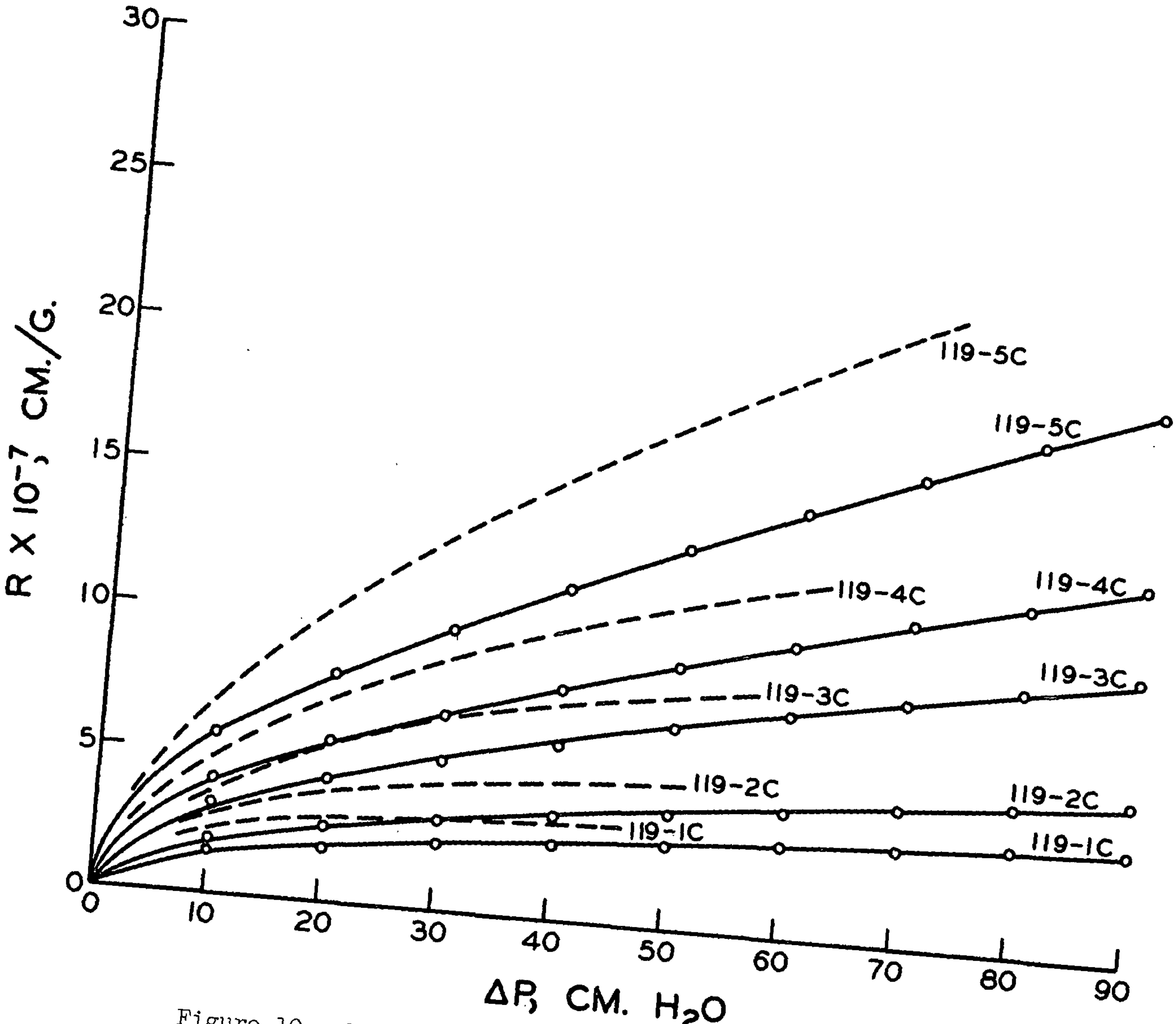

Figure 10. Filtration Resistance Data Obtained with the Research Model Apparatus Plotted in Comparison with Curves Obtained with the A.I.L. Unit (Dashed Lines) - Classified Pulp

Comparative data for the same pulp used in the present work were presented for a sample that had been classified with the Institute's web former on a 70 x 56-mesh wire. These data, plotted in Fig. 11, from the two units were in excellent agreement.

In obtaining this data it was necessary to operate the A.I.L. unit at a consistency of 0.04% and the research apparatus at 0.016%, rather than the customary 0.01% in order to obtain a full-scale pressure drop (95 cm. water) in a reasonable period of time (300 sec.). This consistency was substantially higher than any of the consistencies used in the present experimental design. In the work at the lower consistencies with the classified samples it was not always possible to obtain full-scale pressure drops (see Table II). At the same time the variation accounted for by consistency variations, as shown in Table V, ranged from 10 to 47% for the classified pulps and 0.5 to 7% for the unclassified pulps. From this it would seem that operation of the A.I.L. unit at consistencies too low to produce full-scale pressure drops will yield resistance values higher than the actual filtration resistance of the sample.

In order to affirm this the web-former classified pulp was retested at lower consistencies. Although points could only be obtained at 10 and 20-cm. water-pressure drops with the A.I.L. unit the resulting resistances were higher than those obtained at higher consistencies and on the research unit. These results are shown in Table VI.

