#1956 THE INSTITUTE OF PAPER CHEMISTRY
(Study of Coater)
Project Reports (10)

PROJECT REPORT FORM

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PROJECT NO. 1956
COOPERATOR I.P.C.
REPORT NO. 46
DATE September 17, 1963
NOTE BOOK --
PAGE -- TO --
SIGNED L. E. Leporte
Lawrence E. Leporte

APPLICATION OF POLYVINYLIDENE CHLORIDE EMULSION
TO GLASSINE--USE OF AIR KNIFE

INTRODUCTION

A series of runs was made in order to determine the problems involved in the application of polyvinylidene chloride coatings to lightweight stocks and to determine whether coat weights in the neighborhood of 10 lb./3000 sq. ft. could be dried and rewound without the use of chill rolls to eliminate blocking.

In a coating weight range of 9 to 12 lb./3000 sq. ft. blocking was not encountered to any degree that would damage the surface as the coated roll was unwound. However, curling resulting from contraction of the coating as it was dewatered was a problem. The problem was amplified by the long draw between the air knife and the rewind.

OPERATIONS

Daran 202 emulsion supplied at 60% solids was applied to Nicolet K-3 glassine having a basis weight of 25 lb./3000 sq. ft. at the air knife coating station. The coating was dried using a combination of Red Ray infrared burners and a Gardner high velocity hot air drier.

The air knife was operated at the settings recommended by Warren-Dilts, the orifice was set at 0.030 in. and the breast roll gap was set at 0.125 in. The color roll was rotated in the web direction, initially at a speed of 65 feet per minute, however, it was necessary to increase the color roll speed to 87 f.p.m.

9-18-63
I talked with Mr. W. H. Smith about sharing two projects m.m.

otherwise skip coating would occur--the 65 f.p.m. setting had been used in trials with Daran 210. The air knife was operated at pressures ranging from 1 p.s.i. to $2\frac{1}{2}$ p.s.i. Web speeds of 200 and 500 f.p.m. were run. Coat weights ranged from 9 to 12 lb./3000 sq. ft.

Three to five Red Ray units were operated with the supply fan damper turned down one-half (burner temperatures or heat output is not known at this setting; the maximum is 100,000 b.t.u./hr./unit). The Gardner unit was operated at a nozzle velocity of 14,000 f.p.m. at a distance of approximately one inch from the web; temperature settings ranged from 300 to 500°F. It was found that when supply fans for more than one of the Gardner units were turned on tension wrinkles occurred at the rewind even when running with a dry uncoated web; consequently, only one unit could be used. In none of the runs did the web feel completely dry at the rewind, the web was limp and usually felt slightly tacky.

The Daran 202 was supplied in 5 gallon polyethylene lined drums. When the first of the two drums used was opened many pieces of "skin" or film were found floating in the emulsion. In the second drum the liner had leaked so that about 50% of the emulsion was in contact with the drum; the drum was badly corroded and the emulsion in contact with the drum had a brown color. It was then noted that the words "Do Not Ship" were written in chalk on the sides of all of the containers on hand.

Mount Hope rolls were installed just ahead of the lead-in roll to the Red Rays and just ahead of the Gardner driers in order to minimize curling. Curl was reduced to a minimum with the bow of the roll heading into the Gardner units perpendicular to the web and one run was made at 200 f.p.m. web speed with no curl or folding at the rewind. Folding at the rewind as the result of curl could limit the duration of future runs and produce an unacceptable stock for double coating.

RESULTS

The conditions and results of the runs are shown in the tabulation. These results indicate that curling problems with glassine imposed by the length of the draw and tension incurred because the web is pulled only by the rewind would cause much difficulty in obtaining a coated stock suitable for double coating. In addition, air knife adjustments other than air pressure and color roll speed would be necessary for coat weights less than 9 pounds. Blocking was not evident to any appreciable extent although other than at the edges where a bead of coating sometimes occurred due to difficulties with the edge doctors on the applicator roll--dried coating tended to build up on the doctors causing loss of contact between the doctors and the roll.

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SIGNED Jack D. Hultman
Jack D. Hultman
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INVERTED BLADE COATING TRIALS FOR THE WEYERHAEUSER COMPANY

During the week of February 24 a series of trials were conducted on the IPC experimental coater for the Weyerhaeuser Company of Plymouth, North Carolina. Participating in these trials were Mr. Jules Homans of Weyerhaeuser and Messrs. Don Gilbert, Don Fird, Jack Hultman and Larry Leporte of the Institute staff. The trials were run using an inverted blade mounted on the Dilts Contracoater unit to apply clay-TiO_2 and clay-carbonate coatings with binders of various latices to the sized side of a starch sized and machine calendered 12 point liner-board.

The purpose of these trials was to study the effects of combinations of pigments and latices and drying temperatures on ink holdout properties and streaking. Weyerhaeuser scheduled these trials because of difficulties occurring in the use of their coated paperboard due to excessive ink holdout and streaking problems that occur from time to time due to the buildup of grit and/or coagulum at the blade.

An inverted blade setup was used to simulate the on-machine Beloit inverted blade units in their mill and a single Gardner drier unit was used to simulate their drying facilities which consist of a Beloit air cap and a steam drum (both operated at 350°F). A web speed of 400 f.p.m. was used in the trials; this is Weyerhaeuser's operational speed.

This report is not concerned with the results sought by Weyerhaeuser but with the operation of the inverted blade coater using various coating formulations. The inverted blade used in these trials was hastily designed and constructed on the Friday before the start of the trials (it was not known that an inverted blade was desired until the preceding Thursday). In general it performed satisfactorily and in the sense of the operations described in this report can serve as a prototype for the construction of a more substantial unit.

COATING APPARATUS

An inverted blade unit was devised to operate against the 10 inch diameter rubber backing roll on the Dilts Contracoater using the pan and applicator rolls to apply an excess of coating to the web. The blade was held between two 3-inch wide $\frac{1}{4}$-inch steel plates attached to a pivotable bar that would allow the blade to be rotated into the backing roll for operation and rotated away for shutdown and cleaning. The blade holder and its relationship to the backing roll is shown in Fig. 1. A blade positioning device was constructed to support the blade, provide blade pressure and angle adjustments, and allow quick release of the blade from the web. A Destaco damp was incorporated for the latter operation. A drawing of the left side is shown in Fig. 2, a rod, not shown, was attached to the axis of the blade for easy movement of the blade and holder. The threadup of the unit is shown in Fig. 3.

The blade extension was initially set at 15/16 inch (same extension normally used in pond-type unit) but in the first trial it was found that the metering tended to be excessive, resulting in very low coat weights, and the lack of blade flexibility did allow control of coating weight by means of blade pressure adjustments. The Weyerhaeuser mill normally uses an extension of $1\frac{1}{2}$ inches on its inverted blades. The extension was increased to $1\frac{1}{2}$ inches. The increased extension reduced the blade angle and resulted in higher coat weights and excessive streaking; a slight increase in blade angle rectified this.

Despite the fact that the inverted blade unit was hurriedly designed and constructed its performance was considered quite satisfactory. Because of the design and construction, adjustments were crude and made with difficulty; however, after the unit had been once set up very few adjustments were necessary. In terms of convenience of operation and cleanup the inverted blade was found to be superior to the pond-type trailing blade unit presently available on the pilot coater.

At the beginning of the trials the pan-applicator roll gap was set at approximately 0.020 inches and the web-applicator roll gap was set at 0.016 inches. These settings were arbitrary. The web-applicator gap proved satisfactory; however, it was necessary to reduce the pan-applicator gap. The pan-applicator gap was set to 0.012 inches but, because of an overly tight chain on the applicator drive, the applicator roll cocked and, although the rolls did not touch, the rolls were badly scarred in a band extending roughly one inch from the left hand edges of the rolls in an interim of one run before the situation was discovered. The applicator roll drive chain was lengthened and a gap of 0.013 inches was used for the remainder of the runs.

TRIALS

RAW STOCK

The raw stock used in all of the runs was a 12 point white liner stock starch-sized on one side and machine calendered. The sized side was coated. Basis weight of the stock was 33 lb./1000 sq. ft. It was supplied by Weyerhaeuser.

PREPARATION OF COATING COLORS

The kaolin clay (Hydrosperse produced by Huber) was received in slurry form in 55-gallon drums at 70% solids and did not require any special treatment. The titanium dioxide (Ti-Pure made by duPont) was dispersed by adding it slowly to the clay slurry with agitation supplied by the Cowles dissolver running at 4320 r.p.m. using a 4 inch blade giving a peripheral speed of 4420 ft./min. One per cent Calgon T was added before the titanium dioxide to serve as the dispersing agent.

The calcium carbonate (Purecal O produced by Wyandotte) was dispersed separately at 70% solids in batches of 100 pounds using the Cowles dissolver. The dispersing agents used were 1.5 parts Calgon T and 0.13 parts Tamol 850 based on the weight of Purecal O. The Purecal O was added slowly so as not to overload the Cowles dissolver running with a 4 inch blade at 3600 r.p.m. (3780 ft./min.). After adding all the Purecal O, the agitation was continued for at least 30 minutes. The slurry was found to contain agglomerates that would not pass through a 200 mesh screen (74μ), agitation was continued using a 6 inch blade turning at 3600 r.p.m. giving a peripheral speed of 5650 ft./min. in place of the 4 inch blade to increase the rate of shear. After 30 minutes agitation at the higher shear rate the agglomerates remained. It was decided that the agglomerates could not be broken up so the slurry was used in that form.

The Delta protein (medium viscosity) was cooked in a steam jacketed starch cooker before adding it to the pigment slurry. For 100 pound batches of pigment slurry, one pound of the Delta protein was added with agitation to four liters of tap water. The stream was then turned on and the water was heated to $125^{O}F$ and 59 grams (0.13 parts per 100 parts pigment) of concentrated ammonium hydroxide was added. The protein was cooked for 30 minutes under constant agitation at 125°F.

The protein solution was added very slowly to the pigment slurry under agitation supplied by the Cowles dissolver using a 4 inch blade. Because of protein shock, only very small amounts could be added at once. After the initial shock, a slow trickle of protein could be added without overloading the Cowles dissolver. About 15 minutes was required to add the four liters of protein solution.

Table I gives the coating formulations, with the exception of the defoamer and preservative. Twenty milliliters of Nalco 120 defoamer per 100 pounds of pigment were added to every coating color, 10 ml before adding the protein and 10 ml after. After adding the protein to the pigment slurry, 0.13 parts of Nalcon 248 preservative per 100 parts of clay were added to all of the coating colors.

All of the coating colors were prepared at approximately 65% solids. In most cases the size of the batch of pigment slurry made up for a series of coating colors was 100 pounds of pigment, but a couple of the batches were increased to 120 lbs. The Parez 613 resin, when called for, was added to the pigment slurry before the addition of the binder. After adding the Parez 613, the proper amount of pigment slurry was weighed out in tared stainless steel tanks and the required amount of binder added and stirred in. The pH of the color was then adjusted to 9.0 with concentrated ammonium hydroxide in runs 7-23. The pH of runs 1-6 was not adjusted. The only coating colors whose viscosity seemed to be affected by pH were those containing the Dow QX-2249. The viscosity dropped at the pH was raised to 9.

In a given series of coating colors, the same batch of pigment slurry was used with each of the binders. About 40 to 70 lbs. of coating color was made up for each run, but in most cases about 40 to 45 lbs. was sufficient. Samples of each coating color were taken and solids, Brookfield viscosity and Hercules rheograms were run after coming to equilibrium at 74°F. The rheograms are shown in Fig. 4 thru 26 and the viscosities obtained at 1150 r.p.m. are shown in Table I.

DRYING

Drying was done with the first Gardner unit only. In order to simulate more closely Weyerhaeuser's facilities, the distance from the web to the drier nozzles was set at one inch (as opposed to the 3/8 inch recommended by Gardner) and the nozzle velocity was reduced to approximately 12,000 ft./min. by partially closing the supply damper. In the first attempt to reach 600°F the high temperature sensor actuated and caused the drier to shut down at 500°F.--it was determined that the throttling of the supply fan so reduced burning rate at the burner that the flame was carrying as far as the high temperature sensor. The supply damper was opened full; however, the high temperature sensing system had evidently become misadjusted so that temperatures in excess of 550°F could not be maintained. Runs were made at three drying temperatures, 200, 400 and 550°F, to determine the effects of drying temperature on the coating.

RESULTS

All of the runs were made at a web speed of 400 ft./min. The conditions and results of the runs are summarized in Table I. Although a wide range of colors were used it was possible to maintain a fairly narrow range of coat weights by means of blade pressure adjustments. However, some of the higher viscosity coatings, particularly those exhibiting pseudo plastic behavior (see rheograms, Fig. 15, 18, 21 and 24), required critical adjustment of the pan and applicator roll speeds. These coatings tended to flood the blade because of slow drainage back to the color pan. Pan and applicator roll speed adjustments were made at the start of each run for each formulation; each formulation seemed to have a unique and critical pan-applicator roll speed requirement for optimum coating--often any change in speed would result in skipping due to starving.

TABLE I

SUMMARY OF COATER RUNS

TRIAL	COATING: LATEX TYPE	LATEX % (PIGMENT)	PROTEIN, % (PIGMENT)	PIGMENT RATIO: CLAY	PIGMENT RATIO: TITANIUM DIOXIDE	PIGMENT RATIO: CALCIUM CARBONATE	VISCOSITY, CP.: BROOKFIELD 60 rpm	BROOKFIELD 30 rpm	BROOKFIELD 12 rpm	HERCULES, 1150 rpm	SOLIDS, %	ROLL SPEEDS, RPM.: PAN	ROLL SPEEDS, RPM.: APPLICATOR	DRIER TEMPERATURE, °F	COATING WEIGHT, LB/1000 SQ.FT.	COMMENTS
1-1	TYLAC 3500	16	1	90	10	—	3650	5740	9830	75	68.3	68	27	200		COATING COLOR ALSO
-2	" "	"	1	"	"	—	"	"	"	"	"	"	"	250		CONTAINED 1.2% (PIGMENT)
-3	" "	"	1	"	"	—	"	"	"	"	"	"	"	300		PAREZ 613. BLADE
-4	" "	"	1	"	"	—	"	"	"	"	"	"	"	350		EXTENSION SET AT
-5	" "	"	1	"	"	—	"	"	"	"	"	"	"	400		15/16 IN.
2-1	TYLAC 3500	16	1	90	10	—		3870	6810	90	65.6	68	27	200	1.90	1.2% (PIGMENT) PAREZ 613
-2	" "	"	1	"	"	—		"	"	"	"	68	27	400	1.91	IN COATING. INCREASED
-3	" "	"	1	"	"	—		"	"	"	"	54	28	550		BLADE EXTENSION TO 1 1/2".
3-1	RESYN 25-1103	16	1	90	10	—		860	1105	56	64.9	54	28	200		1.2% (PIGMENT) PAREZ 613
-2	" " "	"	1	"	"	—		"	"	"	"	"	"	400		IN COATING.
-3	" " "	"	1	"	"	—		"	"	"	"	"	"	550		
4-1	TYLAC 3500	16	1	90	10	—	4780	7400		79	65.4	14	23	200		1.2% (PIGMENT) PAREZ 613
-2	" "	"	1	"	"	—	"	"		"	"	"	"	400		IN COATING.
-3	" "	"	1	"	"	—	"	"		"	"	"	"	550		
5-1	RHOPLEX B-15	16	1	90	10	—		875	1350	50	64.9	82	35	200	1.77	1.2% (PIGMENT) PAREZ 613 IN
-2	" "	"	1	"	"	—		"	"	"	"	"	"	400		COATING. SOME DIFFICULTY IN
-3	" "	"	1	"	"	—		"	"	"	"	"	"	550		BRINGING COATING TO WEB.
6-1	DOW QX2249	16	1	90	10	—	7900	11,200		99	65.8	46	23	200	2.46	1.2% (PIGMENT) PAREZ 613
-2	" "	"	1	"	"	—	"	"		"	"	"	"	400		IN COATING.
-3	" "	"	1	"	"	—	"	"		"	"	"	"	550		
7-1	TYLAC 3500	16	—	50	—	50	122.5	166		27	65.9	83	48	200	2.19	SKIPPING.
-2	" "	"	—	"	—	"	"	"		"	"	"	"	400		
-3	" "	"	—	"	—	"	"	"		"	"	"	"	550		
8-1	RESYN 25-1103	16	—	50	—	50	99.5	123		31	65.6	84	48	200	2.18	SKIPPING.
-2	" " "	"	—	"	—	"	"	"		"	"	"	"	400		
-3	" " "	"	—	"	—	"	"	"		"	"	"	"	550		
9-1	RHOPLEX B-15	16	—	50	—	50	126.5	158		39	65.4	148	160	200	2.00	SOME STREAKING.
-2	" "	"	—	"	—	"	"	"		"	"	"	"	400		
-3	" "	"	—	"	—	"	"	"		"	"	"	"	550		
10-1	DOW QX2249	16	—	50	—	50	215	285		45	66.6	148	160	200	2.11	
-2	" "	"	—	"	—	"	"	"		"	"	"	"	400		
-3	" "	"	—	"	—	"	"	"		"	"	"	"	550		

TABLE I (CONTINUED)

SUMMARY OF COATER RUNS

Trial	Coating: Latex Type	Coating: Latex %(Pigment)	Coating: Protein, %(Pigment)	Pigment Ratio: Clay	Pigment Ratio: Titanium Dioxide	Pigment Ratio: Calcium Carbonate	Viscosity, Cp.: Brookfield 60 RPM	Viscosity, Cp.: Brookfield 30 RPM	Viscosity, Cp.: Brookfield 12 RPM	Viscosity, Cp.: Hercules 1100 RPM	Solids, %	Roll Speeds, F.P.M.: Pan	Roll Speeds, F.P.M.: Applicator	Drier Temperature, °F	Coating Weight, LB/1000 SQ.FT.	Comments
11-1	Rhoplex B-15	16	1	50	—	50	370	505		47	63.5	148	48	200	1.66	Some Skipping.
-2	"	"	1	"	—	"	"	"		"	"	"	"	400		
-3	"	"	1	"	—	"	"	"		"	"	"	"	550		
12-1	Tylac 3500	16	1	50	—	50	6550	10,140		83	64.3	25	24	200	2.09	Heavy edges. Skipped
-2	"	"	1	"	—	"	"	"		"	"	"	"	400		Badly toward end of run-back.
-3	"	"	1	"	—	"	"	"		"	"	"	"	550		Flow from blade too slow. (Flooded blade)
13-1	Dow QX2249	16	1	50	—	50		3860	7220	86	64.3	25	28	200	2.32	Skipping.
-2	"	"	1	"	—	"		"	"	"	"	"	"	400		
-3	"	"	1	"	—	"		"	"	"	"	"	"	550		
14-1	Resyn 25-1103	16	1	50	—	50	280	302		43	63.9	84	<86	200	2.46	Run 14-1 slight skipping.
-2	"	"	1	"	—	"	"	"		"	"	84	86	400		Runs 14-2,3 No Skipping.
-3	"	"	1	"	—	"	"	"		"	"	84	86	550		
15-1	Tylac 3500	16	1	20	—	80	9550	14,160		102	65.2	26	26	400	2.74	Coating difficult to apply tower
16-1	Rhoplex B-15	16	1	20	—	80	290	416		50	64.6	148	104	400	2.06	
17-1	Resyn 25-1103	16	1	20	—	80	204	304		34	64.7	148	104	400	2.26	
18-1	Tylac 3500	12	1	50	—	50	3500	5500		77	64.8	148	54	400	2.43	Heavy edges, flooded blade.
19-1	Rhoplex B-15	12	1	50	—	50	290	435		47	62.6	148	96	400	2.18	
20-1	Resyn 25-1103	12	1	50	—	50	260	338		38	63.7	148	96	400	2.32	
21-1	Tylac 3500	20	1	50	—	50	7450	11,000		77	62.9	148	44	400	1.76	Flooded blade, heavy edges.
22-1	Rhoplex B-15	20	1	50	—	50	392	546		48	61.7	148	87	400	0.72	
23-1	Resyn 25-1103	20	1	50	—	50	266	373		34	62.2	148	92	400	1.35	

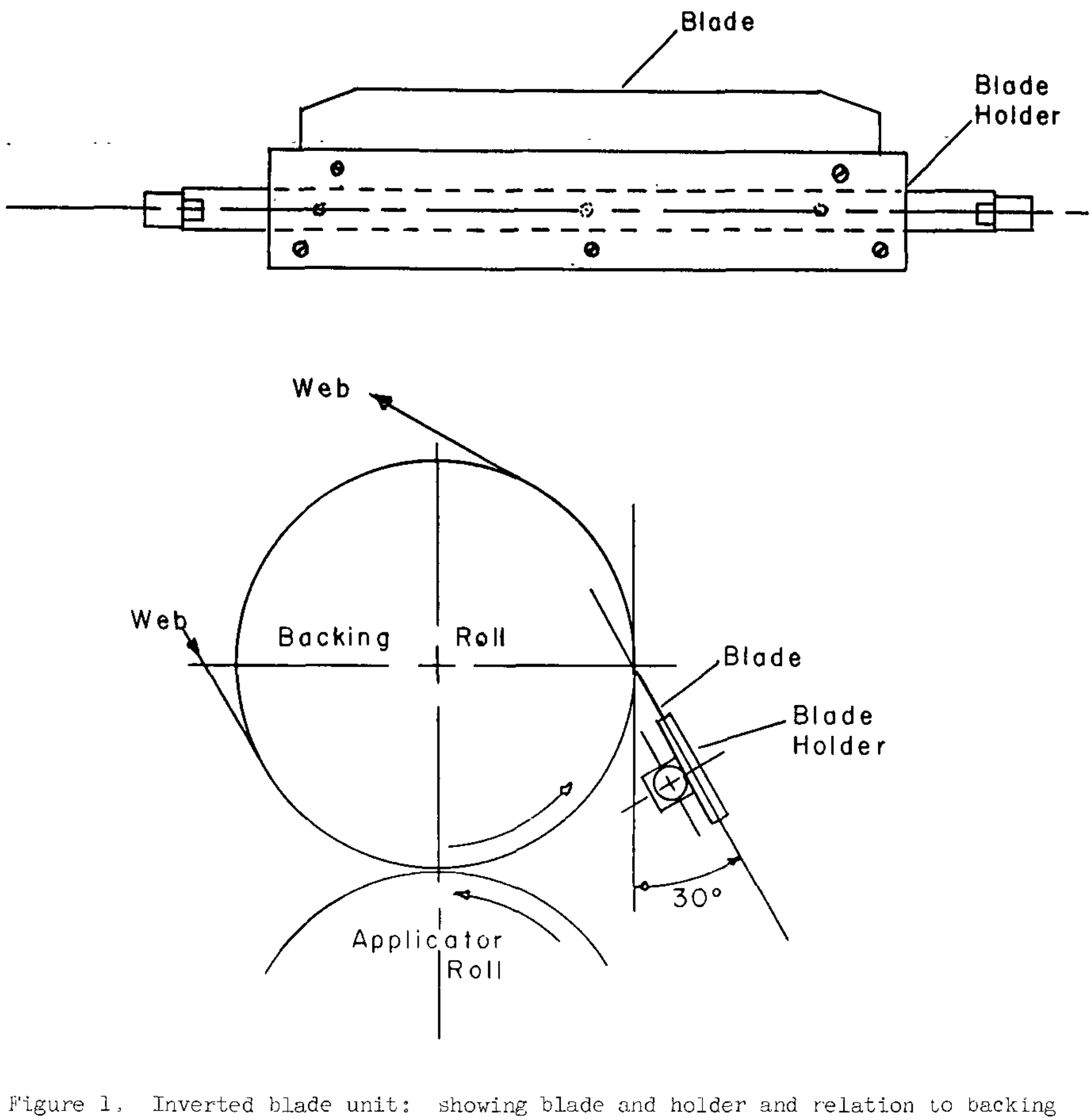

Figure 1. Inverted blade unit: showing blade and holder and relation to backing roll.

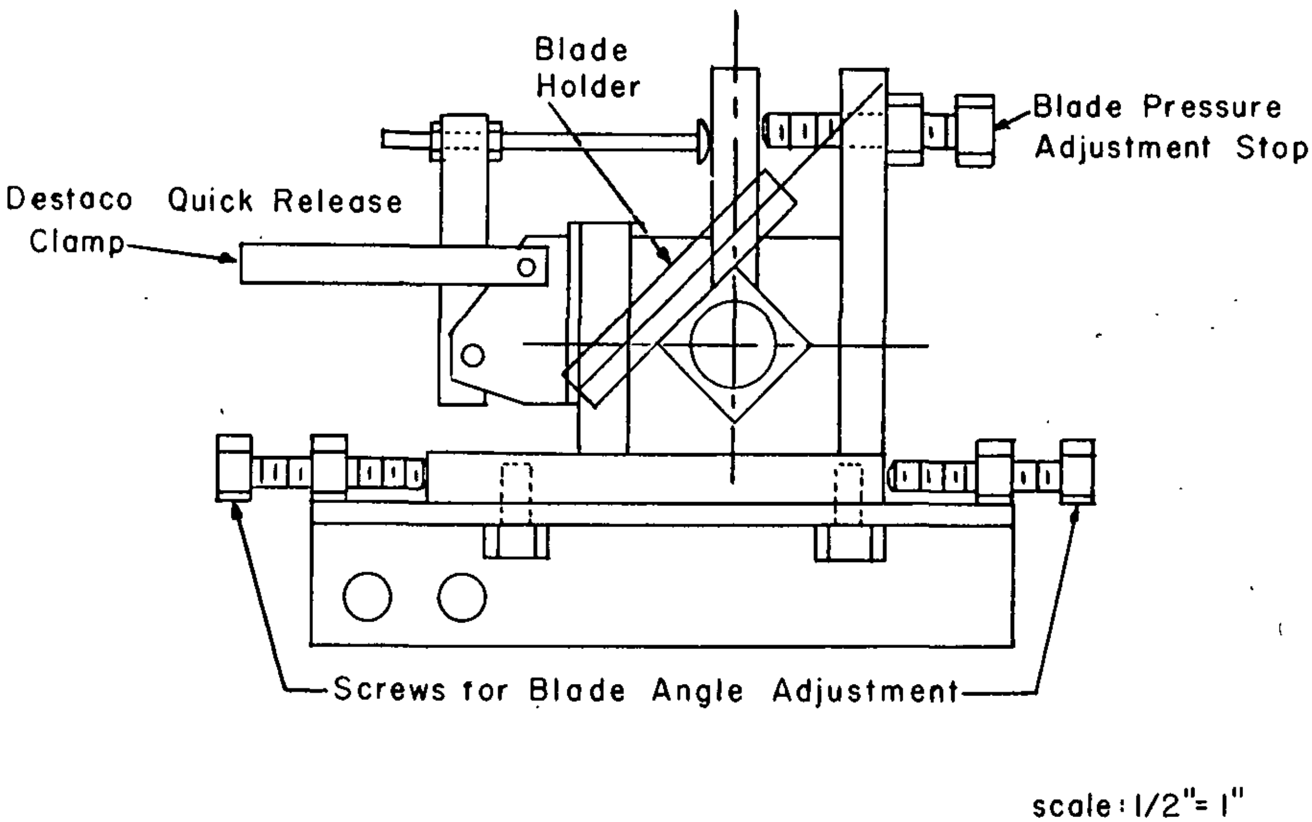

Figure 2. Blade positioning device (left side) with blade and holder superimposed.

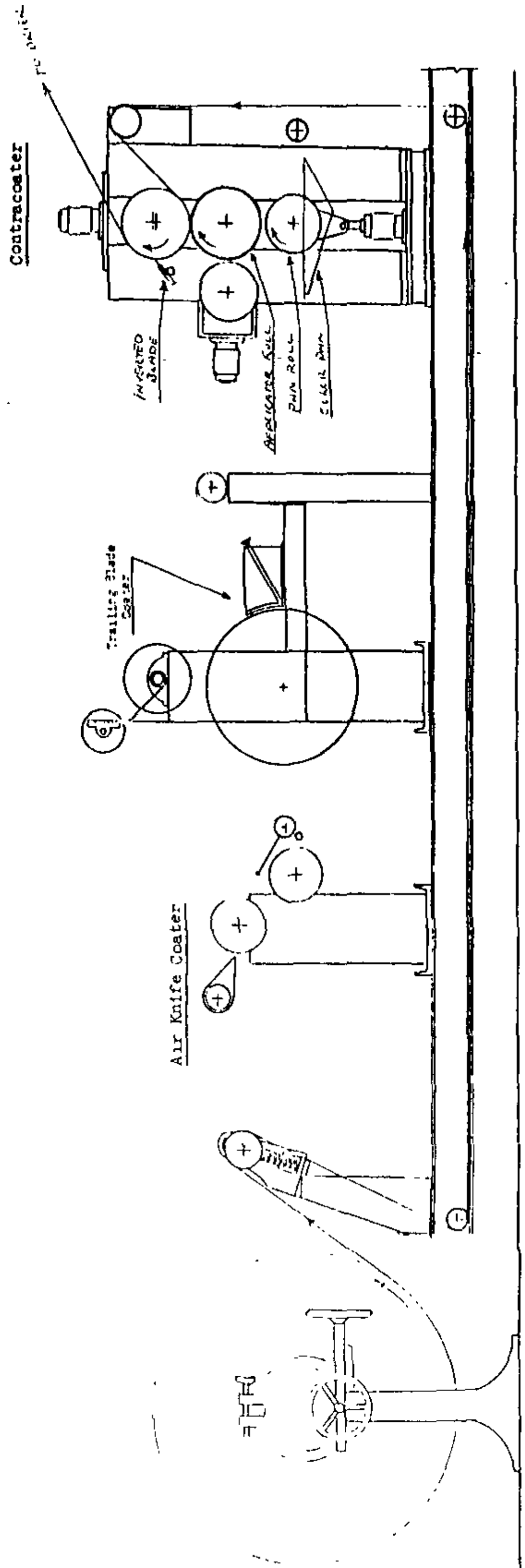

Figure 3. Thread-up of coater.

