The Institute of Paper Chemistry

Appleton, Wisconsin

Doctor's Dissertation

Factors Governing the Strength Development of Kraft Pulps

by Raymond E. Baker

June, 1940

FACTORS GOVERNING THE STRENGTH DEVELOPMENT OF KRAFT PULPS

A thesis submitted by

Raymond E. Baker

A.B., 1935, DePauw University

M.S., 1937, Lawrence College

in partial fulfillment of the requirements
of The Institute of Paper Chemistry for
the degree of Doctor of Philosophy from
Lawrence College, Appleton, Wisconsin

June, 1940

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

INTRODUCTION

From the earliest history of papermaking practical experience has shown the advantage of subjecting fibers in water suspension to a certain mechanical action called beating. The beating process increases the strength and regularity of the sheet formed; the importance of such a treatment can be seen when one considers that, by beating, the papermaker is enabled to produce papers of widely different properties from the same pulp. It is generally agreed that the purposes of beating are: (a) To separate the fibers from each other; (b) to cut them to the desired average length; (c) to fibrillate them to some extent; (d) to wet them and render them more pliable; and (e) to develop some sort of surface condition which will cause the fibers to adhere to each other more strongly when formed into a sheet.

Until the latter part of the 17th century beating was carried out in stamp mills, similar to the mortar and pestle arrangement. About 1690 a great improvement was made in this part of the papermaking process with the invention of the "hollander" beater, so called because it was invented in Holland. The hollander of today is very similar to the original, although it has been made larger and probably more efficient. Some part of the beating action which was formerly accomplished entirely in the hollander is now carried out in more specialized equipment such as jordans and other newer types of refiners which have been introduced during the last few years.

A study of the possibilities of achieving this refining action by a different method was begun in 1924, when the U. S. Forest Products Laboratory started the operation of a rod mill of "semi-commercial" size as a part of their experimental program. Rue and Wells (1) described the earlier work with the mill, the greater part of which was concerned with the application of the rod mill to the defibering of chemically softened (semicooked) chips and its use as a refiner for screenings. However, in this paper they pointed out the potentialities of the rod mill as a beater for chemical pulps and gave a discussion of its effects.

In a recent article Wells (2) pointed out that the rod mill may have an action quite different from that of either the hollander beater or the jordan, the difference in action depending to some extent on the method of operation. With stock of 6 per cent consistency there is a cutting action on the fibers with a considerable loss of power. With stock between 6 and 10 per cent consistency the result is a development of the bursting strength with but little reduction in freeness. The most significant effect of refining with rods is the greatly accelerated rate at which the treated stock developed bursting strength on subsequent refining in a beater or jordan. By giving the stock a pretreatment with rods at 7 per cent consistency for ten minutes and then beating in a laboratory beater, this effect became apparent. When beaten to the same freeness in the beater, the pretreated stock showed a noticeable increase in bursting strength over that of the untreated stock (136.5 as compared to 121 lb./in.^{2}

per 100 pounds basis weight). On the other hand, the pretreated stock could be beaten to a bursting strength corresponding to that of the untreated stock with much less beating action; the freeness would then be considerably higher and there would also be a great saving in power required for refining.

In this investigation no attempt has been made to study the variables of beater operation and their effect on strength development, but rather to study the effect of the original condition of the pulp--i.e., slush, wet lap, or dry lap--on the subsequent strength development. The immediate purpose was to determine why it is possible to pretreat certain pulps in a rod mill and then obtain by subsequent beating a significantly higher strength than is possible from the same pulp without pretreatment. This involves a study of the action of the rod mill on pulp, both from the standpoint of its beating action and of its action when used to pretreat pulps before beating in the regular beating equipment.

HISTORICAL SURVEY

What actually happens to the cellulose fiber in the beater to give it sheetmaking properties has long been a subject of controversy. If other fibrous materials, such as silk, wool, or asbestos, are formed into sheets from dilute suspensions, they produce, on drying, only a felted mass and the sheet has no structural strength except that which results from the entanglement of the fibers used. Adhesion of fiber to fiber is lacking. The action of the beater in cutting and bruising the fiber is fairly obvious, but chemists have felt that some further explanation is needed to account for all of the effects produced. Cross and Bevan (3) stated that the essential requirement of beating is to defiber the pulp completely. A second requirement is the "softening" or "hydrating" effect which causes the fiber to become sufficiently flexible so that a uniformly close web could be formed on the paper-machine wire. Finally, the mechanical action of the beater tackle cuts the fibers and at the same time bruises and flattens them and in some cases splits them longitudinally into smaller units or fibrillae. In addition to these effects the authors also stated:

> "A fresh change takes place in the fibers as a result of their contact with the watery medium; the continued beating and agitation causes the cell-wall of the fiber to adsorb water and pass into the condition of a gelatinous hydrate. In proportion as this change is effected, the stuff is said to work 'greasy' or 'wet', an effect which may be regarded as due to a solution of water by and in the cellulose (hydrate)."

Schwalbe and Becker (4) believed that beaten pulp was more hygroscopic than unbeaten pulp. They attributed this to the formation of a cellulose hydrate.

In 1926 Strachan (5) attacked the chemical theory of beating and proposed that the taking up of water by cellulose be termed "imbibition" rather than hydration. Since the curve for the vapor pressure of beaten pulp plotted against the water content showed no break, he claimed that there could be no hydration in the chemical sense.

The theory which he proposed was based entirely on physical changes. He postulated a fiber structure very similar to that accepted today. The basic unit of the structure was the cell of Mayer and Mark (6) composed of four dextrose units polymerized end to end through the oxygen linkages in chains of fifty to two hundred groups to form the cellulose molecules, or micelles. These rodlike micelles are bound together in bundles to form the unit cellulose crystallites. In turn, the crystallites are bound together in bundles to form the fibrillae. The fibrillae are bound together spirally in layers (7) to form the fibers, those in the same layer lying parallel to each other, but those in adjacent layers lying at an angle. The fibrillae in the innermost layer are almost parallel to the axis of the fiber; those in successive layers are at greater and greater angles to this axis. Finally, the last layer is at an angle of almost 90 degrees to the fiber axis and forms bonds around the fiber. The layers of fibrillae are porous, allowing water to penetrate and cause the fiber to swell.

From this picture of the fiber structure Strachan (5) explained the action of the beater as a loosening of the outer layers and a fibrillation of the surface. Beaten fibers are softer and fibrillated, so that they lie more closely to each other on the paper-machine wire; the increase in strength is due to the fibrillation and entanglement of the resulting fibrils.

In a later paper (8) Strachan admitted that there is an adhesion between swollen cellulose fibers and explained this as "the cohesion between colloidal surfaces according to well-known physical laws." He also showed that there was no increase in the total surface on beating, which was evident from the fact that the Methylene Blue adsorption did not change. This is in agreement with the work of Kress and Bialkowsky (9), who also demonstrated that no appreciable chemical changes occurred on beating.

Kress and Bialkowsky (9) conducted beating experiments in a large number of liquids other than water and measured the swelling power of the different liquids on cellulose. Under similar conditions they found that the swelling power varied directly as the degree of beating. From their results they concluded that in the wet swollen condition the fibers are low in strength but very soft and pliable, and mechanical action tends to bruise and fibrillate the fibers rather than to produce a cutting action. They ascribed the hard, close structure of the sheet made from a so-called hydrated stock to the fibrillation of the fibers and the resultant shrinkage of the fibers on drying.

Campbell's (10) theory of beating is not very much different from that of Strachan, although he believes that a hydrated surface exists on all cellulose fibers in contact with water. This forms a layer of hydrated cellulose which lowers the attraction of the fibrils for each other and allows water to enter and produce imbibition and swelling. Beating and mechanical action further disrupt the structure so that some of the fibrils are frayed out and become visible. Although the apparent or visible surface is increased, the total surface is not, since these fresh surfaces existed previously as parting layers inside the fiber. Campbell pointed out that the strength of a sheet is due to the adhesive bonds between the fibers. These bonds are formed when two wet cellulose surfaces are dried while in contact with each other. The greater external surface produced by beating increases the number of surface contacts and subsequent bonds, and hence, increased sheet strength on beating. Although the nature of these bonds is not known, the author postulated that they are due to the same secondary valence forces which cause crystallization. The strength of the resultant bond then depends on the orientation of the two contacting cellulose crystals. If identical in crystal orientation, a bond of maximum strength is produced, but the strength of the bond becomes less as the crystals are less perfectly oriented.

Sigurd Smith (11) was the first to carry out a thorough study of the mechanical action of the beater. He described the effect as two-fold: first, a cutting action between the edges of the fly-bars and plate and, second, a wet beating action caused by pressure and abrasion between the moving surfaces of the tackle. Heavy rolls, sharp hard tackle, low backfall, and low consistency tend to produce the first effect--a short fiber with relatively high freeness. On the other hand, a light roll, soft steel bars in the roll and bed-plate, high backfall, and high consistency produce the second effect--a slow stock in which the action is more one of abrasion than one of cutting. In addition to the above, there is also the brushing effect which tends to disintegrate any fiber bundles.

Smith proposed the theory that the fibers are actually beaten while lying across the flybars and bedplate bars in the same fashion that they will lie across the edge of a knife blade when the latter is drawn through the stock. There is a definite increase in the size of this "fibrage" with the consistency of the stock and also the length of the fiber. He pointed out that the fibers which straddle the bars are whipped against the bedplate bars, which produces a mechanical action on the fiber. Short-fibered pulps, such as soda pulp from hardwoods, have a very slight tendency to form fibrages and, therefore, are very difficult to hydrate.

In a study of the effect of different beating pressures, Grand (12) found that the condition of a pulp at identical beating degrees, as measured by freeness, changed appreciably. At increasing pressures the mean fiber length decreased, the percentage of fines passing through a 160-mesh screen, which he designated as the slime content, increased, and the felting capacity became less. Associated with these changes and dependent on them, according to Grund, was a decrease in strength properties. As higher beating pressures were used, the mean fiber length at any given freeness was less and the breaking length of the sheets prepared from the pulp was less. Curves and tables showing this relation are given, but no data for the other strength properties are included.

Steinschneider and Grund (13) pointed out that freeness cannot be used for comparing different pulps, especially when processed in different beating instruments. They stated that the beaten condition of a fiber suspension at a certain freeness depends on the mucilage content (lowest fraction passing through a 160-mesh screen), mean fiber length, and the felting power of the individual fibers. Only by a consideration of these factors were they able to compare pulps beaten to the same freeness in different beating instruments.

Shlick (14) emphasized the importance of the influence of fiber length in papermaking and pointed out the dependence of strength development by beating on the amount of fiber cutting that has taken place. He postulated that the maximum plasticity of the pulp fibers must be maintained in order that the fiber structure will be able to withstand sufficiently the relatively harsh, abrasive beating action--hence, the higher test obtainable from pulp purchased wet as compared with that from dry pulps. Unless the dried pulps are properly slushed before beating or are beaten in beaters capable of "rehydration", the strength values will be excessively low. Such improperly hydrated stock will contain fibers actually torn into fragments which serve no purpose other than as a filler for the sheet. Shlick did not explain what is meant by a beater capable of "rehydration" to be used on dried pulps to prevent excessively low strength values but stated only that "powerful rehydrating means built into beating engines will produce better strength values."

In connection with this loss in strength when pulps are dried, Simmonds (15) published in 1933 a survey of the literature dealing with the drying of paper and cellulosic papermaking materials. It was mostly concerned with the chemical reactions taking place on drying, the loss of volatile materials, etc.

Swartz (16) carried out laboratory beating tests on a sulfite pulp of various moisture contents and showed that, as water was removed from the pulp, the maximum bursting strength obtainable by beating decreased and the tear increased. There was no abrupt change from wet to dry pulp as there was a loss of about 8 per cent in bursting strength when the pulps were dried from 23 to 55 per cent ovendry, and when they were air-dried to 91 per cent ovendry there was a further loss of about 10 per cent in bursting strength. The freeness was also affected by the drying and, as the pulps became drier, more beating time was required to reach any given drop in freeness.

In a discussion of the vacuum drying of pulps, Babbitt (17) stated that "many theories and assumptions have been advanced for the loss in strength, but the advent of vacuum drying has clearly demonstrated that oxidation and hydrolysis with or at high temperatures are probably the most important causes of deterioration." He pointed out that, when dried under a vacuum of 28 inches of mercury, there is practically no oxygen present to aid in oxidation. Also, the water in the pulp and, consequently, the pulp itself cannot rise above 100° F. as water boils at this temperature in a vacuum of 28 inches of mercury. From his conclusions on pulp tests he stated that pulps could be dried under vacuum to 100 per cent airdry and still develop approximately the same strength on beating as wet pulp. If the same pulp were dried on driers at atmospheric pressure, there would be a considerable decrease in bursting strength obtainable on beating, which is not compensated for by the slight increase in tear.

In response to letters sent out to a number of technical men having a wide range of experience, asking for their opinions as to the relative papermaking qualities of wet and dry pulp, The Institute of Paper Chemistry received various replies. The consensus of opinion seemed to be that, after drying, pulps are more difficult to hydrate, the bursting strength which can be developed is lower, and the tearing strength is slightly higher. Some claimed that there was no loss up to 80 per cent airdry, while others expressed the view that there was a gradual decrease in the strength obtainable as the pulps were dried; this loss first becomes apparent at a rather low ovendry content.

Müller and Trenschel (18) compared the strength obtained from pulps dried on drying cylinders at atmospheric pressure with that from pulps dried by the Fidalgo system, in which the wet laps are first disintegrated and then dried by heated air. They found an appreciable loss in strength in passing from wet to dry pulps, but this loss did not depend on the method of drying, as it was about the same in each case.

Kehoe (19) stated that dense wet laps, such as are obtained on a Kamyr wet machine, are very difficult to repulp when they are dried on cylinders. In most cases this is very objectionable, because of the difficulty of the reabsorption of water in repulping for use in the paper mills.

Undoubtedly this objection may be very critical in certain cases. Alsted (20) pointed out that, in the case of dried groundwood, the laps are so difficult to disintegrate by the beater that it is practically impossible to prevent small flecks of dried pulp from appearing in the finished paper.

The unique disintegrating action of the rod mill was pointed out by Wells (21) in his process for deinking waste paper, especially catalogue and directory stock. The waste paper can be pulped at high consistencies by rod mills to a condition which can be readily resolved into slush pulp. The pulp obtained has the desirable characteristics of unused pulp and is suitable for the manufacture of paper similar in quality to the original paper.

In a process for separating vegetable fibrous materials, particularly chemically-softened woody material, Wells (22) stated that the pulp is pounded and beaten by the tumbling rods, yet the fiber length is maintained and no fiber debris is produced, as is common where the apparatus includes an abrading and cutting element. The rod mill is selective in its action, the individual fibers are protected by the clumps and will escape further reduction until the clumps are completely disintegrated. Consequently, the rod mill attains its results with the least expenditure of energy.

Schmid (23) described the application of the rod mill to the preparation of stock for paper manufacture. He stated that the crushing action of the rods plays an important part, in that the resulting pulp will give better formation and, therefore, stronger paper.

Rue (24) made several observations relative to the use of the rod mill as a beater. Some free fall of the rods is desirable in crushing brittle material, but with fibrous material the rubbing and pounding action which comes from the rods rolling over each other is to be preferred. This is attained by a proper speed of rotation. Also, it is necessary to have a feeding device, preferably a worm screw, to insure positive transfer of the material into the mill. Rue pointed out in general the effect of stock consistency: at low consistencies the fibers will be cut, whereas at very high consistencies the stock will provide so much of a cushioning action for the falling rods that the mill will be inefficient in so far as the actual development of slowness and bursting strength is concerned.

In a study of the most satisfactory operating conditions, Chidester (25) concluded that the use of lighter rods had the same general effect as that of increasing consistency. In any case, the strength properties will pass through a maximum, provided that the treatment is long enough, and this maximum will vary with the consistency and the weight of the rods.

Wells (26) stated that the two most important factors in beating with rods are the consistency of the stock and the regularity of the feed. The strength development possible for sulfite pulp is materially increased by working at a consistency of 7.5 to 8.5 per cent. Also, the uniformity of beating is increased if the feed is at a uniform rate. At a consistency above about 5 per cent there is no pool of stock at the foot of the pile of rods in a low pulp-line, open-end mill; such a pool would allow some of the stock to pass through the mill without being subjected to the action of the rods. The cushioning effect of high consistencies reduces the wear and, consequently, the discoloration caused by the rods. If the slightest discoloration is objectionable, it is advisable to use either stainless steel or manganese-silicon bronze lining and rods.

In an earlier article Wells (27) stated that a saving of 50 to 70 per cent of the power required in the beaters could be effected by the use of the rod mill. Later work (26) showed that a twenty-minute treatment in a 3 by 5 foot rod mill* shortened the time required to reach maximum strength in the pebble mill by one hour, and the maximum strength attainable was increased by about 4 per cent. When fed at the rate of about 17 tons per day, a 5 by 10 foot rod mill was able to impart about 20 per cent greater beating treatment than that obtained by twenty minutes in the 3 by 5 foot rod mill. On this basis a 7 by 16 foot mill would be capable of treating 55 tons of pulp per day with 160 h.p. required for operation. Freeness tests showed that the rod mill develops maximum strength with much less loss in freeness than when the pulps were developed to the same strength in a beater, thus permitting easy removal of water on the paper-machine wire. Apparently felting properties were developed without the usual accompaniment of excessive slowness.

From his data and experience on the commercial operation of a 7 by 16 foot low pulp-line, open-end rod mill used on kraft pulps, Wells (28) concluded that, for the first third of the beating operation, the rod mills are two to three times more efficient from the standpoint of power consumption than are beaters or jordans; for the second third they are from 50 to 100 per cent more efficient; and for the final third the jordan is more adaptable and as efficient as the

* In all references to the size of a rod mill, the figures given refer to the inside dimensions. The first figure given is the diameter, the second is the length.

rod mill. In an experimental run three mesh rod mills were operated in series, and the paper made showed an increase in bursting strength of 15 per cent and could be run on the machine 15 per cent faster than stock which had been treated by one pass through the rod mill and then treated in the jordans. In both cases the feed was at the rate of about 65 tons per day through each mill. The extra power consumed by the rod mills was largely compensated for by increasing the clearance in the jordans. Microscopic examination showed no appreciable reduction of the fiber length of the triple rod-milled stock. The fibers were more ribbonlike and, after the jordan, showed a markedly increased development of fibrillae. The rod mill proved to be very useful on pulps that were to be subsequently bleached. Shives are broken up into individual fibers so that bleaching is more uniform. This is particularly advantageous for semibleached pulps, as the shives will otherwise be very conspicuous.

In most of the earlier studies of the action of the rod mill on pulps, the results obtained were measured by freeness, strength, and other tests on the pulp as it left the mill. Apparently these alone do not give a true picture of the rod mill action, as more recent work by Wells (2) has indicated that changes take place which are manifest only by observing their effect on the subsequent refining of rod-milled stock. The indications were that this pretreatment with rods changed the relationship obtained by subsequent beating between the reduction of freeness and the development of strength properties of the pulp. The changes as indicated were very desirable and would lead to substantial reductions in the power required for refining and, also, would give improved quality in the paper made from the pretreated stock. In view of the importance of such changes and also because of the diversity of opinion as to why these changes occur, it was decided to study first the effect of rod mill pretreatment to ascertain what factors govern such effects as increased strength by subsequent beating of rod-milled pulps.

MATERIALS AND METHODS

PULPS USED

Pulp A was a jack pine kraft pulp cooked to a permanganate number of 25.8. This pulp was obtained in slush form only; the sample was taken from the diffuser after the pulp had been washed. It was screened on the laboratory screen, pressed to about 20 per cent o.d. content in a wine press, and stored in airtight containers.*

Pulp B was a jack pine kraft pulp cooked to a permanganate number of 22.4. As this pulp was from a mill having a commercial rod mill installation, samples were taken before and after the rod mill. These samples in slush form were pressed to about 20 per cent airdry content and stored in airtight containers for use as required.

Pulp C was a raw kraft pulp from southern pinewood and was available in lap form only. These laps had been made on a Kamyr wet machine and had air-dried to some extent while in storage. The o.d. content varied from 55 to 90 per cent.

Pulp D was a well cooked jack pine kraft pulp cooked under the same condition as Pulp B. This pulp was available in both the slush and wet-lap form. The slush sample was taken at the time the

* The term o.d. content, used throughout this thesis, signifies the percentage ovendry;--i.e., it is the weight of the pulp when dried to constant weight at 105° C., divided by the weight when wet, times 100.

wet machine sheet was being filled so as to be representative of the pulp in the wet-lap form. A Kamyr wet machine was used and the o.d. content of the laps was about 28 per cent. The slush pulp was stored in airtight containers, and the wet laps were wrapped with asphalt paper in such a manner as to prevent air drying.