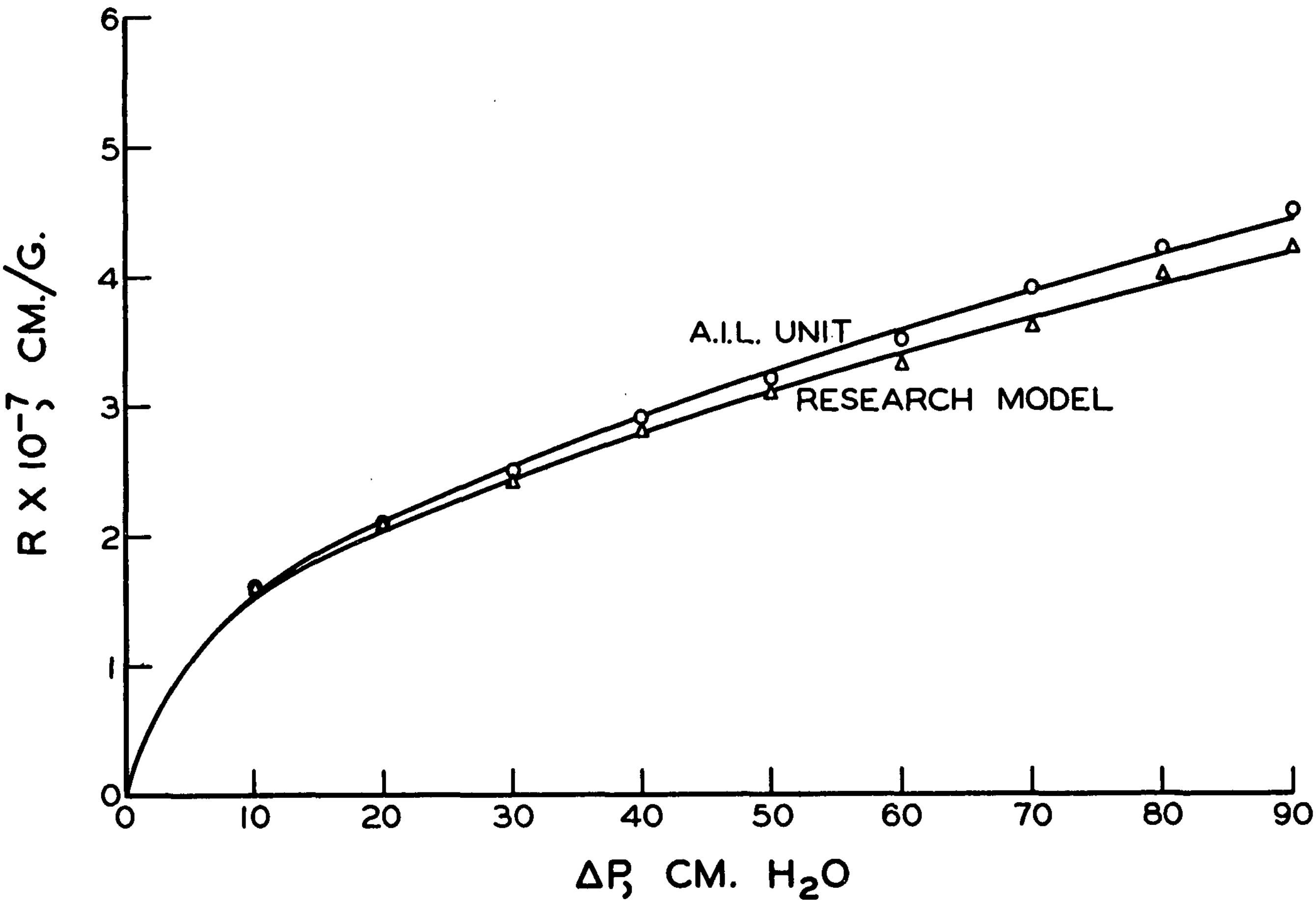

Figure 11. Filtration Resistance Data for Pulp Classified on the I.P.C. Web Former

TABLE VI

FILTRATION RESISTANCES CALCULATED FROM
TESTS AT DIFFERENT CONSISTENCIES

(Pulp sample classified on web-former)

Test Unit	Consistency, %	Filtration Resistance, R x 10^7 cm./g.		
		10-cm. H_2O ΔP	20-cm. H_2O ΔP	50-cm. H_2O ΔP
A.I.L. Drainage Resistance Analyzer	0.04	0.16	0.21	0.32
A.I.L. Drainage Resistance Analyzer	0.01	0.22	0.27	
Research Model Filtration Resistance Apparatus	0.016	0.16	0.21	0.31
Research Model Filtration Resistance Apparatus	0.009	0.16	0.22	0.34

CONCLUSIONS

During the course of these experiments no operational difficulties were encountered with the Drainage Resistance Analyzer. Once warmed up very little drift was noted and with the circuitry left "on" 24 hr. per day calibration once per day was found sufficient. (The pressure cut-off switches were not employed in this work due to previous difficulties which may have been related to faulty performance in the strip-chart recorder circuitry that occurred at the same time; consequently, no comment can be made concerning their use.) The slight bump in the pressure trace at the beginning of each run seemed to have little effect upon the results. The location of the thermometer may introduce some error due to erroneous readings; however, in the regression analysis temperature effects accounted for less than 1% variation in the tests. Reproducibility of the tests was good under conditions sufficient to produce at least a 50-cm. water-pressure drop over a 300-second period with 95% of the change in resistance drop attributable to change in pressure drop. Drainage resistances compared favorably with research model measurements for both classified and unclassified samples providing the deckle consistencies were high enough to produce a 90-cm. water-pressure drop in 300 seconds. Properly used this instrument can provide a reasonably quick measurement of drainage resistance.

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