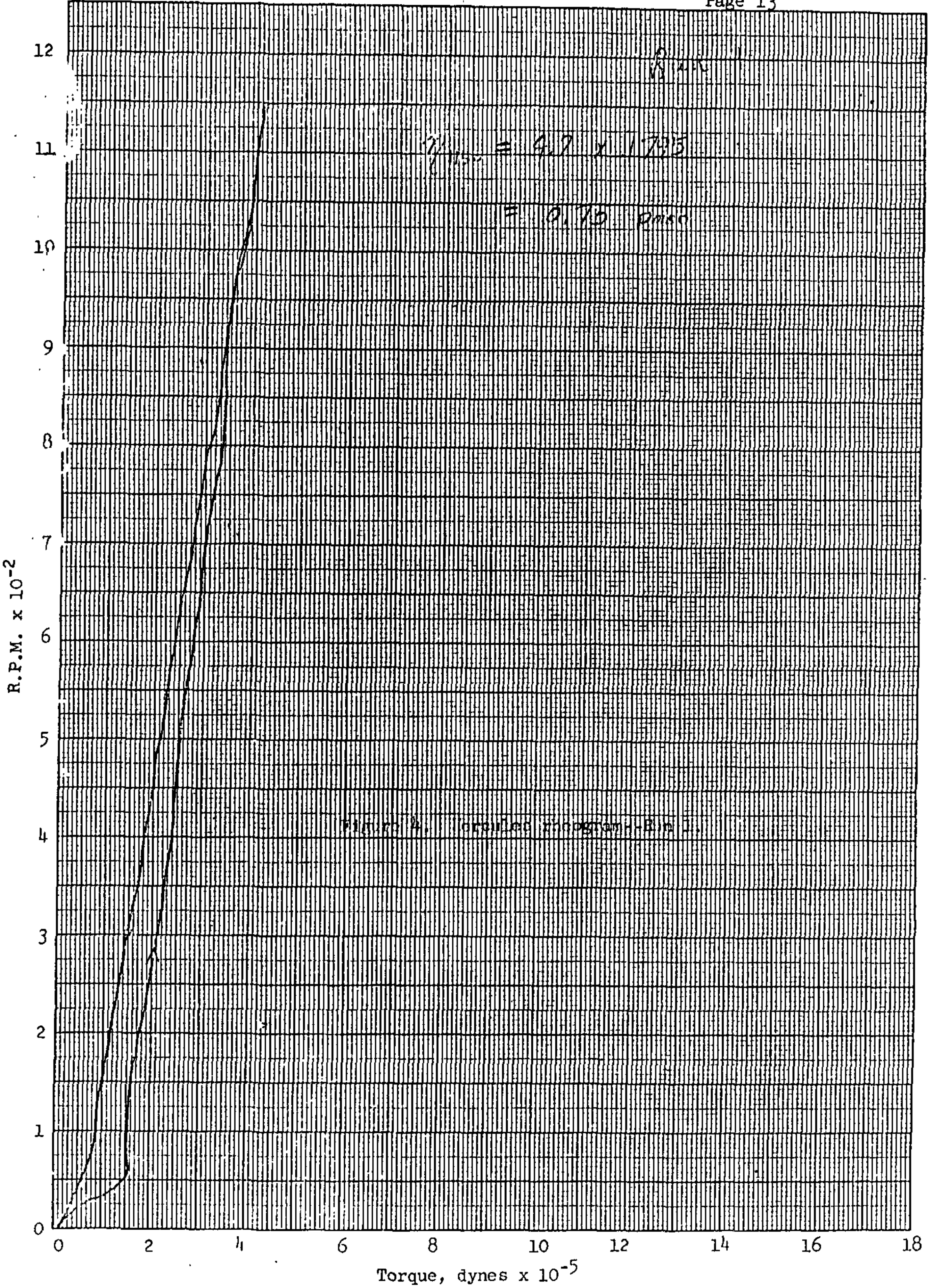

Figure 4. Torsional rheogram--Run 1.

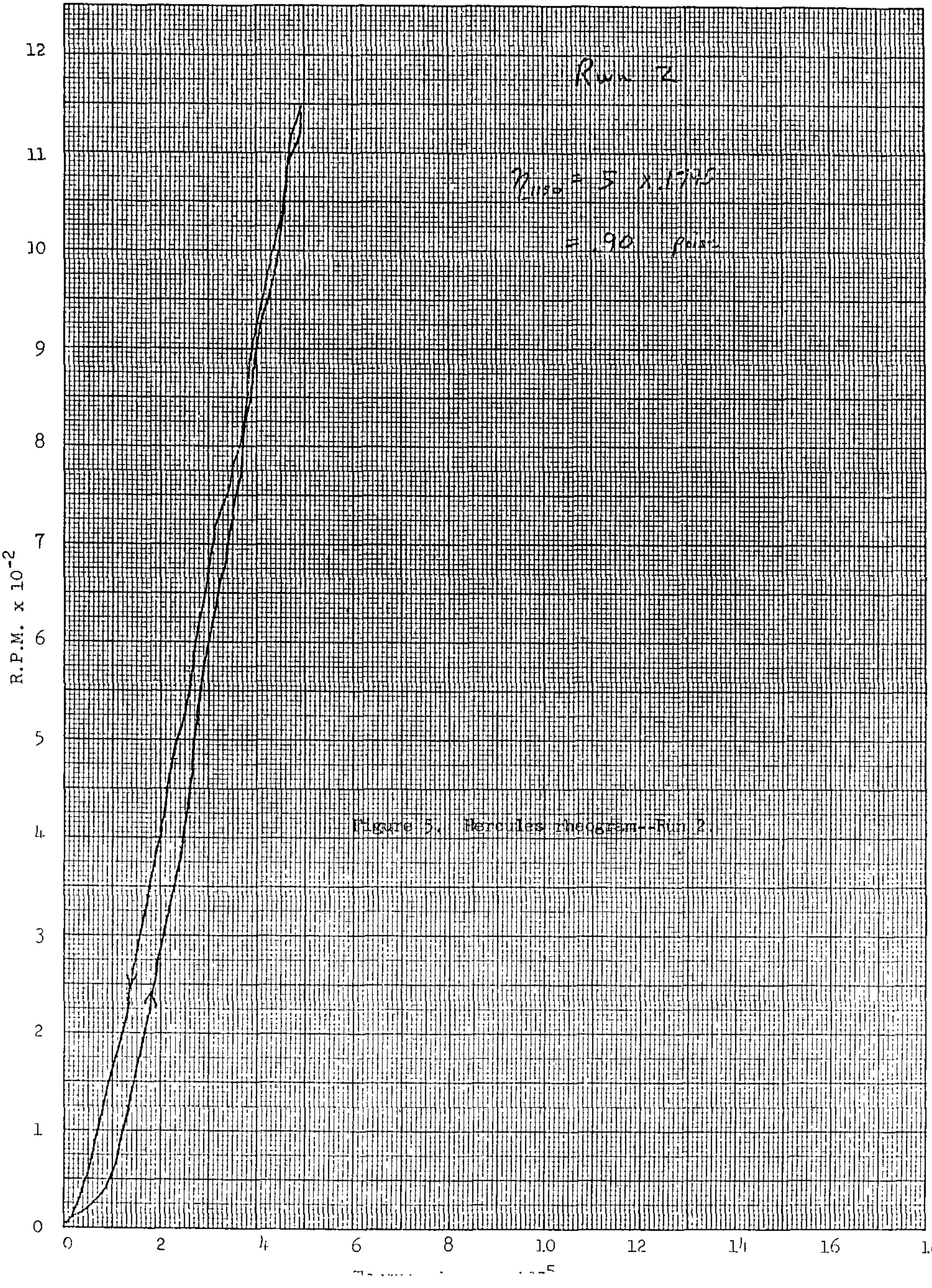

Figure 5. Hercules rheogram--Run 2

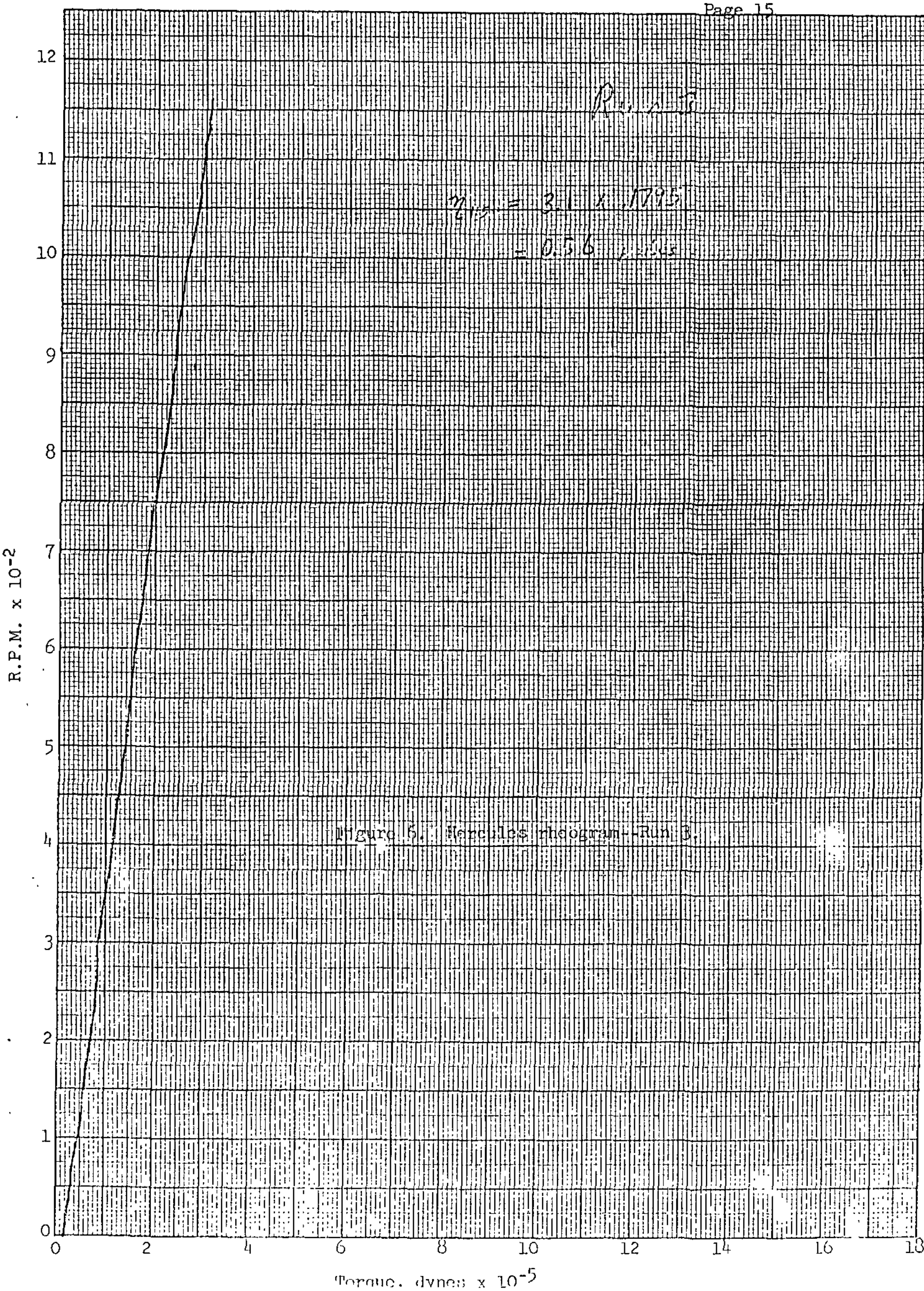

Figure 5. Hercules rheogram--Run 3.

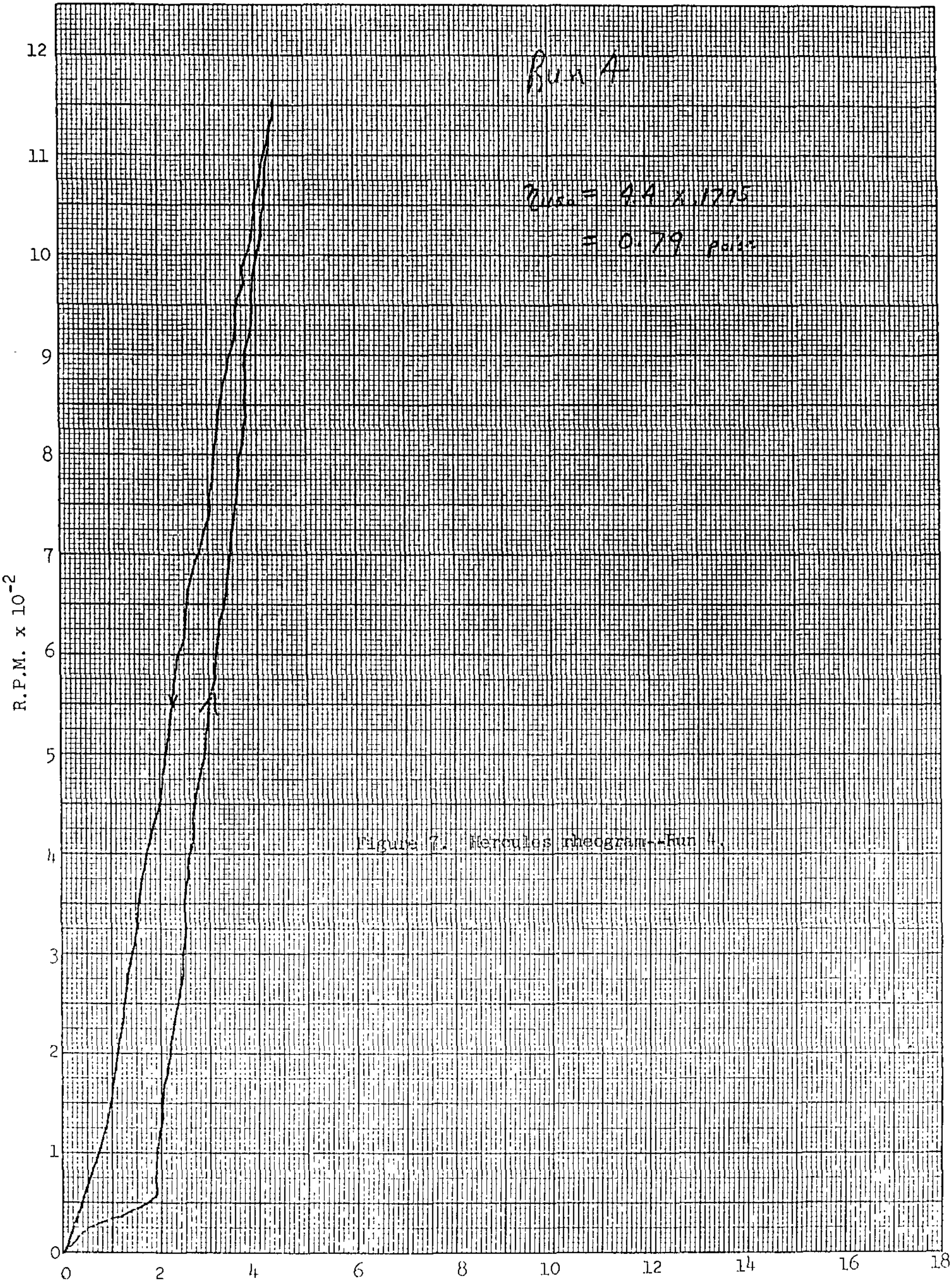

Figure 7. Hercules rheogram--Run 4.

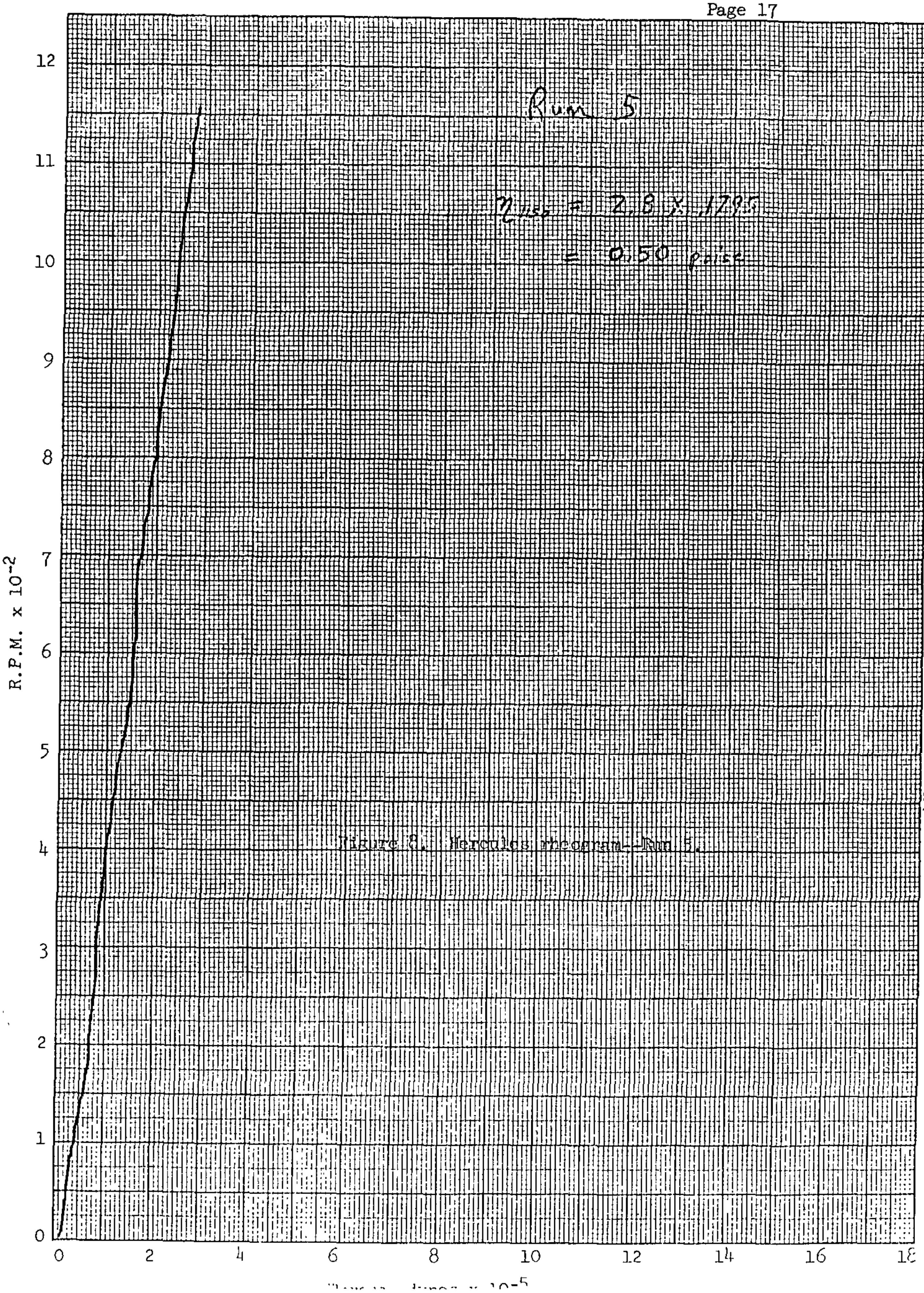

Figure 8. Hercules rheogram--Run 5.

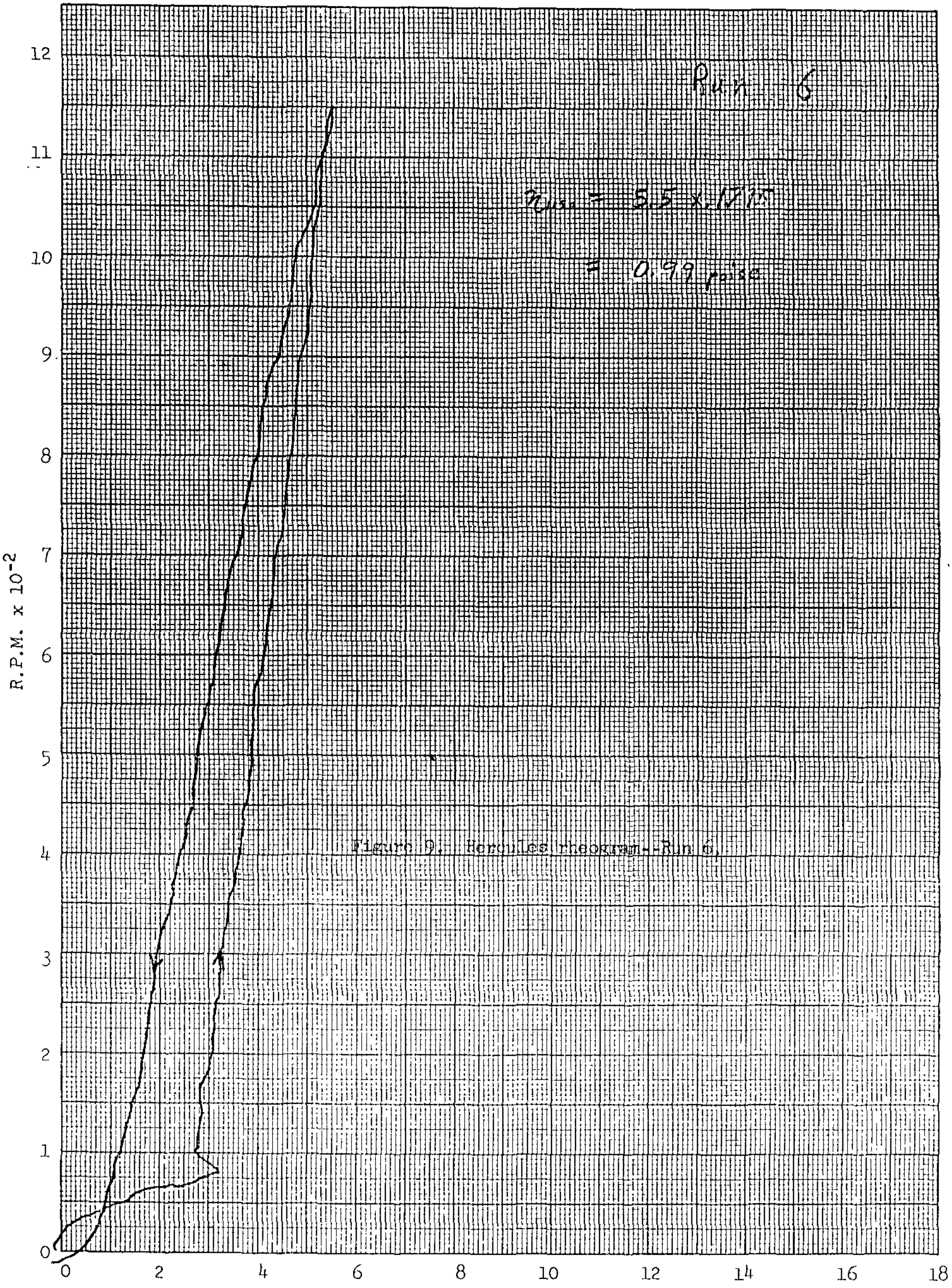

Figure 9. Hercules rheogram--Run 6.

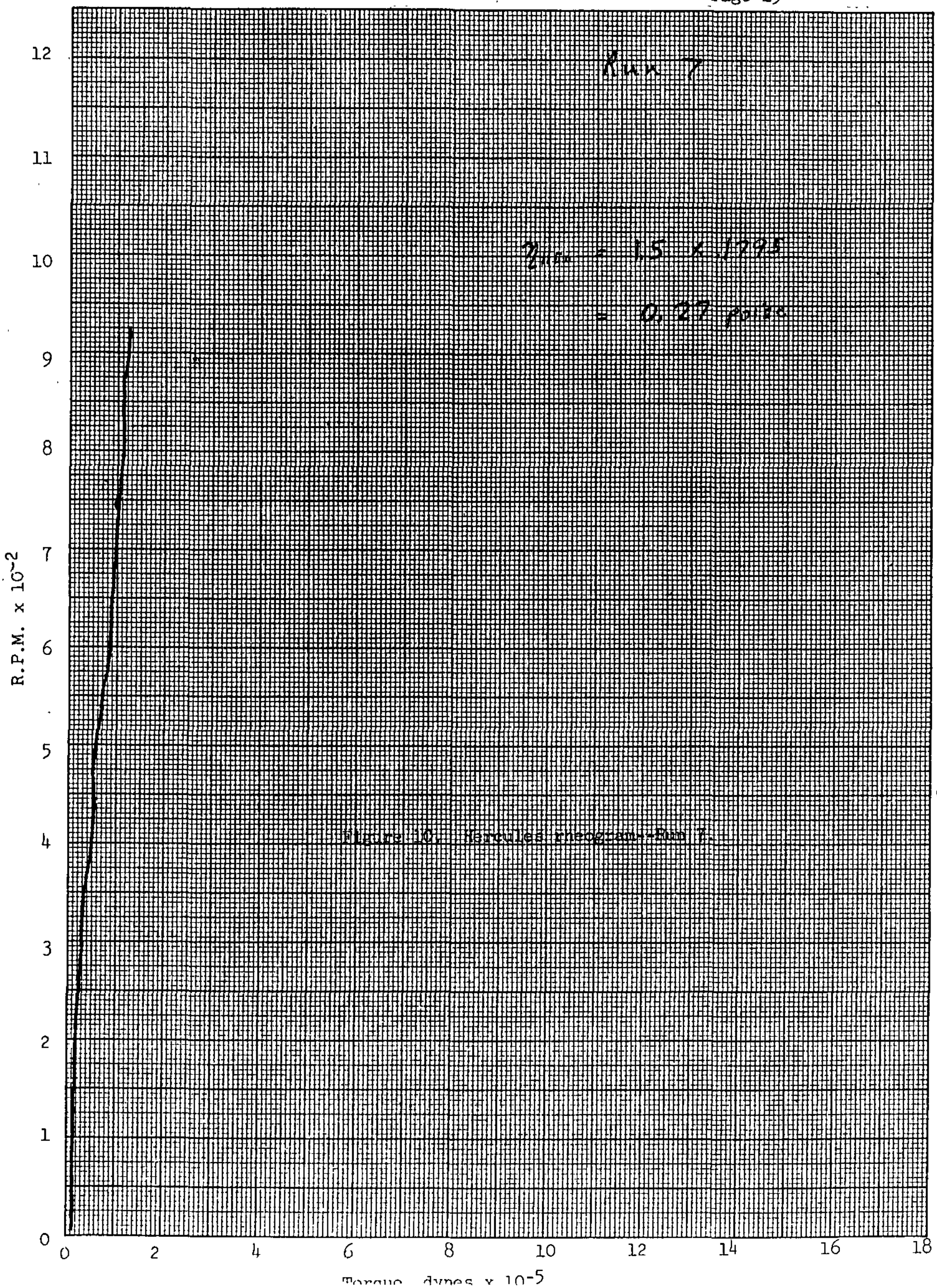

Figure 10. Hercules rheogram--Run 7.

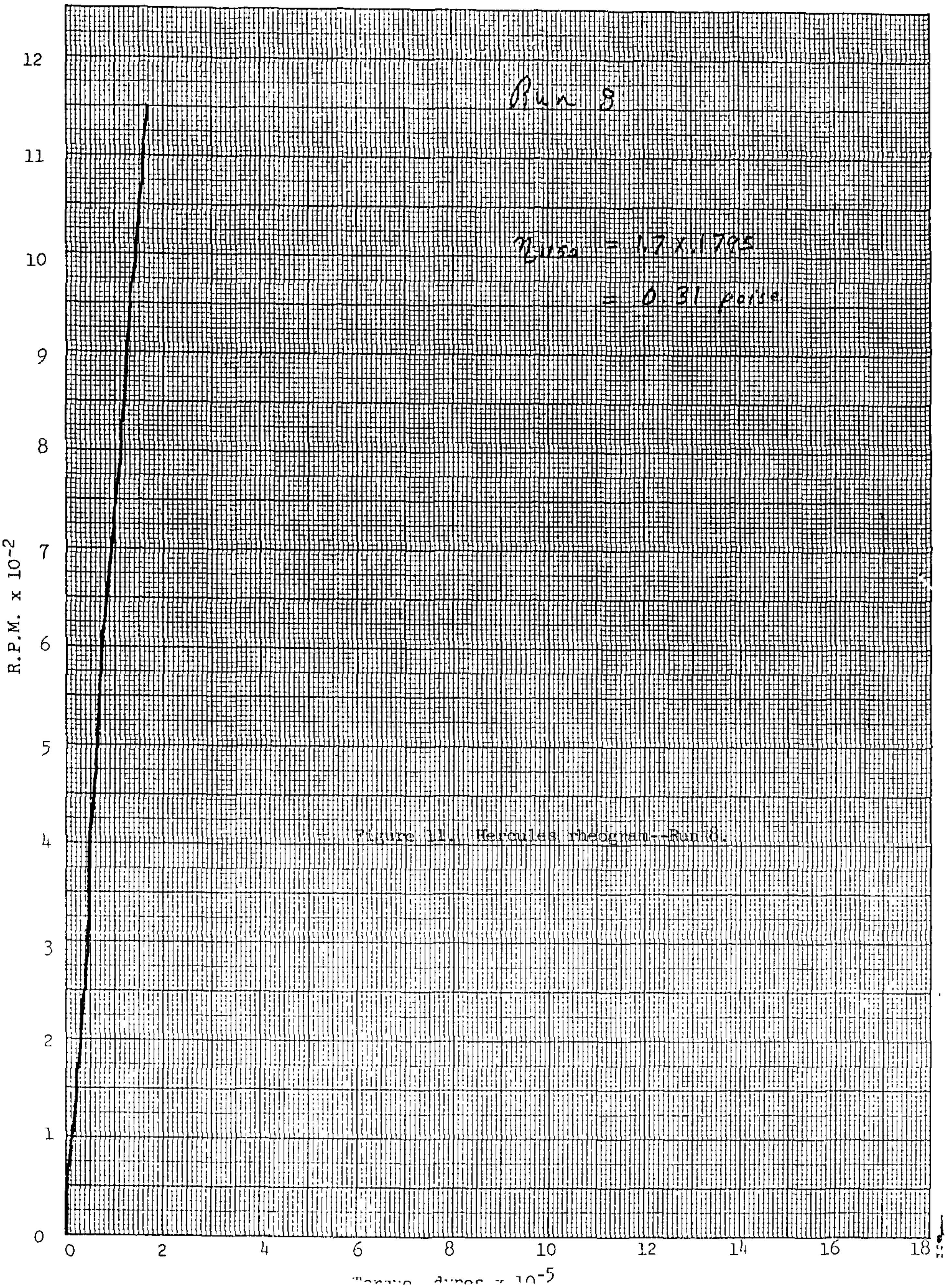

Figure 11. Hercules rheogram--Run 8.