PREPARATION OF SAMPLES

Fifty-gram (o.d. basis) handsheet laps were made from Pulps A and B on the Noble and Wood sheet mold. These were pressed between felts to about 50 per cent o.d. on a hydraulic press.

The commercial laps (Pulp D) were cut into 10 by 30 inch strips and pressed to the desired moisture content before processing. This pressing was accomplished by passing the strip of wet-lap pulp between the press rolls of the Noble and Wood sheet mold equipment. No felts were used. The resulting moisture content of the wet laps was controlled by varying the weights used on the press rolls.

For the machine-dried samples some of the 37 per cent o.d. wet laps (Pulp D) were dried on the cylinder drier of the Noble and Wood sheet mold equipment. The drier temperature was practically constant at 110° F.; the time of drying was varied so as to reach the desired moisture content.

For the air-dried samples the wet laps were merely exposed to the air until they had reached the desired dryness. The laps were spread out sufficiently to insure a somewhat uniform rate of drying throughout the laps.

PRETREATMENT OF PULPS

The laboratory rod mill used was a 12 by 24 inch mill made by Mine and Smelter Company, Denver, Colorado. The total charge of 38 rods weighing 220 pounds varied in size as follows:

Diameter	Number
3/4 inches	9
1	15
1-1/4	12
1-1/2	2
Total	38

The speed of rotation was 45 revolutions per minute.

For the rod-mill pretreatment 500 grams (o.d. basis) of pulp was charged into the mill, care being taken to distribute the pulp throughout the charge of rods as well as possible. When laps were used they were torn into small pieces by hand. After charging, enough water was added to bring the consistency of the stock to 20 per cent; a five-minute treatment was then given to the pulp at this consistency. This was done to insure a thorough distribution of the pulp throughout the rods; that this treatment had little beating action on the pulp is shown in the results. After this treatment, enough water was added to decrease the consistency of the stock in the mill to 7 per cent. The pulp was then rod milled at this consistency for ten minutes unless the time is otherwise specified. After removal from the mill and separation from the rods, the pulp was saved at this consistency for subsequent beater runs.

For the pretreatment by screening, the laps were first disintegrated according to TAPPI Standard Method T 200 m-34 for making beater runs. This pulp was then screened in the small laboratory screen; the accepted stock was thickened on a heavy muslin cloth to prevent the loss of any short fibers. The screenings retained on the 10-cut screen plate were combined with the accepted stock so that, in effect, the only action was to disintegrate the laps completely. There was sufficient agitation caused by the turbulence of the shower water and the vibration of the screen to break up all the clumps remaining from the laps; consequently these screenings consisted only of shives.

BEATERS USED

The beaters used were calibrated, 1.5-pound Valley laboratory beaters. For calibration a West Coast unbleached sulfite pulp in dry-lap form was used as a standard. The results of the standard pulp calibration runs with these three beaters are given in Table I. In those cases where more than one calibration run was made on the same beater, the average was taken and the average results for each beater are plotted in Figure 1 to show comparatively the action of each beater on the standard pulp. This does not show any changes

TABLE I

CALIBRATION OF BEATERS

(Unbleached Sulfite)

Beater	Time When Calibrated	Freeness--cc.						Basis Weight--lb. (25x40--500)					Bursting Strength lb./in.^{2} per 100 lb.					Tear Factor					Apparent Density				
		5'	20'	35'	50'	65'	80'	5'	20'	35'	50'	65'	5'	20'	35'	50'	65'	5'	20'	35'	50'	65'	5'	20'	35'	50'	65'
1	Before A - 1	835	765	585	395	265	190	53.9	55.0	54.5	55.0	53.6	32	67	80	85	89	2.36	1.59	1.34	1.12	0.99	11.7	13.6	14.8	15.5	15.8
1	Before B - 1	840	775	605	430	290	210	46.6	47.0	48.0	48.0	47.5	31	68	82	85	86	2.46	1.54	1.22	1.13	0.97	11.5	13.1	13.9	14.5	15.2
1	Before D - 1	850	785	640	490	345	240	45.7	47.9	47.1	46.9	45.8	36	70	85	88	88	2.45	1.61	1.40	1.23	1.05	11.8	13.1	14.2	14.9	15.3
1	After D - 18	860	785	605	430	315	240	45.5	47.0	47.3	46.8	46.3	33	68	84	92	93	2.34	1.54	1.30	1.16	1.00	11.7	13.2	14.1	14.6	14.9
Average for Beater 1		845	780	610	435	305	220						33	68	83	88	89	2.40	1.57	1.32	1.16	1.00	11.8	13.2	14.2	14.9	15.3
2*	Before C - 4	845	650	365	200	140		50.4	49.7	48.4	48.6	49.1	39	83	92	92	84	2.14	1.34	1.02	0.84	0.62	12.6	15.1	15.6	16.7	17.5
3	Before D -19	860	745	455	245	150		46.4	46.1	46.1	46.4	45.9	38	85	106	109	99	2.43	1.29	1.06	0.84	0.71	11.7	13.6	14.8	15.9	16.3
3	Before D - 24	855	770	515	295	180		46.4	46.2	46.2	47.4	47.3	37	87	107	111	101	2.44	1.33	1.04	0.92	0.76	11.8	13.9	15.1	15.9	16.3
3	Before D - 31	855	760	545	320	210		46.8	47.7	46.5	46.8	45.6	36	78	99	107	106	2.24	1.38	1.13	0.92	0.83	11.8	13.6	14.8	15.5	15.9
Average for Beater 3		855	760	505	285	180							36	83	104	109	102	2.37	1.33	1.08	0.89	0.77	11.8	13.7	14.9	15.8	16.2

* From Institute Staff Data of 5/9/39.

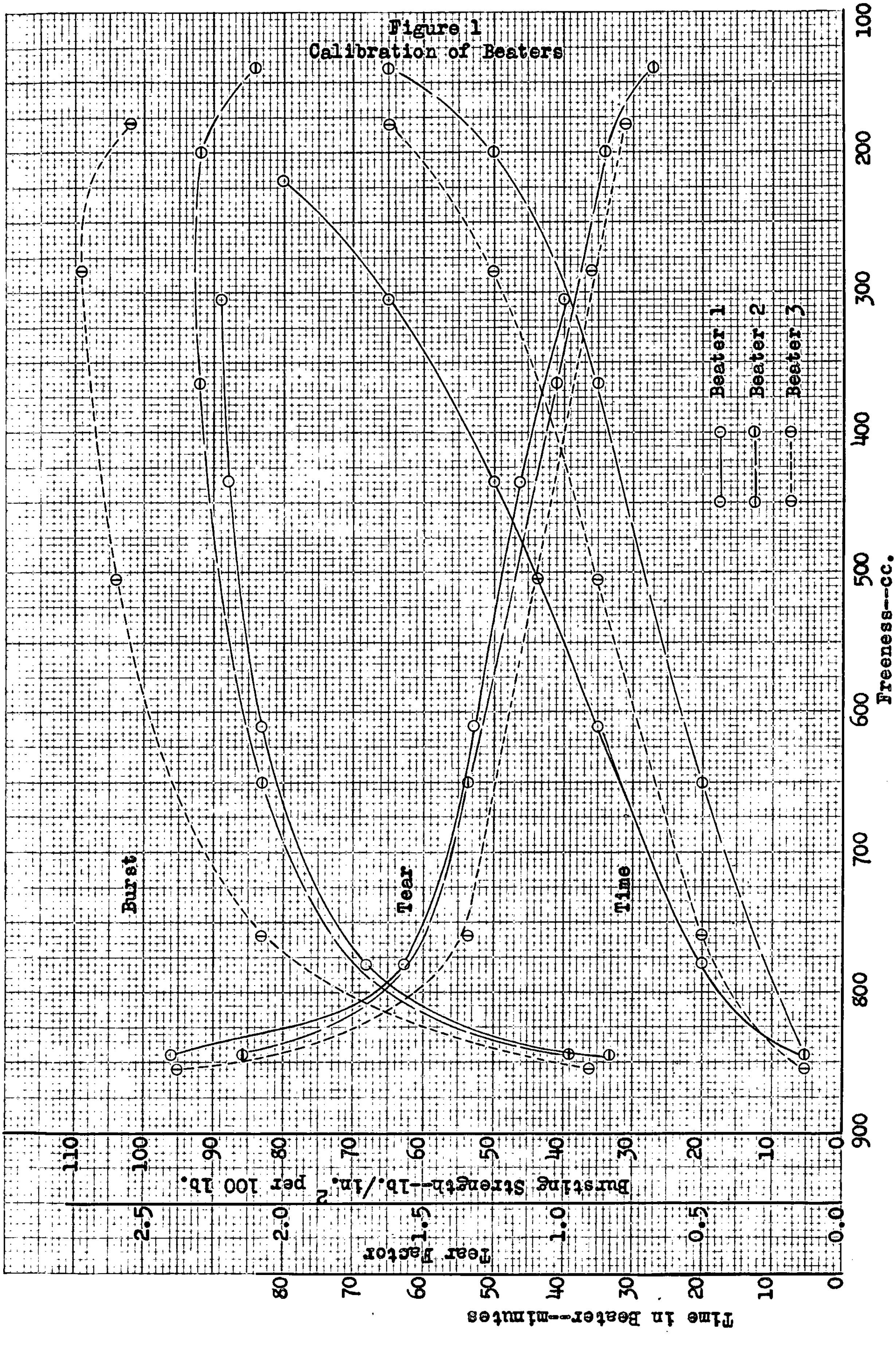


Figure 1
Calibration of Beaters

which may have taken place in any one beater from time to time; these changes, however, can be seen from the results in Table I.

BEATING PROCEDURES

The beater runs were made according to TAPPI Standard Method T 200 m-34, except that the intervals selected for sheetmaking were different from those recommended for kraft pulps. Ten- and fifteen-minute intervals were used in order to obtain a more accurate curve for the strength development, particularly in the earlier part of the beater run where the development of strength is quite rapid.

For all the beater runs on Pulps C and D, except those which had been given a rod mill pretreatment, the pulp was first given the preliminary stirring as provided in TAPPI Standard Method T 200 m-34. This was not done in the case of Pulps A and B, which were obtained in slush form only.

FORMING AND TESTING OF HANDSHEETS

Handsheets were made according to TAPPI Standard Method T 205 m-36. These handsheets were then evaluated by the following methods:

Basis Weight	Institute Method 504
Caliper	Institute Method 508
Bursting Strength	Institute Method 510
Tearing Strength	Institute Method 512.

The apparent density was calculated by dividing the basis weight (25x40--500) by the caliper expressed in thousandths of an inch. The bursting strength represents the bursting strength in pounds per square inch divided by the basis weight and multiplied by 100. The tear factor is the tearing strength in grams divided by the basis weight.

From these tests and the Schopper-Riegler freeness data, beater curves are drawn in which the strength properties are plotted versus freeness. From these curves the properties developed at 700-cc. freeness in each beater were tabulated.

FIBER LENGTH MEASUREMENTS

Small samples of the stock used at each beating interval for sheetmaking were saved for fiber length measurements. The procedure as described in detail by Graff (29) was used for the preparation of the slides and the measurement of the fibers. The width of the fibers was not measured, and the average fiber length given is the arithmetical average. Fiber measurements were made at a minimum of three beating intervals. By plotting the average fiber length versus freeness the average fiber length at any freeness within the range investigated could then be found.

RESULTS AND DISCUSSION

ROD MILL PRETREATMENT OF SLUSH PULP

Beater runs were made on slush Pulp A as received using Beater 1 and, for the purpose of determining the effect of pretreatment, 500-gram batches of this pulp were rod milled for various time intervals. After this rod-mill pretreatment beater runs were made on these samples. The complete results of these runs are given in Table III. In order to facilitate comparison of the different beater runs, an arbitrary freeness of 700 cc. was selected and all properties at this freeness are taken from the beater curves and tabulated. These results are given in Table II.

TABLE II

EVALUATION OF PULP A AT 700-cc. FREENESS

Beater Run	Pretreatment in Rod Mill	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density
A1	None	41	126	1.38	13.4
A5	None	37	127	1.37	13.7
Average of A1 and A5		39	126	1.38	13.6
A6	5 min. at 20%	36	125	1.40	14.0
A2	5 min. at 20% 5 min. at 7%	30	125	1.40	13.5
A3	5 min. at 20% 10 min. at 7%	29	126	1.38	13.4
A7	5 min. at 20% 15 min. at 7%	32	128	1.39	13.7
A4	5 min. at 20% 20 min. at 7%	25	126	1.35	13.6

Beater Run	Condition of Pulp	Pretreat-ment	Freeness--cc. 0'	5'	15'	25'	35'	45'	60'	75'
(Pulp A)										
A1 and A5*	Slush	None	860	850	840	815	750	595	380	215
A11	Wet Lap	None	865	850	840	825	775	670	445	275
A9	Wet Lap	Rod Mill	855	840	825	785	700	575	355	
A10	Dry Lap	None	870	855	850	830	780	680	465	275
A8	Dry Lap	Rod Mill	855	850	835	800	720	600	395	
(Pulp B)										
B1 and B5*	Slush	None	855	845	825	805	740	640	440	295
B6	Wet Lap	None	860	850	830	800	730	630	440	290
B10	Wet Lap	None	860	845	825	800	745	640	435	280
Average of B6 and B10			860	850	830	800	740	635	440	285
B7	Wet Lap	Rod Mill	850	835	815	770	680	555	365	
B11	Wet Lap	Rod Mill	845	835	815	775	695	580	380	
Average of B7 and B11			850	835	815	770	690	570	370	

* From Table III.

Apparent Density							
0'	5'	15'	25'	35'	45'	60'	75'
9.1	10.3	11.9	12.4	12.9	13.7	14.4	15.0
9.1	10.6	12.1	12.8	13.6	14.2	14.9	15.8
9.1	10.4	12.0	12.6	13.2	14.0	14.6	15.4
10.5	11.4	12.5	13.1	14.0	14.4	14.9	15.7
11.2	11.9	12.5	13.3	13.8	14.3	15.1	
11.3	11.9	12.6	13.3	13.5	14.3	14.8	
11.4	12.1	12.7	13.3	14.1	14.7	15.2	
11.7	11.9	12.7	13.7	14.3	14.5	15.8	
9.7	11.3	12.5	13.2	13.7	14.3	14.9	15.4
9.7	11.0	12.2	12.8	13.5	13.9	14.5	15.0
9.7	11.2	12.4	13.0	13.6	14.1	14.7	15.2
11.9	12.4	13.1	13.6	14.0	14.4	14.8	
10.6	11.9	12.8	13.7	14.0	14.5	15.0	
9.4	11.4	12.6	14.0	14.8	15.7		
10.4	11.9	13.5	14.5	15.3	15.8		

Basis Weight--lb. (25x40--500)

0'	5'	15'	25'	35'	45'	60'	75'
46.8	48.2	47.5	47.8	48.0	47.6	47.6	48.2
47.1	47.7	46.4	47.2	47.4	47.5	48.1	48.3
44.5	48.1	48.1	47.6	47.6	47.5	48.5	
45.9	47.1	46.8	46.2	46.7	47.1	47.3	47.7
45.2	45.8	46.8	47.8	47.6	47.3	47.8	
47.6	47.3	48.0	47.9	47.4	47.6	48.0	47.6
46.4	47.4	48.2	47.6	48.9	48.2	46.6	47.6
47.7	47.0	46.8	46.4	46.4	46.9	47.4	47.2
47.7	47.0	46.6	46.6	46.4	47.3	46.6	
48.2	47.0	47.7	47.1	47.0	47.2	47.4	

TABLE III

BEATER EVALUATION OF [illegible] SLUSH PULP

Bursting Strength—lb./in.² per 100 lb.

0'	5'	15'	25'	35'	45'	60'	75'
41	82	113	124	124	128	136	134
44	88	110	120	126	130	129	125
42	85	112	122	125	129	133	130
40	90	110	120	123	128	130	130
70	109	125	123	122	126	131	
77	110	123	123	126	132	128	
91	114	124	127	131	128	128	
85	116	129	124	129	126	137	
48	85	111	120	125	128	130	135
43	84	108	121	125	133	136	138
46	84	110	120	125	130	133	136
77	106	116	125	127	129	134	
49	92	113	118	127	130	132	
39	75	100	112	116	119		
38	79	104	111	115	113		

Tear Factor

0'	5'	15'	25'	35'	45'	60'	75'
3.01	2.63	1.88	1.67	1.47	1.30	1.22	1.13
3.15	2.37	1.82	1.58	1.39	1.24	1.17	1.02
3.08	2.50	1.85	1.62	1.43	1.27	1.20	1.08
3.12	2.38	1.80	1.65	1.46	1.30	1.25	1.22
3.00	2.10	1.65	1.50	1.34	1.30	1.08	
2.68	1.93	1.72	1.43	1.32	1.28	1.26	
2.39	1.88	1.66	1.51	1.35	1.23	1.18	
2.36	1.77	1.49	1.37	1.17	1.12	1.05	
2.51	2.11	1.58	1.36	1.30	1.26	1.14	1.07
2.56	2.24	1.68	1.58	1.45	1.28	1.14	1.11
2.54	2.18	1.63	1.47	1.38	1.27	1.14	1.09
2.43	1.79	1.51	1.39	1.30	1.18	1.07	
2.74	1.91	1.49	1.31	1.24	1.17	1.10	
2.76	2.21	1.56	1.37	1.26	1.08		
2.59	2.09	1.56	1.34	1.13	1.05		

Basis weight—lb. (25x40—500)

0'	5'	15'	25'	35'	45'	60'	75'
47.2	48.3	47.3	47.9	48.0	47.7	47.5	47.7
46.3	48.0	47.7	47.7	48.1	47.6	47.6	48.8
48.3	47.4	48.0	47.8	47.6	47.8	48.7	47.8
50.6	52.9	51.2	51.3	52.0	50.6	51.6	
50.0	50.3	50.9	51.6	50.6	47.3	47.6	
47.1	47.3	47.7	47.2	46.7	48.3	48.2	
47.0	46.6	48.2	47.6	48.3	47.5	48.6	
47.4	48.3	46.3	48.9	47.4	47.6	48.3	48.5
47.8	46.3	47.7	46.9	47.3	47.0	47.6	46.6
47.8	46.8	47.4	47.1	47.6	47.8	47.2	
46.8	46.9	48.5	47.5	47.3	48.0	48.8	
47.6	47.8	46.7	47.7	47.8	47.3		
52.5	48.0	48.2	47.4	47.3	47.7		

Beater Run	Pretreatment in Rod Mill	Freeness—cc. 0'	5'	15'	25'	35'	45'	60'	75'
Pulp A (slush pulp) (Beater 1)									
A1	None	860	850	840	820	780	640	420	225
A5	None	860	850	840	810	720	550	345	205
Average of A1 and A5		860	850	840	815	750	595	380	215
A6	5 min. at 20%	860	850	840	805	720	570	355	225
A2	5 min. at 20% 5 min. at 7%	845	840	820	750	620	465	265	
A3	5 min. at 20% 10 min. at 7%	850	840	810	750	615	465	280	
A7	5 min. at 20% 15 min. at 7%	845	840	815	765	655	495	305	
A4	5 min. at 20% 20 min. at 7%	845	840	795	690	540	390	240	
Pulp B (slush pulp) (Beater 1)									
B1	None	855	840	825	805	740	635	440	290
B5	None	855	850	825	805	745	640	445	300
Average of B1 and B5		855	845	825	805	740	640	440	295
B4	Laboratory Mill	850	840	820	780	700	590	405	
B2	Commercial Mill	855	845	815	785	710	590	400	
Pulp B (slush pulp) (Beater 2)									
B13	None	860	850	830	765	620	415		
B12	Commercial Mill	860	840	815	750	580	380		

The pretreatment of the slush pulp in the rod mill did not cause an increase in the strength obtainable on subsequent beating, as the freeness-bursting strength and the freeness-tear relationships were practically the same before and after the pretreatment. This is shown more clearly by the beating curves given in Figures 2 to 6. In all of the rod-mill runs the first five minutes at 20 per cent consistency were used to distribute the pulp throughout the charge of rods; that this five-minute treatment had very little effect on the pulp is shown in Figure 2, where the bursting strength, tear, and freeness drop are practically the same on beating as for the untreated slush pulp; also the freeness, bursting strength, and tear of the unbeaten stock are the same before and after this pretreatment. However, after the pulp was rod milled at the lower consistency, the time required to reach a certain freeness drop on beating with the corresponding strength development was lessened; this decrease in time required depended on the time of the rod-mill treatment. From Figure 7 it is seen that each five minutes at 7 per cent consistency in the rod mill reduced the time required in the beater to reach 700-cc. freeness and 126 $lb./in.^2$ per 100 pounds bursting strength by about three minutes. Apparently the action of the rod mill on this slush pulp was the same as that of the beater, except that 50 to 60 per cent more time was required to produce the same amount of action. Even though an increment in bursting strength and drop in tear was produced by this rod-mill pretreatment, the freeness also dropped, and the magnitude of these changes was practically the same as that taking place in the beater in about 50 per cent less time.