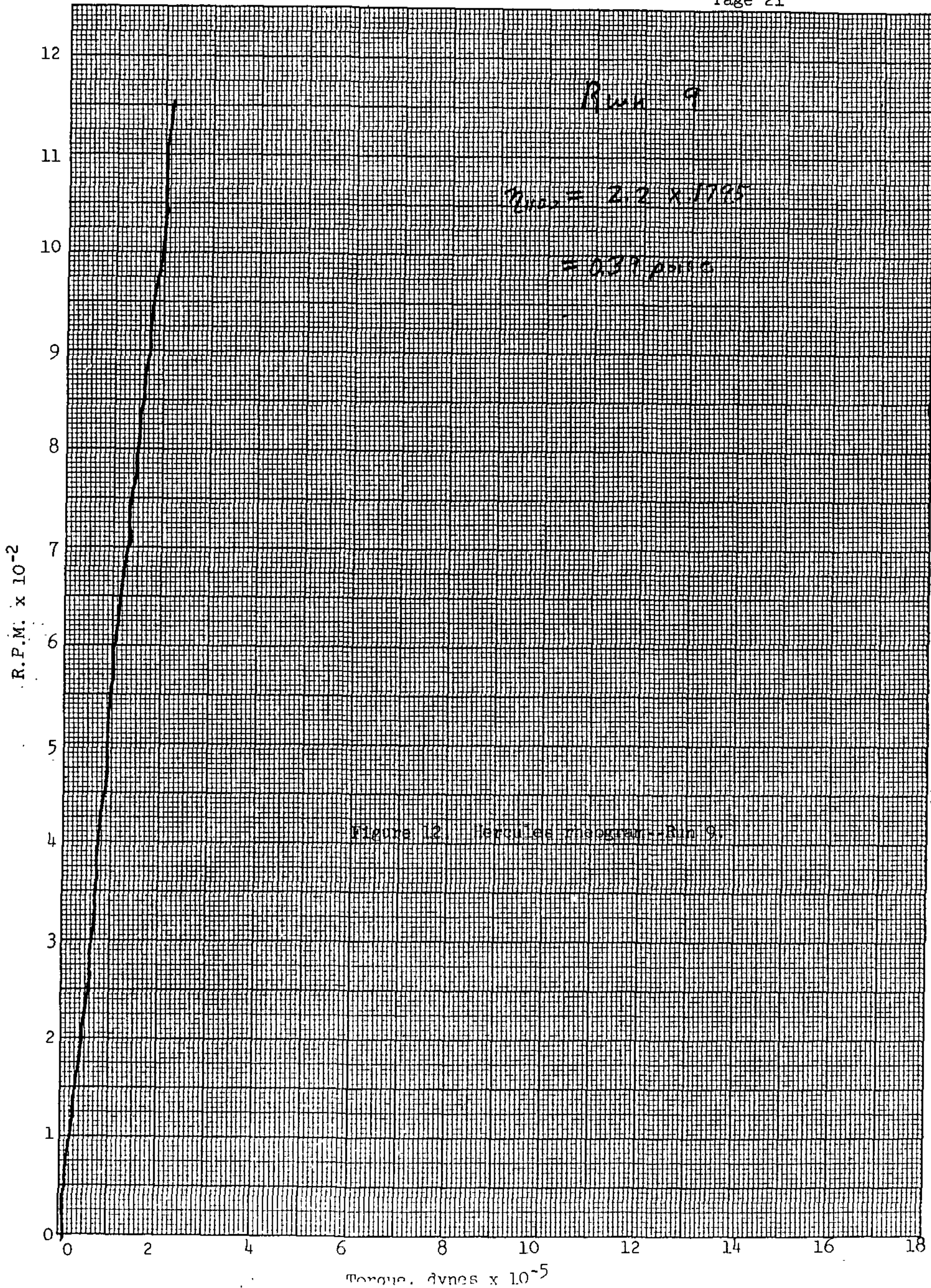

Figure 12. Hercules rheogram--Run 9.

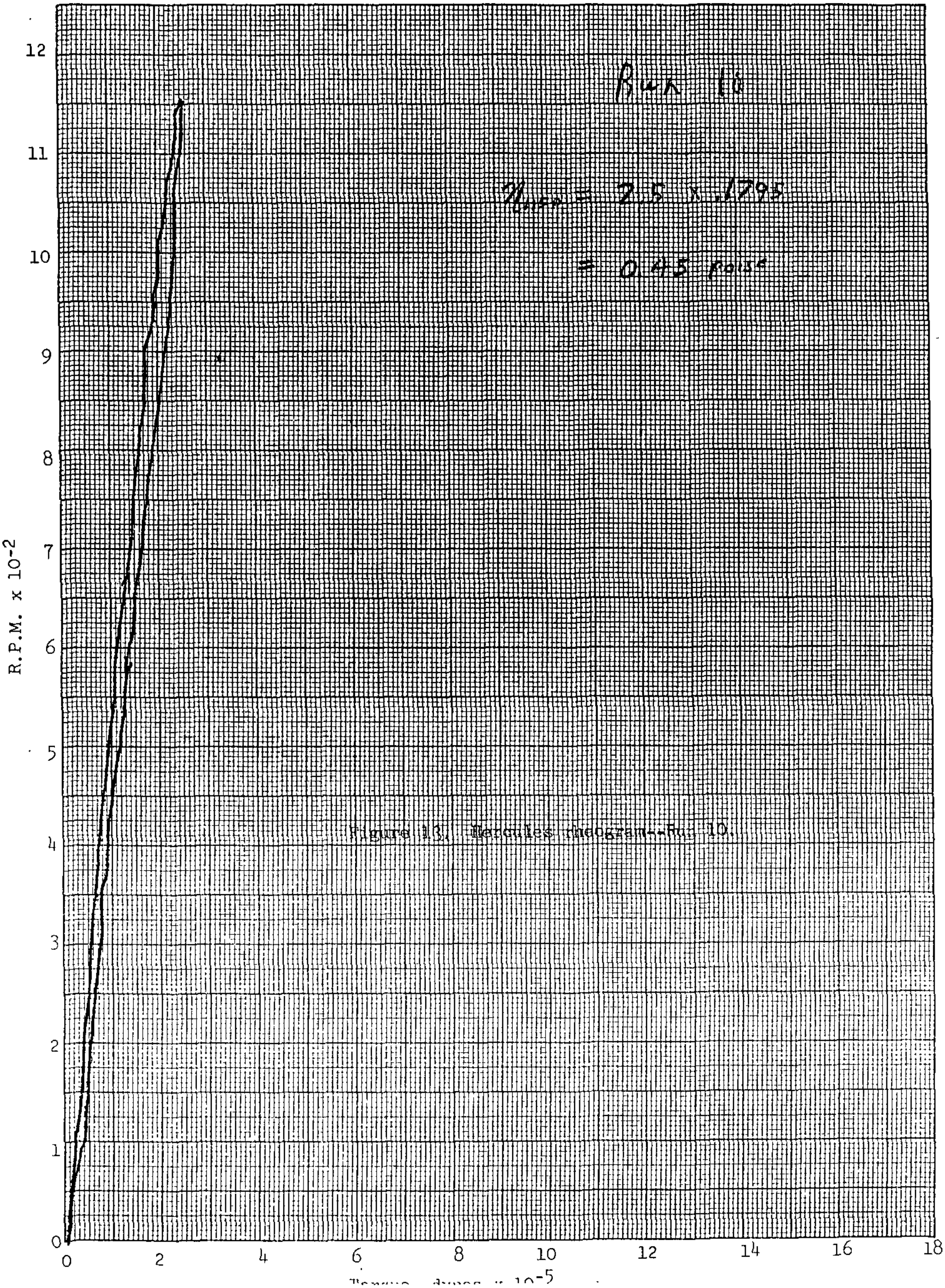

Figure 13. Hercules rheogram--Run 10.

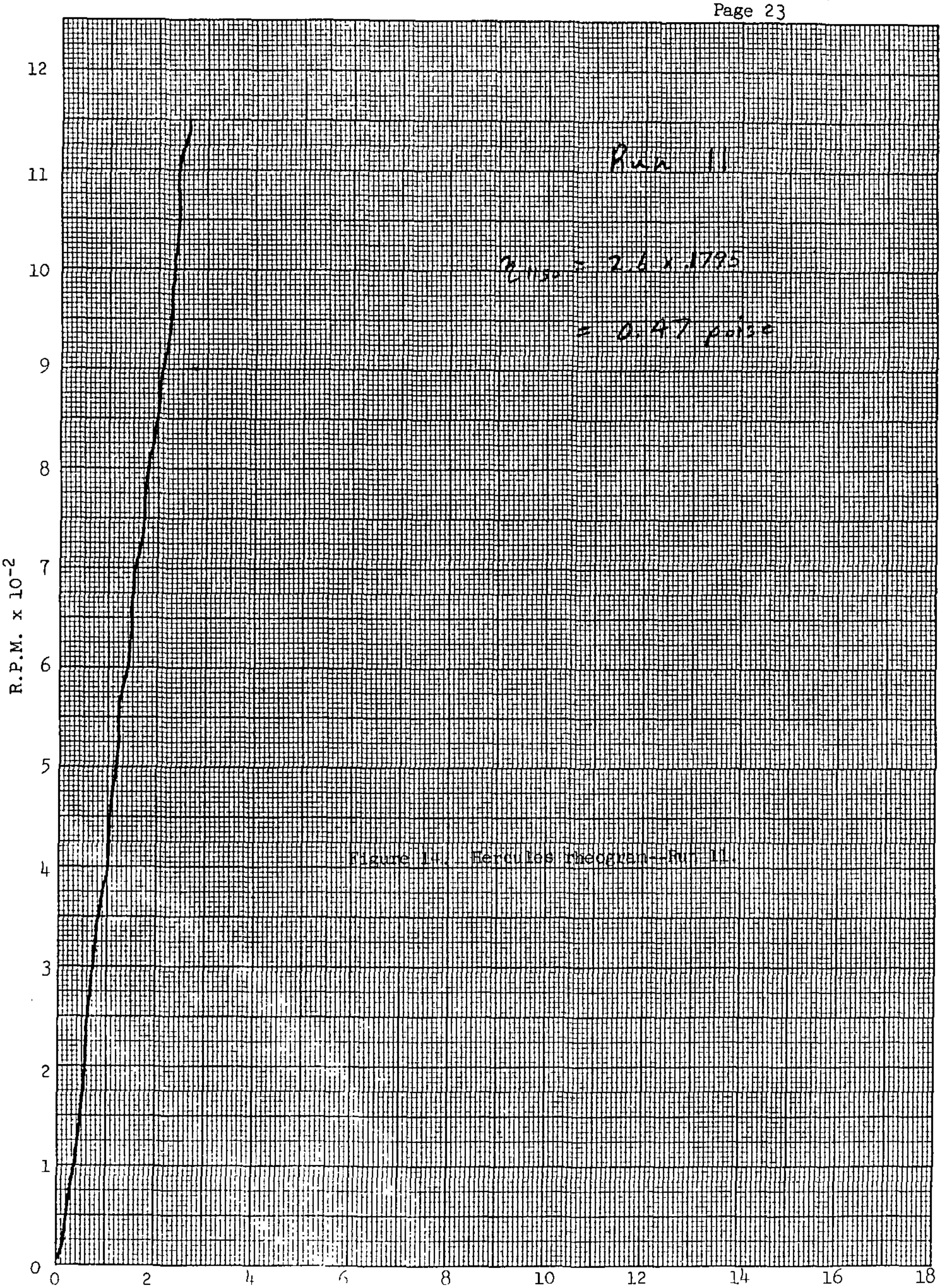

Figure 14. Hercules rheogram--Run 11.

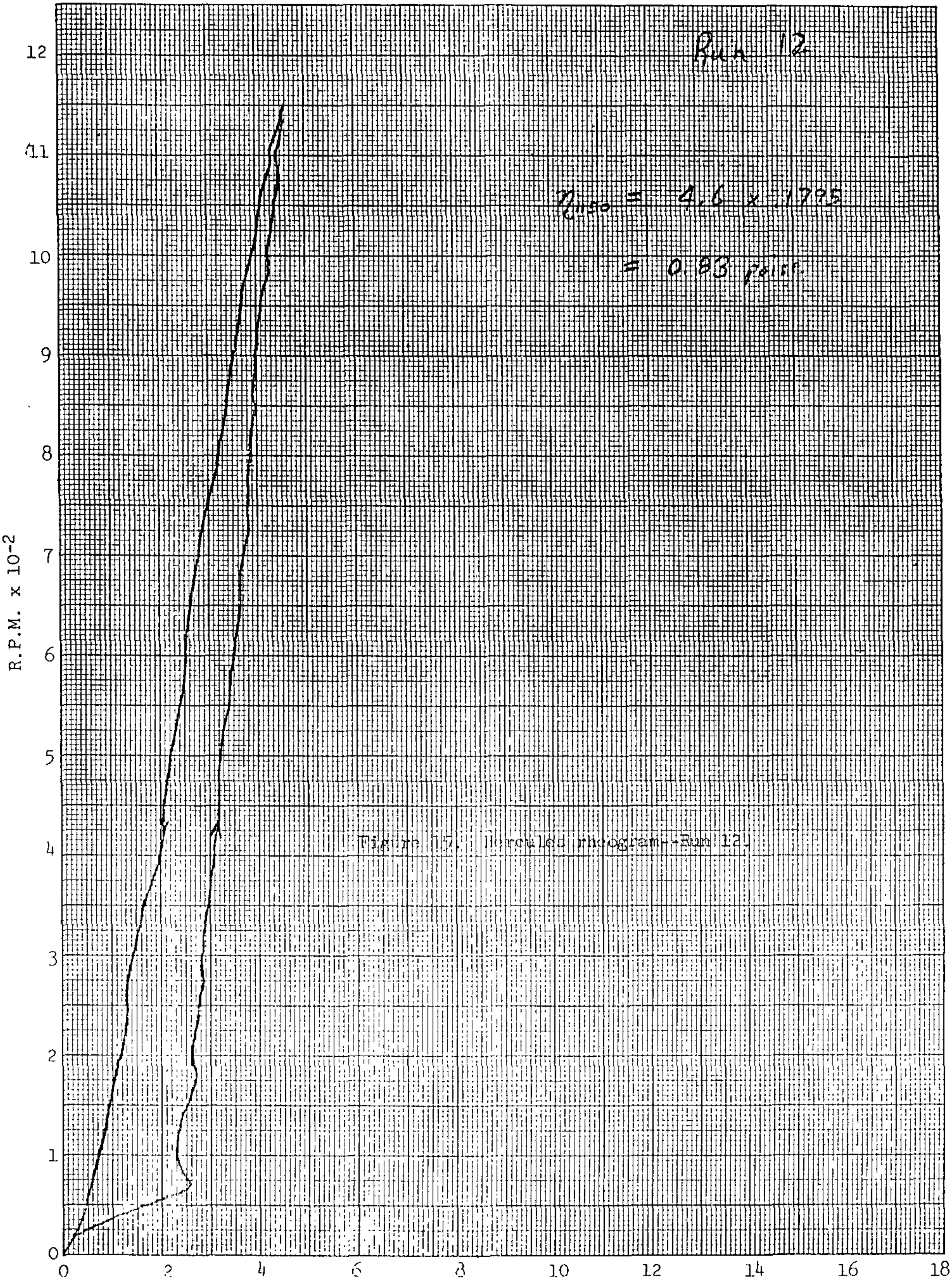

Figure 17. Hercules rheogram--Run 12.

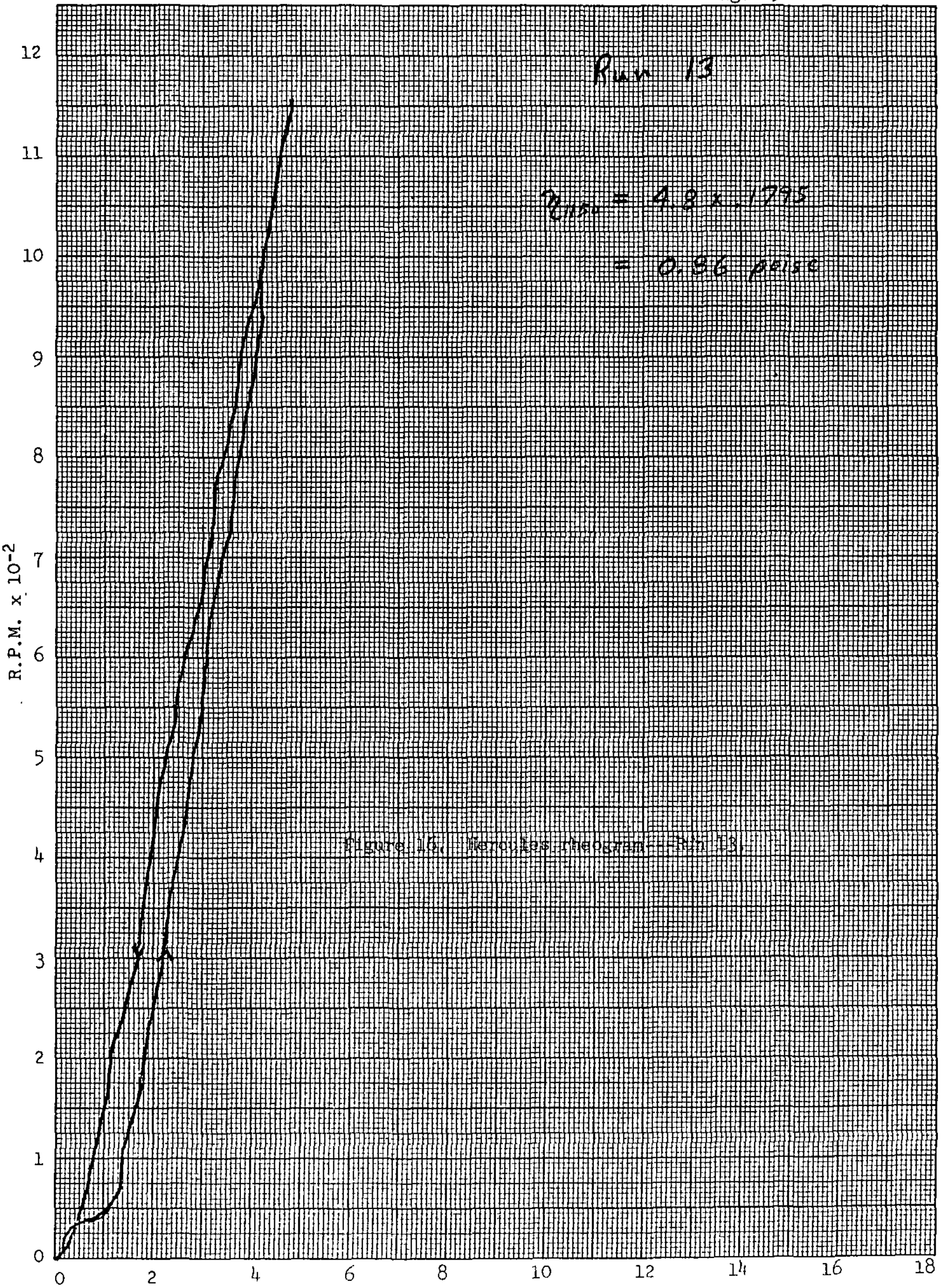

Figure 16. Hercules rheogram--Run 13.

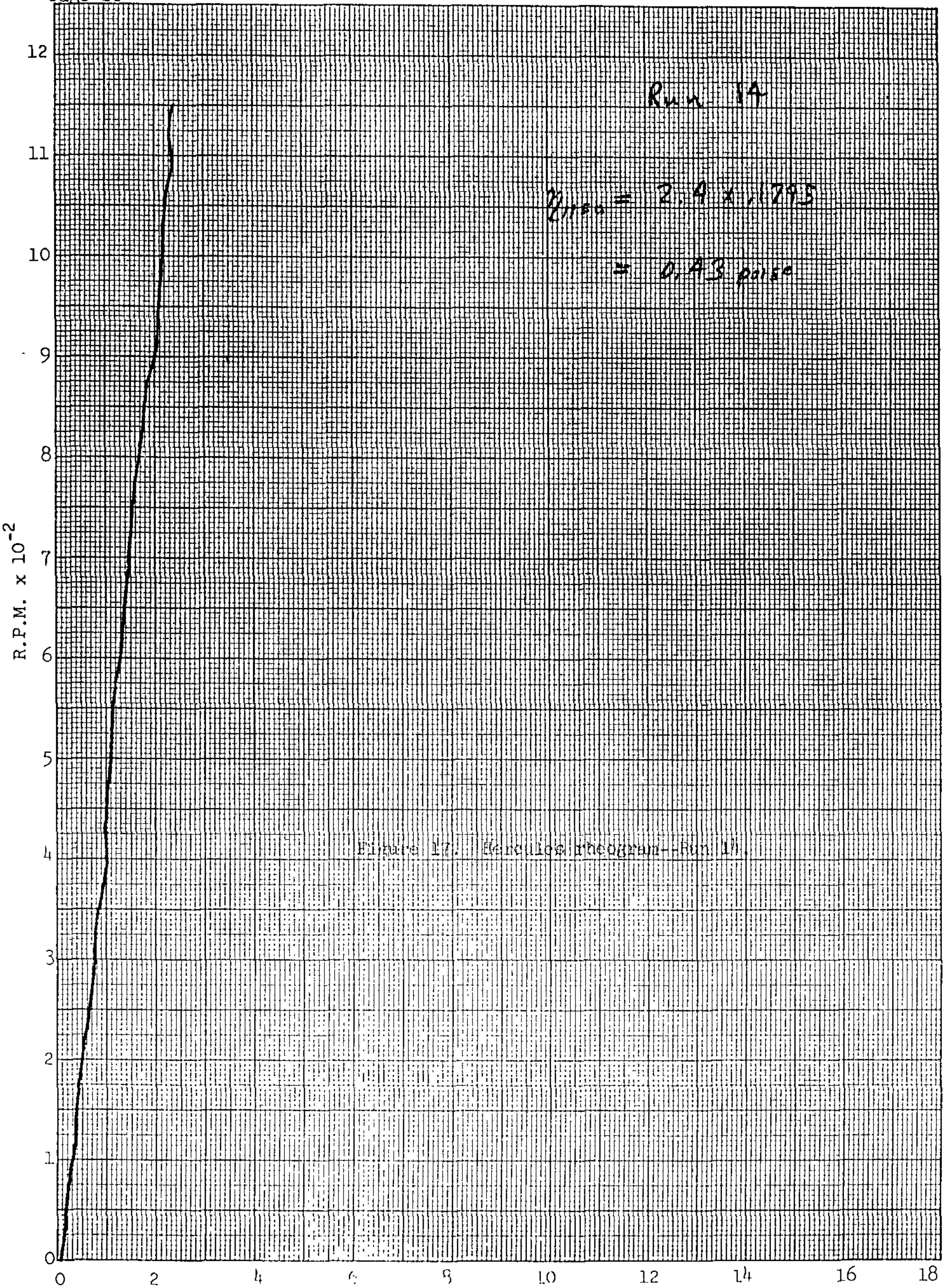

Figure 17. Hercules rheogram--Run 14.

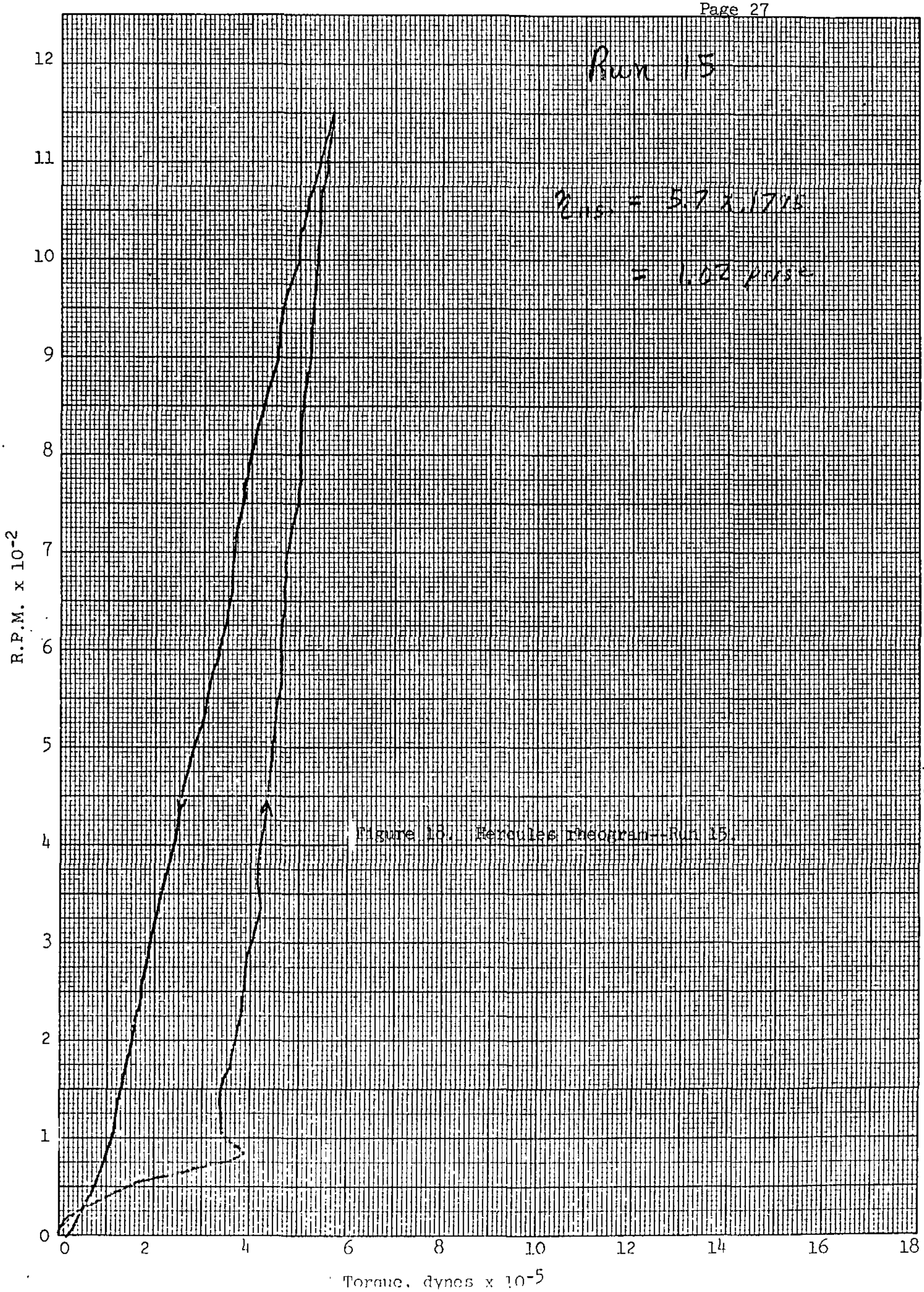

Figure 18. Hercules rheogram--Run 15.

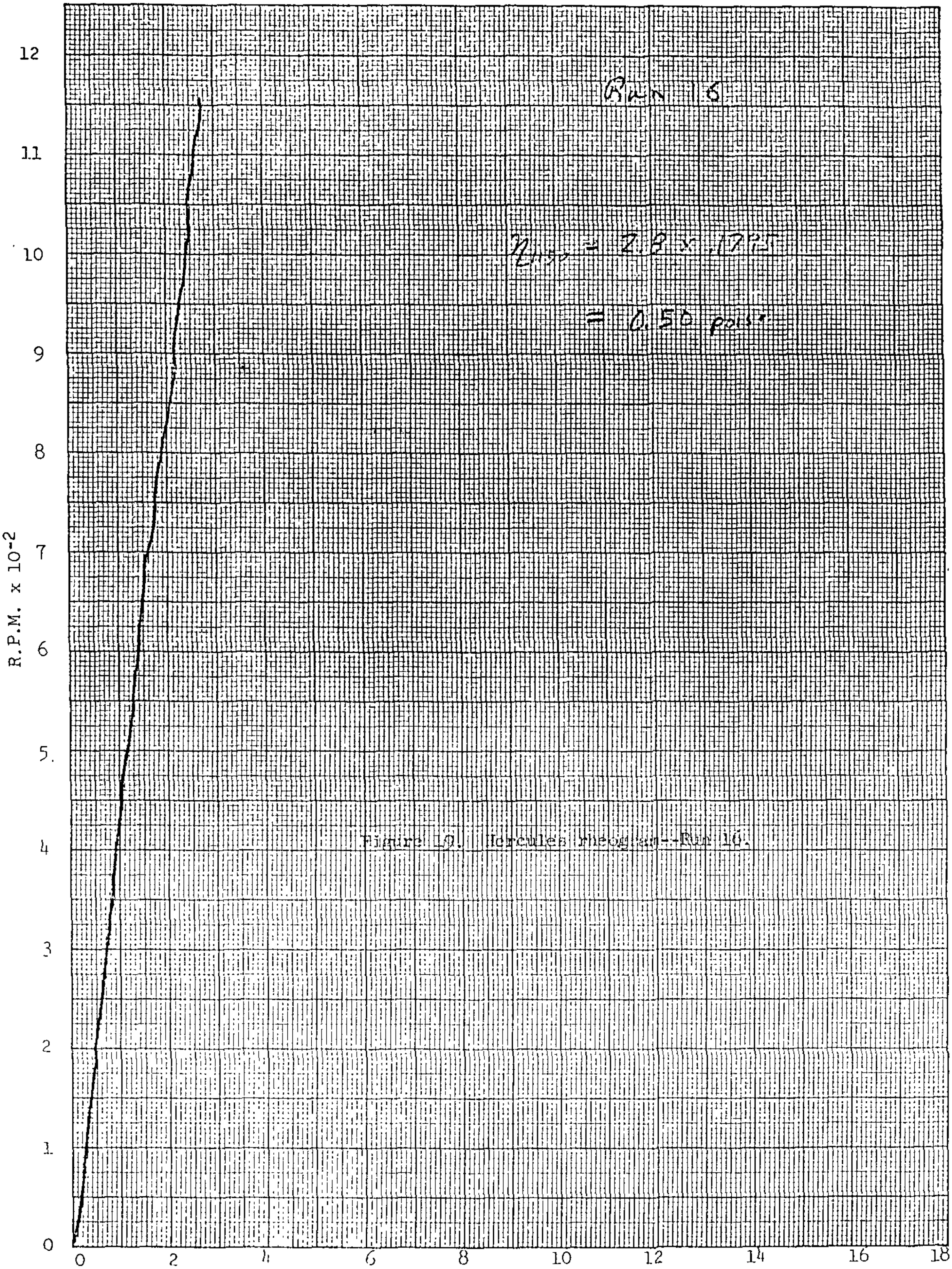

Figure 19. Hercules rheogram--Run 16.