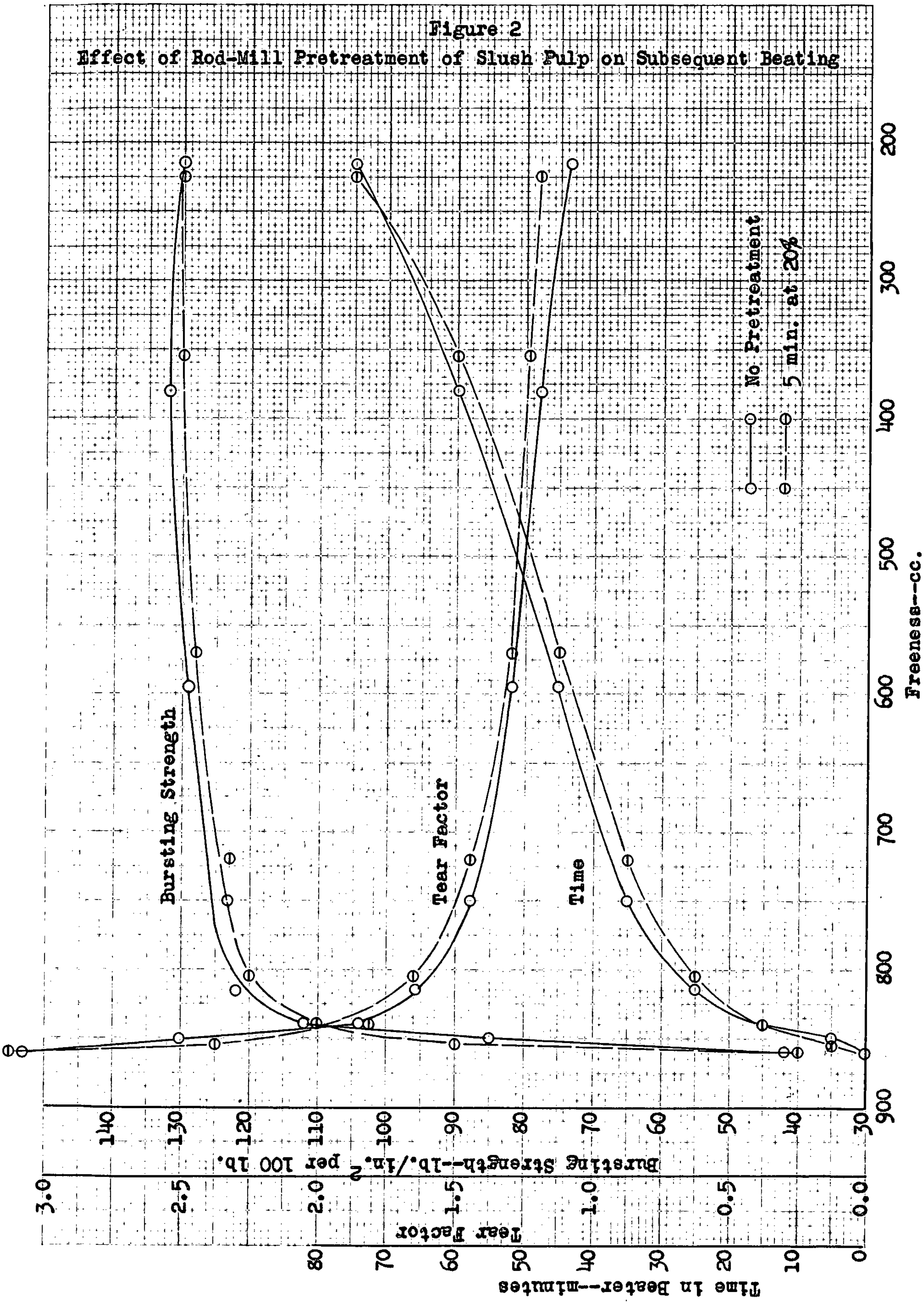
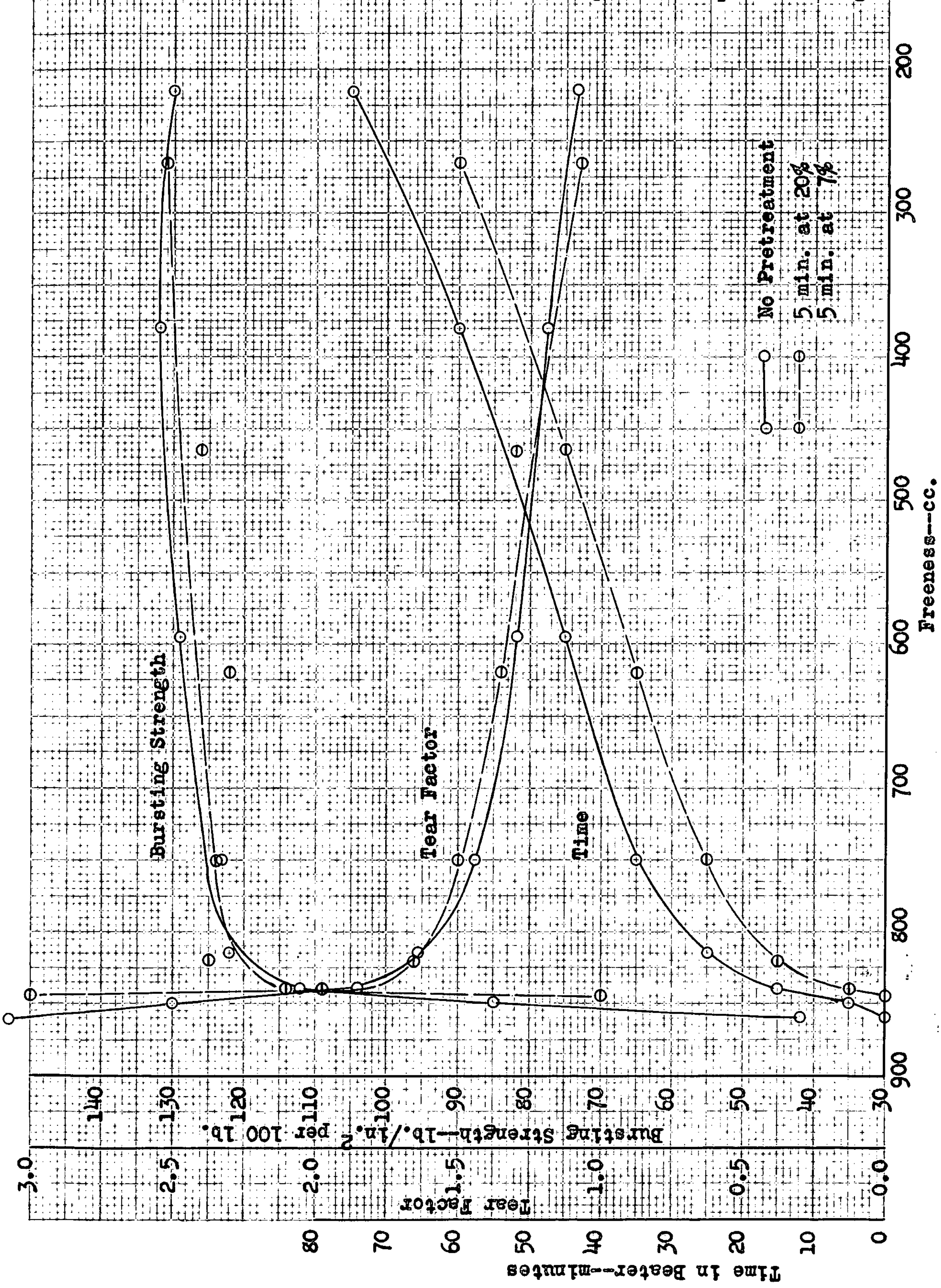


Figure 2
Effect of Rod-Mill Pretreatment of Slush Pulp on Subsequent Beating

Figure 3

Effect of Rod-Mill Pretreatment of Slush Pulp on Subsequent Beating



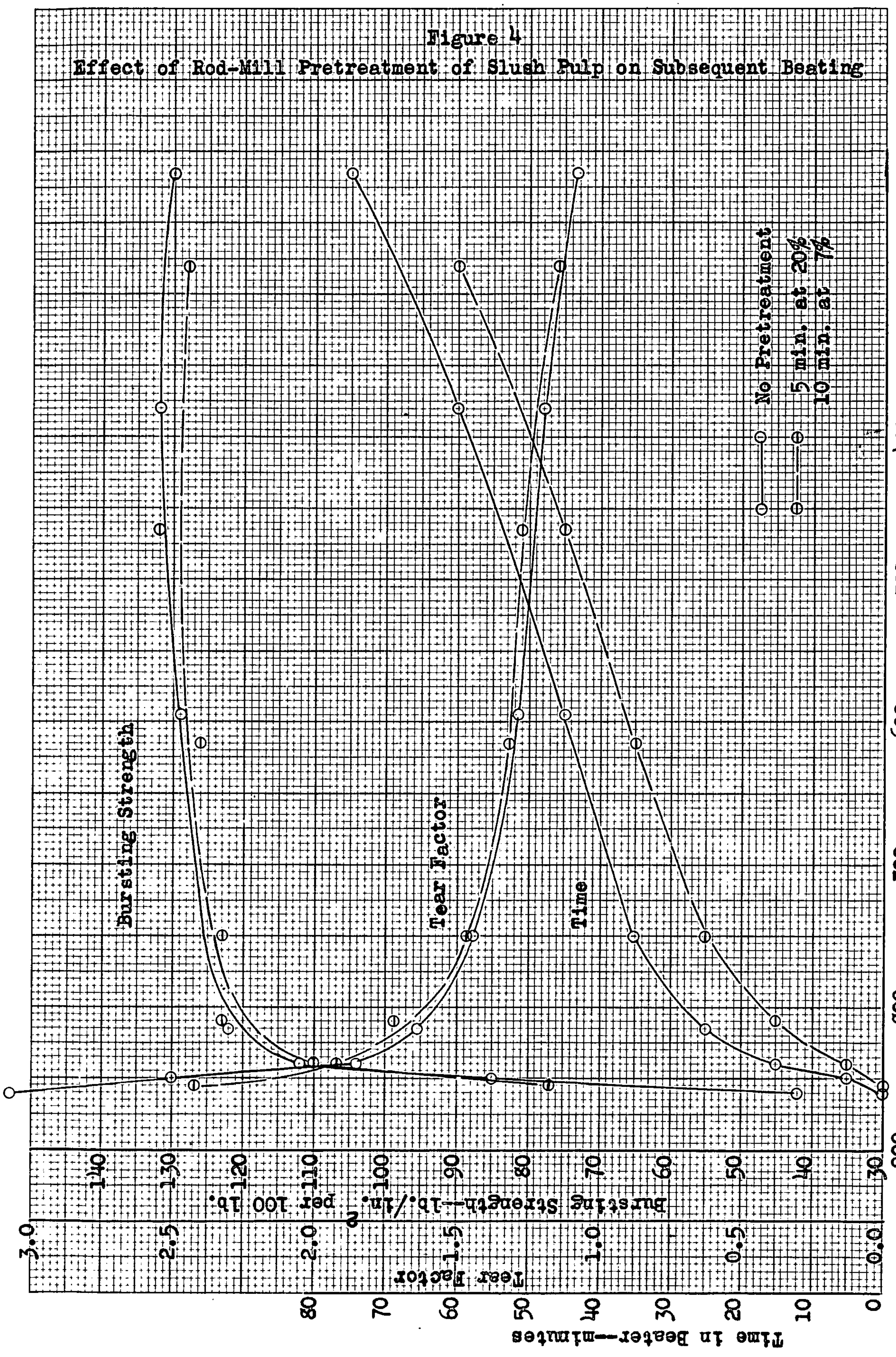


Figure 4
Effect of Rod-Mill Pretreatment of Slush Pulp on Subsequent Beating

Figure 5

Effect of Rod-Mill Pretreatment of Slush Pulp on Subsequent Beating

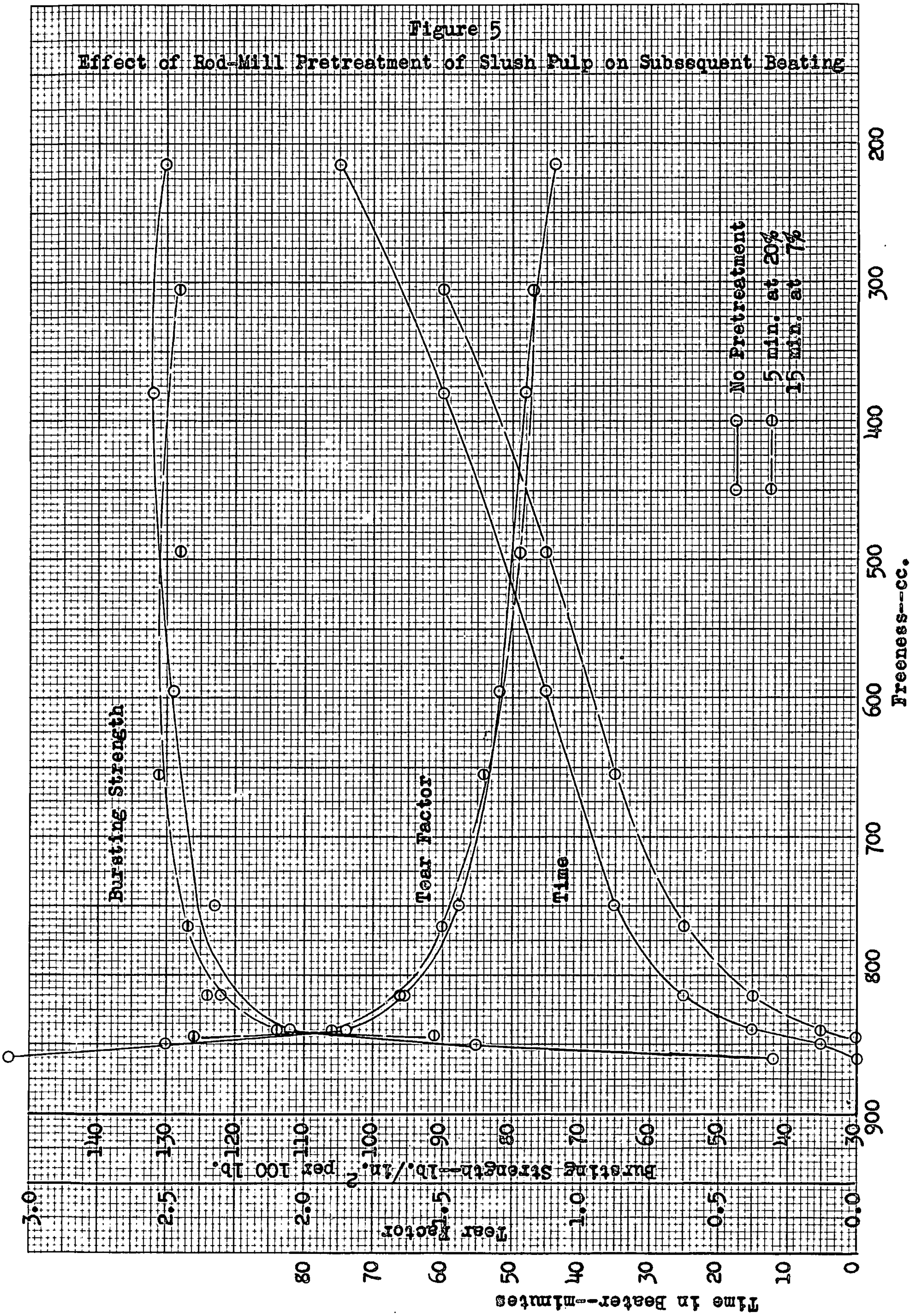


Figure 6

Effect of Rod-Mill Pretreatment of Slush Pulp on Subsequent Beating

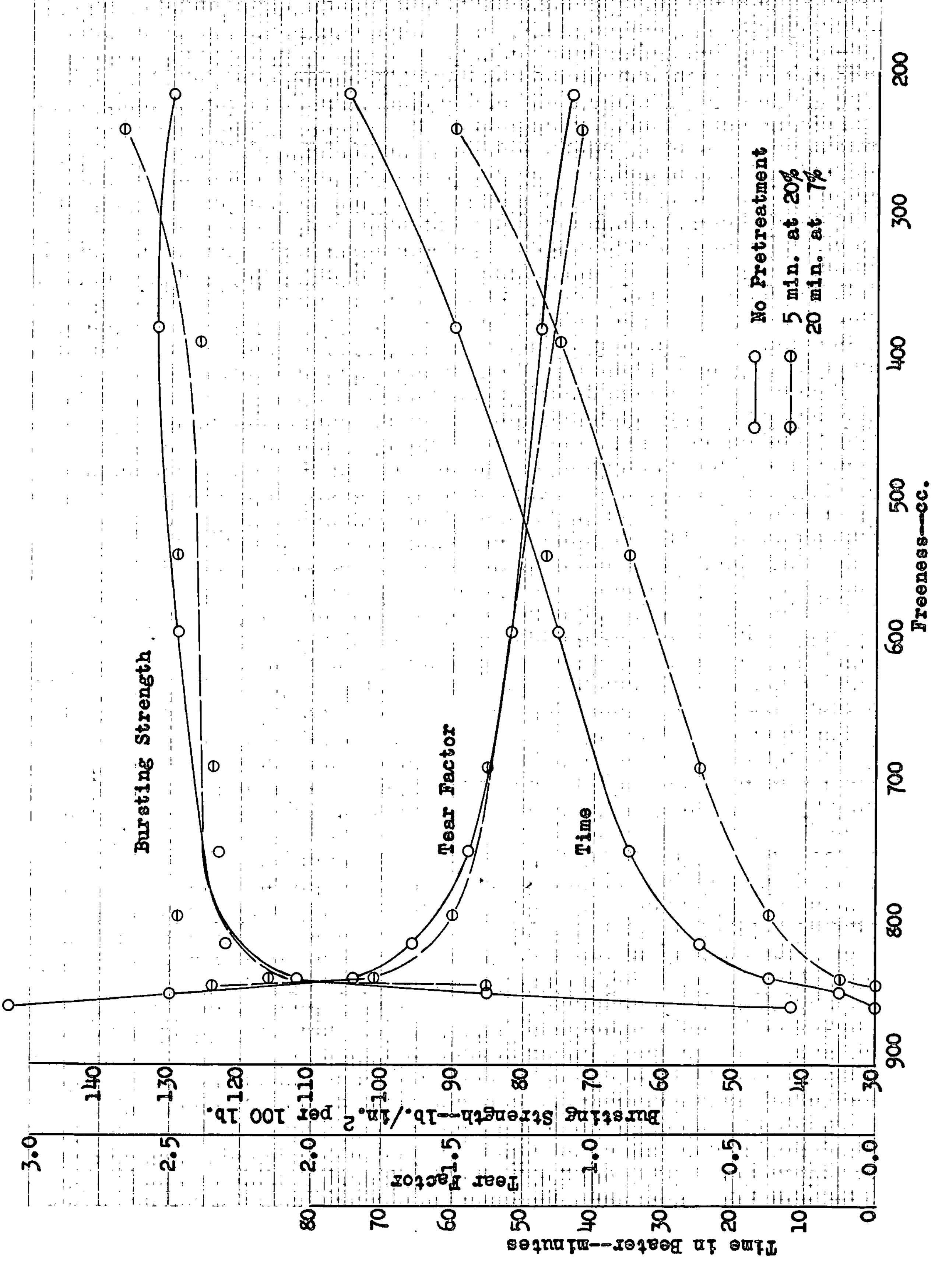
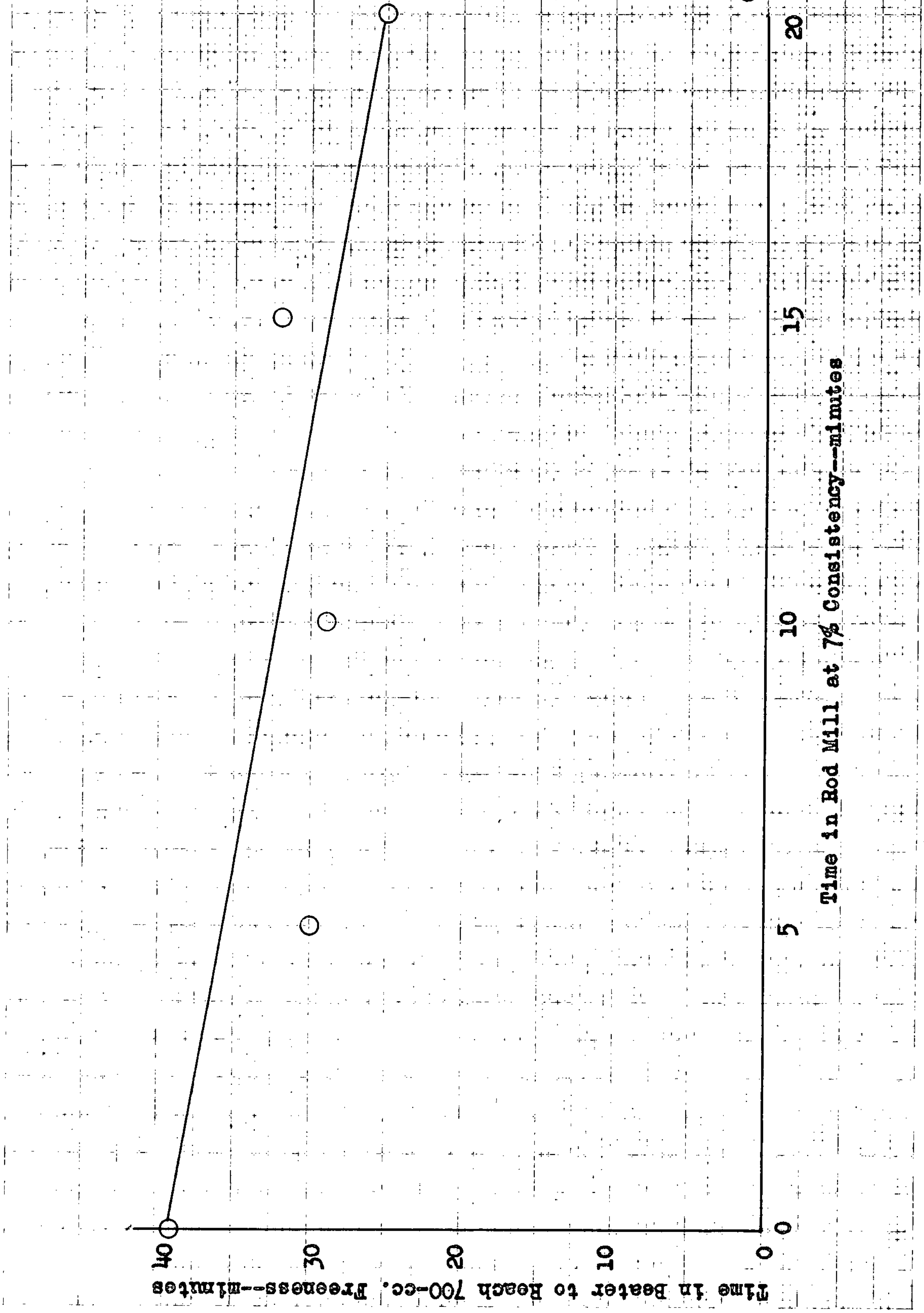


Figure 7
Effect of Time of Rod-Mill Pretreatment on Beating Time



As a further check on the pretreatment of slush pulp and also for the purpose of obtaining some power data from a commercial rod mill installation, some slush pulp (Pulp B) was obtained from a mill using three 7 by 16 foot low pulp-line rod mills, each driven by a 182 h.p. motor. Forty-eight to fifty tons of pulp per day were fed continuously at 7 per cent consistency to each mill. Samples were taken before and after the mill; since only a few minutes were required for sampling, both samples should have been from approximately the same pulp. Beater runs were made on the slush pulp both before and after the commercial rod mill using Beaters 1 and 2. Also, a sample of the pulp taken before the rod mill was pretreated for five minutes at 20 per cent and ten minutes at 7 per cent consistency in the laboratory rod mill; then a beater run was made on this stock in Beater 1. The complete results of these runs are given in Table III; the properties at 700-cc. freeness are taken from the beater curves and are given in Table IV.

The results with this pulp confirmed those found with Pulp A; i.e., the pretreatment of slush pulp in the rod mill did not increase the strength which could be obtained by subsequent beating but did decrease the time required to reach a certain drop in freeness or development in bursting strength owing to the beating action of the rod mill. This was also true for an entirely different beater (Beater 2), which gave a lower bursting strength for both the pretreated and untreated samples than Beater 1 gave.

TABLE IV

EVALUATION OF PULP B AT 700-cc. FREENESS

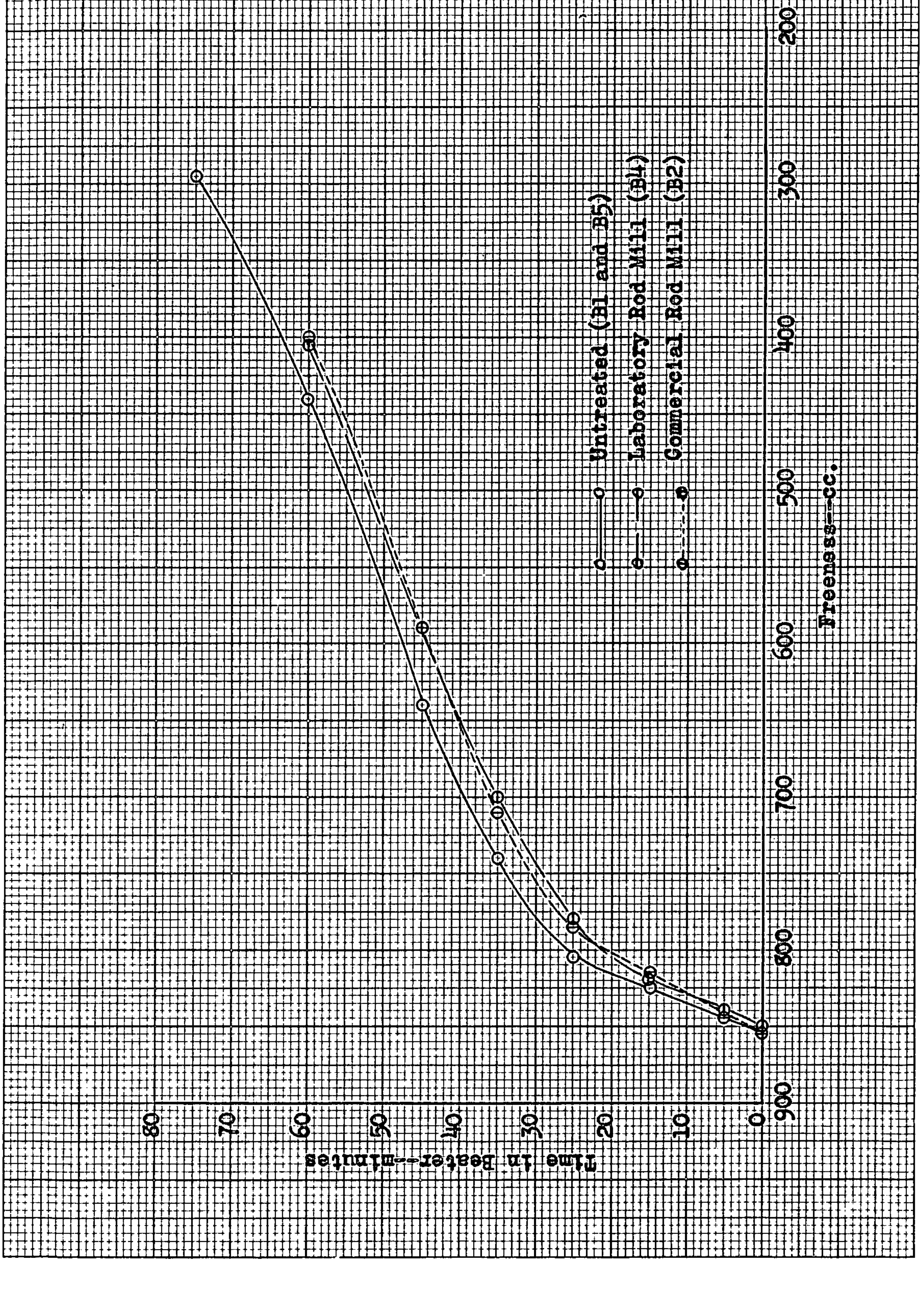
Beater Run	Pretreatment	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density
		(Beater 1)			
B1	None	39	127	1.29	14.0
B5	None	39	129	1.37	13.8
Average of B1 and B5		39	128	1.34	13.9
B4	Laboratory Rod Mill	35	127	1.30	14.0
B2	Commercial Rod Mill	36	128	1.26	14.0
		(Beater 2)			
B13	None	27	112	1.32	14.4
B12	Commercial Rod Mill	25	111	1.30	14.7

Inasmuch as the rod mill pretreatment did not effect the bursting and tearing strength obtainable by beating, the only method of comparing the action of the commercial and laboratory rod mills was by their effect on the freeness of the pulps. The freeness drop for the laboratory pretreated stock was the same as for a stock which had one pass through the commercial rod mill, as shown in Figure 8. On this basis ten minutes in the laboratory mill at 7 per cent consistency had the same beating action as one pass through the commercial rod mill operated under the conditions described previously. This would provide a factor for calculating the power requirements of a

Figure 8

Comparative Action of Laboratory and Commercial Rod Mill

(Slush Pulp B - Beater 1)



commercial installation from the time requirement of the laboratory rod mill. That is, ten minutes at 7 per cent consistency in the laboratory mill would correspond in beating action to a power expenditure of 3.64 h.p. days per ton in the 7 by 16 foot rod mill. This agreed very well with the conversion factor used by Wells (26) for the same laboratory mill.

ROD-MILL PRETREATMENT OF HANDSHEET LAPS

In view of the fact that the pretreatment in the rod mill of the slush pulp did not show any particular advantage and that the results reported by Wells (2) were for lap pulp, it was decided to make laps on a sheet mold from this slush pulp to determine whether or not this was a significant factor. Fifty-gram (o.d. basis) sheets were made from Pulps A and B on the Noble and Wood sheet mold and pressed to about 50 per cent o.d. content. One batch of these laps from Pulp A was allowed to airdry to 94 per cent o.d. content. Beater runs were made on the untreated and pretreated laps for both the 50 and 94 per cent o.d. laps using Beater 1. For the pretreatment, the laps were rod milled for five minutes at 20 per cent and ten minutes at 7 per cent consistency. The results of these runs are given in Table VI, and the strength values at 700-cc. freeness are given in Table V.

In the case of Pulp A the bursting strength of both the wet and dry lap throughout the whole freeness range was appreciably lower than that of the slush pulp; this is shown very clearly by the beating

TABLE V

EVALUATION OF HANDSHEET LAPS AT 700-cc. FREENESS

Beater Run	Condition of Pulp	Pretreatment	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density
			(Pulp A)			
A1 and A5*	Slush	None	39	126	1.38	13.6
A11	Wet Lap	None	42	119	1.40	13.4
A9	Wet Lap	Rod Mill	35	128	1.45	13.6
A10	Dry Lap	None	43	116	1.45	13.1
A8	Dry Lap	Rod Mill	36	117	1.45	13.5
			(Pulp B)			
B1 and B5**	Slush	None	39	128	1.34	13.9
B6	Wet Lap	None	39	127	1.34	13.8
B10	Wet Lap	None	40	126	1.38	14.0
Average of B6 and B10			40	126	1.36	13.9
B7	Wet Lap	Rod Mill	33	127	1.30	14.1
B11	Wet Lap	Rod Mill	34	125	1.32	14.2
Average of B7 and B11			34	126	1.31	14.2

* From Table II
** From Table IV

TABLE VI

BEATER EVALUATION OF HANDSHEET LAPS

Bursting Strength--lb./in.^{2} per 100 lb.

0'	5'	15'	25'	35'	45'	60'	75'
42	85	112	122	125	129	133	130
33	71	99	111	114	119	121	125
75	106	116	118	128	131	131	
22	60	97	108	111	116	120	127
70	96	110	119	117	120	126	
46	84	110	120	125	130	133	136
46	81	109	119	126	130	130	134
43	77	108	115	125	127	134	138
44	79	108	117	126	128	132	136
84	102	114	121	127	130	133	
79	96	111	116	125	128	136	
82	99	112	118	126	129	134	

Factor				Apparent Density							
35'	45'	60'	75'	0'	5'	15'	25'	35'	45'	60'	75'
1.43	1.27	1.20	1.08	9.1	10.4	12.0	12.6	13.2	14.0	14.6	15.4
1.56	1.38	1.32	1.20	9.7	10.7	11.7	12.4	12.9	13.4	14.2	14.7
1.48	1.50	1.24		11.1	12.0	12.6	13.1	13.6	14.0	14.5	
1.60	1.43	1.29	1.23	9.3	10.2	11.4	12.0	12.4	13.2	13.8	14.6
1.40	1.43	1.28		10.9	11.4	12.1	12.9	13.5	13.8	14.5	
1.38	1.27	1.14	1.09	9.7	11.2	12.4	13.0	13.6	14.1	14.7	15.2
1.35	1.25	1.14	1.09	10.6	11.6	12.4	13.0	13.7	14.2	14.6	15.3
1.44	1.30	1.15	1.11	10.8	11.8	12.8	13.5	13.9	14.4	14.8	15.5
1.40	1.28	1.14	1.10	10.7	11.7	12.6	13.2	13.8	14.3	14.7	15.4
1.27	1.17	1.00		12.3	12.9	13.5	13.9	14.2	14.9	15.3	
1.31	1.26	1.19		12.2	12.8	13.5	14.1	14.2	14.7	15.1	
1.29	1.22	1.10		12.2	12.8	13.5	14.0	14.2	14.8	15.2	

curves given in Figure 9. At 700-cc. freeness the bursting strength of the wet lap was about 6 per cent lower; however, when the wet-lap pulp was pretreated in the rod mill, it gave, on subsequent beating, a bursting strength curve identical with that of the original slush pulp. The air-dried laps exhibited a slightly further loss in strength, but pretreatment of the dry-lap pulp in the rod mill did not give an appreciable improvement in the strength available on subsequent beating.

The results obtained with Pulp A were not reproduced with Pulp B; in the case of Pulp B there was no loss in strength when the pulp was made into wet laps. The observation was made that the laps made from Pulp A were slightly harder to disintegrate than those from Pulp B. Although these pulps were obtained from different mills, both were from jack pine and had been cooked to about the same permanganate number. It was felt that the method of making the laps on a sheet mold was difficult to reproduce and that probably the failure to reproduce the results was due to the method rather than to any inherent differences in the pulp.

To summarize rather briefly, the work thus far showed that no improvement could be obtained by pretreating slush pulp in the rod mill before beating. It appeared probable, however, that in certain cases there was a loss in strength when slush pulp was made into wet laps and that this loss could be restored by pretreating the wet-lap pulp in the rod mill. In the next section this problem was investigated in a more comprehensive manner to determine whether or not this

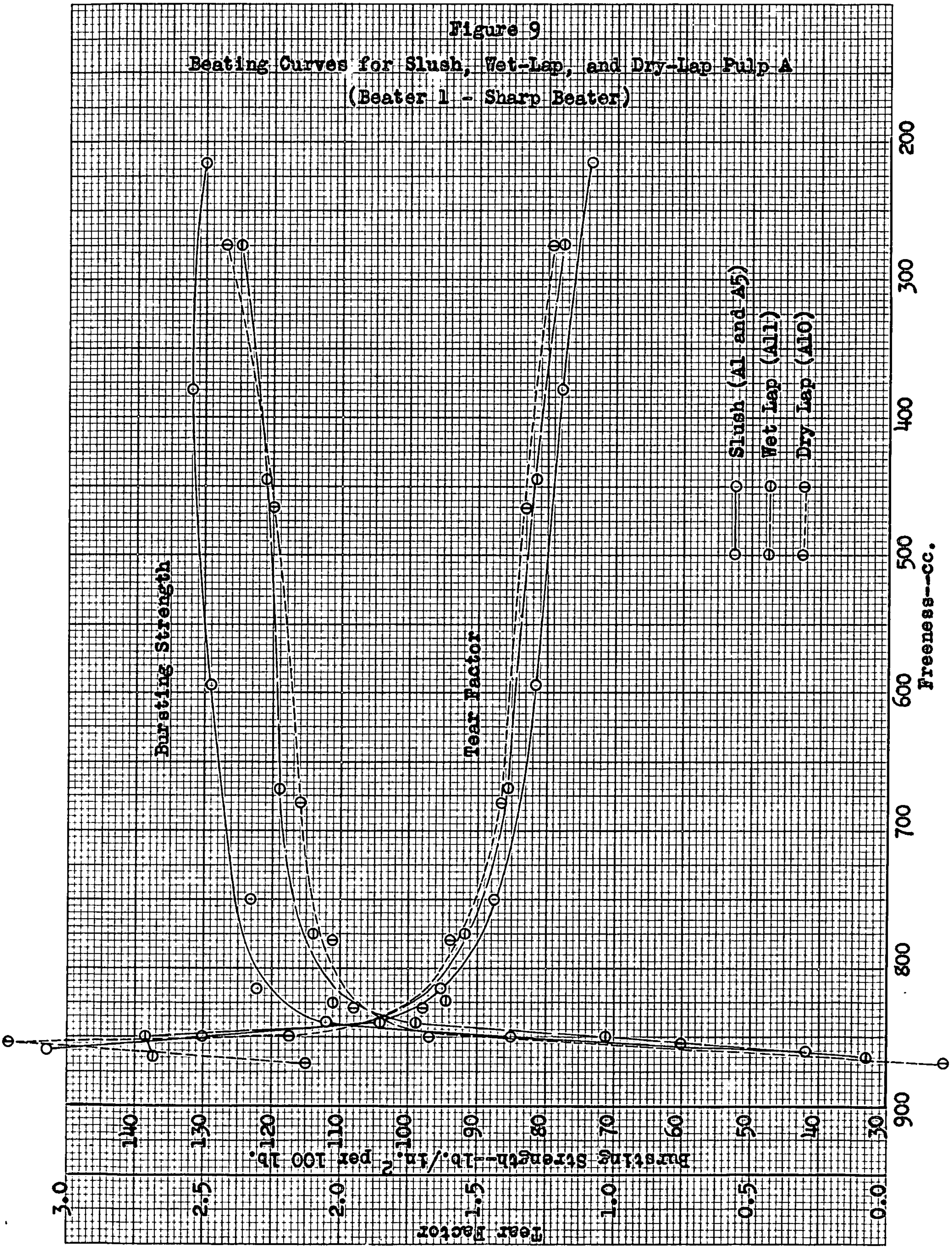


Figure 9
Beating Curves for Slush, Wet-Lap, and Dry-Lap Pulp A
(Beater 1 - Sharp Beater)

was an actual fact and, if so, the cause.

REFINING COMMERCIAL LAPS IN A SHARP BEATER

Pulp D was obtained in both slush and wet-lap condition, the slush sample being taken at the same time that the wet machine chest was being filled so as to be representative of the lot of wet laps. The wet laps were made on a Kamyr wet machine and pressed to about 26 to 28 per cent o.d. content; some of these laps were pressed to a higher o.d. content in the laboratory. Beater runs were made in Beater 1 with the slush pulp and wet laps at three different moisture contents; also, samples of the 37.6 per cent o.d. wet laps were machine-dried to 77, 89.5, and 100 per cent o.d. before beating. A sample of the stock used for making sheets was saved at each interval, and fiber length measurements were made on a number of these to determine the relative cutting of the fibers taking place during the beating. The laps at these different moisture contents were also pretreated in the rod mill, and beater runs were made on these rod-milled laps and also on the laps slushed by screening. Since the work on the handsheet laps from Pulp A had indicated that the advantage of rod-mill pretreatment was to reduce lap pulp to slush condition effectively, this treatment was used to show whether that advantage was due merely to a mechanical separation of fiber clumps remaining from the laps. The complete results of these runs are given in Table VIII, and the properties at 700-cc. freeness are given in Table VII.