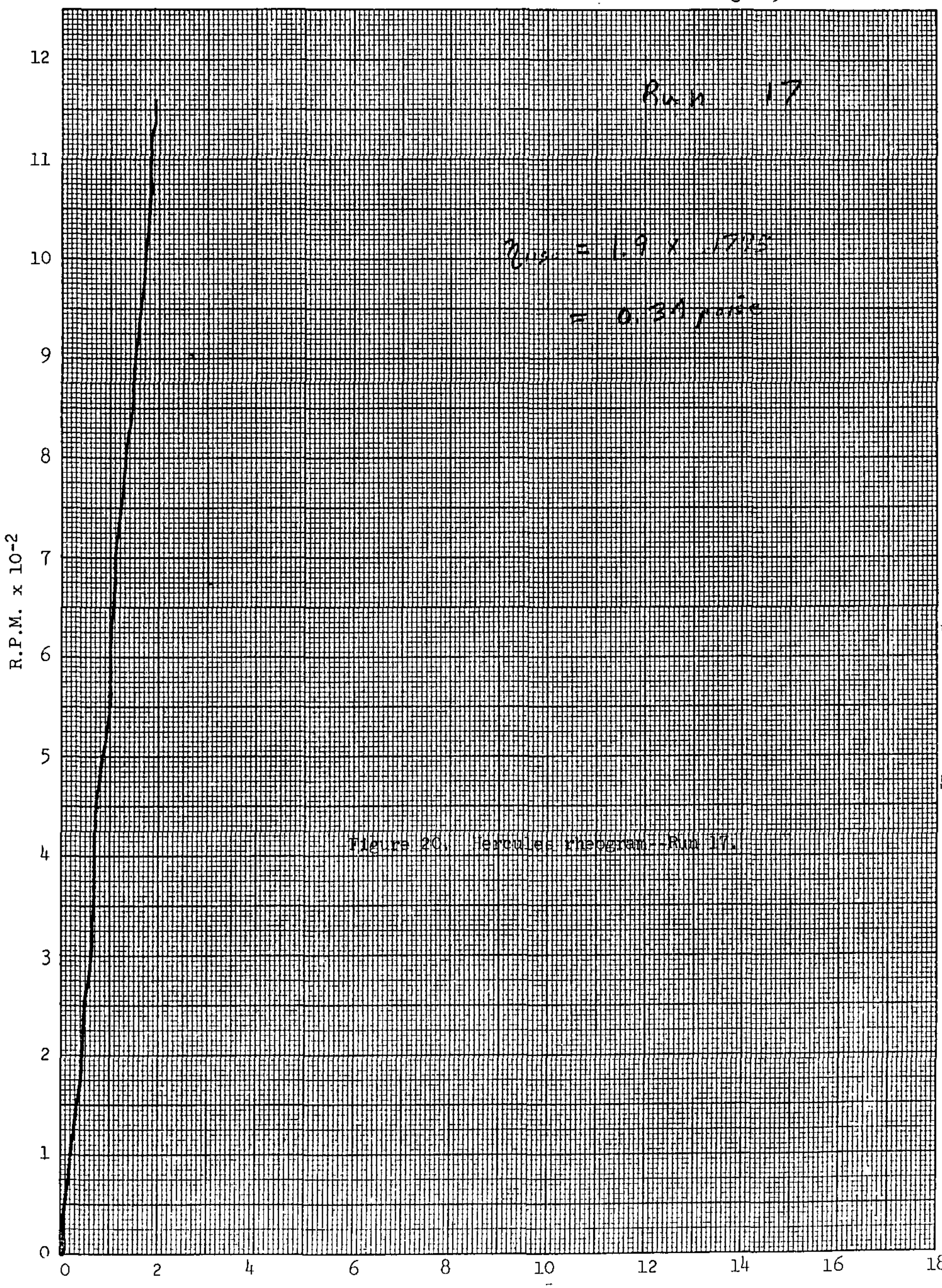

Figure 20. Hercules rheogram--Run 17.

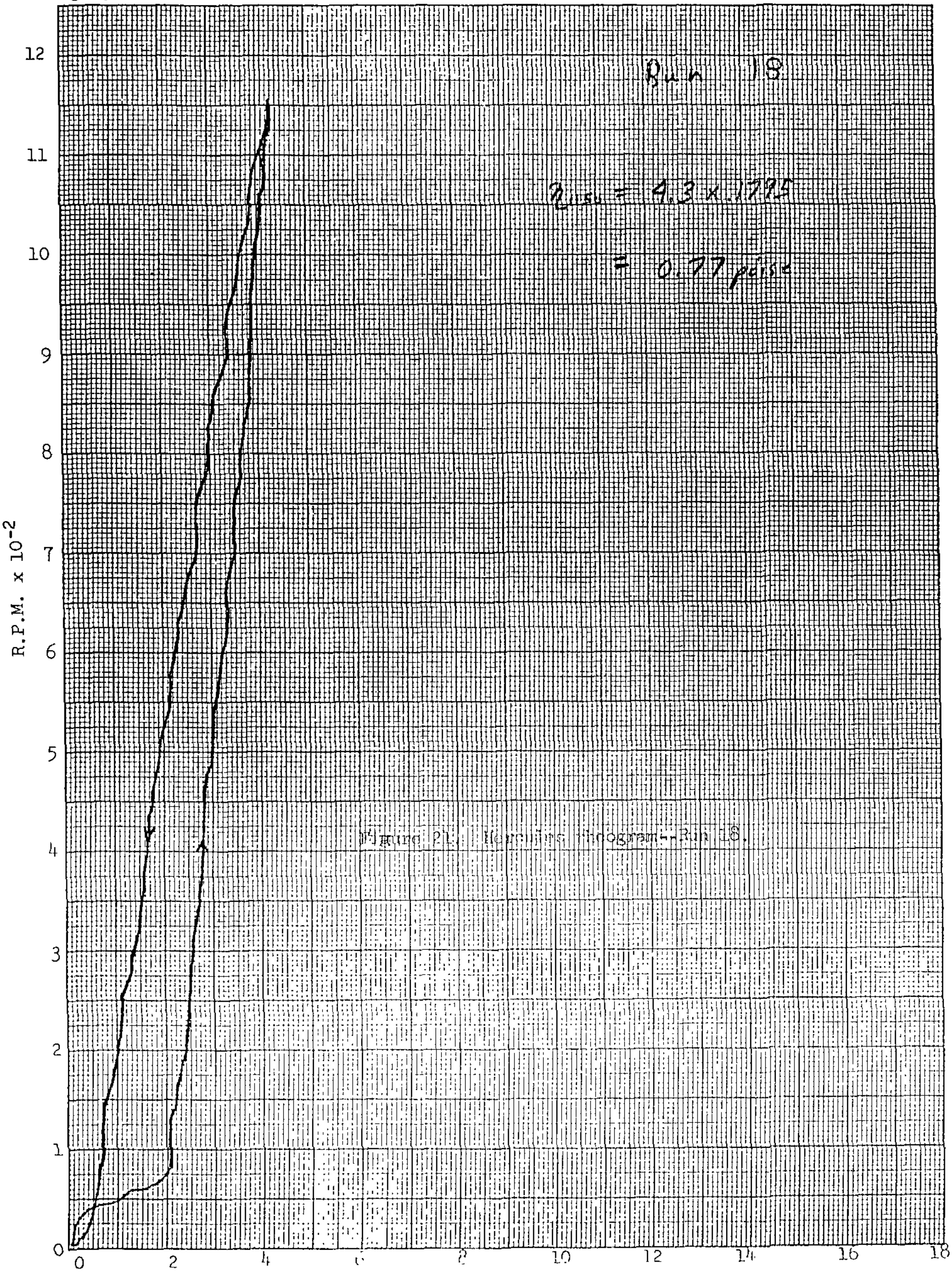

Figure 21. Hercules Rheogram--Run 18.

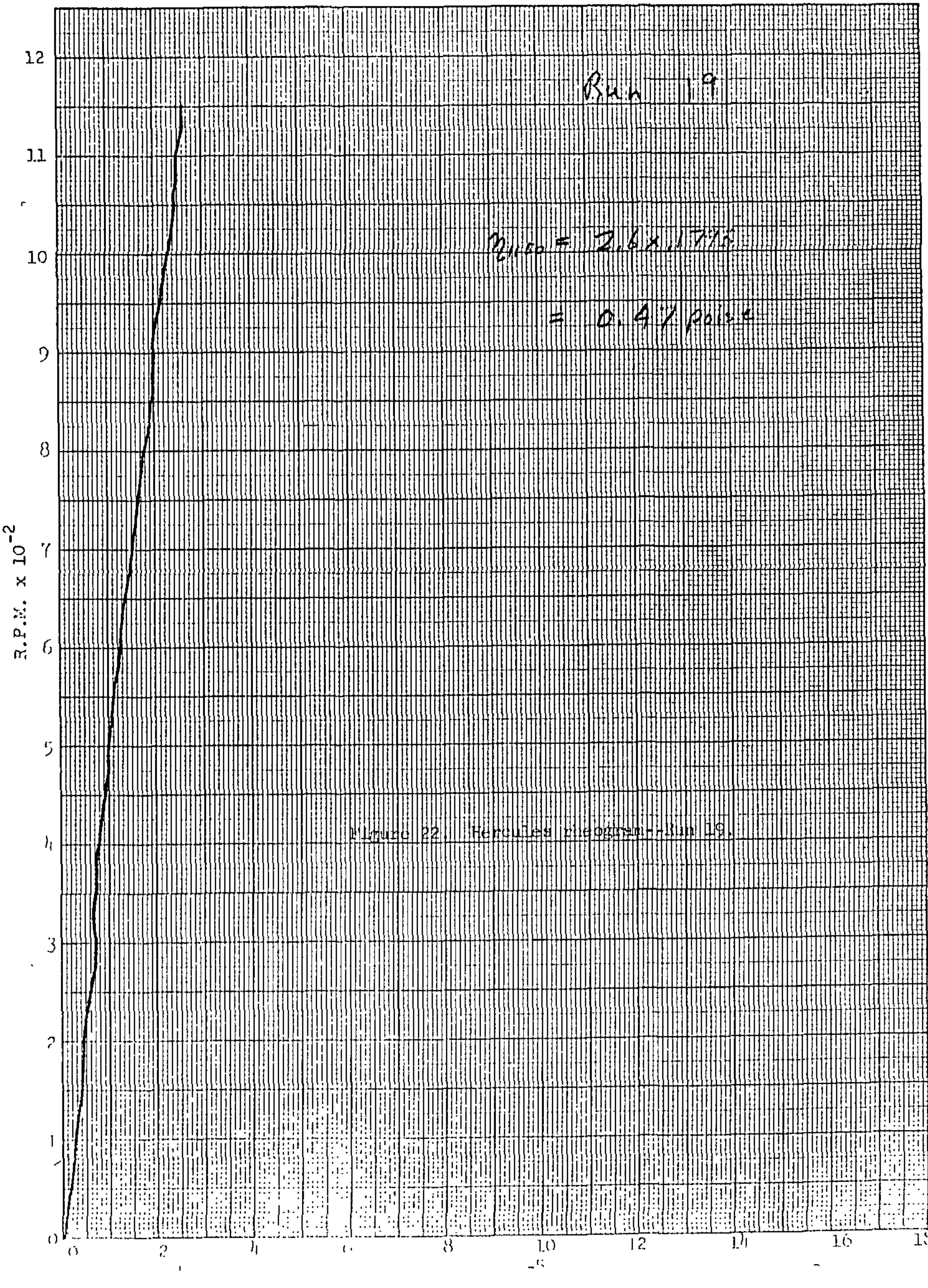

Figure 22. Hercules rheogram--Run 19.

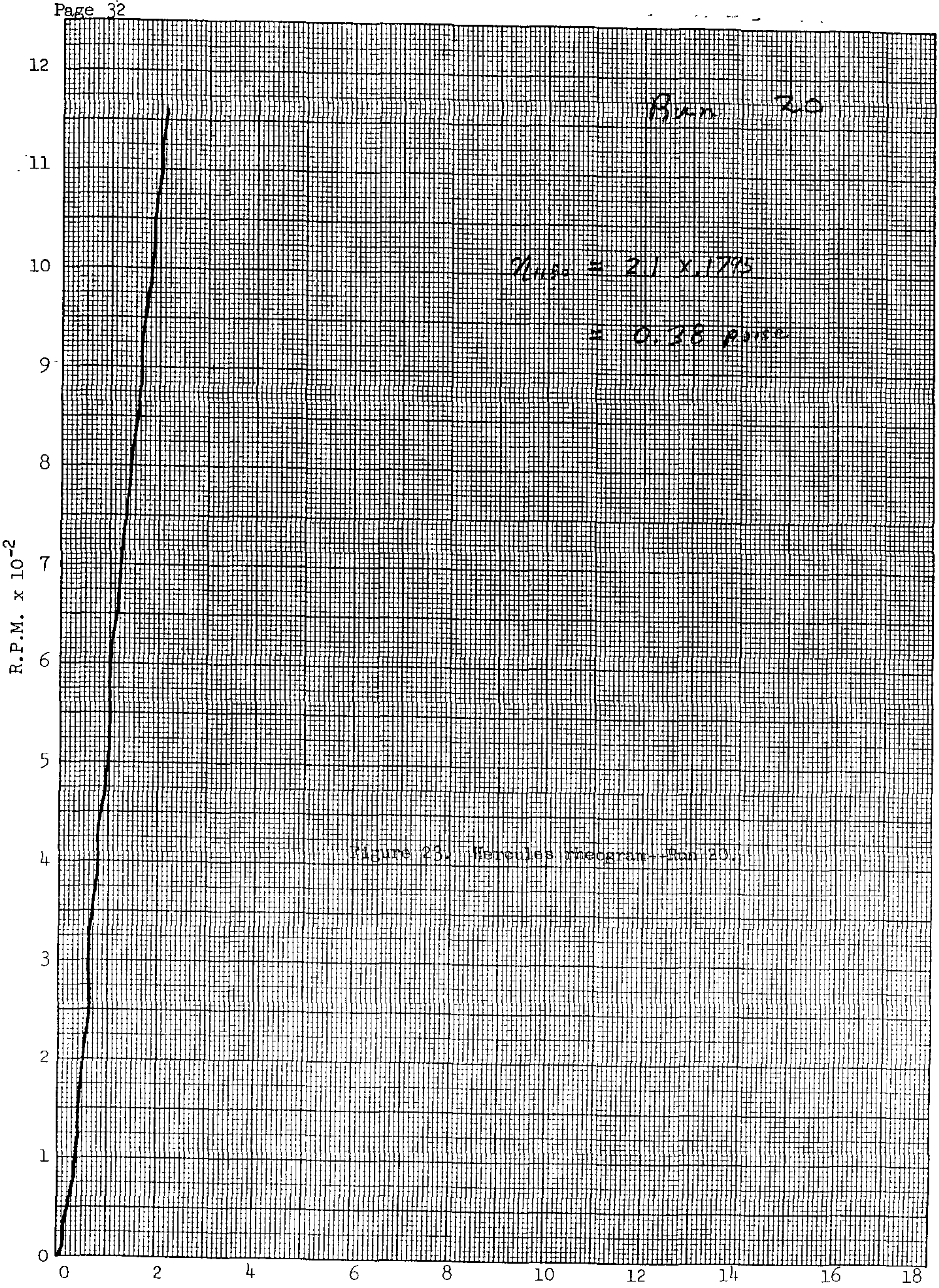

Figure 23. Hercules rheogram--Run 20.

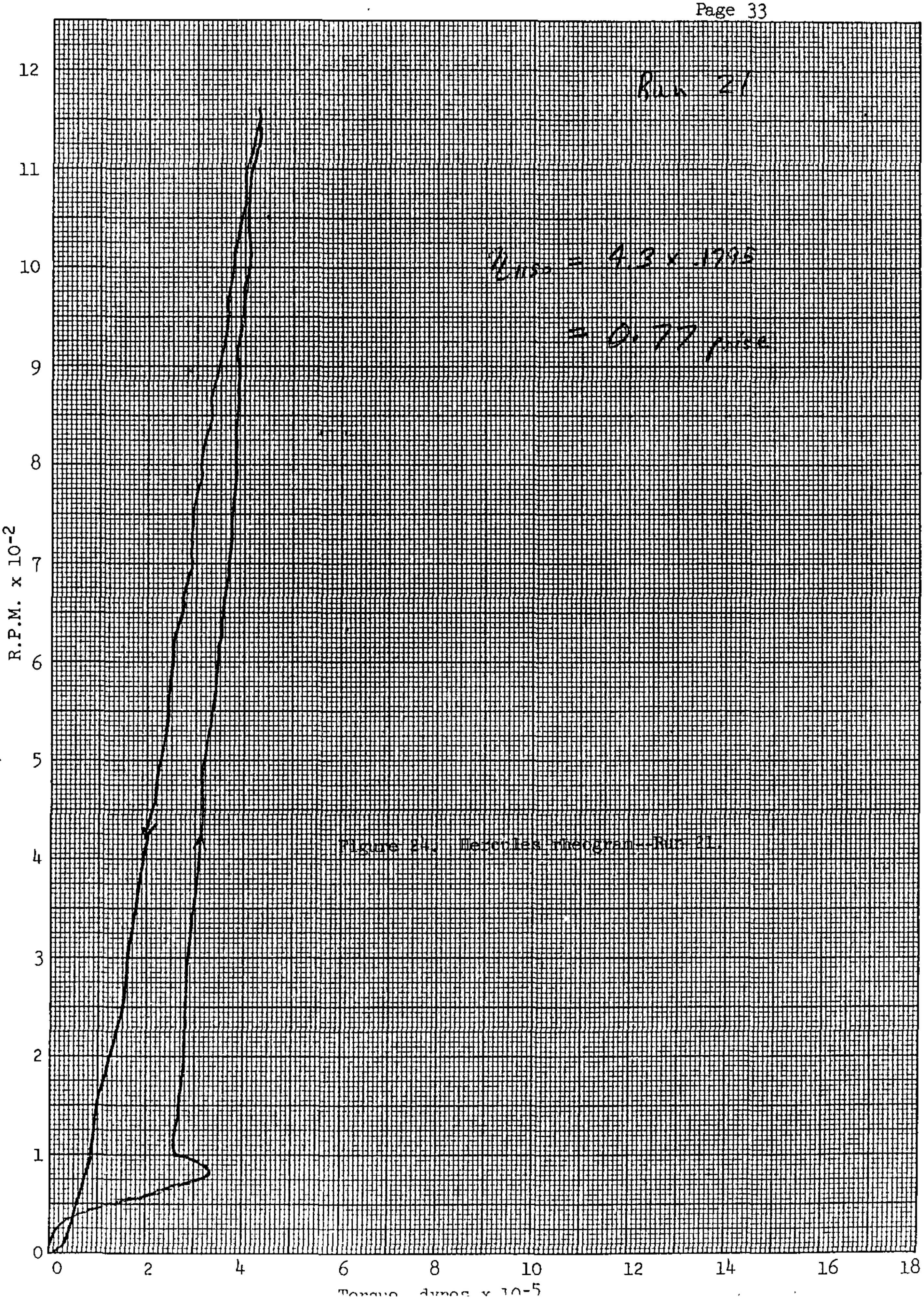

Figure 24. Hercules rheogram--Run 21.

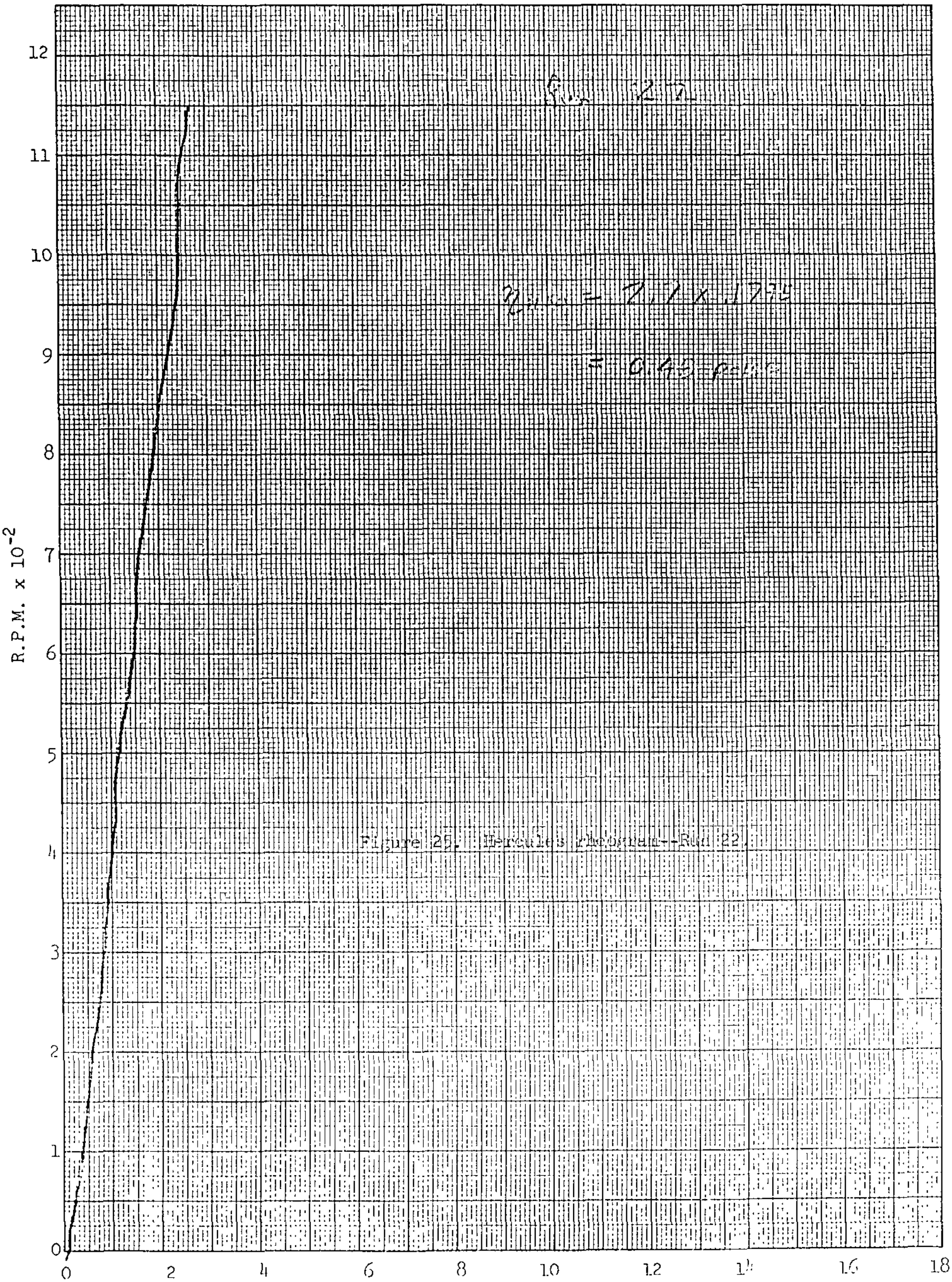

Figure 25. Hercules rheogram--Run 22

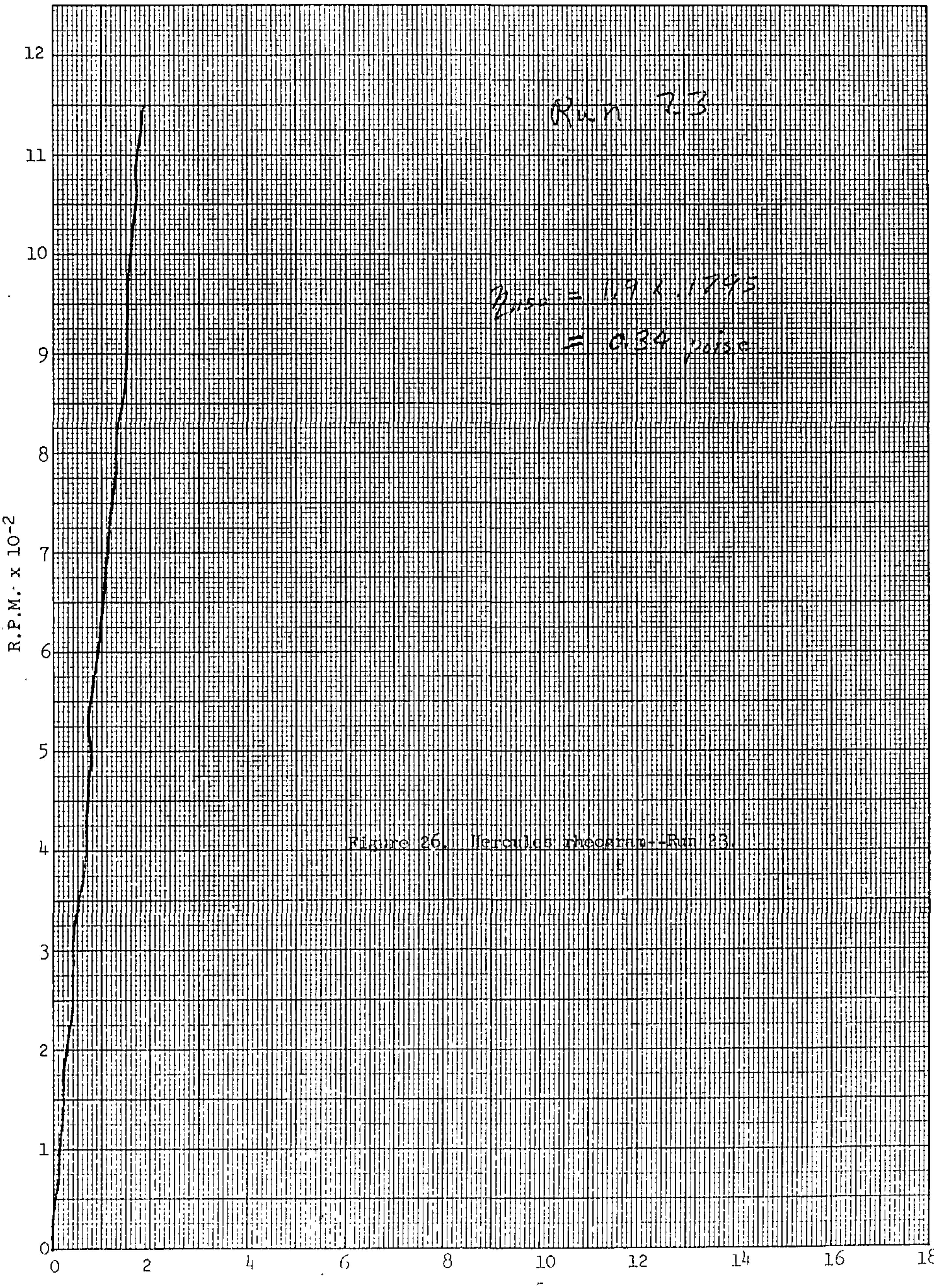

Figure 26. Hercules Rheogram--Run 23.

PROJECT REPORT FORM

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PROJECT NO. 1956
COOPERATOR IPC
REPORT NO. 48
DATE October 20, 1964
NOTE BOOK -
PAGE - TO -
SIGNED L. E. Leporte
Lawrence E. Leporte

OPERATION OF THE NEW INVERTED BLADE COATER

INTRODUCTION

This report describes the operation and performance of the inverted blade unit recently constructed and installed on the pilot coater. The blade unit was constructed for precise adjustment of blade extension and angle with the basic construction sufficiently heavy to maintain settings and prevent chatter. A trial was run at web speeds of 400 and 1800 f.p.m. without difficulty and with satisfactory performance. Two additions to the unit are recommended in order to aid in making settings--these are graduated scales between the ways and sliders that support and position the blade horizontally and a strain gage bonded to a small lever arm device attached to the blade holder shaft for reproducible adjustment of the blade pressure.

DESCRIPTION OF THE INVERTED BLADE UNIT

The unit consists of a blade holder, a driven color roll, and a color pan operating against a 22-inch diameter rubber-covered backing roll. The complete unit is shown schematically in Fig. 1. The separation between the point of application of the color to the web and the point of contact of the blade is nominally 8 inches.