TABLE VII

EVALUATION OF PULP D AT 700-cc. FREENESS BY BEATER 1

Beater Run	Percentage Ovendry	Pretreatment	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
D1	Slush	None	42	136	1.36	14.2	
D2	Slush	None	42	133	1.36	14.0	
Average of D1 and D2			42	134	1.36	14.1	0.46
D3	28.8	None	42	127	1.36	14.2	
D4	37.6	None	45	127	1.38	14.1	
D5	45.6	None	44	126	1.38	14.4	0.37
D15	77.0	None	47	127	1.40	14.0	
D6	89.5	None	45	126	1.43	13.6	
D7	100.0	None	51	126	1.41	13.8	0.39
D9	28.8	Rod Mill	40	135	1.36	14.0	
D18	45.6	Rod Mill	41	132	1.37	14.2	
D17	77.0	Rod Mill	42	129	1.34	14.1	
D11	89.5	Rod Mill	44	128	1.40	14.0	
D13	100.0	Rod Mill	44	126	1.39	13.9	
D8	28.8	Screen	46	137	1.36	14.0	
D14	45.6	Screen	44	134	1.36	14.4	0.47
D16	77.0	Screen	48	131	1.37	13.9	
D10	89.5	Screen	49	128	1.40	13.7	
D12	100.0	Screen	52	127	1.39	13.9	0.40

Apparent Density								Average Fiber Length--mm.						
0'	5'	15'	25'	35'	45'	60'	75'	0'	5'	15'	25'	35'	45'	60'
	11.6	12.6	13.2	14.0	14.4	15.0	15.4							
	11.3	12.3	13.0	13.7	14.3	14.8	15.6							
	11.4	12.4	13.1	13.8	14.4	14.8	15.5	0.69				0.53	0.42	
	11.8	12.9	13.4	14.0	14.4	15.0	15.7							
	11.8	12.6	13.3	13.8	14.1	14.5	15.4							
	12.2	12.8	13.1	13.8	14.6	14.7	15.4	0.69			0.45	0.39	0.37	
9.3	10.2	11.4	12.3	13.0	13.9	14.5	15.3							
	10.8	11.8	12.5	12.9	13.5	14.1	14.6							
	11.0	12.0	12.5	12.9	13.4	14.2	14.6	0.69					0.41	0.37
	12.1	12.7	13.4	13.9	14.4	15.1								
12.4	12.7	13.1	13.5	14.1	14.4	14.9	15.3							
11.9	12.3	12.9	13.4	13.8	14.2	14.7	15.2							
	11.8	12.4	12.8	13.4	14.2	14.6	14.8							
	12.0	12.3	12.9	13.4	13.9	14.2	14.8							
	11.6	12.2	13.1	13.6	14.0	14.7	15.0							
10.9	11.4	12.3	12.8	13.8	14.4	14.6	15.1	0.69			0.55		0.47	
9.6	10.8	12.0	12.5	13.0	13.8	14.2	14.8							
	11.2	12.0	12.6	13.1	13.5	14.3	14.5							
	11.0	11.7	12.4	12.9	13.8	14.1	14.5	0.69					0.40	0.40

TABLE VIII

BEATER EVALUATION OF PULP D BY BEATER 1

Basis Weight--lb. (25x40--500)

0'	5'	15'	25'	35'	45'	60'	75'
	46.1	47.0	47.7	47.0	47.4	46.1	46.7
	46.7	46.1	46.7	48.0	48.1	48.1	48.9
	47.5	47.6	47.7	47.8	48.1	47.9	49.0
	47.7	48.6	47.6	48.7	48.1	47.9	49.1
	47.0	47.4	47.6	47.7	48.1	47.2	47.6
46.7	45.2	46.9	46.7	46.8	46.6	46.8	47.7
	46.0	46.0	46.6	46.9	46.6	47.3	47.4
	46.1	46.6	[illegible]	46.6	46.6	47.7	47.5
	46.3	46.6	47.3	46.9	[illegible]	46.6	47.7
48.5	47.5	46.5	46.8	46.6	47.0	46.4	46.8
48.1	45.8	46.4	47.3	45.8	46.6	46.4	47.0
	46.7	47.3	47.4	47.5	47.3	47.4	46.6
	47.2	46.3	46.3	46.3	46.9	46.7	46.9
	46.8	46.9	47.0	46.1	46.8	47.5	46.3
45.6	46.2	46.3	46.5	46.3	46.6	46.4	46.6
45.8	45.1	47.5	46.1	46.5	46.5	46.8	47.0
	46.2	46.2	46.6	47.2	46.8	46.9	46.7
	47.0	45.9	46.5	47.0	46.6	46.5	46.1

Bursting Strength--lb./in.^{2} per 100 lb.

0'	5'	15'	25'	35'	45'	60'	75'
	87	122	131	135	136	138	142
	85	114	126	131	133	135	139
	86	118	128	133	134	136	140
	88	113	121	124	128	132	136
	83	107	120	124	127	133	137
	90	112	123	125	126	130	135
31	59	98	113	122	127	130	137
	58	95	113	121	125	130	133
	57	94	111	118	122	131	133
	104	121	131	134	136	138	
83	109	124	127	129	131	138	143
72	91	109	120	124	129	130	133
	91	109	117	124	129	131	135
	94	110	118	122	126	131	132
	85	118	129	134	137	138	140
49	80	108	124	131	134	137	140
38	68	99	119	124	131	132	134
	59	91	110	118	126	131	133
	51	89	104	117	123	131	134

Tear Factor

0'	5'	15'	25'	35'	45'	60'	75'
	2.46	1.73	1.57	1.42	1.28	1.16	1.10
	2.64	1.80	1.60	1.44	1.30	1.20	1.09
	2.55	1.76	1.58	1.43	1.29	1.18	1.10
	2.56	1.84	1.49	1.39	1.33	1.24	1.13
	2.51	1.84	1.55	1.40	1.38	1.26	1.18
	2.56	1.77	1.59	1.45	1.38	1.27	1.14
2.39	3.12	2.01	1.77	1.55	1.44	1.30	1.20
	3.07	2.10	1.72	1.58	1.45	1.35	1.24
	2.82	2.13	1.71	1.63	1.42	1.37	1.22
	2.03	1.75	1.50	1.43	1.26	1.18	
2.60	1.94	1.65	1.56	1.40	1.33	1.23	1.19
2.83	2.08	1.71	1.53	1.34	1.29	1.23	1.12
	2.18	1.73	1.58	1.49	1.38	1.22	1.19
	2.16	1.78	1.59	1.48	1.38	1.24	1.15
	2.44	1.79	1.57	1.40	1.38	1.21	1.09
3.07	2.36	1.75	1.56	1.40	1.35	1.24	1.13
2.74	2.50	1.97	1.67	1.55	1.39	1.29	1.23
	3.05	2.09	1.69	1.53	1.39	1.35	1.22
	2.79	2.05	1.72	1.58	1.44	1.32	1.20

Beater Run	Percentage Ovendry	Pretreat-ment	Freeness--cc.							
			0'	5'	15'	25'	35'	45'	60'	75'
D1	Slush	None		855	835	810	760	655	460	295
D2	Slush	None		855	835	815	760	670	455	310
Average of D1 and D2				855	835	810	760	660	460	300
D3	28.8	None		855	830	805	770	650	425	280
D4	37.6	None		850	835	820	775	705	535	365
D5	45.6	None		855	840	820	770	690	485	335
D15	77.0	None	865	860	840	820	785	720	535	380
D6	89.5	None		860	850	835	795	730	560	350
D7	100.0	None		860	850	830	805	750	580	400
D9	28.8	Rod Mill		850	835	800	750	635	455	
D18	45.6	Rod Mill	855	840	830	805	755	660	495	345
D17	77.0	Rod Mill	855	850	835	805	760	675	510	340
D11	89.5	Rod Mill		850	835	805	770	690	490	320
D13	100.0	Rod Mill		855	845	815	785	695	555	395
D8	28.8	Screen		855	845	825	785	710	505	325
D14	45.6	Screen	865	855	840	820	780	695	520	335
D16	77.0	Screen	865	860	845	825	790	725	580	390
D10	89.5	Screen		860	850	830	800	735	575	365
D12	100.0	Screen		865	855	835	805	760	600	420

With this beater there was a loss in bursting strength at any freeness when the slush pulp was made into wet laps of 28.8 per cent o.d. content. This loss amounted to about 5 per cent and is shown more clearly in Figures 10 and 11. There was no further loss when the wet laps were pressed to 46 per cent o.d., or even when dried to 100 per cent o.d. The beating time necessary remained practically constant for the wet laps but, on drying, slightly more time was required for beating. Any differences in the tearing strength given in Table VII were well within the limits of experimental error; however, it appeared that there was a slight increase in the tear at any given freeness when the pulps were dried; associated rather closely with this increase in tear was a slight decrease in apparent density of the sheets. The fiber-length measurements showed that on beating the wet laps the fiber was cut much more than was the case with the slush pulp. This same increased rate of cutting held true for laps dried up to 100 per cent o.d., as the average fiber length at 700-cc. freeness for the o.d. stock was practically the same as that for the wet-lap stock.

When the wet-lap pulp was disintegrated completely by screening, or when it was pretreated in the rod mill, the resulting strength development on beating was about the same as that for the original slush pulp. Also, the average fiber length on beating was greater after screening than before, and, in fact, the rate of cutting was practically the same as for the slush pulp. Since the screening of the lap pulp would have no effect other than a complete mechanical

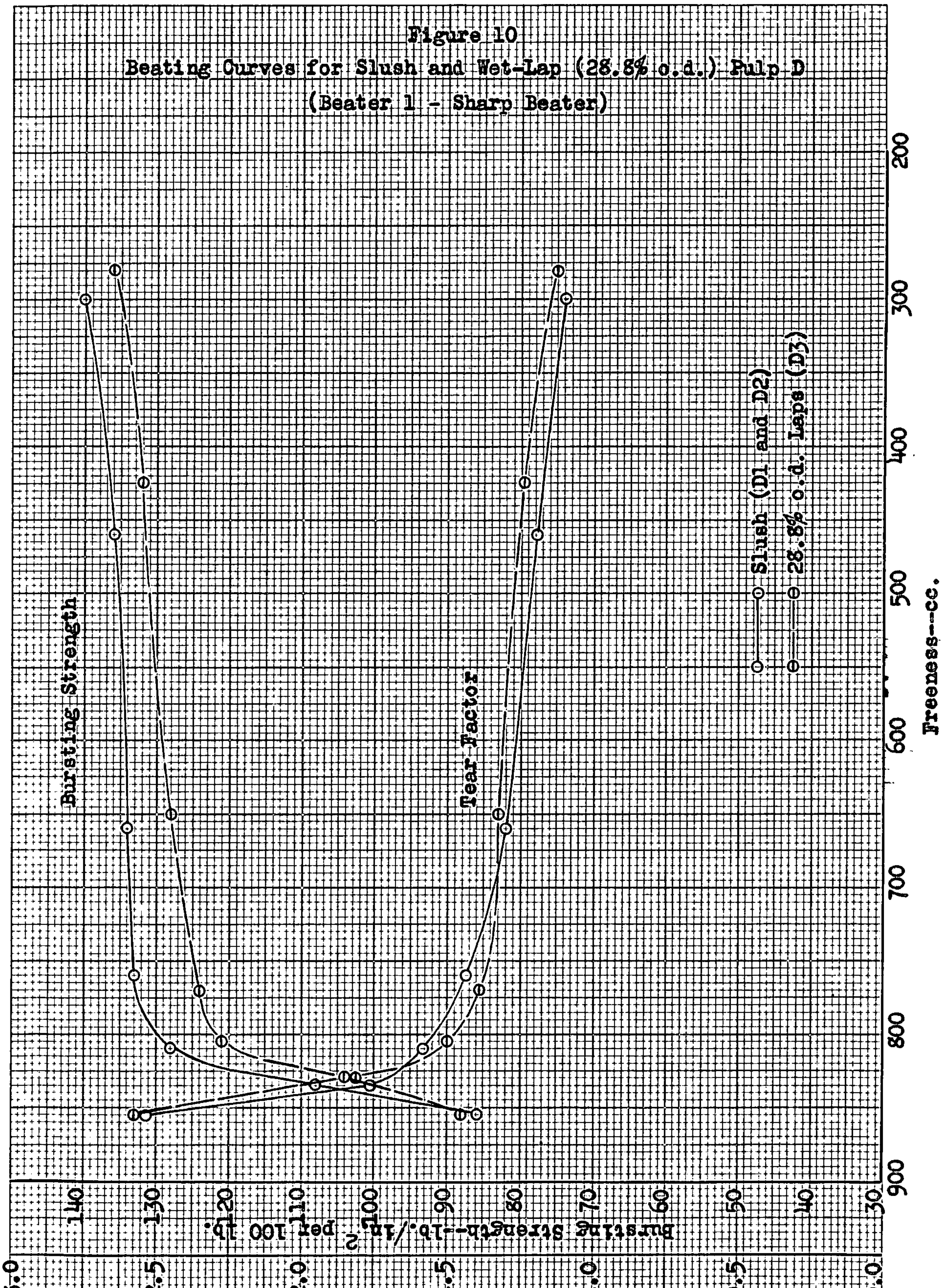


Figure 10
Beating Curves for Slush and Wet-Lap (28.8% o.d.) Pulp D
(Beater 1 - Sharp Beater)
Bursting Strength
Tear Factor
Slush (D1 and D2)
28.8% o.d. Laps (D3)
Freeness--cc.
200
300
400
500
600
700
800
900
140
130
120
110
100
90
80
70
60
50
40
30
Bursting Strength--lb./in.2 per 100 lb.
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Tear Factor

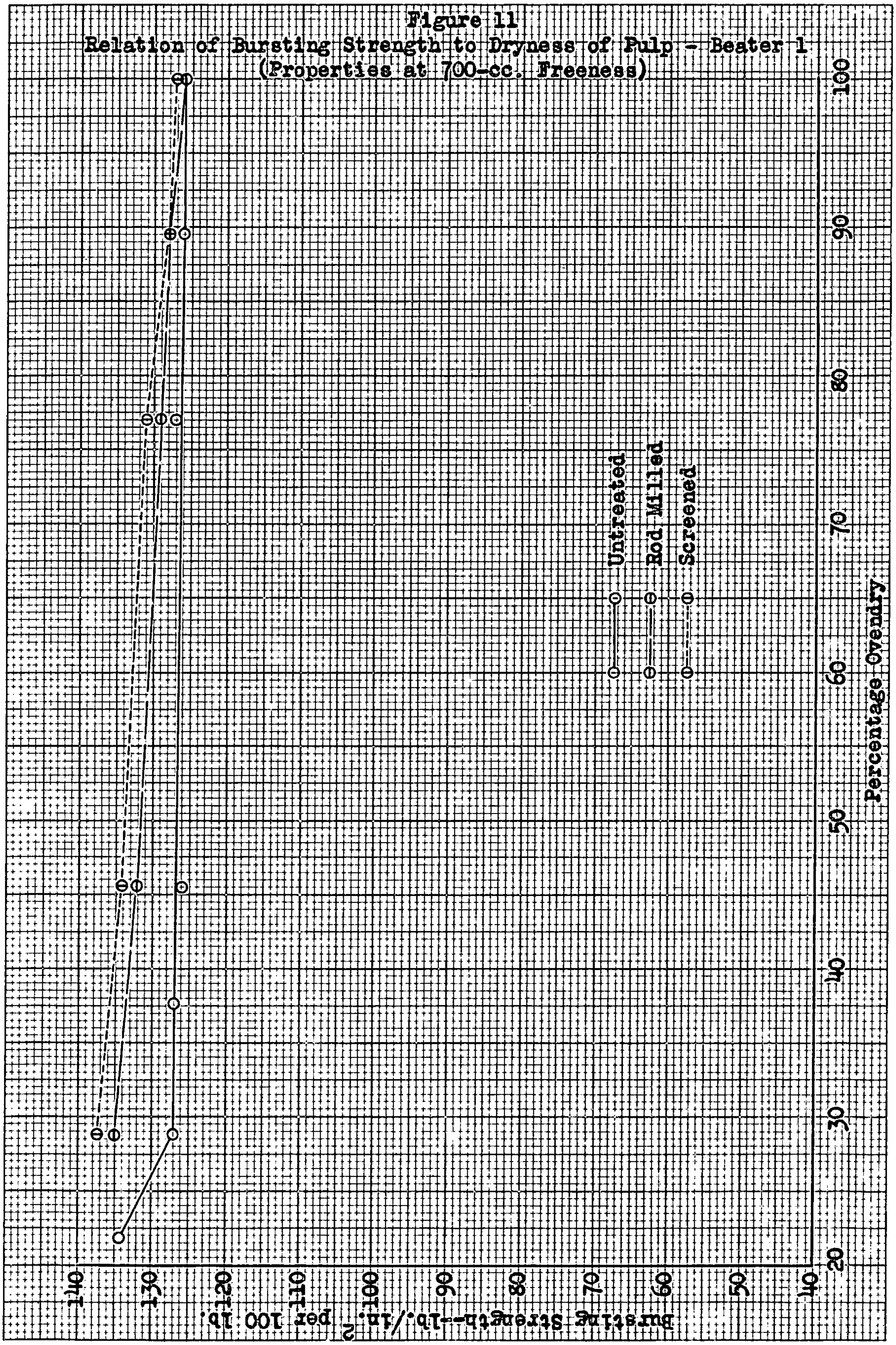


Figure 11
Relation of Bursting Strength to Dryness of Pulp - Beater 1
(Properties at 700-cc. Freeness)

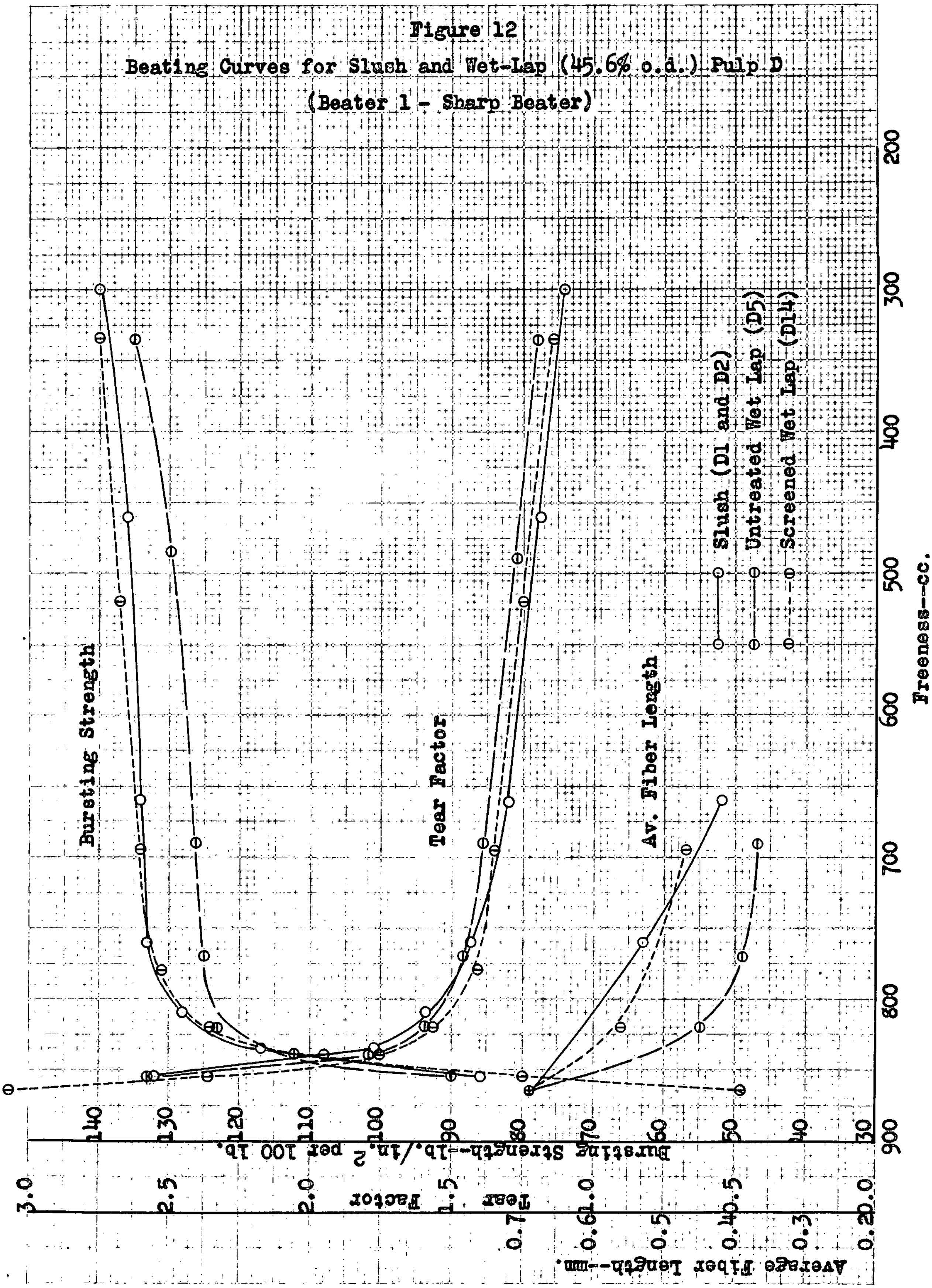
separation of all the clumps of fibers remaining after the laps were given the preliminary stirring before beating, it appeared that the strength lost when the slush pulp was made into laps was due to the presence of these clumps. Such clumps of fibers on entering the beater tackle would be cut rather than beaten out--hence, the resulting shorter length of fiber at a certain freeness. The complete beater curves, bursting strength, tear, and fiber length, for the 46 per cent o.d. laps are shown in Figure 12 to illustrate these differences; that for the slush pulp is included for comparison.

Since the laps pretreated in the rod mill gave practically the same increased bursting strength on beating as was obtained by screening the laps, it was quite evident that the beneficial action of the rod mill was to disintegrate the laps completely. It was not quite as efficient as the screen, however, since the bursting strength for the screened laps in nearly every case was slightly higher than that for the rod-milled laps (<u>see</u> Figure 11). Most of the strength lost when slush pulp was made into laps up to 77 per cent o.d. could be restored if they were completely disintegrated before beating; i.e., unless the pulps were dried beyond this point, any loss in strength was due to clumps of pulp in the beater charge, which would result in a greater cutting of the fiber during beating. If these clumps were disintegrated by screening or by pretreating the laps in the rod mill before beating, there was no difference in the strength of the so-treated laps and the slush pulp. When the pulps were dried beyond 77 per cent o.d., however, even after completely disintegrating

Figure 12

Beating Curves for Slush and Wet-Lap (45.6% o.d.) Pulp D

(Beater 1 - Sharp Beater)



the laps by screening or by pretreating in the rod mill, the bursting strength obtainable by beating was about 5 per cent lower than that of the slush pulp. There was also more cutting; i.e., at a freeness of 700 cc. the average fiber length of the dried pulp was appreciably lower than that of the slush pulp beaten to the same freeness. Thus far there were indications that the bursting strength obtained at a certain freeness was dependent on the average fiber length at that freeness; a direct relationship between fiber length and bursting strength is shown in a later section.

By a consideration of the beater results for the wet-lap pulp given in Table VIII it can be seen that much less beating time was required to reach a certain development of bursting strength for the laps pretreated in the rod mill than for the untreated laps. For instance, in the case of the 28.8 per cent o.d. laps pretreated in the rod mill, a bursting strength of 134 lb./in.^{2} per 100 lb. was obtained by thirty-five-minute beating, but for the same laps without pretreatment about sixty-five-minute beating time was required to reach the same bursting strength. The same relation was true for the 45.6 per cent o.d. laps. On this basis, large savings in power could be calculated for this type of beater; i.e., by the expenditure of 3.64-h.p. days per ton for a rod-mill pretreatment, the beating time necessary to reach this given bursting strength was decreased almost half for this beater. This saving was not due to the beating action of the rod mill but to its disintegrating action. In other words, when these laps were disintegrated by the screen, the same beating time, thirty-five minutes, was required to reach a bursting strength of 134 lb./in.^{2} per 100 lb. as for the rod-milled laps. However, this method of calculating power saving could hardly be said to be valid, since, if a slightly higher bursting strength were selected, an infinite time in the beater would be required for the untreated laps to reach this bursting strength. For instance, after sixty minutes in the beater the pretreated 45.6 per cent o.d. laps developed a bursting strength of 138 lb./in.^{2} per 100 lb.; on the other hand, this bursting strength was never developed using the same laps without pretreatment. Therefore, before the above calculation could be applied to a given set of conditions, it would be necessary to determine whether incomplete disintegration of the laps before beating was causing a lower bursting strength at any freeness, and, as a result of this incomplete disintegration, more time was being given in the beater to develop a desired bursting strength. Only in cases where this were true would the above indications of power saving be valid.

REFINING COMMERCIAL LAPS IN A DULL BEATER

The results obtained with Beater 1 seemed rather peculiar, because a difference in bursting strength between slush pulp and very wet laps was obtained. Although this difference for laps up to about 77 per cent o.d. was shown to be due to incomplete disintegration of fiber clumps before beating with a resulting greater cutting of the fiber, it was felt that such effects would not occur when a beater giving less cutting was used. The same pulps without pretreatment or screening were run in Beater 3. The complete results are given in Table X, and the properties at 700-cc. freeness are tabulated in Table IX.

As shown in this table and also in Figure 13, there was little difference in the strength obtained in this beater between slush and wet-lap pulp, and very little loss for laps up to 72 per cent o.d. Beyond this dryness, however, whether air-dried or machine-dried, there was about a 5 to 7 per cent loss in bursting strength. As with the other beater, the differences in tear and apparent density were so slight that any conclusions would be questionable. However, it seemed that there was a slight rise in tear and decrease in apparent density at this freeness when the pulps were dried before beating.

In Figure 14 the complete beating curves for the slush, wet-lap, and dry-lap pulps are given. In contrast to the results obtained with the sharp beater (given in Figure 10, 11, and 12), there was very little cutting of the fiber in this beater, and the cutting of the slush and wet-lap pulps was about the same. However, as with Beater 1, the dry pulp was cut more and the bursting strength was lower than that of the slush pulp.

Since the work so far had shown that pretreatment, either by rod milling or by slushing in the screen, was beneficial only in restoring the strength lost when slush pulp was made into wet laps,

TABLE IX

EVALUATION OF PULP D AT 700-cc. FREENESS BY BEATER 3
(No Pretreatment)

Beater Run	Percentage Ovendry	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
D19	Slush	39	152	1.37	14.2	
D31	Slush	38	153	1.37	14.4	0.62
Average of D19 and D31		38	152	1.37	14.3	
D20	45.6	43	150	1.38	14.1	
D25	48.6	43	153	1.39	14.3	0.63
D32	45.0	49	150	1.39	14.6	
D36	45.0	47	149	1.40	14.5	
Average of 4 runs		46	150	1.39	14.4	
D38	72.5	50	148	1.45	14.2	
D33	77.4	52	143	1.45	14.1	
D34	88.4	52	141	1.51	14.1	
D21	100.0	49	141	1.43	13.8	
D27	100.0	50	144	1.43	13.9	0.57
Average of D21 and D27		50	142		13.8	
D37*	77.8	51	141	1.40	14.3	
D35*	92.5	52	144	1.44	14.2	

* Air-dried samples; others machine-dried.

TABLE X

BEATER EVALUATION OF PULP D BY BEATER 3

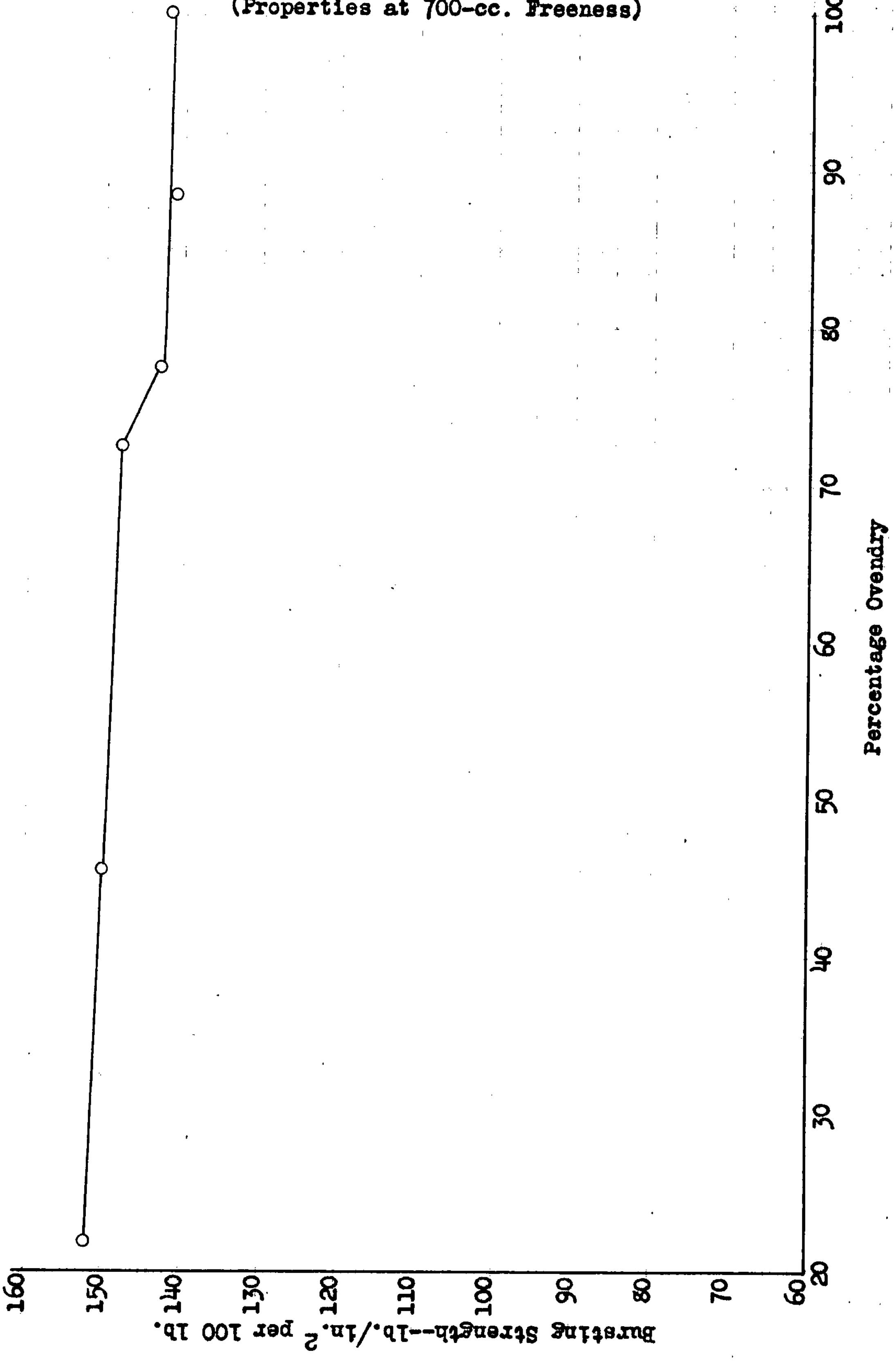
Beater Run	Percentage Ovendry	Pretreatment	Freeness--cc. 5'	20'	35'	50'	65'	80'	Basis Weight--lb. (25x40--500) 5'	20'	35'	50'	65'	80'
D19	Slush	None	850	820	735	560	320		46.7	46.0	45.8	46.7	46.6	
D31	Slush	None	850	820	730	535	350		47.4	46.0	47.4	47.4	46.7	
Average of D19 and D31			850	820	730	550	335							
D20	45.6	None	850	820	765	620	415		45.2	46.2	45.5	46.4	47.3	
D25	48.6	None	850	830	770	635	445		48.1	47.8	48.3	48.5	47.8	
D32	45.0	None	850	830	780	695	570	380	47.6	47.2	47.5	47.3	46.4	47.5
D36	45.8	None	850	825	780	675	515	350	49.4	48.2	47.2	48.9	47.8	48.0
Average of D20, 25, 32, and 36			850	825	775	655	485	365						
D38	72.5	None	850	830	790	700	585	435	48.5	46.4	47.8	46.9	47.6	47.6
D33	77.4	None	855	835	790	715	580	440	49.4	46.9	46.8	46.5	47.5	46.9
D34	88.4	None	860	830	790	710	580	430	47.7	48.0	48.0	48.7	47.1	47.8
D21	100.0	None	865	835	785	690	520	330	45.2	45.7	48.7	46.4	46.4	46.3
D27	100.0	None	860	835	790	705	555	360	46.1	46.9	47.4	47.7	48.0	48.2
Average of D21 and D27			860	835	790	700	540	345						
D37*	77.8	None	855	830	790	705	590	440	47.0	47.5	47.0	47.4	49.3	47.5
D35*	92.5	None	855	835	790	715	570	385	47.2	47.1	47.4	46.5	48.2	48.3
D40	45.8	Rod Mill	835	810	770	670	525	360	48.3	48.0	47.6	47.3	47.4	48.5
D41	77.5	Rod Mill	845	820	790	710	585	465	47.6	47.6	47.7	49.1	47.7	47.3
D39	100.0	Rod Mill	840	820	780	700	590	470	49.5	48.6	48.7	48.6	48.1	48.2
D23	45.6	Screen	855	830	770	655	455		46.0	46.9	45.9	46.4	46.5	
D26	48.6	Screen	855	830	775	660	475		48.5	48.0	47.7	48.0	47.2	
Average of D23 and D26			855	830	770	660	465							
D22	100.0	Screen	860	835	795	690	505	335	46.3	45.9	44.9	45.2	46.0	45.7
D28	100.0	Screen	860	840	795	710	555	380	47.3	45.8	47.9	47.6	47.4	46.9
Average of D22 and D28			860	840	795	700	530	360						

Beater Run	Bursting Strength lb./in.² per 100 lb. 5'	20'	35'	50'	65'	80'	Tear Factor 5'	20'	35'	50'	65'	80'
D19	84	133	150	155	160		2.69	1.67	1.47	1.25	1.17	
D31	75	127	152	156	159		2.56	1.62	1.41	1.31	1.16	
Average of D19 and D31	80	130	151	156	160		2.62	1.64	1.44	1.28	1.16	
D20	82	128	144	153	155		2.36	1.59	1.43	1.34	1.23	
D25	74	129	145	155	154		2.60	1.77	1.46	1.36	1.23	
D32	78	120	141	150	156	154	2.71	1.83	1.58	1.39	1.34	1.21
D36	75	121	142	150	154	151	2.59	1.80	1.49	1.39	1.33	1.22
Average of D20, 25, 32, and 36	77	125	143	152	155	152	2.56	1.75	1.49	1.37	1.28	1.22
D38	67	110	132	148	154	157	2.73	1.89	1.62	1.45	1.40	1.33
D33	53	99	125	141	149	150	3.08	2.01	1.64	1.46	1.37	1.34
D34	51	99	125	140	146	149	3.28	2.03	1.62	1.52	1.39	1.30
D21	44	106	124	142	148	153	2.72	2.10	1.68	1.42	1.31	1.24
D27	56	109	135	144	150	149	3.04	1.85	1.51	1.43	1.32	1.14
Average of D21 and D27	50	108	130	143	149	151	2.88	1.98	1.60	1.42	1.32	1.19
D37*	61	106	132	141	147	152	2.81	1.94	1.57	1.40	1.34	1.35
D35*	60	107	128	144	150	146	2.78	1.93	1.58	1.46	1.37	1.31
D40	106	131	146	150	152	153	2.04	1.56	1.44	1.30	1.26	1.24
D41	93	118	132	142	143	148	2.26	1.82	1.64	1.51	1.38	1.32
D39	95	120	135	142	144	151	2.14	1.80	1.56	1.47	1.43	1.28
D23	83	130	147	154	157		2.59	1.68	1.53	1.33	1.20	
D26	80	128	148	154	157		2.76	1.74	1.49	1.36	1.23	
Average of D23 and D26	82	129	148	154	157		2.68	1.71	1.51	1.34	1.22	
D22	56	115	135	146	153	158	3.04	1.95	1.58	1.40	1.31	1.19
D28	52	105	130	144	151	155	3.04	1.98	1.59	1.43	1.31	1.17
Average of D22 and D28	54	110	132	145	152	156	3.04	1.96	1.58	1.42	1.31	1.18

Beater Run	Apparent Density 5'	20'	35'	50'	65'	80'	Average Fiber Length--mm. 5'	20'	35'	50'	65'
D19	11.4	13.2	14.0	14.7	15.3						
D31	11.6	13.4	14.3	14.9	15.5				0.64	0.61	
Average of D19 and D31	11.5	13.3	14.2	14.8	15.4						
D20	11.3	13.0	13.8	14.5	15.0						
D25	11.6	12.9	13.9	14.6	15.2			0.67	0.64	0.62	
D32	11.6	12.9	13.9	14.6	15.0	15.7					
D36	11.6	13.1	14.0	14.7	15.0	15.5					
Average of D20, 25, 32, and 36	11.5	13.0	13.9	14.6	15.0	15.6					
D38	11.0	12.4	13.3	14.2	14.6	15.2					
D33	11.0	12.3	13.4	14.1	14.7	15.0					
D34	10.8	12.4	13.3	14.1	14.5	15.3					
D21	10.4	12.0	13.2	13.9	14.8	15.1					
D27	10.5	12.3	13.2	13.9	14.5	15.0			0.60	0.57	0.56
Average of D21 and D27	10.4	12.2	13.2	13.9	14.6	15.0					
D37*	11.0	12.6	13.6	14.3	14.8	15.1					
D35*	11.2	12.8	13.5	14.2	14.9	15.5					
D40	12.4	13.3	14.3	14.8	15.2	15.8					
D41	12.3	12.9	13.7	14.2	14.6	15.0					
D39	12.4	13.2	14.0	14.5	14.8	15.4					
D23	11.6	13.0	13.9	14.7	15.3						
D26	11.5	12.8	13.8	14.4	14.8			0.70	0.66	0.62	
Average of D23 and D26	11.6	12.9	13.8	14.6	15.0						
D22	10.9	12.5	13.4	14.0	14.7	15.0					
D28	10.3	12.1	12.9	13.8	14.4	15.1			0.61	0.55	0.54
Average of D22 and D28	10.6	12.3	13.2	13.9	14.6	15.0					

*Air-dried samples; others machine-dried.

Figure 13
Relation of Bursting Strength to Dryness of Pulp - Beater 3
(Properties at 700-cc. Freeness)



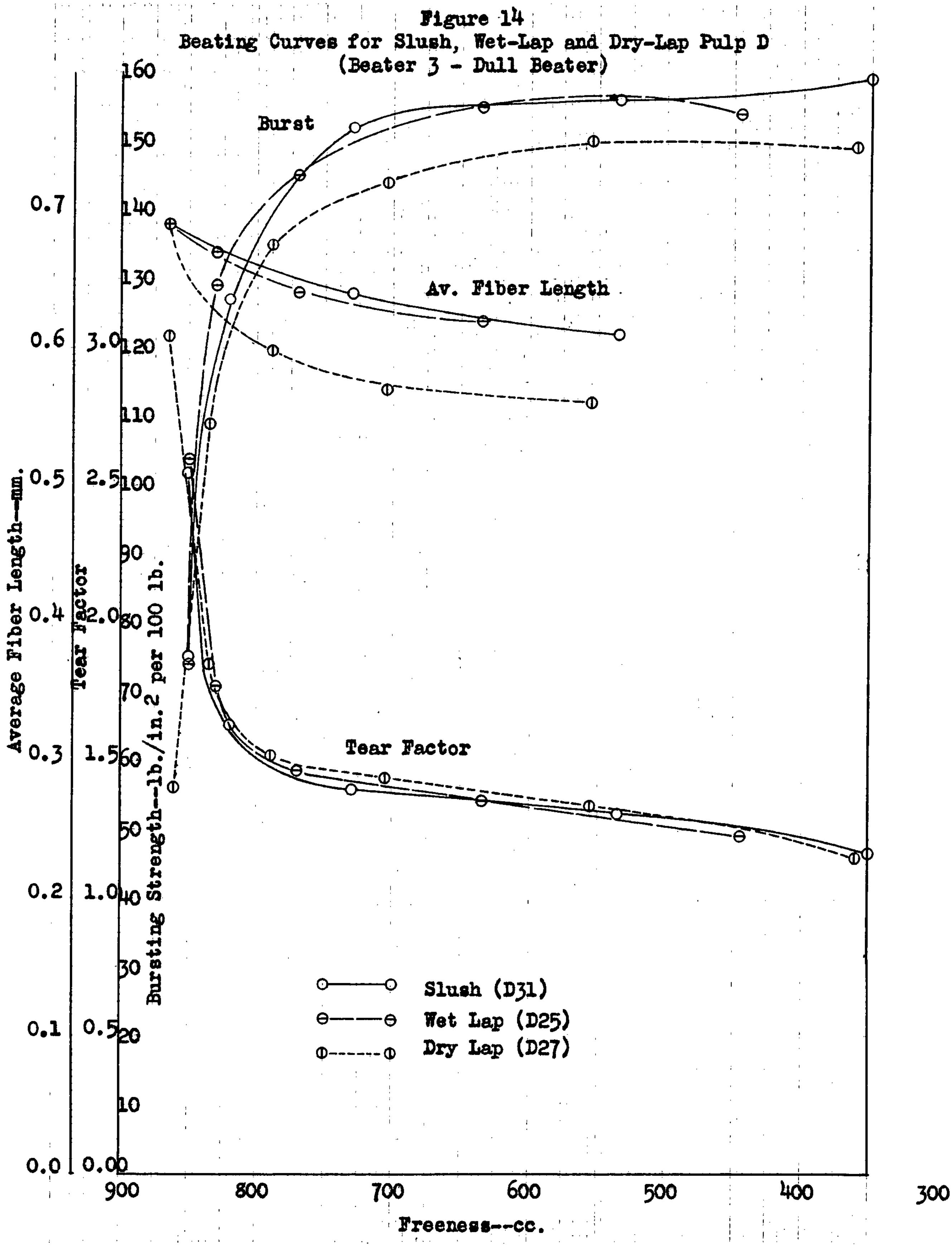


Figure 14
Beating Curves for Slush, Wet-Lap and Dry-Lap Pulp D
(Beater 3 - Dull Beater)
Burst
Av. Fiber Length
Tear Factor
Slush (D31)
Wet Lap (D25)
Dry Lap (D27)
Average Fiber Length--mm.
Tear Factor
Bursting Strength--lb./in.2 per 100 lb.
Freeness--cc.
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.00
0.5
1.0
1.5
2.0
2.5
3.0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
900
800
700
600
500
400
300

and since with this beater there was no difference in strength between slush and wet-lap pulp, no advantage was expected by pretreating before beating in this beater. Apparently the cutting action of this beater was so slight that any clumps present in the original beater charge were thoroughly disintegrated by the beater itself before any appreciable damage was done to the fiber. Likewise, the previous work had shown that in the case of the dry-lap pulp, even though the fiber was cut more on beating than was true for the original slush pulp, pretreatment before beating did not lessen this increased amount of cutting. For the dry pulp the greater amount of cutting of the fiber was not due to fiber clumps but either to the fact that the fiber was made more brittle by drying beyond the fiber saturation point, or merely because more beating time was required to reach a certain drop in freeness, and by the time this drop in freeness was reached the greater mechanical action of the beater necessary had caused more cutting of the fiber.