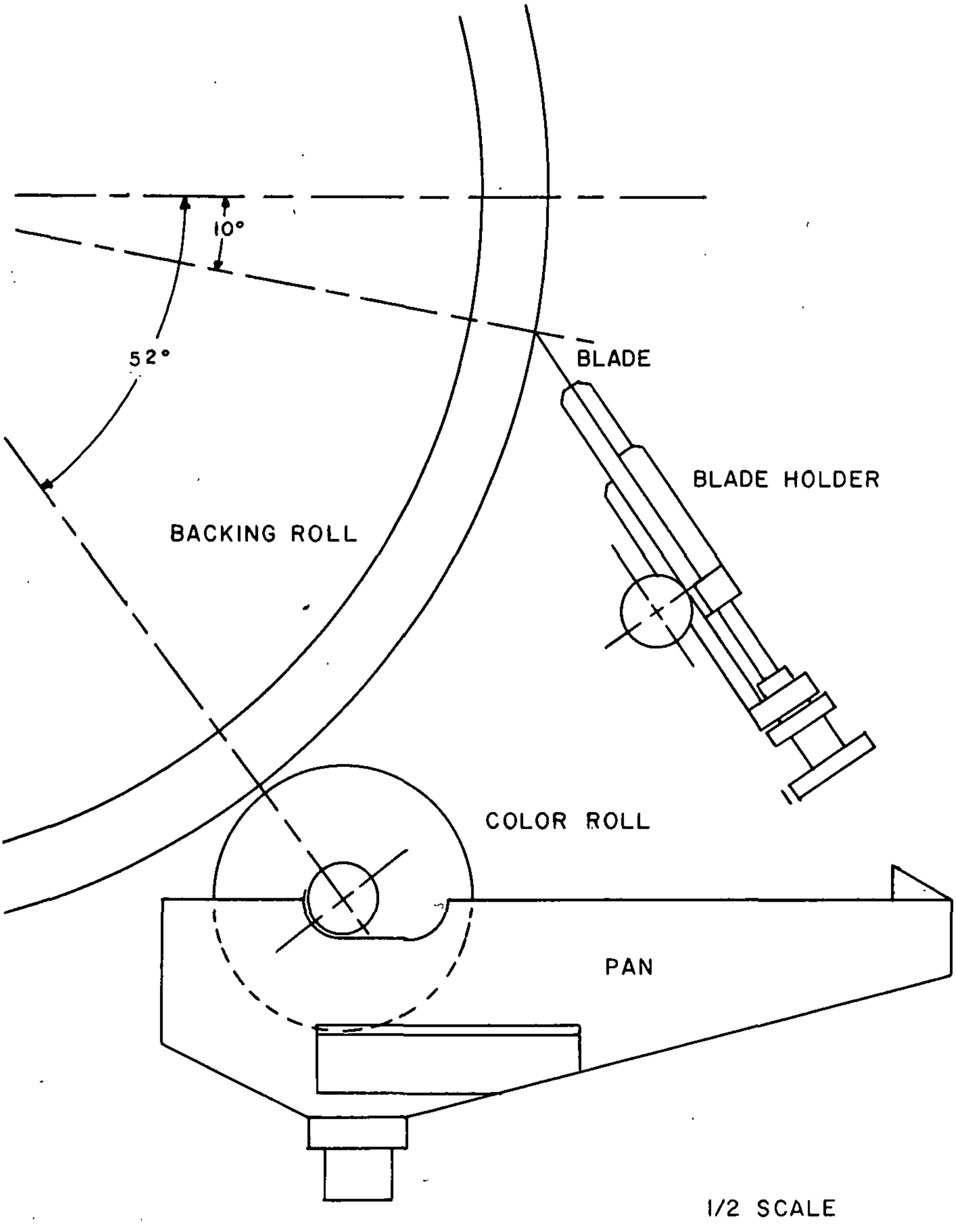

Figure 1. Schematic Representation of Inverted Blade Unit

Blade Holder

The holder is designed to hold a 15 inch long by 3 inch wide blade less than 0.025 inch thick. The blade fits in a slot between two brass plates and is clamped by a third plate as shown in Fig. 2. This holder is attached to a bed-plate which in turn is attached to a shaft. The unit is supported from the machine frame by bearings on the shaft.

The extension of the blade is adjusted by fine-threaded screws attached to the bed-plate. When the blade extension is adjusted the blade holder moves on the bed-plate to compensate for the extension or retraction of the blade so that the distance from the support shaft center to the leading edge of the blade does not change. Thus, the extension of the blade can be changed without affecting the blade angle.

The support shaft bearings are mounted on brass blocks that slide in horizontal ways attached to the machine frame. These blocks are positioned by fine-threaded screws over a span of about two inches to set the blade angle in a range of 20 to 50 degrees to the tangent of the point of contact on the backing roll.

The blade is locked into the operating position by a 10 inch lever arm attached to the support shaft. The level arm fits over a pin on the machine frame in such a manner that the blade can be rotated away from the operating position by bending the lever slightly to release it from the pin and rotating it counter clockwise in a 60 degree arc. The pin can be adjusted in a slot on the machine frame to accommodate changes in the blade angle.

The blade pressure is adjusted by a second lever attached to the support shaft. Once the blade angle is set the locking lever is loosened on the support

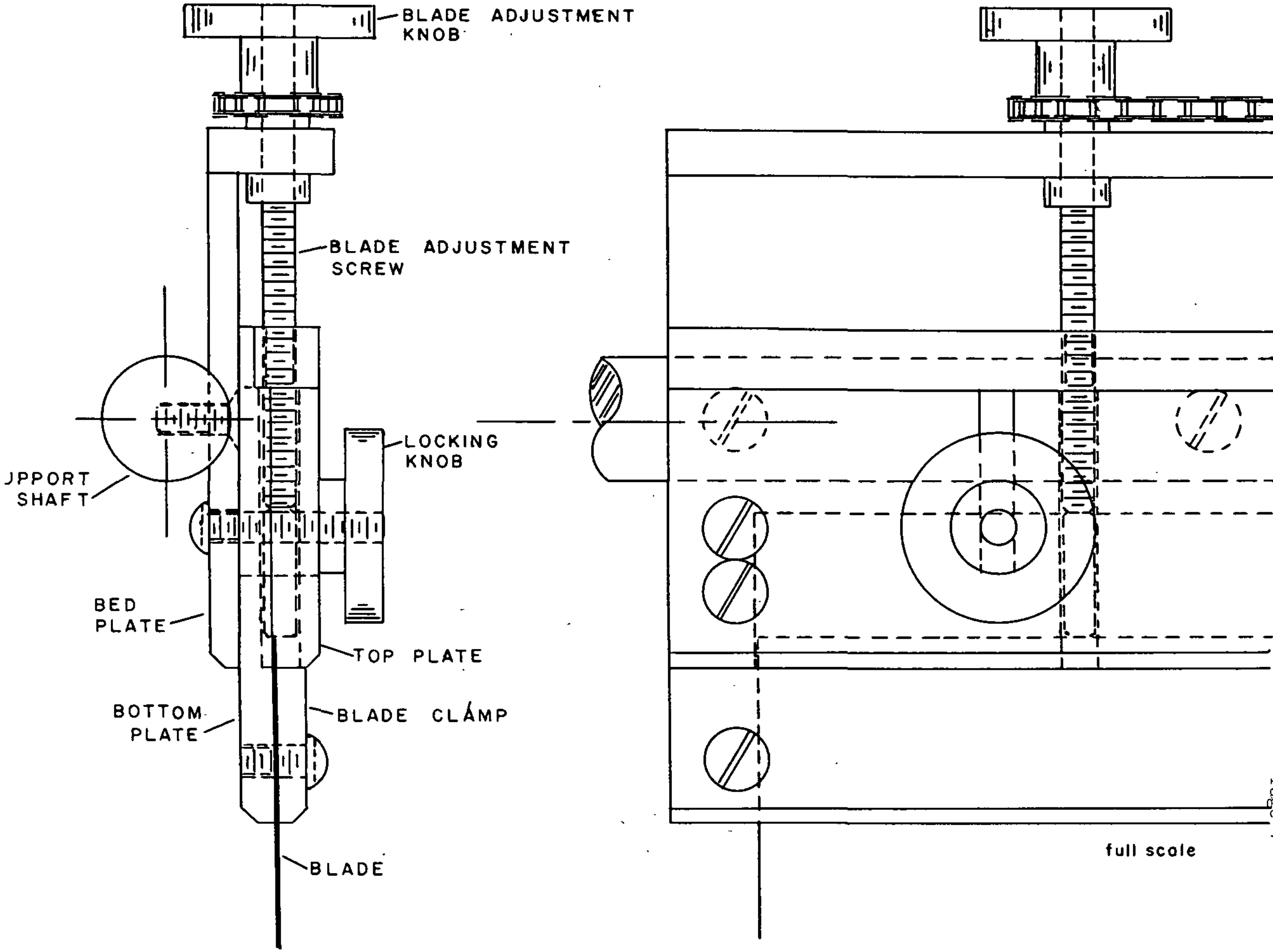

Figure 2. Side and Top Views of Blade Holder Showing Blade Adjusting Screw

shaft with the blade in the operating position by loosening the Allen screw that clamps the lever to the shaft. The pressure adjusting lever is moved to give the desired blade pressure and the locking lever is retightened onto the support shaft. The blade can then be rotated in and out of the operating position without affecting its adjustments and settings.

This unit was constructed to tolerances less than 0.002 inches and should give settings of high reproducibility. However, it will be necessary to construct a scale for quick and easy adjustment of the blade angle and a lever arm device on the support bar with an attached strain gage so that the blade pressure can be adjusted by applying a given amount strain to the lever against a stop on the machine frame.

Application of Coating Color

The coating is applied to the web ahead of the blade by means of a 4-inch diameter chrome-plated roll with a 12-inch face. The roll rotates in a one gallon capacity stainless steel pan. It is driven by a one-half horsepower dynamatic drive over a speed range of 20 to 340 f.p.m. in the web direction. The roll bearings are mounted in adjustable ways to provide fine threaded screw adjustment of the roll-web clearance; the roll contacts the backing roll at a point about 38° above bottom dead center so that the adjusting movement can be in the horizontal plane.

The roll and the bearing and adjusting assembly is mounted along with the color pan supports on sliders on a second set of ways allowing the complete color roll and pan assembly to be moved as a unit along the horizontal. This allows the coating operation to be started and stopped simply by moving the color roll and pan assembly in and out of the operating position. The movement of the assembly is accomplished with two 2-inch diameter, three inch stroke, air cylinders. The cylinders always retract to the full length of their stroke when the assembly is brought into the operating position in order to have a positive stop and maintain clearance settings. The color roll drive is arranged so that the shift can be made with the color roll running.

OPERATION

A shakedown trial was run to evaluate the performance and to determine whether any modifications were in order.

Coating Color

The following materials were used to make up approximately five quarts of coating color:

Clay Slurry:

Material	Gm.	%
Huber H. T. Predispersed Clay	2980	70
Water	1270	30
Quadrafos	9	--

Total Solids of Clay Slurry: 70%

Binder:

Material	Gm. Added	Gm. Solids	Percent of Clay Solids
Dow 512L Latex	1072	536	18
10% solution of DuPont 72-60 Polyvinyl Alcohol	600	60	2
Dilution Water	530	--	--

Total Solids of Coating: 55.4%

The clay was added to the Quadrafos solution with agitation by a 1/4 hp. Homo-mixer and dispersed by an additional 1/2 hour of agitation. The latex along with the dilution water was stirred into the slurry with a 1/4 hp. Lightnin' mixer.

The polyvinyl alcohol solution was made up by adding 60 gm. of polyvinyl alcohol to 540 gm. of cold water under rapid agitation with a 1/4 hp. Lightnin' mixer, then the mixture was heated to 90°C with an electric mantle for a period of one hour with continued agitation to achieve solution. The solution was allowed to cool to 35°C and added to the clay-latex system under agitation by the Lightnin' mixer.

The coating was used at 55.4% solids after storage for one day. The Brookfield viscosity just prior to use was 1230 cp. as measured with a No. 2 spindle at 60 r.p.m.

Base Stock

The base stock was 3.7 mil raw stock primed for latex coating obtained in 1959 for use in Project 2139. This stock was designated PA-42. The basis weight determined from the weight of 12-8 in. x 12 in. sheets was 41.05 lb./3000 sq. ft.

Machine Settings

The blade angle was set at 45° to the tangent of the backing roll at the point of contact and the blade extension was set at one inch. The blade pressure was set by rotating the blade holder about 5 degrees into the web and backing roll after initial contact. The clearance between the color roll and the web was set at 0.010 and a roll speed of 80 f.p.m. was used.

All three Gardner high velocity hot air units were used for drying. They were run with all the dampers open at a temperature setting of 250°F and a nozzle-web distance of 1/4 inch.

The machine was run at web speeds of 400 and 1800 f.p.m. The rewind drive was operated in second gear and 1800 f.p.m. was the maximum speed attainable in that gear.

Results

The coating weights were determined by comparing the weight of twelve 8 in. x 12 in. coated sheets with twelve uncoated sheets. A coat weight of 3.1 lb./3000 sq. ft. was obtained at 400 f.p.m. and a coat weight of 6.9 lb./3000 sq. ft. was obtained at 1800 f.p.m.

Although the blade was new and had not been run in, streaking was not too bad with exception of one wide streak evidently caused by a particle of grit.

Samples of raw stock and coated stock before and after supercalendering are appended to this report. Samples were calendered with three passes at a nip load of 965 lb./in. at a temperature of 220°F.

Examination of the blade under a binocular microscope showed that the blade had worn evenly during the run except for a slight roughness on the left side. Considering the short duration of the runs the wear-in of the blade was quite rapid.

PROJECT REPORT FORM

PROJECT NO. 1956
COOPERATOR IPC
REPORT NO. 49
DATE March 23, 1965
NOTE BOOK 1819 and 2378
PAGE 153-160 TO 8-15
SIGNED *L. E. Leporte*

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USE OF THREE COATING FORMULATIONS
UNDER VARIED DRYING CONDITIONS

Trials were run using the Gardner high velocity driers at various temperature settings in combinations with the Red Ray infrared units to dry three different coating formulations applied to white linerboard, Consolidated Papers Gloss B base stock, and a Nekoosa-Edwards base stock by means of the air knife and inverted blade coating units. Samples from each run were tested for coating weight, wax pick, and in one case, moisture content and gloss before and after supercalendering.

I. CLAY-POLYVINYL ALCOHOL FORMULATION

Formulation

A clay slurry was made up at a solids content of 69% by dispersing the following materials, listed in the order of addition, for one-half hour in a Cowles dissolver:

Clay Slurry:

Ingredient	Parts	Amount Added
Water	42.8	21.4 lb.
Quadrafos	0.3	70 gm.
Clay, HT Predispersed	100.0	50.0 lb.

A 10% polyvinyl alcohol solution was made by adding 2.5 lb. of Elvanol 72-60 to $22\frac{1}{2}$ lb. of cold water and heating with agitation to 90°C for a period of one hour. The material was cooled slightly and added directly to the clay slurry while agitating with a Lightnin' mixer. The mixture was diluted to 45% solids by addition of 20.3 lb. of water, however, settling occurred and the solids content of the color used in the trials was 29% with a Brookfield viscosity of 57 centipoises at 12 rpm.

Base Stock

This coating was applied to the wire side of a 33 lb/1000 sq. ft. uncoated white linerboard having a caliper of 8 mils and an oven-dry basis weight of 31.3 lb/1000 sq. ft.

Application of Coating

The coating was applied at the air knife station. The orifice of the air knife was set to 0.030 in., the angle of the airstream to the web was 45°, the orifice-web gap was 0.125 in. and a static air pressure of 1.0 psig was maintained. The color roll speed was adjusted for best performance but not measured. All of the runs were made at a web speed of 50 ft./min.

Drying

All three Gardner units were operated at the same temperature settings which were varied from 250 to 550°F. in increments of 100°F. in conjunction with the operation of zero, three, and six Red Ray units.

Results

Samples from the runs were tested for coating weight by comparison of the ovendry weights of ten coated and uncoated die cut 3.472 inch diameter discs. Wax pick numbers were recorded as the average of 5 tests. The results are shown in Table I. Although the coating conditions were not changed during the runs the coating weight went down as the runs progressed. An explanation for this would be that the coating continued to settle during the runs thereby reducing the solids. As this was not suspected during the runs a solids determination was not run at the conclusion of the runs. Despite the coating weight variation a trend seems evident in the wax pick tests with a reduced pick with increased Gardner drier temperature and with an increase in the number of Red Ray units operating.

II. CLAY-STARCH-LATEX FORMULATIONS

Formulation

A clay slurry was made in the same manner used in Formulation I using a non-predispersed clay.

Six pounds of Superfilm 40 starch were cooked with 24 lb. of water for one-half hour at 95°C to provide the starch component of the binder. This was cooled down and added to the clay slurry followed by the addition of 3.1 lb. of Dow 512L latex emulsion having a solids content of 48%. The formulation was diluted from 54 to 49% solids with 13.3 lb. of water. The ingredients of the completed formulation are tabulated as follows.

Component	Dry Weight	Wet Weight
Clay slurry	50 lb.	71.4 lb.
Cooked Starch, Superfilm 40	6	30.0
Latex, Dow 512L	1.5	3.1
Water	--	13.3
Total	57.5	117.8

TABLE I

COATING TRIALS WITH CLAY-P.V.A. FORMULATION

Base Stock = 33 lb. White Liner

Air Knife Application--1 psig.

Run	Web Speed f.p.m.	Coating Wgt., lb./3000 sq. ft.	Gardner Drier Temp., °C 1/	Red Ray Units Operating	Wax Pick No.
1	50	16.1	250°	0	5.8
2	50	19.6	350°	0	5.4
3	50	19.1	450°	0	4.8
4	50	18.2	550°	0	3.8
5	50	14.9	350°	3	4.8
6	50	16.8	450°	3	5.6
7	50	16.6	550°	3	4.6
8	50	8.1	250°	6	4.0
9	50	7.7	350°	6	4.6
10	50	9.6	450°	6	5.0
11	50	9.9	550°	6	2.0

1/ Trials made with all three units operating.

The viscosity of the color prior to use was 2500 cp at 12 rpm on a Brookfield viscometer.

Base Stock

Two base stocks were used. The first was the 33 lb/1000 sq. ft. white linerboard used in the previous trials. The second was Consolidated Papers, Inc. Gloss B uncoated base stock having a basis weight of 27 lb/3000 sq. ft.

Application of Coating

The inverted blade coater was used in all of the runs at a blade angle of 30°. The blade extension was initially set at one inch and later shortened to 3/4 inch during the trials with the Gloss B stock. The blade pressure was varied in the runs with the linerboard from 1.28 to 0.22 lb./in. with seemingly little effect on coat weight while the blade pressure was maintained at 0.88 lb./in. in the runs with the Gloss B stock. In all of the runs, the color roll-web gap was held at 0.012 inch and the color roll speed was adjusted to obtain a curtain flow from the blade. The linerboard runs were made at a web speed of 50 ft./min. The web speed with the Gloss B stock runs was varied from 100 to 1200 ft./min. with two excursions to 2000 ft./min. which were unsuccessful due to web breaks.

Drying

Drying was done with the Gardner units only. All three units were operated in unison at temperatures ranging from 250 to 550°F.

Results

Samples were tested for coating weight and wax pick. The conditions of the runs and the test results for the white linerboard runs and the Gloss B stock are shown in Tables II and III respectively.

TABLE II

COATING TRIALS WITH CLAY-STARCH-LATEX FORMULATION

Base Stock = 33 lb. White Liner

Inverted Blade Application; high velocity
Hot air drying only

Run	Web Speed, f.p.m.	Coating Wgt., lb/3000 sq. ft.	Gardner Drier Temp., °C 1/	Wax Pick No.	Blade Pressure lb./in.
1	50	0.4	250°	7.2	1.28
2	50	1.0	250°	7.8	0.97
3	50	3.1	350°	8.8	0.97
4	50	2.9	450°	8.4	0.97
5	50	2.7	550°	8.6	0.97
6	50	2.5	550°	7.0	0.49
7	50	2.3	450°	7.0	0.49
8	50	3.5	350°	7.4	0.49
9	50	3.6	250°	7.2	0.49
10	50	3.4	250°	7.0	0.71
11	50	2.6	250°	6.6	0.22

1/ Trials made with all units operating.

TABLE III

COATING TRIALS WITH CLAY-STARCH-LATEX FORMULATION

Base Stock: Consolidated Gloss B

Trailing Blade Application; high velocity
Hot air drying only; blade pressure
0.88 lb./in.

Run	Web Speed, f.p.m.	Coating Wgt., lb/3000 sq. ft.	Gardner Drier Temp., °C 1/	Wax Pick No.
1	100	3.0	250°	5.6
2	100	2.6	300°	5.8
3	100	2.4	350°	6.6
4	100	2.5	400°	6.4
5	100	2.4	450°	6.6
6	100	2.3	500°	6.4
7	400	2.9	250°	4.6
8	400	2.4	300°	4.4
9	400	2.6	350°	4.8
10	400	2.6	400°	5.8
11	400	2.4	450°	5.8
12	800	2.9	250°	4.6
13	800	2.8	300°	5.0
14	800	2.6	350°	5.2
15	800	3.8	400°	3.8
16	800	3.0	450°	5.0
17	800	3.5	500°	4.0
18	1200	2.9	500°	4.4
19	1200	3.2	450°	4.6
20	1200	2.9	400°	5.4
21	1200	2.7	350°	5.4
22	1200	2.4	300°	5.2
23 2/	--	-	300°	-
24	100	2.5	300°	5.8
25	400	2.6	300°	6.2
26	800	2.6	300°	6.0
27 2/	--	-	300°	-

1/ Trials made with all three units operating.

2/ Unable to reach 2000 f.p.m. due to web breakage.

The data in Table II indicates a trend toward increased pick with increased temperature contrary to the trend of the polyvinyl alcohol coating data. The data in Table III also show a trend toward increased pick with increased drier temperature and the pick seems to decrease with increased web speed reflecting the effect of shorter dwell time in the drier.

III. CLAY-TITANIUM DIOXIDE-CASEIN-LATEX FORMULATION

Formulation

A clay-titanium dioxide slurry was made up of the following ingredients:

Clay Slurry:

Ingredient	Parts	Amount Added
Water	42.7	23.5 lb.
Calgon T	0.1	23 gm.
Titanium Dioxide, Titanox RA-50	9.1	5.0 lb.
Quadrafos	0.3	68 gm.
Clay, HT Predispersed	90.9	50.0 lb.

The titanium dioxide was first dispersed with the Calgon T, the Quadrafos was added followed by the clay and the mixture was dispersed for one-half hour in the Cowles dissolver.

The casein was cooked at 20% solids with 10% 28° ammonium hydroxide by adding 3.3 lb. of Argentine casein, 12.9 lb. of water, and 150 gm. of concentrated ammonium hydroxide to a steam-jacketed starch cooker and cooking for one-half hour at 76-78°C.

Twenty pounds of water added to the clay slurry with agitation by a Lightnin' mixer and the cooked casein was added slowly followed by 6.6 lb. (solids) of Dow 512L latex. A five percent solution containing 23 gm of Dowicide G was added to prevent spoilage. The final mixture was diluted from 50.6 to 45% solids with 35.4 lb. of water. The complete formulation consisted of the following:

Component	Dry Weight	Wet Weight
Clay-TiO_2 slurry	55.2 lb.	78.7 lb.
Casein cook	3.3 lb.	16.5
Latex	6.6	13.8
Water	--	35.4
Total	65.1	144.4

The actual solids of the coating mixture determined on an ovendry (105°C) basis was 49.1% before the trials and 50.7% after the trials. The Brookfield viscosity at 60 rpm was 246 centipoises before the trials and 344 centipoises after the trials.

Base Stock

The coating was applied to the felt side of a 42 lb/25 x 38--500 Nekoosa-Edwards uncoated stock having a caliper of 3.4 mil.

Application of Coating

Trials were run first with the air knife unit, then with the inverted blade unit. The air knife settings were:

Orifice: 0.030 in.

Orifice-Web Gap: 0.135 in.

Angle: 45°

Static air pressure: 1.5 p.s.i.g.

Color roll speed: adjusted for best operation

The following inverted blade settings were used:

Blade extension: 0.50 in.

Angle: 45°

Color roll-web gap: 0.010 in.

Blade pressure: 0.34 lb./in.

Color roll speed: adjusted to give curtain flow from blade

The air knife trials were run at a web speed of 100 ft./min. as were the inverted blade trials with exception of the final two runs which were made at 2000 and 2400 ft./min. respectively. The "blow-off" collected from the air knife trials was the source of coating for the inverted blade trials.

Drying

All three Gardner units were operated in unison at temperatures of 250, 350, and 450°F. At the 250°F setting of the Gardner units runs were made with 0, 2, 4, and 6 Red Ray units in operation.

Sheets of Mylar film, 12 inches wide and several feet long were inserted into the roll at the rewind during the runs to separate the inverted blade runs and minimize moisture diffusion. When the trials were completed the rolls were cut down and samples from the runs were quickly placed in weighing bottles for moisture determinations by ovendry (105°C overnight) weight loss.

Results

Samples from both runs were tested for coating weight and wax pick (described under the polyvinyl alcohol trial). In addition samples were measured for Bausch and Lomb 70° gloss before and after supercalendering with three nips (coated side against the chilled iron roll) at a filled roll temperature of approximately 185°F and a chilled iron roll temperature of 220°F under a nip pressure of 11.6 lb./in. The inverted blade runs, as stated above, were tested for moisture content. The results of the air knife runs are shown in Table IV and the results of the inverted blade runs are shown in Table V.

The wax pick of the air knife coated samples seemed to increase with an increase in the number of Red Ray units in operation while the calendered and uncalendered gloss was reduced. The results of the inverted blade runs also showed an increase in wax pick with the number of Red Ray units in operation and a very slight decrease in uncalendered gloss, but contrary to the air knife results the calendered gloss seemed to increase with the number of Red Ray units. In addition, the wax pick of the blade coated samples increased with increased Gardner drier temperature. The moisture contents of the dried samples were below 1% in all cases indicating that the drying had probably progressed beyond the "constant rate" period. A consistent decrease in moisture was nevertheless noted with an increase in Gardner drier temperature, however, the moisture content was not appreciably changed by the operation of the Red Ray units.

Considering the apparent effect of the Red Ray operation on gloss and wax pick in light of the small effect on final moisture content it seems that the use of the infrared driers enhances the migration and distribution of the liquid components of the coating while the high velocity units effect the moisture removal.

The product of the high speed inverted blade runs was slightly damp at the rewind and tended to block but not to the extent that the layers could not be separated. Assuming a final moisture content of 15% the over-all drying rate for the Gardner drier was calculated from a material balance, neglecting the moisture changes in

TABLE IV

COATING TRIALS WITH CLAY-CASEIN-LATEX FORMULATION

Base Stock = 42 lb. per 25 x 38/500 Air Knife Application--1.5 psig.

Run	Web Speed, f.p.m.	Coating Wgt., lb/3000 sq.ft.	Gardner Drier Temp., °F 1/	Red Ray Units Operating	Wax Pick No.	Gloss-Calendered	Gloss-Uncalendered	Remarks
1	100	0.50	250°	0	-	17.0	6.0	Little or no coating on this run-reason unknown
2	100	14.21	350°	0	7.0	68.0	22.0	
3	100	15.19	450°	0	6.4	67.5	24.0	
4	100	13.86	250°	2	6.4	65.0	16.0	
5	100	13.79	250°	4	6.6	65.5	16.0	
6	100	13.85	250°	6	7.4	60.5	15.0	

1/ Trials made with all three units operating.

TABLE V

COATING TRIALS WITH CLAY-CASEIN-LATEX FORMULATION

Base Stock = 42 lb. per 25 x 38/500

Trailing Blade Application; Blade Pressure 0.34 lb./in.

Run	Web Speed, f.p.m.	Coating Wgt., lb/3000 sq.ft.	Gardner Drier Temp., °F 1/	Red Ray Units Operating	Wax Pick No.	Gloss-Calendered	Gloss-Uncalendered	% Moisture
1	100	5.48	250°	0	7.4	33.0	6.5	0.93
2	100	4.93	350°	0	8.8	31.5	6.5	0.34
3	100	6.08	450°	0	9.4	30.5	6.5	0.21
4	100	6.83	250°	2	7.6	40.0	6.5	0.93
5	100	5.85	250°	4	9.0	34.5	5.5	0.84
6	100	5.77	250°	6	8.8	36.5	5.5	0.88
7	2000	9.38	350°	0	6.6	47.0	6.5	--
8	2400	8.38	350°	0	6.4	52.5	7.5	--

Remarks: Web tended to curl in Run 6; coating spotty and still wet at rewind in Run 8.

1/ Trials made with all three units operating.

the base stock, for Run 7 of the inverted blade trials. The drying rate thus calculated was 12.42 lb. water/sq. ft./hr. On the basis of the water evaporated the over-all heat transfer coefficient "U" was calculated using the Keenan & Keyes steam tables* and found to be 69.2 btu/sq. ft./hr/°F.

Calculations with the data of Run 1 of the inverted blade trials indicated an evaporation rate of 0.44 lb. water/sq. ft./hr. and a "U" coefficient of 5.9 btu/sq. ft./hr./°F. The former values are in keeping with the rates and coefficients quoted by Overly's, Inc. concerning the design characteristics of their driers while the latter values might indicate the expense of drying to low moisture contents. A typical calculation of the evaporation rate and "U" coefficient is the Appendix to this report.

CONCLUSIONS

1. An increase in Gardner drier temperature can reduce the wax pick test properties of coatings formulated with polyvinyl alcohol while increasing the pick properties of coatings formulated with starch and casein.
2. The use of the infrared driers in conjunction with the high velocity driers can reduce the wax pick of coatings formulated with polyvinyl alcohol but the pick of coatings formulated with casein is increased.
3. Drying conditions can affect the gloss of the product before and after calendering, the use of infrared drying in addition to high velocity air may reduce gloss as observed with the air knife coated samples, however, a slight increase was observed with trail blade coated samples.
4. Drying rates of 12.4 lb. water/sq. ft./hr. can be achieved with the Gardner units at a setting of 350°F with heat transfer rates of 69 btu/sq.ft./hr./°F.

* Keenan, J. H., and Keyes, F. G. "Thermodynamic Properties of Steam", 1st Ed. John Wiley & Sons, Inc., New York (1955).

APPENDIX

Calculation of drying rate for inverted blade, Run 7, Formulation III.

Coating solids: 50.7%

Web speed: 2000 ft./min.

Oven dry coating weight: 9.38 lb./3000 sq. ft.

Rate of application of wet coating: $\frac{(9.38)(2000)}{(0.507)(3000)} = 12.33$ lb./min.

Rate of application of dry coating: $\frac{9.38}{(3000)}(2000) = 6.26$ lb./min.

Rate of application of water: 6.07 lb./min.

Assume the moisture content of coating at the rewind to be: 15%

Water not removed in drier: $\frac{(9.38)(2000)(0.15)}{(1-0.15)(3000)} = 1.10$ lb./min.

Water removed in drier: 4.97 lb./min.

Water removed per unit of surface: $\frac{4.97}{(2000)(1)} = 0.00248$ lb./sq. ft.

Dwell time in drier (3 eight ft. units): $\frac{24}{2000} = 0.012$ min.

Drying rate: $\frac{0.00248}{0.012} = 0.207$ lb. water/sq. ft./min.

$= 12.42$ lb. water/sq. ft./hr.

Calculation of over-all heat transfer coefficient "U".

Neglect heat capacities of paper and coating solids

Assume a drier exit web temperature of 200°F and an entrance temperature of 70°F.

Water evaporated: 0.207 lb./sq. ft./min.

Drier temperature: 350°F.

Enthalpy change of liquid from 70°F to 200°F:

(0.207)(167.99 - 38.04) = 26.9 btu/sq. ft./min.

Heat of vaporization at 200°F: (0.207)(979.9) = 201.8 btu/sq.ft./min.

Enthalpy change of steam from 200°F to 350°F:

(0.207)(1192.3 - 1145.9) = 9.6 btu/sq. ft./min.

Total enthalpy change: 238.3 btu/sq. ft./min.

Log mean temperature differential in drier:

$$\frac{(350-70) - (350-200)}{\ln\left(\frac{350-70}{350-200}\right)} = 206.7^{\circ}F$$

$$U = \frac{238.3}{206.7} = 1.15 \text{ btu/sq. ft./min./}^{\circ}F$$

$$= 69.2 \text{ btu/sq. ft./hr/}^{\circ}F$$

PROJECT REPORT FORM

PROJECT NO.	1956
COOPERATOR	IPC
REPORT NO.	50
DATE	March 9, 1967
NOTE BOOK	2378
PAGE	15 TO 51
SIGNED	L. E. Leporte

Lawrence E. Leporte

Copies to: Dr. Howells
Dr. Garey
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METERING CHARACTERISTICS OF THE INVERTED BLADE COATER

SUMMARY

Coating trials were run with clay coatings (starch-latex binder) applied to permeable and impermeable substrates by means of the inverted blade unit on the I.P.C. experimental coater. The impermeable substrate used was a polyvinylidene chloride-over polyethylene coated MG base stock. It was determined that the volume of coating metering onto the impermeable substrate could be related to the factor $(\eta \, {}^{V}/_{F})^{0.75}$ where η was the viscosity at the blade tip, V the web speed, and F the blade loading per unit width. It was found that the volume of coating applied to the permeable substrate could be equated to $(\frac{S}{V})^{0.61} (\frac{V}{F})^{0.75}$ where S was the distance between the applicator roll and the blade tip. The latter relation was arrived at by assuming a contact-time dependent change in the solids content of the coating applied to the sheet prior to the blade.

INTRODUCTION

For the case of a lubricated boundary between a moving plate and a slide Freeman (1) derived a relationship between the volume of lubricant passing between the plate and slide and a factor that can be reduced to $(\eta \, {}^{V}/_{F})^{0.5}$ where η is the viscosity, V the velocity, and F the force on the plate edge. Arnold (2) derived the factor $(\eta \, {}^{V}/_{F})^{x}$ through dimensional analysis for the volume of liquid metered by a metal roll running on an inclined plane. From data presented by Arnold a value of 0.74 can be calculated for x.

The purpose of the work presented in this report was to apply a similar relationship to metering data obtained in the operation of the inverted blade unit on the I.P.C. experimental coater.

EXPERIMENTAL

Three series of trials were run, the first (26-I) using a 42 lb./25 x 38--500 Nekoosa-Edwards coating grade base stock calipering 3.4 mils, while the second and third (28-I and 28-II) were run on Thilmany 48 lb./3000 sq. ft. National MG coated with 6 lb. of polyvinylidene chloride over 10 lb. of polyethylene. The latter base stock was used in order to present an impermeable surface to the coating and minimize the roughness factor thereby reducing or eliminating coating pickup due to penetration and roughness and isolating the effect of metering by the blade. This stock was supplied to the Institute through the courtesy of the Thilmany Pulp and Paper Company.

A starch-latex-clay coating formulation was used in all three trials. Depletion of the Dow 512 latex supply on hand made it necessary to switch to Dow 636 latex in the formulation for Trial 28-II.

Coating Formulations:

A separate batch of coating was prepared for each trial. The following formulation was used:

Component	Dry Weight	Wet Weight
Kaolin clay slurry	50.0 lb.	76.2 lb.
Cooked starch, Superfilm 40	6.0	30.0
Latex, Dow 512R (Trials 26-I and 28-I)	1.5	3.1
Latex, Dow 636 (Trial 28-II)	1.5	3.1
Total/Batch	57.5	109.3

The clay slurries were prepared in a Cowles dissolver by dispersing 50 lb. of clay in a solution of 26 lb. of water and 100 gm. of Quadrafos for 1/2 hour.

The starch cook was carried out in an open steam jacketed vessel at 90°C for 1/2 hour beginning at 20% solids and diluting at the end of the cook to make up evaporation losses.

The starch, clay, and latex components were combined in a 20 gal. tank using a Lightnin' mixer for agitation.

The following measurements were made on the individual batches of coating:

<u>Trial Series 26-I:</u>

Oven-dry solids (before trial): 55.9%

Brookfield viscosity (after trial), No. 3 spindle:

10,880 cp @ 6 rpm
6,240 cp @ 12 rpm
3,128 cp @ 30 rpm
489 cp @ 60 rpm

<u>Trial Series 28-I:</u>

Oven-dry solids (before trials): 57.6%

Oven-dry solids (after trials--sampled from color pan): 58.1%

Pycnometric density (before trials): 1.56 gm./ml.

Pycnometric density (after trials--sampled from color pan): 1.54 gm./ml.

Hercules viscosity (before trials)[a]: 86.4 cp @ 1150 rpm.

Hercules viscosity (after trials--samples from color pan)[a]: 91.4 cp @ 1150 rpm.

Trial Series 28-II:

Oven-dry solids (before trials): 57.6%

Oven-dry solids (after trials--sampled from color pan): 58.8%

Pycnometric density (before trials): 1.55 gm./ml.

Pycnometric density (after trials--sampled from color pan): 1.56 gm./ml.

Hercules viscosity (before trials)[a]: 75.6 cp @ 1150 rpm

Hercules viscosity (after trials--sampled from color pan)[a]: 98.1 cp. @ 1150 rpm.

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[a]Hercules rheogram appended to this report.

Blade Coater

The inverted blade coater used in these trials has been described in IPC Project Report 48. The blade pressure was controlled by means of a lever arm attached to the blade holder shaft as shown in Fig. 1. The blade and holder pivoted on the shaft and the blade was forced into the web and backing roll by means of a load applied to the lever arm. A thumbscrew attached to the coater frame was used to apply load to the lever arm.

Strain gauges (foil type) were attached to the lever arm and connected in a bridge circuit to a phono pre-amplifier (gain of approximately 200). The output from the pre-amplifier was rectified and read out on a 0-50 microamp taut band meter. The bridge was excited from a 10 VAC transformer and a Sorensen constant voltage power supply was used for both the amplifier and the transformer in order to minimize drift due to voltage fluctuations. A 20 minute warm-up time was allowed to reduce drift due to temperature changes. Potentiometers were incorporated to provide a null balance of the bridge and adjust the range of the meter.

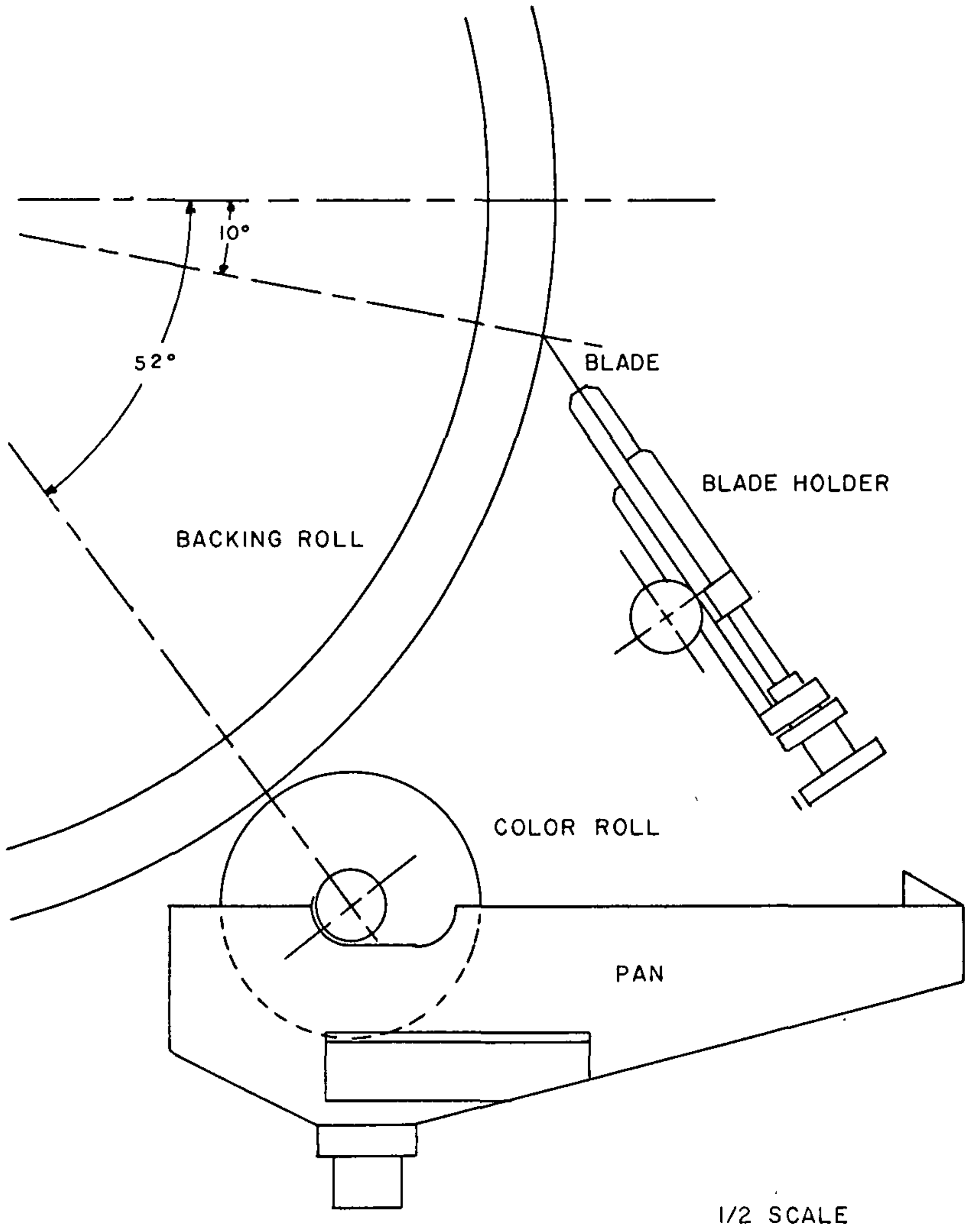


Figure 1. Schematic Representation of Inverted Blade Unit.

The system was calibrated by dead weight loading of the lever arm, the apparatus being designed in such a manner that the system could be readily recalibrated between coater runs.

Trials

Trials were run at web speeds of 100 to 1600 ft./min. and blade loadings of 0.3 to 2.0 lb./in. corresponding to 30.5 to 488 m./min. and 53.5 to 356.6 gm./cm. respectively. All three units of the Gardner high velocity drying system were operated at temperature settings ranging from 200 to 300°F depending upon the amount of coating applied.

In Trial Series 26-I coat weights of the order 3 to 13 lb./3000 sq. ft. were obtained and the weight of base stock remained relatively constant as indicated by random samplings between runs. In Trial Series 28-I and 28-II, however, lower coat weights were obtained, two rolls of base stock were used, and the base stock was pre-coated thereby introducing greater base stock weight variations. Consequently, it was felt necessary to take samples of the base stock after each run.

Basis weights of the coated and uncoated samples were determined for $8\frac{1}{2}$ x 11 inch samples in lb./17 x 22--500 ream on a Testing Machines, Inc. basis weight scale. Average values for six specimens were determined for Trial 26-I while ten specimens were used in Trials 28-I and 28-II and, in the case of Trials 28-I and 28-II, after drying for 1 hr. at 105°C. As a check for possible coating weight variations across the sheet due to uneven metering, specimens of Trial 26-I were cut in half lengthwise (machine direction) and tested for basis weight--no variation was discerned.

Results

From the knowledge of the coating solids and the density it was possible to calculate the volume of wet coating applied per ream and from this the thickness of coating metered onto the web (this includes pickup due to penetration and roughness in Trial Series 26-I). The density determination of Trials 28-I and 28-II corresponded closely with the data for clay-water suspensions given in the TAPPI Technical Information Sheets and the latter were used to estimate the density of the 26-I coating.

The results of the trials along with the calculated coating thicknesses are listed in Table I along with the average shear rate estimated as the web speed divided by half of the calculated coating thickness. The basis weights of coated and corresponding uncoated run samples of Trials 28-I and 28-II are plotted in Fig. 2 and 3.

METERING ACTION OF THE TRAILING BLADE

Both Freeman's (1) equation for the metering of lubricant between a plate and a slide and Arnold's (2) relationship for the metering of a liquid spread by a roll running down an inclined plane contain the factor $(\eta \, V/F)$ where η is viscosity, *V* the velocity, and *F* load per unit width. In order to apply this factor it is necessary to know the viscosity in the region of the metering action. In the case of the trailing blade the metering action occurs near the blade tip where, as shown in Table I, shear rates in excess of 100,000 $sec.^{-1}$ can be expected. In contrast, the maximum shear rates obtained in the Hercules viscometer measurements were of the order 5000 $sec.^{-1}$.

TABLE I

SUMMARY OF COATING RUNS

Run	Web Speed, ft./min.	Blade Angle, Degrees	Blade Load, lb./in.	Coating Weight, lb./17 x 22--500	Coating Volume, cc./sq.m.	Shear Rate, 10^5 sec.$^{-1}$
Trial Series 26-I						
1	100	32	1.0	1.25	5.52	1.84
2	100	32	0.5	2.25	9.95	1.02
3	100	32	0.3	2.75	12.17	0.84
4	100	32	1.5	1.00	4.42	2.30
5	500	32	0.5	2.50	11.05	4.60
6	500	32	1.0	1.50	6.63	7.66
7	500	32	0.3	4.00	17.70	7.86
8	500	32	1.5	1.25	5.52	9.20
9	1000	32	1.0	1.75	7.74	13.12
10	1000	32	0.5	3.00	13.27	7.66
11	1000	32	0.3	5.75	25.40	4.00
12	1000	32	1.5	1.25	5.52	18.40
Trial Series 28-I						
1	100	32	0.3	0.48	2.01	5.06
2	100	32	0.5	0.72	3.02	3.36
3	100	32	1.0	0.33	1.38	7.36
4	100	32	1.5	0.60	2.51	4.04
5	500	32	1.5	0.77	3.22	15.77
6	500	32	1.0	0.94	3.94	12.89
7	500	32	0.5	2.02	8.46	6.00
8	500	32	0.3	3.92	16.42	3.09
9	1000	32	0.3	5.12	21.47	4.73
10	1000	32	0.5	3.40	14.25	7.13
11	1000	32	1.0	1.62	6.79	14.97
12	1000	32	1.5	0.76	3.18	31.95
13	1600	32	0.3	4.68	19.60	8.29
14	1600	32	0.5	3.84	16.09	10.10
15	1600	32	1.0	2.10	8.80	18.47
16	1600	32	1.5	0.74	3.10	52.40

TABLE I (CONTINUED)

Run	Web Speed, ft./min.	Blade Angle, Degrees	Blade Load, lb./in.	Coating Weight lb./17 x 22--500	Coating Volume, cc./sq.m.	Shear Rate, 10^5 sec.$^{-1}$
Trial Series 28-II						
1	100	32	0.3	0.66	2.74	3.70
2	100	32	0.5	0.48	2.00	5.08
3	100	32	1.0	0.51	2.12	4.80
4	100	32	1.5	0.64	2.66	3.82
5	100	32	2.0	0.11	0.46	22.06
6	500	32	0.3	1.25	5.20	9.76
7	500	32	1.0	0.44	1.83	27.75
8	500	32	1.5	0.48	2.00	25.40
9	500	32	2.0	0.24	1.00	50.80
10	500	32	0.5	0.74	3.08	16.49
11	100	26.3	0.3	1.25	5.20	1.95
12	100	26.3	0.5	0.58	2.41	4.21
13	100	26.3	1.0	0.66	2.74	3.85
14	100	26.3	1.5	0.36	1.50	6.77
15	100	26.3	2.0	0.46	1.91	5.32
16	500	26.3	0.3	2.34	9.74	5.22
17	500	26.3	0.5	1.62	6.74	7.54
18	500	26.3	1.0	0.78	3.24	15.68
19	500	26.3	1.5	0.88	3.66	13.88
20	500	26.3	2.0	0.90	3.74	13.58
21	100	40	0.3	1.12	4.61	2.20
22	100	40	0.5	0.80	3.32	3.06
23	100	40	1.0	0.60	2.50	4.06
24	100	40	1.5	0.62	2.58	3.94
25	100	40	2.0	0.55	2.29	4.43
26	500	40	0.3	0.47	1.95	26.07
27	500	40	0.5	0.62	2.58	19.69
28	500	40	1.0	0.56	2.33	21.80
29	500	40	1.5	0.64	2.66	19.10
30	500	40	2.0	0.08	0.33	153.9
31	100	45	0.3	0.46	1.91	5.32
32	100	45	0.5	0.72	3.00	3.38
33	100	45	1.0	0.54	2.24	4.53
34	100	45	1.5	0.40	1.66	6.12
35	100	45	2.0	0.41	1.71	5.94
36	500	45	0.3	1.02	4.24	11.98
37	500	45	0.5	0.67	2.78	18.28
38	500	45	1.0	0.71	2.96	17.17
39	500	45	1.5	0.45	1.87	27.17
40	500	45	2.0	0.46	1.91	26.60

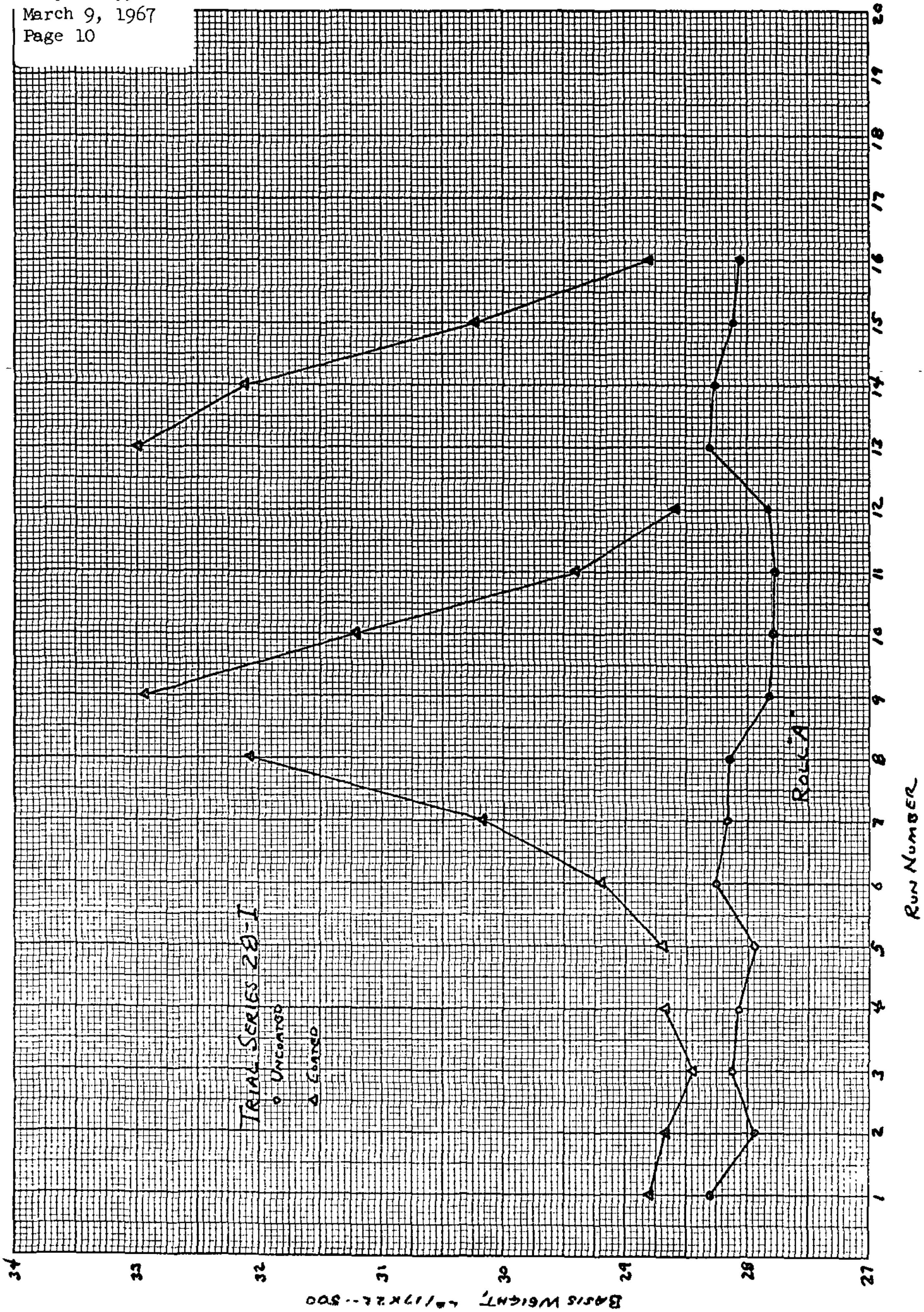
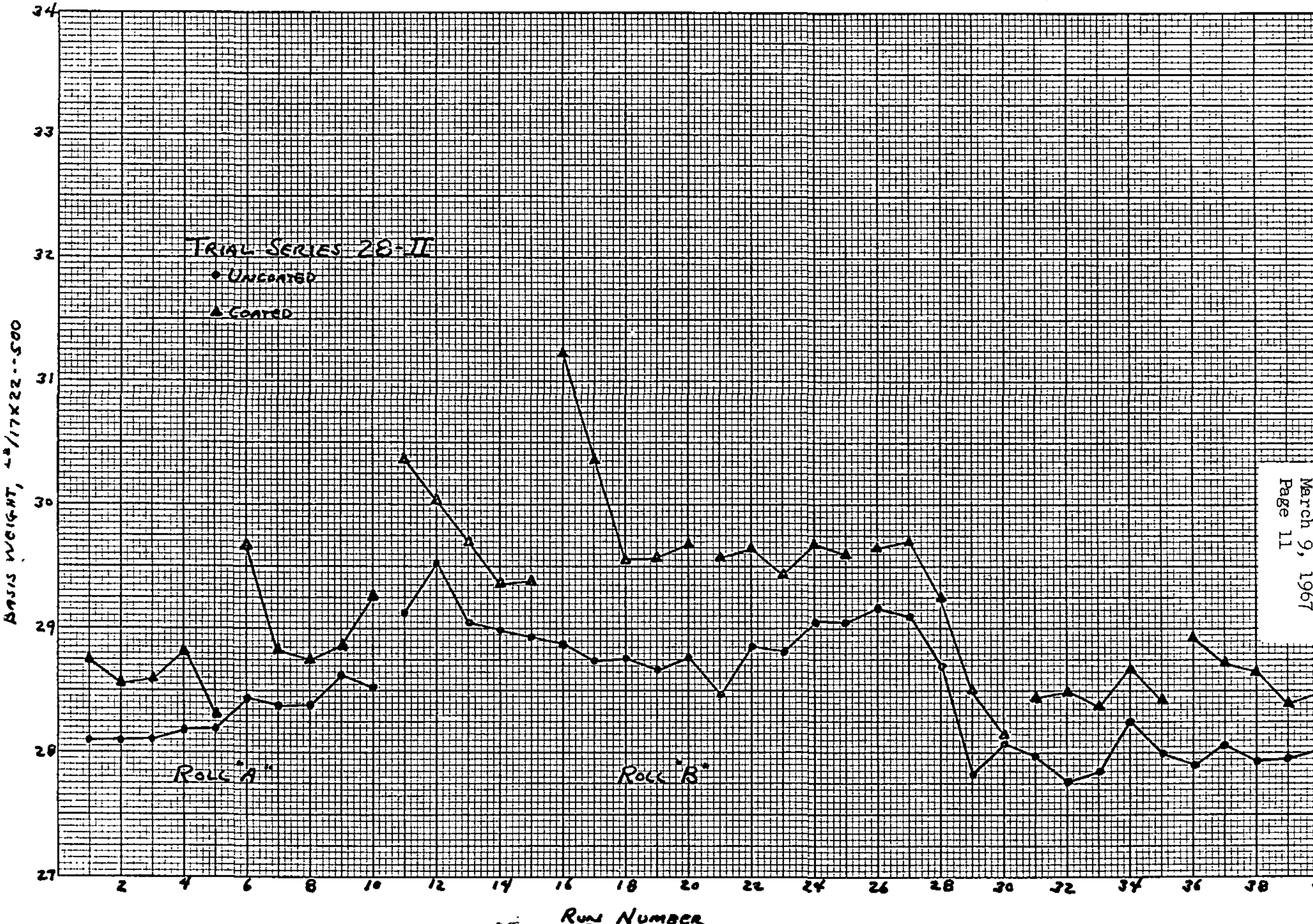


Figure 2. Trial Series 28-I. Basis Weights Before and After Clay Coating.

Figure 3. Trial Series 28-II. Basis Weights Before and After Clay Coating.



The coating formulations used in these trials were nearly Newtonian, as indicated by the appended Hercules rheograms, providing a justification, admittedly tenuous, for extrapolation to shear rates of 10^7 sec.$^{-1}$. Viscosities were calculated at several points on the increasing rate curve (lower curve) of the Hercules rheograms according to the equation:

$$\eta = \frac{(T)(2 \times 10^{-4})}{(\frac{S}{60})\ 2\pi}$$

where: T = torque, dyne-cm.

S = rotational speed of the bob, revolution per minute

These points were plotted on a log-log graph as a function of average shear rate calculated from twice the peripheral velocity of the bob divided by the gap between the bob and the cup. A straight line was drawn through the points and extrapolated to 10^7 sec.$^{-1}$. Extrapolations for before-trial samples from Trials 28-I and 28-II are shown in Fig. 4. Viscosities determined from these extrapolations were then used to calculate the $(\eta\ ^V/_F)$ factors shown in Table II in which V was the web speed and F the blade load.

A log-log plot (Fig. 5) of wet coating thickness as a function of this "metering" factor for Trial 28-I indicates a straight line with a slope of 0.75 which is in agreement with the data of Arnold which indicated a slope of 0.74. Thus, the wet coating thickness metered by the blade is proportional to $(\eta\ ^V/_F)^{0.75}$.

Among the geometric factors that would be expected to influence metered thickness are blade material and thickness, blade extension, and blade angle. The purpose of the 28-II trials was to determine the effect of blade angle (defined

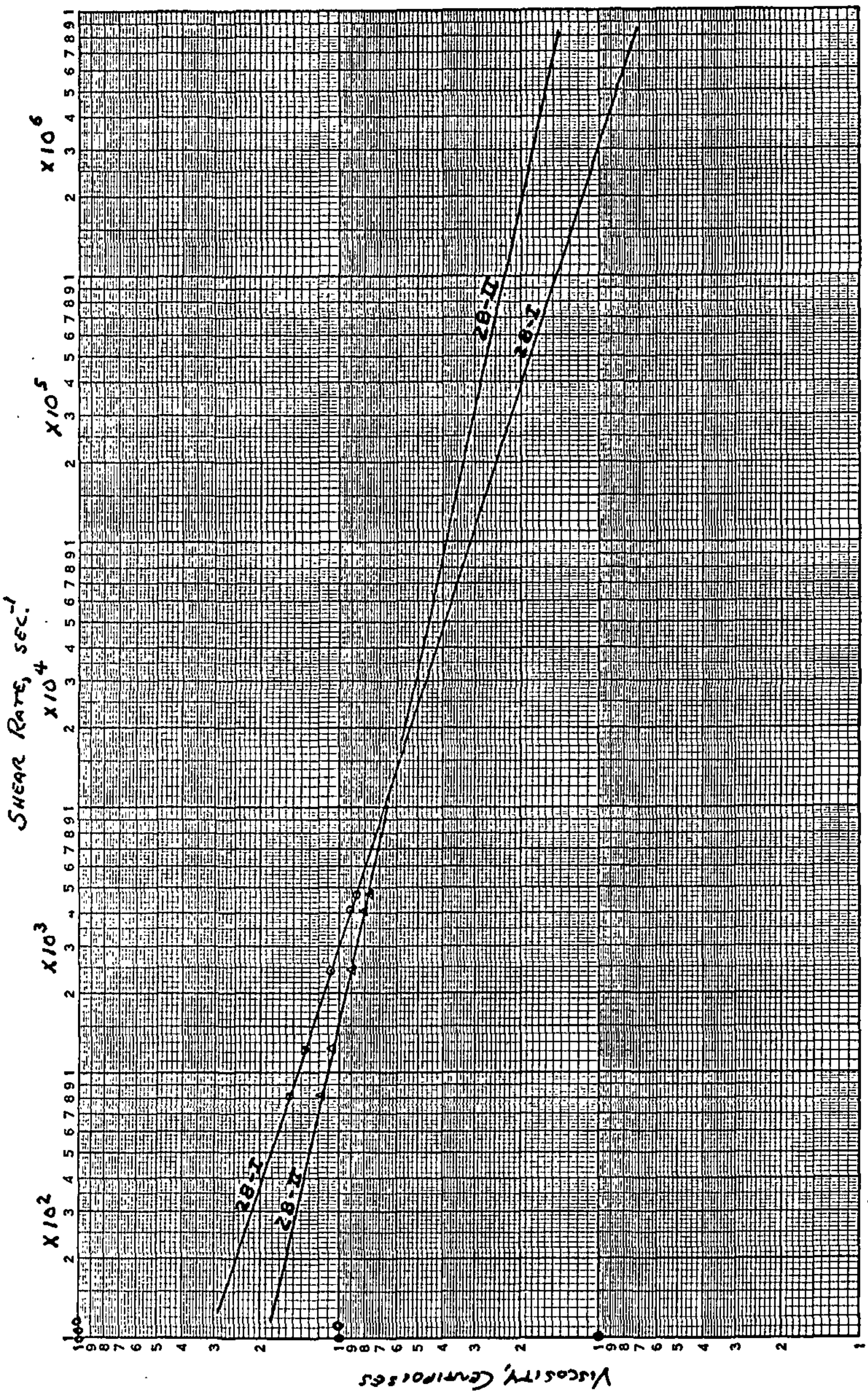


Figure 4. Extrapolation of Hercules Viscosity Data from Trials 28-I and 28-II.