The wet laps and ovendry laps were pretreated by rod milling and by slushing in the screen and, also, the 77.5 per cent o.d. lap was pretreated in the rod mill. Beater runs using the dull beater (Beater 3) were made; the complete results are given in Table X. The properties at 700-cc. freeness are given in Table XI and compared with those of the untreated stocks of the same dryness (Table IX).

As was expected from the previous argument, there was no difference in the pretreated and untreated stocks when beaten in Beater 3. Since this beater disintegrated the pulp by its own action before

TABLE X

EFFECT OF PRETREATMENT BEFORE BEATING IN BEATER 3
(Properties at 700-cc. Freeness)

Beater Run	Percentage Ovendry	Pretreatment	Time to Develop min.	Bursting Strength lb./in.² per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
D19 and 31*	Slush	None	38	152	1.37	14.3	0.62
D20, 25, 32, and 36*	46	None	46	150	1.39	14.3	0.63
D23	46	Screen	45	152	1.39	14.3	
D26	46	Screen	45	153	1.40	14.2	0.64
Average of D23 and D26			45	152	1.40	14.2	
D40	46	Rod Mill	47	149	1.35	14.6	
D33	77.5	None	52	143	1.45	14.1	
D41	77.5	Rod Mill	51	142	1.50	14.2	
D21 and 27*	100	None	50	142	1.43	13.8	
D22	100	Screen	49	145	1.42	13.9	
D25	100	Screen	51	144	1.43	13.8	0.56
Average of D22 and D25			50	144	1.42	13.8	
D39	100	Rod Mill	50	142	1.47	14.5	

* From Table IX.

cutting to any appreciable extent, any pretreatment of this type would not be advantageous.

RELATION OF BURSTING STRENGTH TO FIBER LENGTH

Thus far in the work there appeared to be a striking parallelism between the average fiber length at a given freeness and the bursting strength at that freeness; i.e., when a certain stock was beaten to a freeness of 700 cc., the bursting strength would be dependent on the average fiber length. For the same pulps, Beater 3 gave considerably higher bursting strength and less cutting at any freeness than Beater 1. The properties at 700-cc. freeness and the average fiber length at that freeness are given in Table XII; this includes data from both beaters.

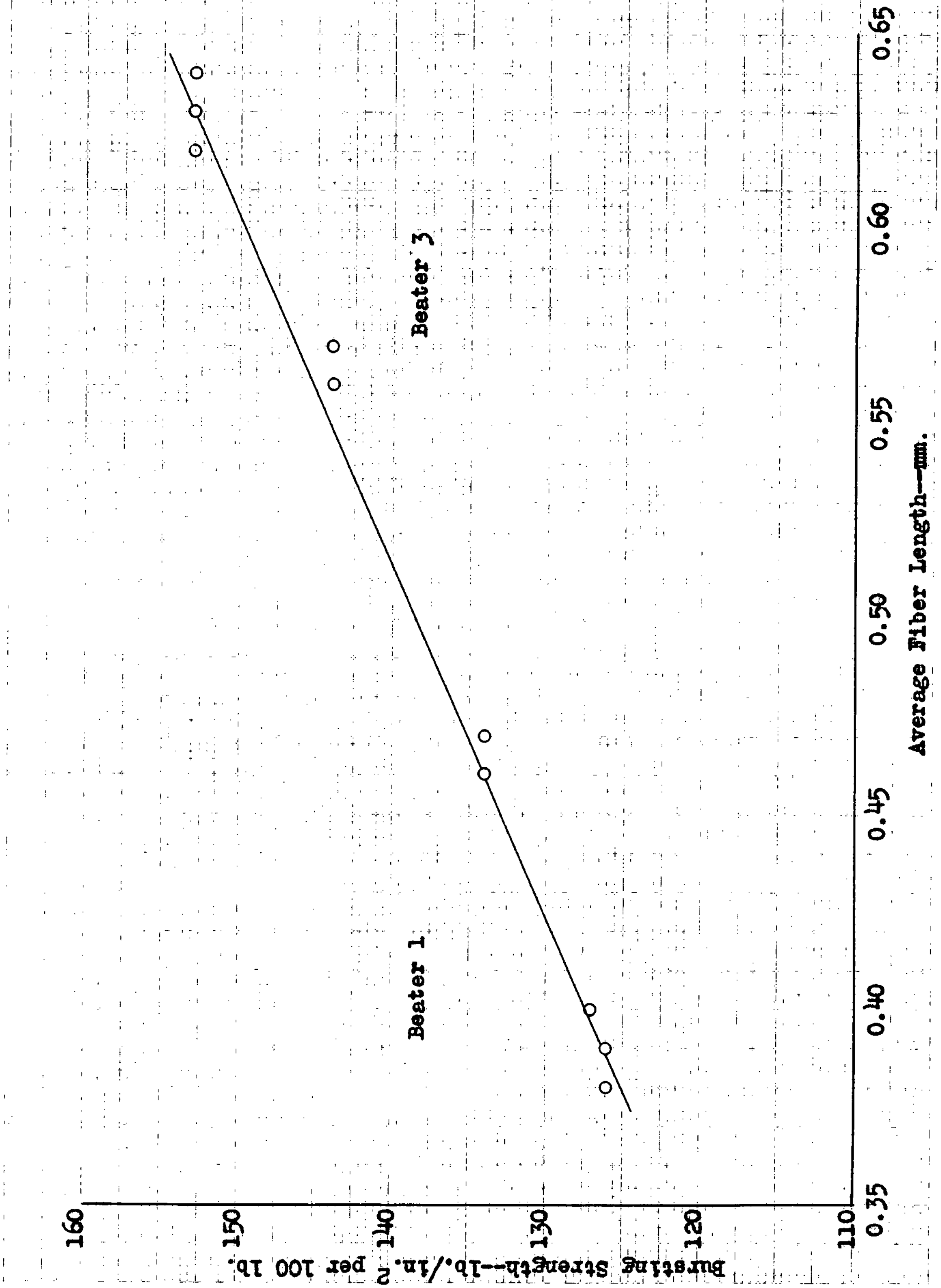
From this table the dependence of the bursting strength obtained on the average fiber length is very apparent; this is shown even more clearly in Figure 15. In this figure the bursting strength at 700-cc. freeness is plotted against fiber length; when a straight line is drawn between the points for the values from the two beaters with slush pulp, all of the other points fall on this line. With Beater 1, the wet-lap pulp gave a bursting strength of 126 (D5) at 700-cc. freeness and had a fiber length of 0.35 mm. at this freeness. From the curve a bursting strength of 125 would be predicted for this pulp beaten to 700-cc. freeness with an average fiber length of 0.35 mm. at this freeness; this fact established definitely that the difference in bursting strength of slush and wet-lap pulp, when beaten

TABLE XII

DEPENDENCE OF STRENGTH ON FIBER LENGTH
(Properties at 700-cc. Freeness)

Beater Run	Beater	Condition of Pulp, Percentage Ovendry	Pretreatment	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
D1 and 2	1	Slush	None	42	134	1.37	14.2	0.46
D31	3	Slush	None	38	153	1.37	14.4	0.62
D5	1	46	None	44	126	1.38	14.4	0.38
D14	1	46	Screen	44	134	1.36	14.4	0.47
D7	1	100	None	51	126	1.41	13.8	0.39
D12	1	100	Screen	52	127	1.39	13.9	0.40
D25	3	46	None	43	153	1.39	14.1	0.63
D26	3	46	Screen	45	153	1.40	14.2	0.64
D27	3	100	None	50	144	1.43	13.9	0.57
D28	3	100	Screen	51	144	1.43	13.8	0.56

Figure 15
Relation of Bursting Strength and Average Fiber Length
(Properties at 700-cc. Freeness)



in Beater 1, was due to more cutting of the fiber in the case of laps. That this greater cutting was due to clumps of fibers was shown by completely disintegrating the laps with a screen; when beaten to this freeness (D14), the average fiber length was the same as that for the slush pulp beaten to the same freeness and, as a result of this longer fiber length, the bursting strength was also the same as for the original slush pulp. For the dry pulp (D7 and D12), whether disintegrated before beating or not, there was a greater cutting of the fiber, and the loss in bursting strength was the same as might be predicted from the difference in average fiber length using the relationship given in Figure 15.

For Beater 3, which gave much less cutting of the fiber than Beater 1, there was no difference in the average fiber length when beaten to a freeness of 700-cc. of slush, wet lap, and wet-lap pulp disintegrated by screening, and consequently no difference in bursting strength. In this beater, which cut the fiber very little, the presence of fiber clumps from the laps made no difference; apparently it disintegrated them by its own action before cutting to any extent. With the dry-lap pulp, however, the average fiber length at 700-cc. freeness was much less, and this difference in fiber length between the slush or wet-lap pulp and the dry-lap pulp accounted for the loss in bursting strength when the pulps were dried.

One very striking result of this work was that for the slush pulp both beaters gave the same tearing strength at any given freeness, even though there was a very great difference in the average fiber length. This is shown more clearly in Figure 16. When the pulps were dried, there was a slight increase in the tearing strength and a decrease in the apparent density; this was true for both beaters. Although these differences were very small and subject to experimental error, the tear and apparent density values given in Table XII are plotted versus fiber length in Figure 17. In either beater there was an increase of about 0.04 to 0.06 in the tear factor when the pulps were dried, even though the fiber length was shorter for the dried pulps. This drying produced a decrease of about 0.5 in the apparent density of the sheets. Dixson (30) found that, for bleached sulfite pulp beaten to a freeness of 700 cc., a decrease in apparent density of 0.5 caused an increase in the tear factor of about 0.06. Assuming even approximately the same relationship to hold true for a kraft pulp, the decrease in apparent density of the sheets when the pulps were dried would account for the increased tearing strength obtained. That neither of these was due to a difference in fiber length was shown by the fact that for the wet pulps, even though there were very great differences in the fiber length at 700-cc. freeness, the tear factor and apparent densities remained practically the same. Apparently the dried pulps gave a bulkier sheet, not because of any differences in the fiber length, but because the fibers after drying had less tendency to mat together to form a dense sheet. Dixson also found that this same decrease in apparent density (0.5) caused a decrease in bursting strength of 1.8, but this was not sufficient to account for the differences in bursting strength obtained between wet and dry pulp in the present work.

Figure 16

Relation of Tear to Average Fiber Length

(Slush Pulp D)

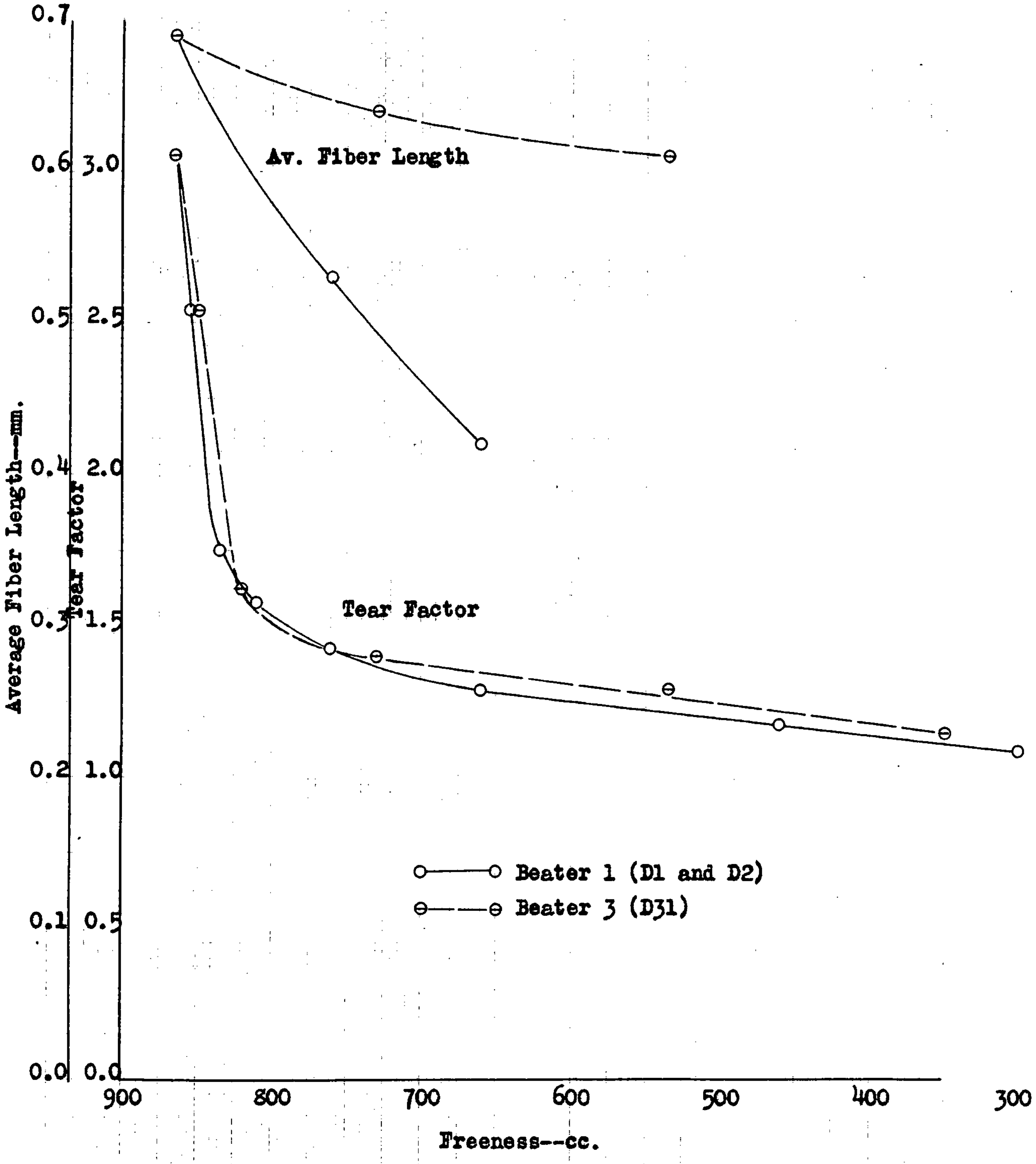
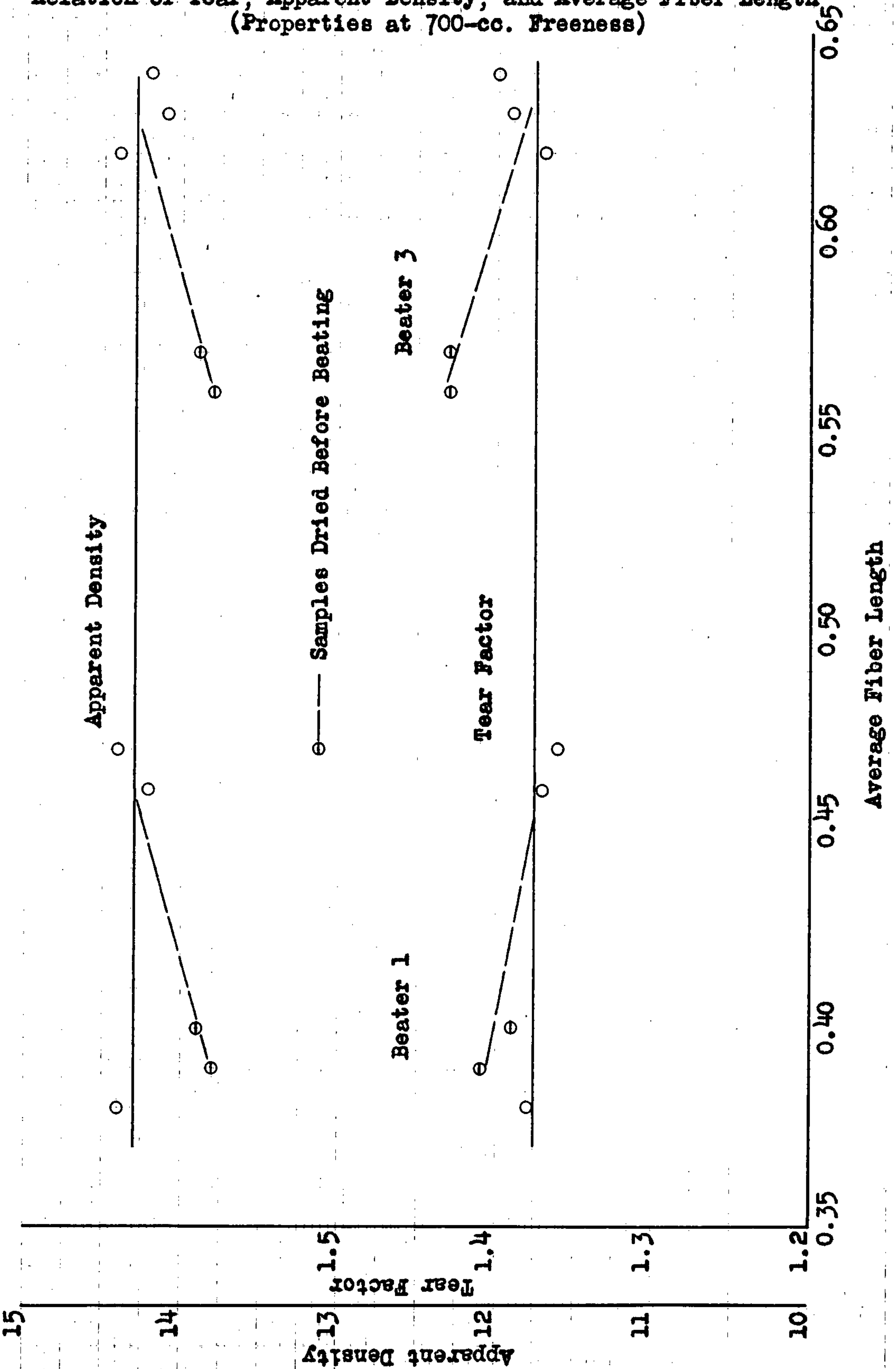


Figure 17
Relation of Tear, Apparent Density, and Average Fiber Length
(Properties at 700-cc. Freeness)



From these results it can be seen that the differences in bursting strength of wet and dry pulps was due to a greater cutting or shortening of the fiber on beating when the pulp had been dried, and that the bursting strength obtained at any given freeness was dependent on the average fiber length. A dull beater, as exemplified by Beater 3, did not give any difference in bursting strength of slush and wet-lap pulp, while a sharp beater did, owing to the fact that it cut the fibers in the slumps rather than disintegrating them. The advantage of pretreating wet laps was to disintegrate the laps completely, so that the rate of fiber cutting in a sharp beater would be about the same as for the slush pulp.

THE ACTION OF A VERY SHARP BEATER

Since pretreatment was advantageous only for wet laps, and that only before beating in a sharp beater, a very sharp beater (Beater 2) was used to determine whether these advantages would not be exaggerated. The pulp selected (Pulp C) was a very raw southern pine kraft in wet-lap form. The laps had been made on a Kamyr wet machine and were very difficult to disintegrate; further, they had air-dried to some extent. Runs were made before and after pretreating in the rod mill and also after slushing in the screen. The same pulps were run in Beater 1, the sharpest of the two beaters used in the work thus far, to obtain an idea of the comparative cutting action of this beater. The complete results of these runs are given in Table XIII; the values at 700-cc. freeness are given in Table XIV.