TABLE II

Run	Web Speed cm./sec.	Viscosity, gm./cm.-sec.	Blade Load, gm./cm.	$\eta\ V/F$, $\frac{cm}{sec^2}$	Coating Thickness, 10^{-4} cm.
Trial Series 28-I					
1	50.8	0.181	53.5	0.172	2.01
2	50.8	0.209	88.2	0.120	3.02
3	50.8	0.160	178.3	0.046	1.38
4	50.8	0.195	267.5	0.037	2.51
5	254.0	0.124	267.5	0.118	3.22
6	254.0	0.132	178.3	0.188	3.94
7	254.0	0.171	88.2	0.492	8.46
8	254.0	0.214	53.5	1.016	16.42
9	508.0	0.186	53.5	1.766	21.47
10	508.0	0.162	88.2	0.933	14.25
11	508.0	0.126	178.3	0.359	6.79
12	508.0	0.098	267.5	0.186	3.18
13	812.5	0.154	53.5	2.329	19.60
14	812.5	0.144	88.2	1.327	16.09
15	812.5	0.117	178.3	0.533	8.80
16	812.5	0.082	267.5	0.249	3.10
Trial Series 28-II Blade Angle: 32°					
1	50.8	0.290	53.5	0.276	2.74
2	50.8	0.270	88.2	0.155	2.00
3	50.8	0.273	178.3	0.078	2.12
4	50.8	0.282	267.5	0.054	2.60
5	50.8	0.194	356.6	0.028	0.46
6	254.0	0.232	53.5	1.101	5.20
7	254.0	0.184	178.3	0.262	1.83
8	254.0	0.197	267.5	0.177	2.00
9	254.0	0.160	356.6	0.114	1.0[illegible]
10	254.0	0.206	88.2	0.593	3.08
Blade Angle: 26.3°					
11	50.8	0.336	53.5	0.319	5.20
12	50.8	0.281	88.2	0.162	2.41
13	50.8	0.286	178.3	0.082	2.74
14	50.8	0.252	267.5	0.048	1.50
15	50.8	0.266	356.6	0.038	1.91
16	254.0	0.268	53.5	1.272	9.74
17	254.0	0.246	88.2	0.708	6.74
18	254.0	0.209	178.3	0.298	3.24
19	254.0	0.215	267.5	0.204	3.66
20	254.0	0.215	356.6	0.153	3.74

TABLE II (CONTINUED)

Run	Web Speed, cm./sec.	Viscosity, gm./cm.-sec.	Blade Load, gm./cm.	$\eta\, V/F$, $\frac{cm}{sec^2}$	Coating Thickness, 10^{-4} cm.
	Blade Angle: 40°				
21	50.8	0.326	53.5	0.310	4.61
22	50.8	0.302	88.2	0.174	3.32
23	50.8	0.284	178.3	0.081	2.50
24	50.8	0.285	267.5	0.054	2.58
25	50.8	0.278	356.6	0.040	2.29
26	254.0	0.187	53.5	0.888	1.95
27	254.0	0.199	88.2	0.572	2.58
28	254.0	0.193	178.3	0.275	2.33
29	254.0	0.200	267.5	0.190	2.66
30	254.0	--	--	--	--
	Blade Angle: 45°				
31	50.8	0.267	53.5	0.254	1.91
32	50.8	0.295	88.2	0.170	3.00
33	50.8	0.276	178.3	0.079	2.24
34	50.8	0.259	267.5	0.049	1.66
35	50.8	0.260	356.6	0.037	1.71
36	254.0	0.221	53.5	1.049	4.24
37	254.0	0.202	88.2	0.582	2.78
38	254.0	0.205	178.3	0.292	2.96
39	254.0	0.185	267.5	0.176	1.87
40	254.0	0.185	356.6	0.132	1.91

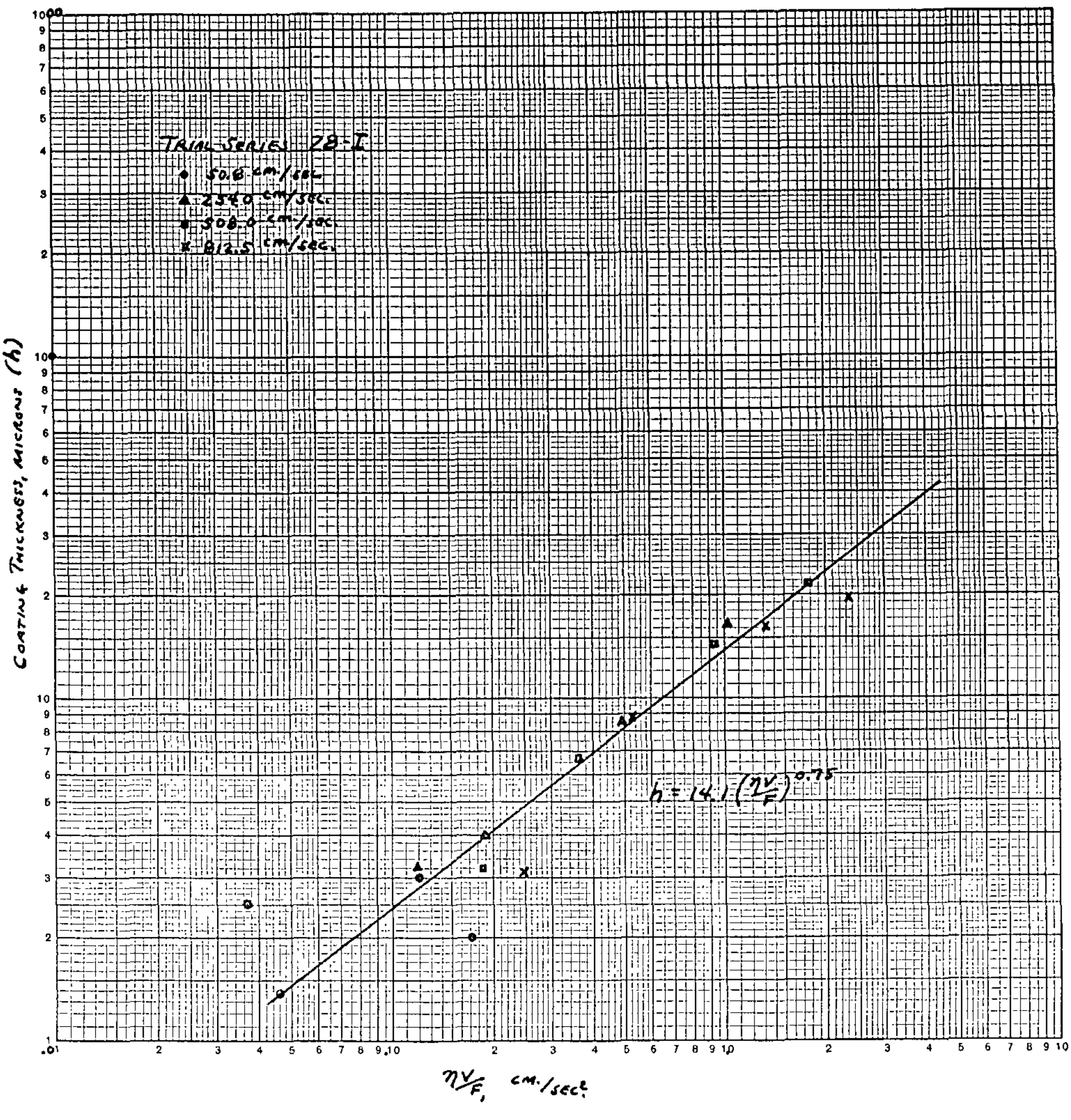


Figure 5. Trial Series 28-I, Metered Coating Thickness as a Function of "Metering" Factor.

as the angle of the unloaded blade to the tangent at the point of contact). A similar coating formulation was used in these trials; the only real difference being the use of the Dow 636 latex in place of the 512R. Under equivalent conditions lower coat weights were obtained with the 28-II coating even though its extrapolated viscosity was higher. Comparative inspection of coated samples indicated that somewhat poorer wetting seemed to be obtained when the 636 latex was used. A plot of the calculated coating thickness against the "metering" factor (Fig. 6) had a high degree of scatter particularly with points lying between 2 and 3 microns tending to be independent of the "metering" factor. A similar situation was noticed in Trial 28-I, however, fewer data points were obtained in the 2-3 micron range. It would seem likely that this scatter could be attributed to the surface roughness of the substrate. Subsequently a sample of the base stock was submitted to the Paper Evaluation Section for permeability and surface roughness measurements by the nip spreading technique. The permeability was found to be zero,while the surface roughness was found to be less than 3.2 microns, probably between 2.5 and 3.2 microns, confirming the postulated explanation for the independence of the data below 3 microns. Attempts to fit straight lines having slopes of 0.75 to the data plots in Fig. 6 were of questionable success due to the low coat weights obtained. Trends of the data do, however, indicate decreasing coat weight with increasing blade angle.

COATING A PERMEABLE SUBSTRATE

The effects of migration over a time interval short enough that the process can be treated as a constant rate capillary flow phenomenon would seem to be akin to a drainage-filtration problem. A layer of high solids is built up next to the sheet and the adjacent color is drained of its liquid component thereby increasing its solids. This visualization opens the door to two

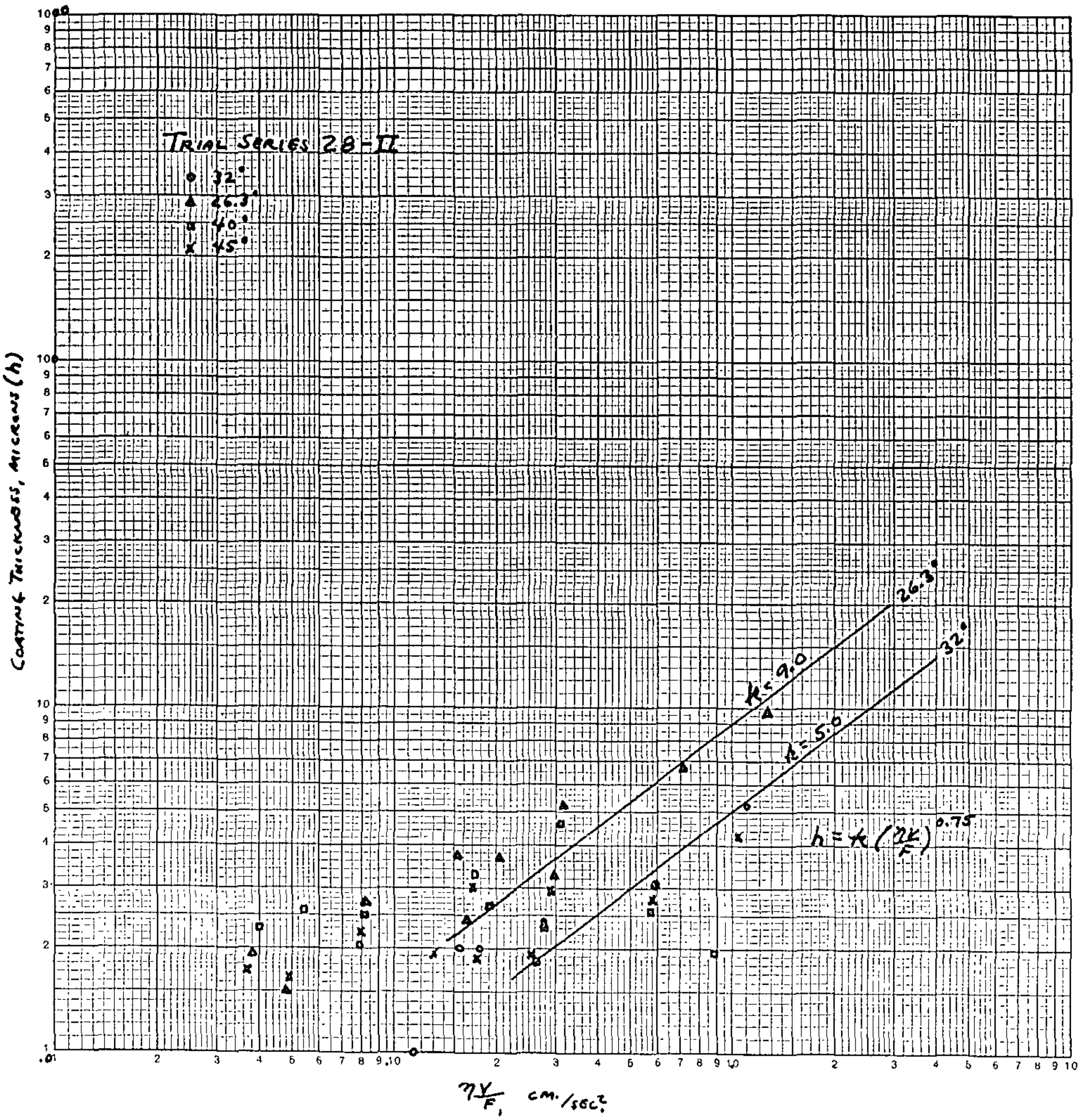


Figure 6. Trial Series 28-II, Metered Coating Thickness as a Function of "Metering" Factor.

semi-empirical approaches within the scope of this work. In the first it may be assumed that what happens between the color roll and the blade tip occurs at a constant rate over the range of web speeds involved and that the result may be treated as an effective change in coating solids with a concomitant change in viscosity. On this basis the "metering" factor can then be modified to account for contact-time dependent changes in viscosity.

The second approach would be based upon the assumption of a time dependent build-up of a high solids layer of coat virtually immobilized adjacent to the substrate. In this case the process would be considered as a filtration problem meaning that the solids content of the coating color above the "immobilized" layer would be unchanged.

Increasing Solids Approach

Integration of the Darcy equation shows that the depth of penetration of a fluid into a porous bed at a constant pressure drop is proportional to the square root of the time interval. On the presumption that this penetration produces an effective change in solids, the change in solids can be related to the contact-time by the equation:

(1) $$\frac{c}{c_o} = k_1 \, t \, \alpha$$

where c_o is the initial solids concentration, c the effective solids at the blade, k_1 a constant, and t the time interval between the roll and the blade.

A similar relationship would be expected for the change in viscosity with solids providing the basic rheology remains unchanged (e.g. does not become dilatant). A small quantity of the coating formulation used in the trial series

28-II was made up to determine the solids-viscosity relationship. Samples were diluted to solids concentrations ranging from 45 to 55%. Hercules viscosity measurements were run on the samples and the calculated viscosities at 1150 rpm (shear rate 4700 sec.$^{-1}$) were plotted against solids on a log-log scale (Fig. 7--viscosities at before and after trial solids contents of 28-II color are also plotted). The linearity of the plot shows the relationship to be of the form:

(2) $$\frac{\eta}{\eta_o} = \left(\frac{c}{c_o}\right)^{\beta}$$

where η and η_o are viscosities at solids concentrations c and c_o, respectively. In this particular case β equals 5.5.

As shown earlier the metering action of the blade is related in the equation:

(3) $$W_m = K \left(\eta \, V/_F\right)^{0.75}$$

where W_m is the wet coating volume per unit area and is equal to coating thickness η for an impermeable substrate.

Rearranging and substituting equations 1 and 2 and the distance S between the applicator roll and the blade divided the web speed V for t, equation 3 becomes:

(4) $$W_m = \left[K' \; \eta_o \left(\frac{S}{V}\right)^{\gamma}\right]^{0.75} \left(\frac{V}{F}\right)^{0.75}$$

where K' is Kk, and γ is $\alpha \beta$. This equation does not present a wholly accurate model of the processes taking place between the color roll and the blade. The value of α in equation 1 at constant pressure and permeability is 0.5, consequently, the value of γ for the case at hand should be 2.75, whereas, as will be shown, it is substantially less. Possibly this is due to time dependent changes

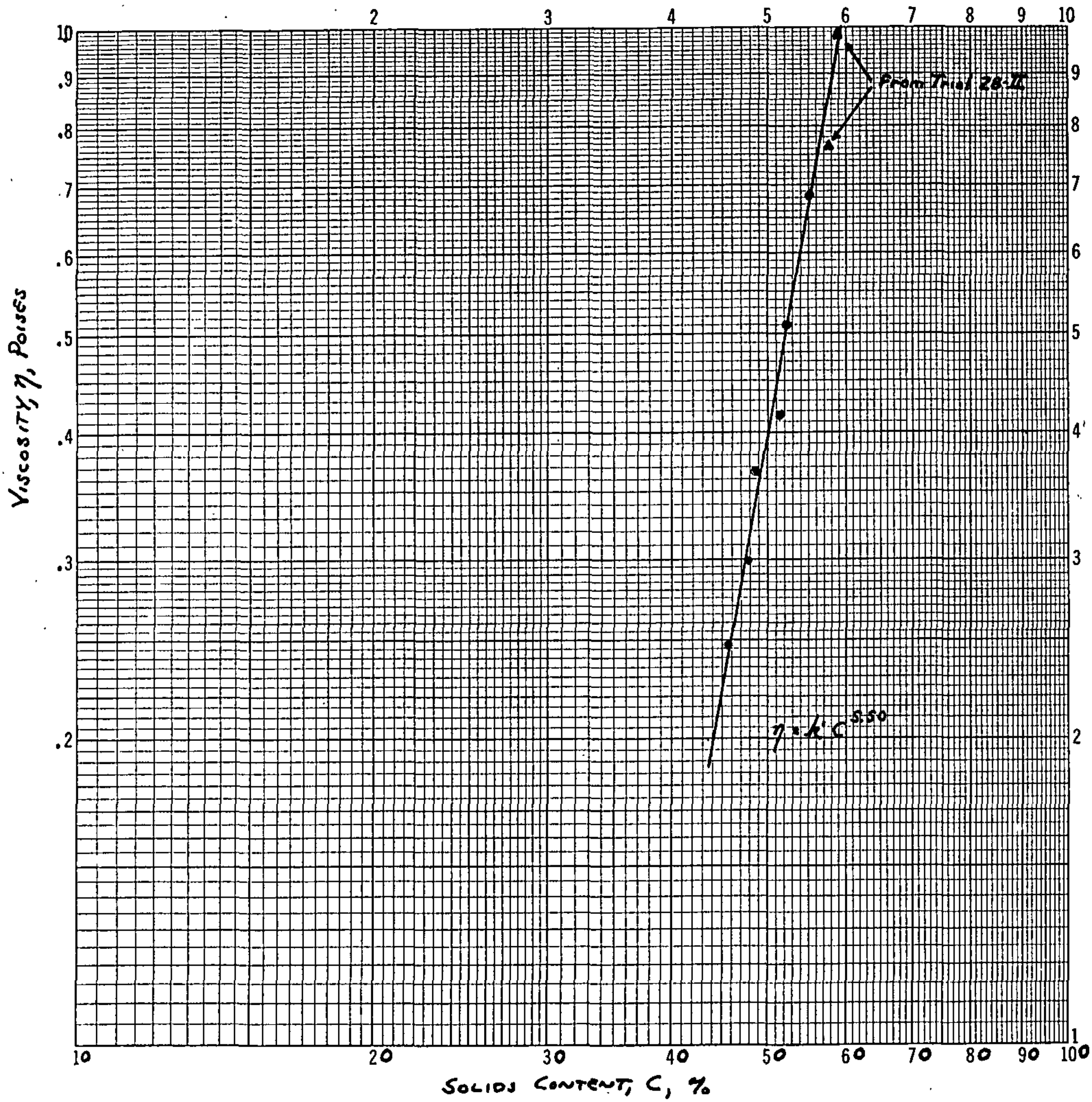


Figure 7. Effect of Solids Content on Hercules Viscosity at 1150 r.p.m.--clay-latex-starch coating.

in permeability resulting from plugging of capillaries, fiber swelling, and the build-up of a thin layer of solids at the surface. Each of these conditions might modify the rate of liquid migration into the sheet as a function of contact-time so that the experimentally determined value of γ may represent the time dependency of several factors affecting permeability.

The experimental values of W_m (Trial Series 26-I, see Table-I) were plotted on a log-log scale against $(V/F)^{0.75}$ and fitted by a straight line of unity slope with web speed as a parameter in Fig. 8. The coefficients k of the lines are equal to $[k' \eta_o (S/V)^{\gamma}]^{0.75}$. The value of S was known to be 25.4 cm. so that a log-log plot of $k^{1/0.75}$ versus S/V could be used to determine the values of $K' \eta_o$ and γ. This plot is shown in Fig. 9; the value of $K' \eta_o$ was found to be 59.7 and the value of the exponent γ was found to be 0.81.

Inserting these values in equation 4, the wet coating volume applied is related by the equation:

(5) $$W_m = 21.5 \left(\frac{S}{V}\right)^{0.61} \left(\frac{V}{F}\right)^{0.75}$$

A linear regression analysis of the coating volume data as a function of $\left(\frac{S}{V}\right)^{0.61} \left(\frac{V}{F}\right)^{0.75}$ (omitting run 11 which seemed to be a wild point) resulted in a slope of 21.2, an intercept of 0.18 and a correlation coefficient of 0.99. A plot of this data and its regression line is shown in Fig. 10.

Immobilized Layer Approach

Presuming the build-up of an immobilized layer the layer, h_m, of the coating undergoing shear at the blade tip would be:

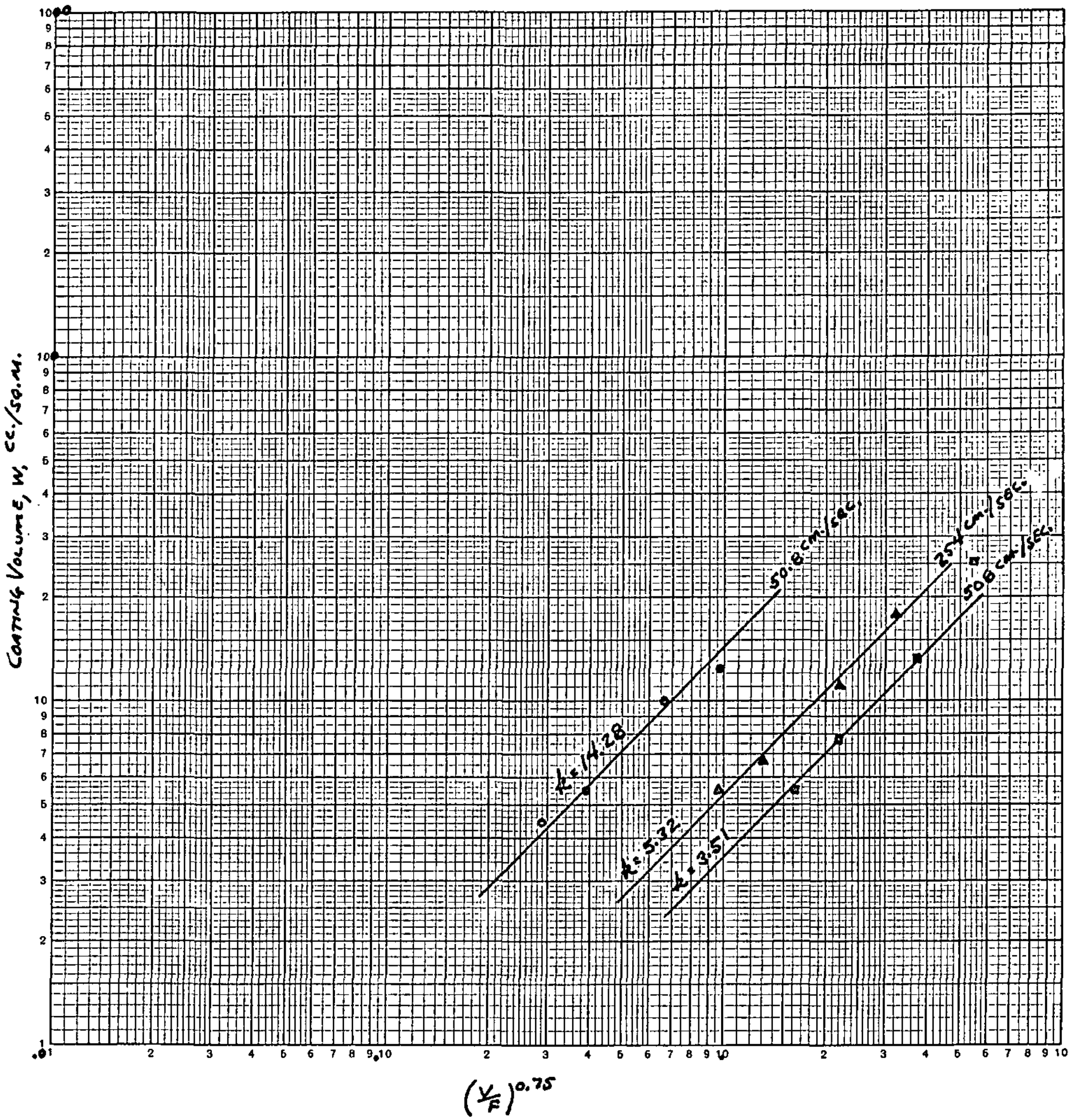


Figure 8. Trial Series 26-1, Volume of Coating Applied as a Function of Web Speed-Blade Pressure Factor.

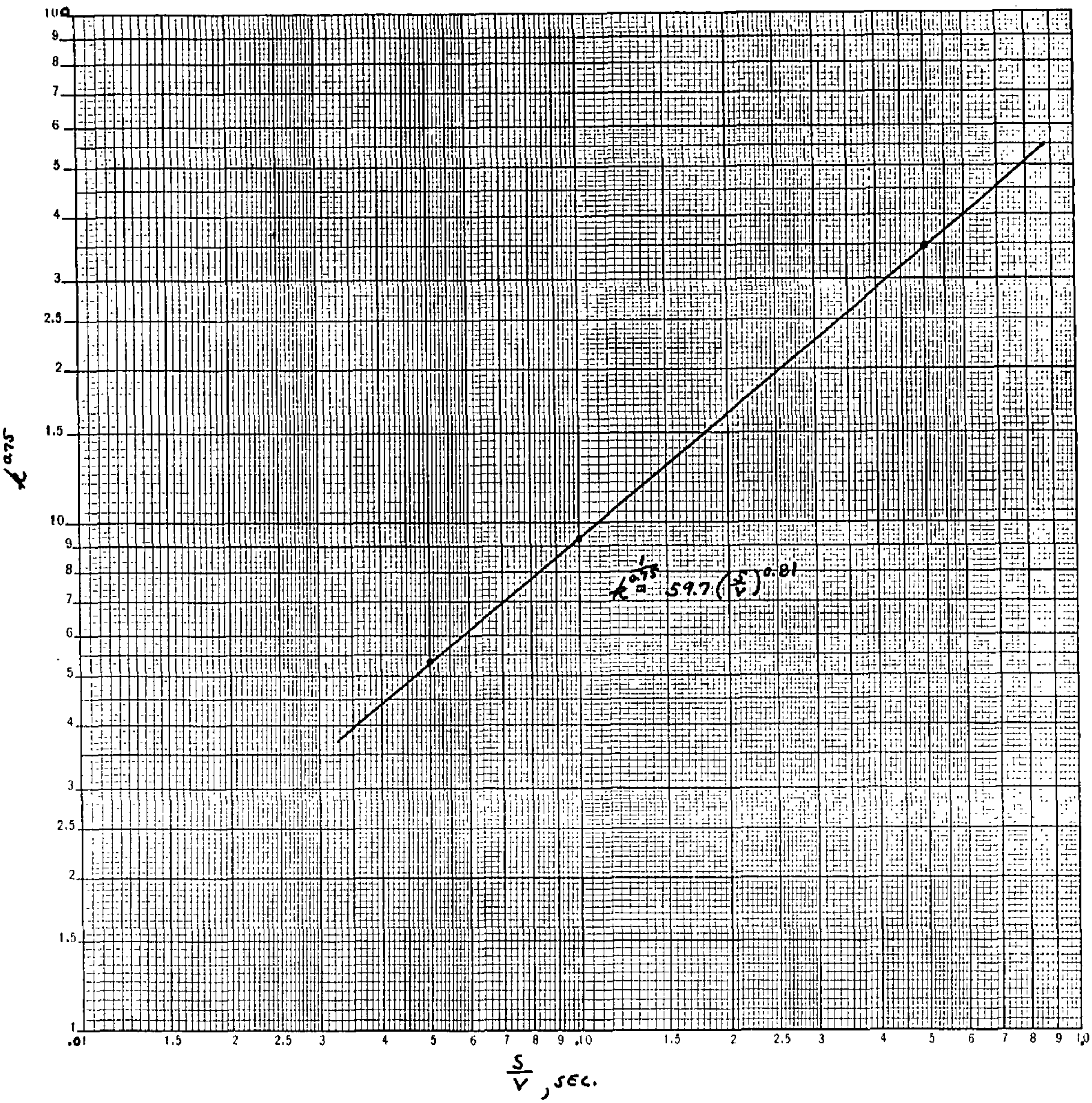


Figure 9. Trial Series 26-I, Slope (see Fig. 8) as a Function of Contact Time Prior to Blade Tip.

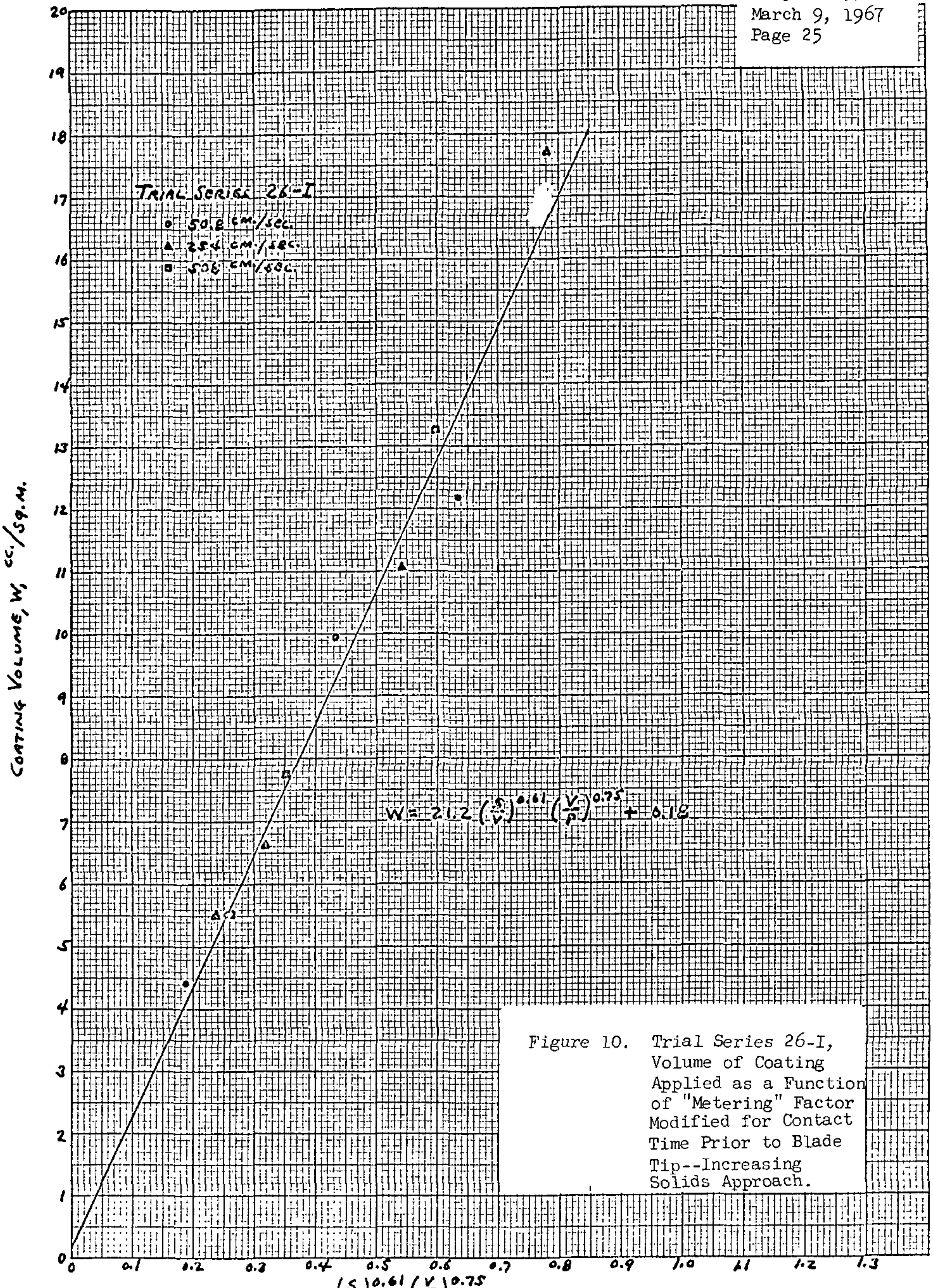


Figure 10. Trial Series 26-I, Volume of Coating Applied as a Function of "Metering" Factor Modified for Contact Time Prior to Blade Tip--Increasing Solids Approach.

(6) $$h_m = h_o - h_s$$

where h_o is the distance from the blade tip to the substrate and h_s is the thickness of the immobilized layer. The layer h_m should be a function of the metering factor as shown previously while the viscosity as a function of shear rate would be related to h_m by:

(7) $$\eta = k \left(\frac{2V}{h_m}\right)^n$$

which when substituted into the meter factor results in the equation:

$$h_m = K' \left(\frac{2V}{h_m}\right)^{0.75n} \left(\frac{V}{F}\right)^{0.75}$$

From the viscosity data for the Trial 28-I coating n and k are equal to -0.341 and 15.48 respectively. Inserting these values and solving equation (7) for h_m results in the expression:

(8) $$h_m = 15.5\ K''\ (2V)^{-.34} \left(\frac{V}{F}\right)$$

The wet coating thickness h_m is also equal to the wet volume applied per unit area. Since the values of h_o calculated from the solids, wet density, dried coating weight represents the total wet volume applied per unit area, the difference, h'_s between h_o and h_m can be used to describe the amount of coating pickup in the formation of the immobilized layer.

In a plot of the total volume of coating applied, h_o, versus $(2V)^{-.34} \left(\frac{V}{F}\right)$ the intercept would be h'_s while the slope would be equal to 15.5 K''. Should the assumptions used in this description hold, then such a plot with web speed as a parameter should result in a set of parallel lines. The plot in Fig. 11 indicates that this is not the case, rather the slopes vary and the intercepts are common, with an equivalent wet coating thickness of 2.5 microns. An interpretation of this would be that if an immobilized layer is formed, it is formed rapidly, does not increase with contact time, and is somewhat less than the probable roughness factor of the substrate. On the other hand the change in slope may be interpreted to represent a change in viscosity as was assumed in the varying solids approach.

DISCUSSION AND CONCLUSIONS

Extrapolation is always a questionable practice and extrapolation over several magnitudes may seem unreasonable, however, the response to increasing shear rates would not be expected to change extensively unless the coating were to become dilatant. Had dilatancy occurred to a very large degree during the trials it would have become apparent in the treatment of the data. In addition, the fractional power relationship tends to minimize the effects of any differences that are not extensive. Metzner (3) indicates that thixotropic fluids degenerate into systems that obey the so-called "power law" which states that the shear stress is proportional to the shear rate raised to an exponential power. He also states that most clay coating suspensions obey this law to the extent the other behavior can often be neglected. Böhmer (4) goes on to say that the exponent of the power law for high solids pigment suspensions for blade coaters usually ranges between 0.7 and 1.0 (the exponents for coating colors 28-I and 28-II were 0.65 and 0.77, respectively) and the behavior is approximately Newtonian. Thus, it would seem that the approach used in this work to calculate a "metering" factor was a reasonable one. Böhmer's evaluation of shear rate distribution indicates that the region of maximum shear rate progresses from the blade surface on the entering side to the substrate surface at the blade tip. His shear rate

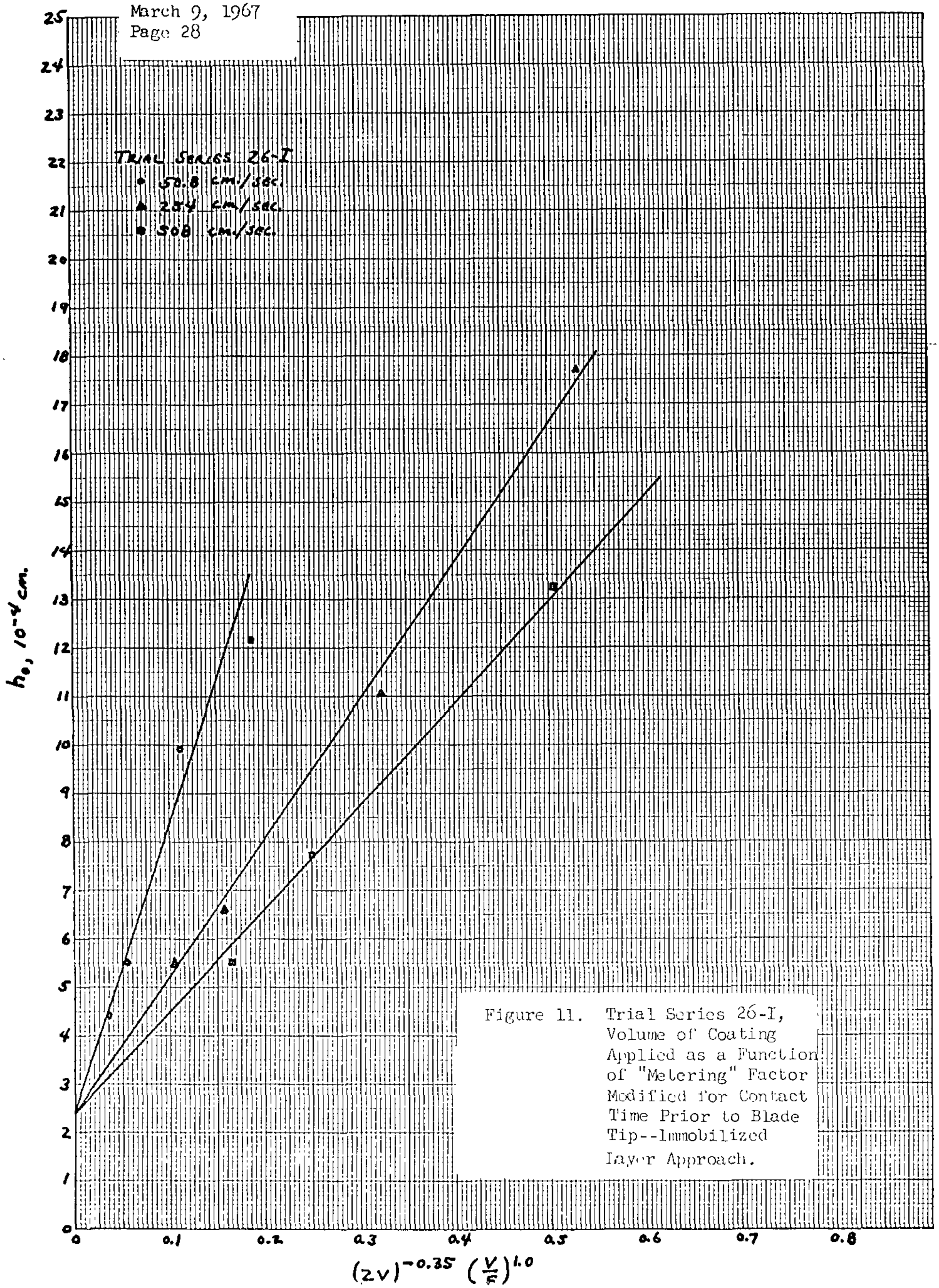


Figure 11. Trial Series 26-I, Volume of Coating Applied as a Function of "Metering" Factor Modified for Contact Time Prior to Blade Tip--Immobilized Layer Approach.

calculations based upon a blade caliper of 0.3 mm, an angle of 41° and a wet film thickness of 10 microns indicate maximum shear rates ranging from U/h_o on the entering side at the blade surface (where U is the web speed and h_o is the wet film thickness) to 2.2 U/h_o at the paper surface under the blade tip. Similar calculations using data from the work covered in this report indicate maximum shear rates at the blade tip ranging from $2U/h_o$ to 3.1 U/h_o. It may be recalled that a value of $2U/h_o$ was used as an estimation of shear rate in this work for the determination of metering factors. This estimate was based upon the shear rate calculations used in Hercules viscometer measurements and as applied in this work seems roughly consistent with Böhmer's evaluation.

Migration of the coating or components of a coating into a permeable substrate involves a complexity of factors such as initial surface character, permeability, migration rates, plugging of the surface and formation of a cake of solids at the surface. The drainage of the liquid components from the coating color probably results in some sort of gradient of solids content ranging from nearly 100% at the surface of the substrate to a level approaching the solids content in the color pan. As the result of these factors, the rheology of the coating at the trailing blade is no doubt somewhat different than the rheology of the coating in the color pan. In attempting to define a simplified approach for application to the work covered in this report two modes of behavior were considered:

(1) A time dependent build-up of an immobilized layer was assumed and it was further assumed that the coating metered between this layer and the blade tip suffered no change in solids content or rheology.

(2) Migration of the liquid components of the coating was assumed to produce a change in the solids of the applied coating without the build-up of an immobilized layer and an equal distribution of the solids throughout the coating.

Treatment of the data in terms of the former mode of behavior indicates that an immobilized layer does not exist to an extent significant to this work and that the rheological behavior of the metered coating varies with contact time. This supports the assumptions of the latter mode of behavior. Through this latter approach, by modifying the viscosity coefficient of the "metering" factor, it was possible to correlate data over a magnitude of web speeds.

Further work in order would be first of all an analysis of the geometric factors affecting the metering action of the blade. Böhmer's (4) evaluation of shear distribution would represent an interesting point of departure for experimental analysis of the conditions in the region of the blade tip and their influence upon the metering action of the blade.

Further studies in which migration and base stock permeability are factors would be of interest to test the approach applied in this work and to determine the constancy of the exponential relationships. The processes involved, however, seem to be too subtly inter-related to be delineated by studies on the pilot coater.

ACKNOWLEDGMENTS

The pilot coater trials were run with the co-operation of Messrs. Donald E. Beyer, James Tierney, and Lester Nett. Mr. Tierney and Mr. Nett also ran the basis weight determinations. The Hercules rheograms were run by Mr. Jack Hultman.

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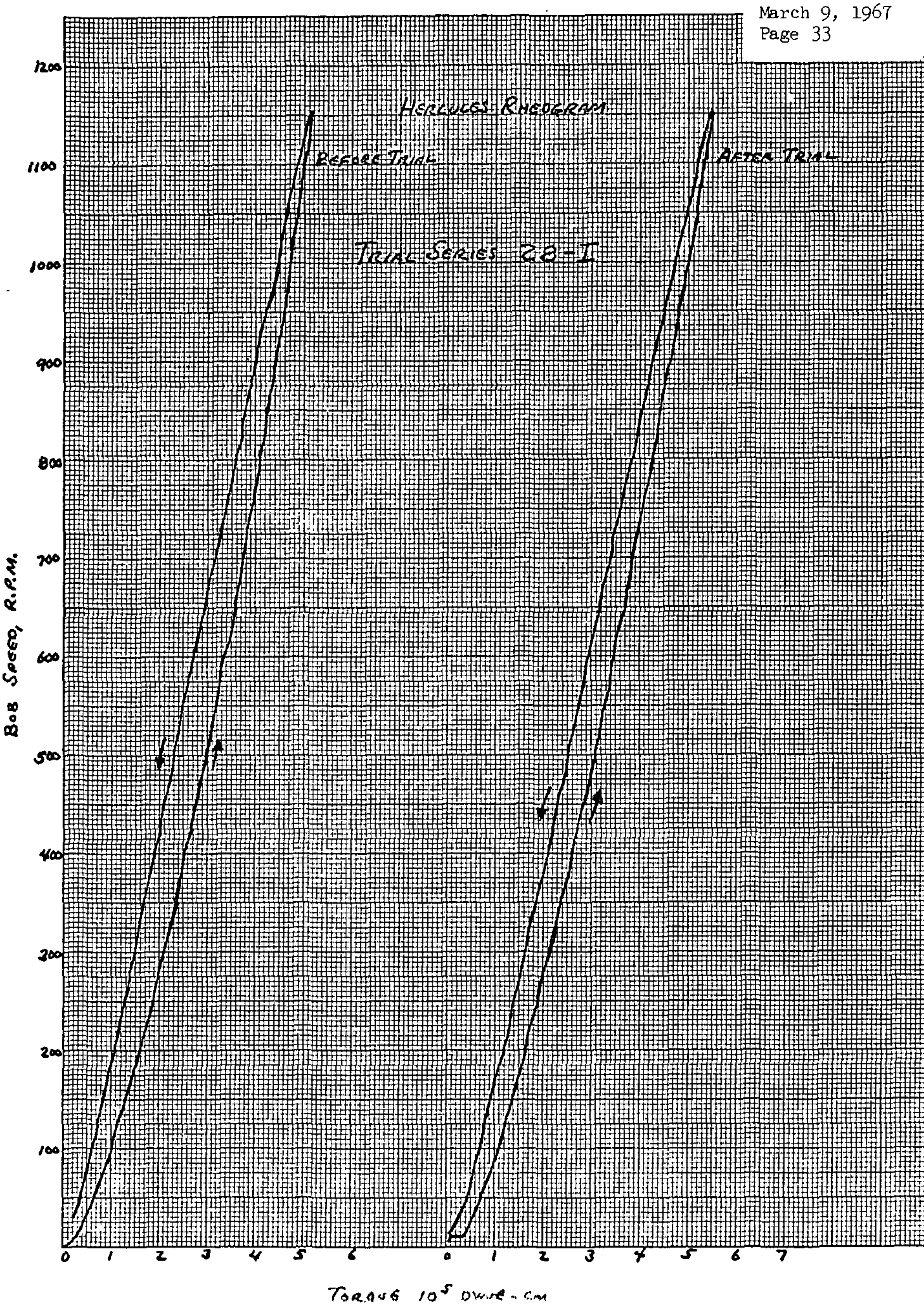
HERSCHEL'S RHEOGRAM
BEFORE TRIAL
AFTER TRIAL
TRIAL SERIES 28-II
1200
1100
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900
800
700
600
500
400
300
200
100
BOB SPEED, R.P.M.
0
1
2
3
4
5
6
0
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7
TORQUE 10^5 DYNE-CM

Project 1956
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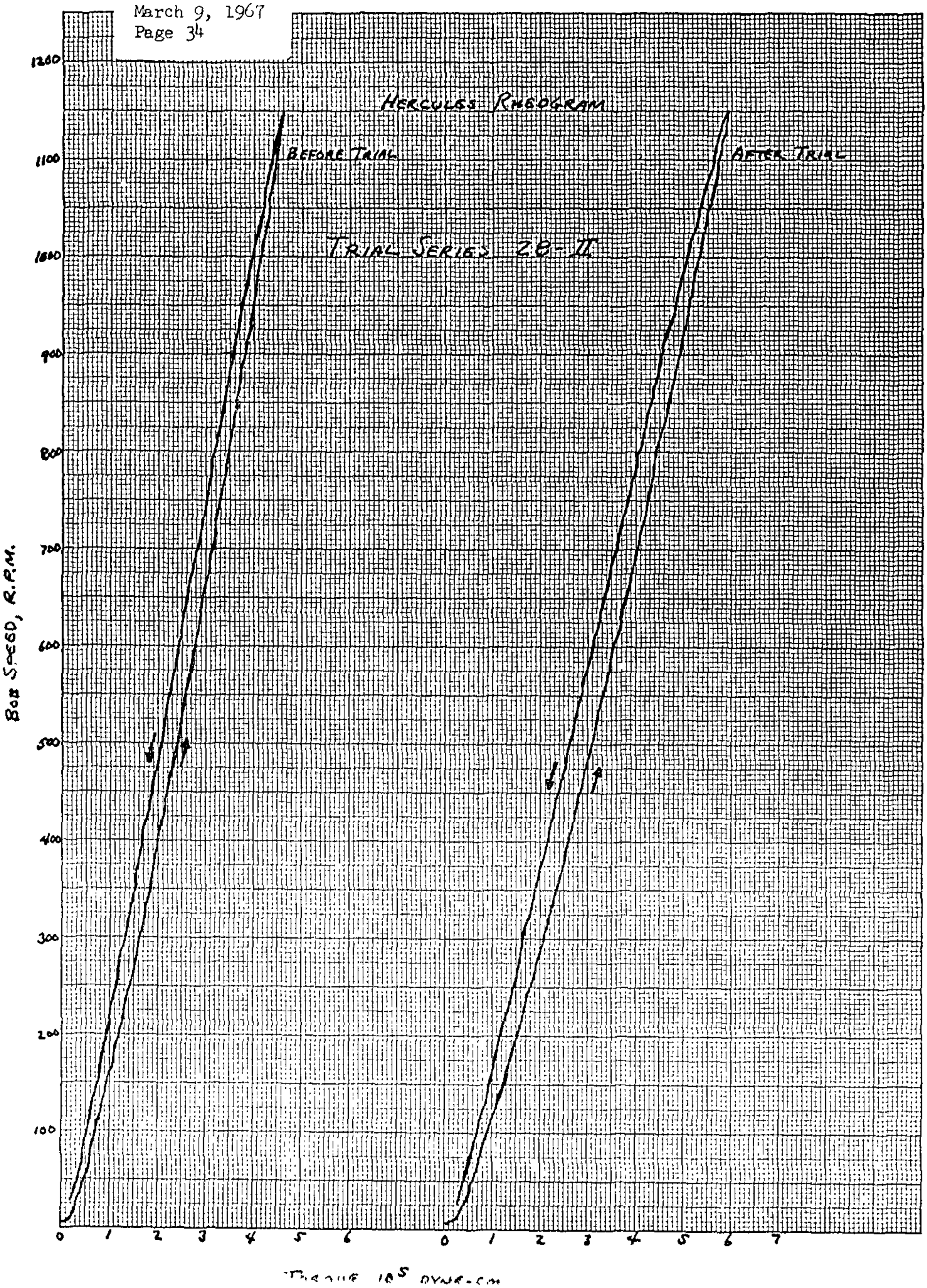

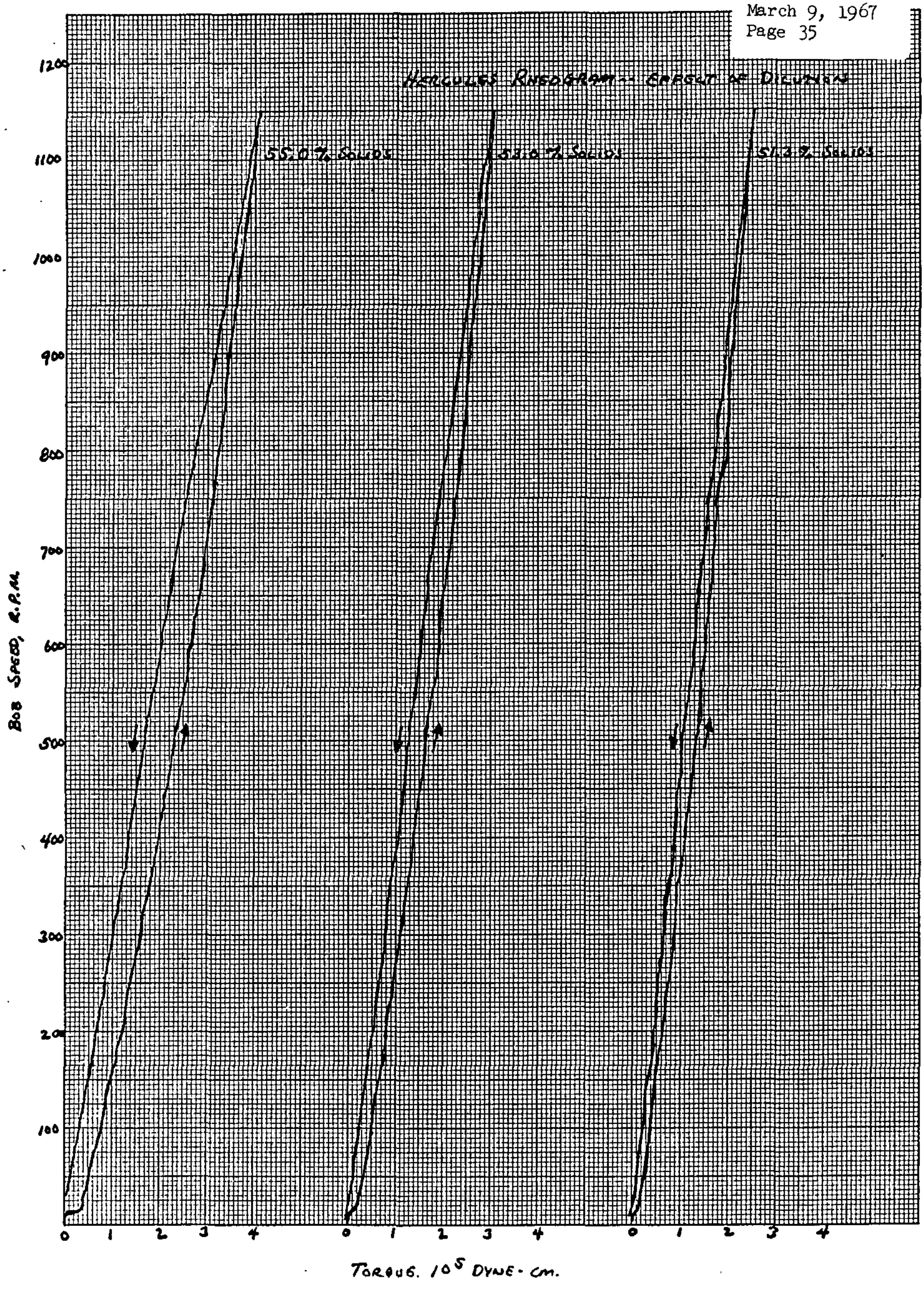
HERCULES RHEOGRAM -- EFFECT OF DILUTION
55.0% SOLIDS
53.0% SOLIDS
51.2% SOLIDS
BOB SPEED, R.P.M.
1200
1100
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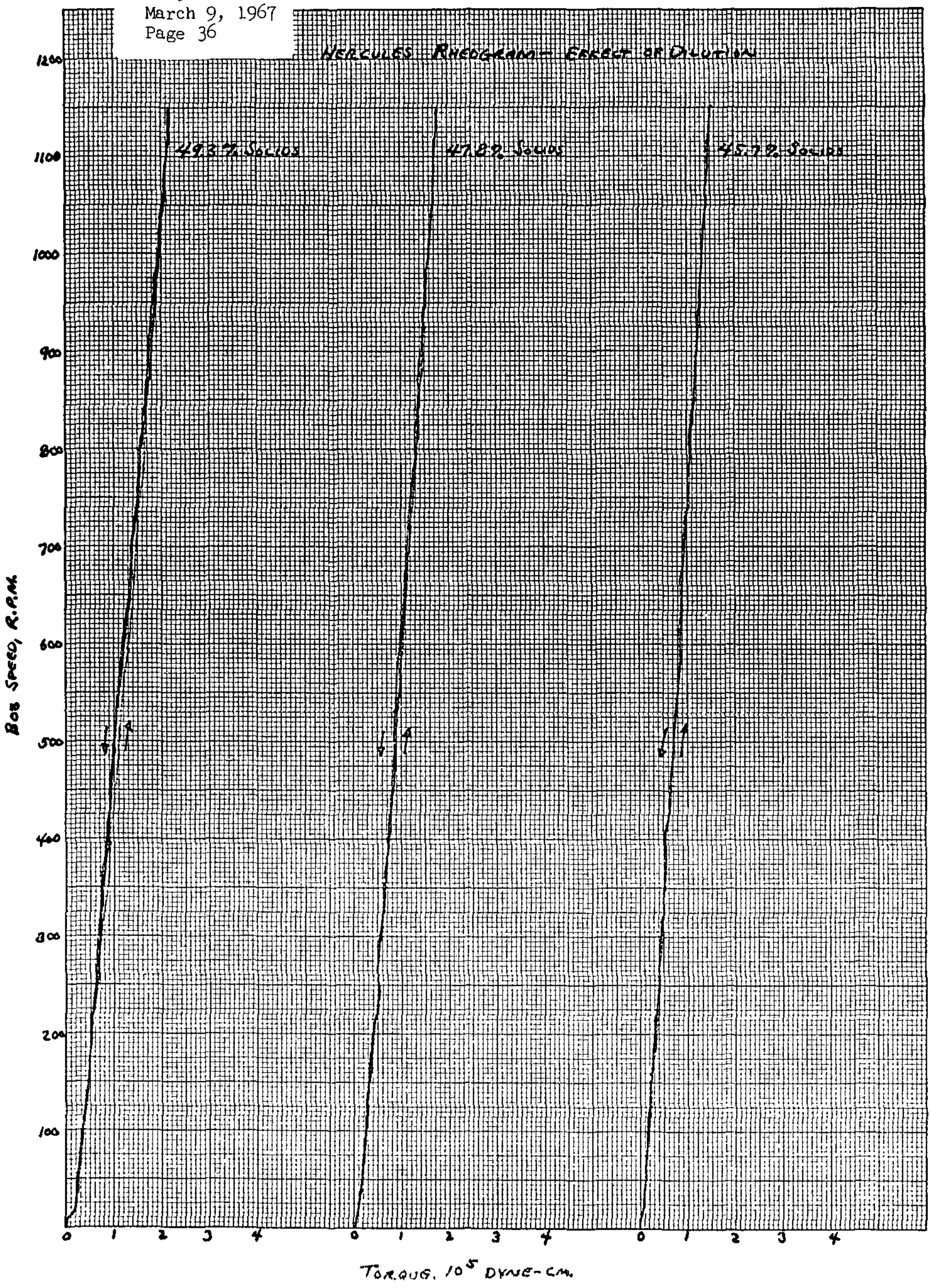
TORQUE. 10^5 DYNE-CM.


HERCULES RHEOGRAM - EFFECT OF DILUTION
49.3% SOLIDS
47.8% SOLIDS
45.7% SOLIDS
BOB SPEED, R.P.M.
1200
1100
1000
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800
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TORQUE, 10⁵ DYNE-CM.