TABLE

EVALUATION OF COMMERCIAL

Basis Weight—lb. (25x40—500) 0'	5'	15'	25'	35'	45'	60'	75'	Bursting St lb./in.² per 0'	5'	15'	25'	35'
	48.2	46.6	46.8	47.3	47.5	47.0			39	58	68	73
49.4	47.3	47.3	47.9	47.3	48.0	47.0		42	57	75	84	93
49.2	47.6	47.7	47.9	48.3	47.8	47.8		17	37	64	78	[illegible]
	47.1	46.3	46.0	46.9	47.9	46.5			35	58	66	73
48.6	48.3	47.4	47.2	47.4	48.0	47.4		43	57	76	90	96
50.5	48.7	49.3	48.0	48.3	46.6	47.7		16	37	65	83	93
	48.5	47.1	46.7	48.6	46.6	45.0	47.6		35	65	83	92
48.8	46.2	47.4	46.4	47.6	48.6	48.7		44	64	82	90	100
45.2	47.7	49.1	47.9	48.2	47.4	46.8	47.9	14	36	66	80	92

[illegible]

[illegible]APS BY A VERY SHARP BEATER

Strength [illegible] lb.			Tear Factor								
[illegible]	60'	75'	0'	5'	15'	25'	35'	45'	60'	75'	[illegible]
[illegible]	82			3.04	2.41	1.75	1.45	1.21	0.91		
[illegible]	102		3.18	2.85	2.22	1.91	1.76	1.50	1.31		[illegible]
[illegible]	101		1.82	2.92	2.53	2.20	1.80	1.49	1.27		[illegible]
[illegible]	77			2.99	2.61	1.87	1.47	1.30	0.89		
[illegible]	105		3.19	2.69	2.26	1.87	1.69	1.46	1.20		[illegible]
[illegible]	106		1.76	2.90	2.86	2.22	1.88	1.66	1.41		[illegible]
[illegible]	105	118		2.94	3.01	2.49	2.33	2.13	1.86	1.63	
[illegible]	111		3.02	2.96	2.53	2.15	1.94	1.92	1.71		9.4
[illegible]	107	117	1.95	3.04	3.26	2.63	2.32	2.18	1.87	1.70	[illegible]

Apparent Density							Average Fiber Length--mm.					
5'	15'	25'	35'	45'	60'	75'	0'	5'	15'	25'	35'	45'
9.2	10.0	11.3	12.1	13.0	14.6			0.78		0.51	0.38	0.34
10.1	10.9	11.3	12.1	12.9	14.0		1.02	0.83		0.66	0.45	0.41
8.6	10.0	10.9	11.7	12.3	13.1		0.98	0.82		0.68	0.50	0.40
9.3	10.1	11.0	11.7	12.7	14.0			0.80		0.54	0.43	0.34
10.0	10.7	11.3	11.9	12.6	13.4			0.80	0.58	0.45	0.45	
9.1	9.9	10.7	11.7	12.0	13.0			0.84		0.65	0.57	0.44
8.9	9.6	10.6	11.2	11.5	12.0	12.5						
9.9	10.7	11.3	11.6	11.9	12.4							
8.8	9.7	10.2	10.8	11.2	11.8	12.2						

Beater Run	Percentage Ovendry	Pretreat-ment	Freeness—cc. 0'	5'	15'	25'	35'	45'	60'	75'
Beater 2										
07	56.0	None		880	860	810	635	445	220	
05	56.0	Rod Mill	880	875	855	785	630	435	245	
09	56.0	Screen	890	880	860	820	675	440	230	
06	87.0	None		890	875	835	675	450	290	
04	87.0	Rod Mill	885	875	850	780	610	405	220	
08	87.0	Screen	890	880	860	830	740	525	265	
Beater 1										
01	64.5	None		880	870	840	800	720	515	[illegible]
02	64.5	Rod Mill	875	865	845	815	745	630	415	
03	64.5	Screen	890	880	865	845	815	755	575	370

TABLE XIV

ACTION OF A VERY SHARP BEATER ON COMMERCIAL LAPS
(Properties at 750-cc. Freeness)

Beater Run	Percentage Ovendry	Pretreatment	Time to Develop min.	Bursting Strength lb./in.² per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
			Beater 2				
C7	56.0	None	32	74	1.54	11.7	0.41
C5	56.0	Rod Mill	31	89	1.80	11.7	0.50
C9	56.0	Screen	34	88	1.82	11.6	0.52
C6	87.0	None	33	73	1.50	11.5	0.44
C4	87.0	Rod Mill	30	94	1.74	11.6	0.50
C8	87.0	Screen	37	94	1.80	11.7	0.52
			Beater 1				
C1	64.5	None	46	97	2.10	11.5	
C2	64.5	Rod Mill	39	103	1.98	11.7	
C3	64.5	Screen	49	101	2.04	11.4	

That Beater 2 was sharper than Beater 1 was shown by the fact that it gave a much lower bursting strength; also, the time required to reach a given freeness drop was much less. Whereas Beater 1 gave about a 6 per cent increase in bursting strength when the laps were pretreated in the rod mill or slushed by the screen, Beater 2 gave about a 20 to 25 per cent increase. Although this pulp was not available in the original slush form, the slush would probably have given about the same bursting strength as the rod-milled or screened laps.

This demonstrated the fact that a beater which cut the fiber to a very great extent gave a difference in bursting strength between slush pulp and wet-lap pulp, and that the sharper the beater used for refining, the greater the difference.

Unlike the results obtained with either of the other two beaters, this very sharp beater gave a higher tearing strength for the rod-milled or screened laps as compared with the untreated laps. There was no difference in the apparent density of the sheets from the different runs; in this case (where the very sharp beater was used) the increased amount of cutting obtained when untreated laps were used caused a decrease in the tearing strength of the sheets.

THE ROD MILL AS A BEATER

The disintegrating action of the rod mill on lap pulp was very well demonstrated by the fact that its effect was the same as that of a screen, whose only action would be one of completely separating the lap pulp. In all cases where the rod mill had been used to pretreat the stock, a certain amount of bursting strength was developed and the tear and freeness had dropped; seemingly this action was very similar to the first few minutes in the laboratory beater. In order to secure a better comparison of the beating action of the rod mill and beater, some of the wet-lap Pulp D (46 per cent o.d.) was beaten in the rod mill at 7 per cent consistency. At the end of each milling interval the complete charge of pulp was removed for sheet-making; thus, each interval represented a separate 500-gram batch of pulp. The results are given in Table XV.

TABLE XV

BEATING ACTION OF THE ROD MILL ON PULP D

Time in Rod Mill min.	Freeness cc.	Basis Weight lb. 25x40-500	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
0	865	45.6	49	3.07	10.9	0.69
10	855	48.5	83	2.60	12.4	0.67
60	815	48.2	118	1.64	13.8	0.51
120	650	47.7	132	1.26	14.6	0.37

For the purpose of comparing these results with those obtained with the two beaters on this pulp, the properties at 700-cc. freeness are given in Table XVI.

TABLE XVI

COMPARATIVE ACTION OF THE ROD MILL AND BEATERS ON PULP D
(Properties at 700-cc. Freeness)

Beater Used	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density	Fiber Length mm.
Rod Mill	105	130	1.33	14.4	0.41
1 (D5)	44	126	1.38	14.4	0.38
3 (D25)	43	153	1.39	14.1	0.63

As far as the resulting strength was concerned, the beating action of the rod mill was exactly the same as that of a beater giving the same amount of cutting. From Figure 15 it is seen that a beater which would cut this pulp to such an extent that the average fiber length at 700-cc. freeness would be 0.41 mm. would give a bursting strength of 128 lb./in.^{2} per 100 pounds ream weight, which checks very well with the value of 130 obtained in this mill. The time requirement of the rod mill is too great to make it practical for its beating action alone; using the factor of 3.64-h.p. days per ton for each ten minutes in the laboratory mill, 38.2-h.p. days per ton would be required to beat this stock to a freeness of 700 cc. in a 7 by 16 foot commercial rod mill.

There was little difference in the tearing strength and apparent density of the sheets between either of these two beaters and the rod mill. In Figure 18 the bursting strength, fiber length,

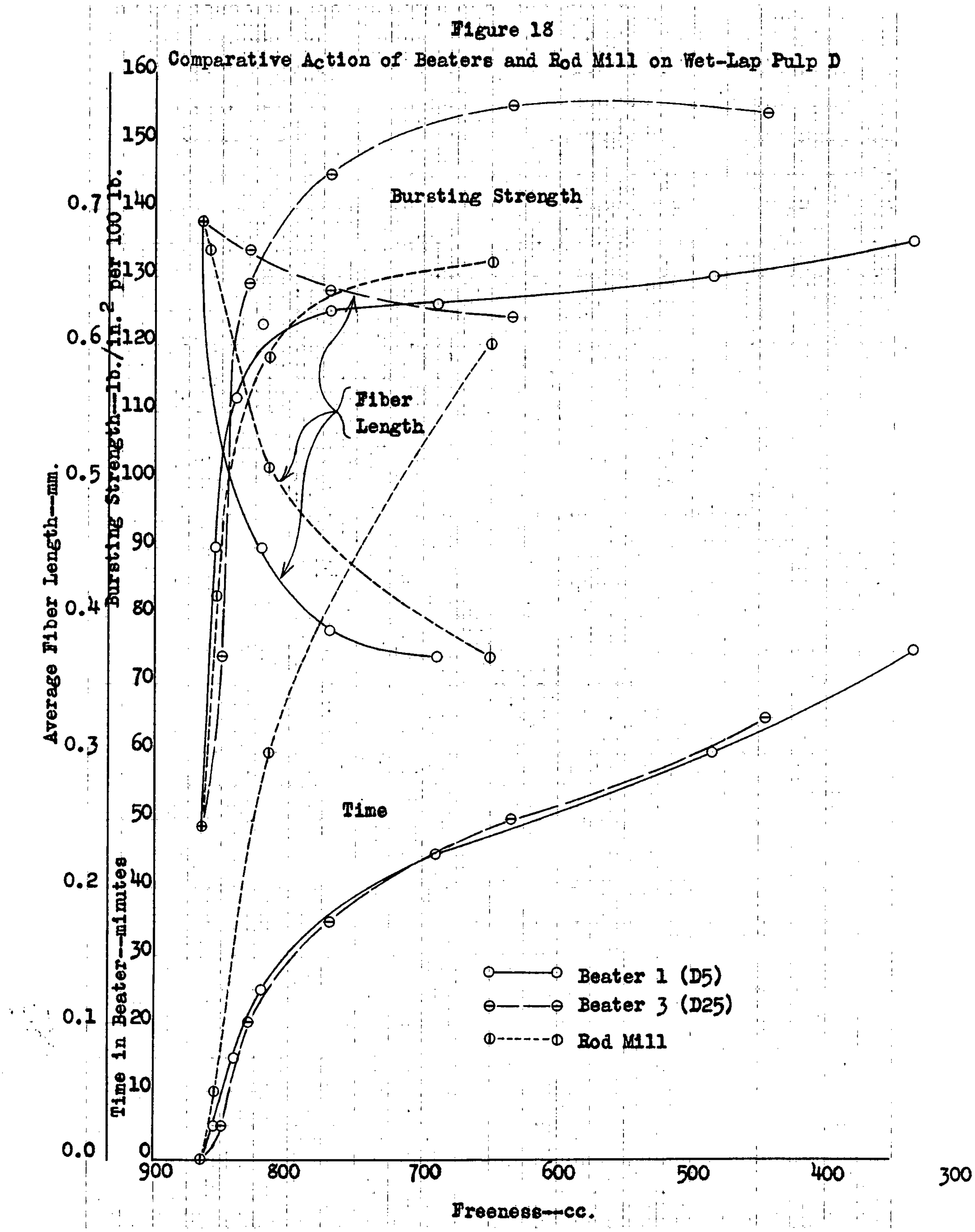


Figure 18
Comparative Action of Beaters and Rod Mill on Wet-Lap Pulp D
Bursting Strength
Fiber Length
Time
Beater 1 (D5)
Beater 3 (D25)
Rod Mill
Average Fiber Length--mm.
Bursting Strength--lb./in.² per 100 lb.
Time in Beater--minutes
Freeness--cc.
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
900
800
700
600
500
400
300

and time required are shown graphically. The similarity of the action of the rod mill to a beater can be seen from a consideration of the bursting strength and fiber length curves.

When considering the data given in Figure 18, it is very interesting to compare the action of these two beaters on the same pulp. This figure shows that exactly the same time was required in each beater to reduce this wet-lap pulp to any given freeness; yet the beaters are totally different in their cutting action and also very different in the development of bursting strength. In the case of Beater 3, forty-four minutes were required to reach 700-cc. freeness, 1.39 tear factor, and 153 points per hundred pounds bursting strength. In the case of Beater 1, the same time (forty-four minutes) was required to reach 700-cc. freeness, the tear factor was the same (1.38), but the bursting strength was about 16 per cent lower (126 as compared to 153). Also, the average fiber length was much less at this freeness, being 0.38 mm. as compared to 0.63 mm. for Beater 3. Whereas the rate of beating as measured by freeness reduction was the same, the rate of strength development was materially greater in the case of Beater 3 and the rate of fiber cutting was much smaller.

Beater 3 is referred to as a dull beater, but the term is used in reference to the rate of fiber cutting and development of bursting strength and not in reference to the freeness drop or any opinion which would be derived from a visual inspection or "feel" of the beater tackle. The beater roll knives in Beater 3 felt equally as sharp or sharper than those in Beater 1, yet in its cutting action on the fibers it was very much duller than Beater 1. Aside from actual fiber measurements, a comparison of the bursting strength development, and not the freeness or tearing strength drop, is more nearly indicative of the comparative cutting action of any two beaters.

ATTEMPTS TO PREVENT THE LOSS IN STRENGTH ON DRYING

It has been shown definitely that the lower bursting strength obtained at any freeness from dry pulps as compared with wet pulps was due to a greater cutting of the fiber after the pulp had been dried beyond the fiber saturation point. There also appeared to be a slight increase in tear after drying, owing to a decrease in the apparent density of the sheets. It seemed that it might be possible, if the pulps were first impregnated with some fairly hygroscopic material, that, on subsequent addition of water, the water would be absorbed in the fiber somewhat in the original manner, so that the fiber would be as pliable and easily beaten as in the original wet state. If this could be accomplished, then the dried fibers should not be cut more than the wet fibers when beaten and should give the same bursting strength.

The materials selected were kneaded into the slush pulp at 10 per cent consistency, the pulp was allowed to stand in the wet condition for several hours, and dried on a radiator for about twenty-four to thirty hours.

The beater runs were made in Beater 3, which gave the least cutting of the fiber of any of the beaters available. The complete results of these attempts are given in Table XVIII, and the properties at 700-cc. freeness are given in Table XVII. The results for the untreated wet and dry lap given in Table IX are included for comparison.

None of these materials helped to prevent even a part of the loss in strength on drying as the bursting strength of the pulp dried in the presence of these was no better than the pulp dried alone to 100 per cent o.d. in the oven at 105° C. Since there were no indications that this was in any way beneficial, no further work was done along this line.

TABLE XVII

EFFECT OF HYGROSCOPIC MATERIALS ON LOSS IN STRENGTH BY DRYING
(Properties at 700-cc. Freeness)

Beater Run	Material Added	Percentage Ovendry	Time to Develop min.	Bursting Strength lb./in.^{2} per 100 lb.	Tear Factor	Apparent Density
D20, 25, 32, and 36	None	46.0	46	151	1.39	14.4
D42	2% Saccharinic acid*	98.0	52	138	1.50	14.2
D43	2% Saccharinic acid* and 1/2% Triethanolamine	93.0	50	142	1.49	14.0
D44	2% Triethanolamine	93.0	52	140	1.51	14.1
D45	2% Malemeline	94.0	52	143	1.46	14.2
D29	None. Soaked 3 days	100	50	144	1.47	13.6
D21 and 27	None	100	58	142	1.43	13.8

* About 50 per cent as the sodium salt.

TABLE XVIII

BEATER EVALUATION OF PULP DRIED IN THE PRESENCE OF HYGROSCOPIC MATERIALS

Basis Weight--lb. (25x40--500)						Bursting Strength lb./in.^{2} per 100 lb.					
5'	20'	35'	50'	65'	80'	5'	20'	35'	50'	65'	80'
47.6	47.4	47.1	47.8	47.3	47.8	77	125	143	152	155	152
47.6	48.0	48.5	48.2	47.9	48.6	54	99	126	136	141	144
48.8	47.5	48.0	48.1	48.1	48.3	66	111	131	142	146	152
48.4	48.1	49.5	48.7	48.8	48.4	64	108	130	140	141	151
49.0	48.1	48.8	48.8	47.3	47.9	59	106	129	142	146	151
48.0	46.5	48.1	47.4	47.1	46.4	51	104	128	144	149	152
45.6	46.3	48.0	47.0	47.2	47.2	50	108	130	143	149	151

Tear Factor						Apparent Density					
5'	20'	35'	50'	65'	80'	5'	20'	35'	50'	65'	80'
2.56	1.75	1.49	1.37	1.28	1.22	11.5	13.0	13.9	14.6	15.0	15.6
2.94	2.18	1.82	1.51	1.45	1.34	10.9	12.5	13.5	13.8	14.3	15.5
3.14	2.08	1.65	1.49	1.38	1.30	11.3	12.5	13.2	14.1	14.8	15.3
3.10	1.94	1.62	1.53	1.35	1.30	11.3	12.5	13.6	14.1	14.8	15.3
3.12	2.02	1.67	1.47	1.40	1.28	11.3	12.7	13.4	14.2	14.6	15.2
2.92	1.94	1.66	1.47	1.31	1.26	10.3	11.9	13.0	13.6	14.3	14.7
2.88	1.98	1.60	1.42	1.32	1.19	10.4	12.2	13.2	13.9	14.6	15.0

Beater Run	Material Added	Percentage Ovendry	Freeness--cc. 5'	20'	35'	50'	65'	[illegible]
D20, 25, 32, and 36*	None	46.0	850	825	775	655	485	[illegible]
D42	2% Saccharinic Acid**	98.0	860	835	785	715	595	[illegible]
D43	2% Saccharinic Acid** + 1/2% Triethanolamine	93.0	855	830	785	700	560	[illegible]
D44	2% Triethanolamine	93.0	855	835	765	715	585	[illegible]
D45	2% Nulomoline	94.0	855	835	795	720	590	[illegible]
D29	None. Soaked 3 days	100.0	860	835	785	700	560	[illegible]
D21 and 27*	None	100.0	860	835	790	700	540	[illegible]

* From Table X.
** About 50 per cent as the sodium salt.

SUMMARY AND CONCLUSIONS

When considering the results obtained in this investigation it must be emphasized that they were obtained with laboratory beaters and that the strength tests were made on handsheets which had been air-dried rather than machine-dried. With this thought in mind the following conclusions may be drawn.

Pretreatment of slush pulp in the rod mill before refining in the laboratory beater had no advantage as far as the resulting strength obtainable by beating was concerned. The time and, consequently, power required for subsequent beating were reduced, however, owing to the beating action of the rod mill.

When refining in a beater that cut the fiber to an appreciable extent, the bursting strength of wet-lap pulp was lower than that of slush pulp unless the laps were first thoroughly disintegrated in a rod mill or with a screen. This loss was due to clumps of fibers remaining in the beater charge when the roll was lowered; some of the fibers in the clumps were cut instead of beaten. The magnitude of this difference depended on the sharpness of the beater tackle and the dryness of the pulp; the dull beater gave no difference except on dry pulps. Even the sharp beaters may not have given a difference for wet-lap pulps if the roll had been lowered slowly enough to disintegrate the clumps before they were cut; but under these conditions the time and, consequently, power necessary for beating would have been increased.

Ten minutes at 7 per cent consistency in the laboratory rod mill, which corresponded to one pass through a commercial 7 by 16 foot rod mill fed continuously at the rate of fifty tons of pulp per day, disintegrated lap pulp as completely as though it were screened; after this disintegration there was no appreciable difference in strength obtainable even in a sharp beater between slush pulp and laps up to about 75 per cent o.d. This rod-mill treatment, which required about 3.64-h.p. days per ton, showed these advantages only for lap pulp and only when the subsequent beating was carried out in a beater that cut instead of disintegrated the clumps remaining from the laps.

When beaten to a given freeness in the laboratory beater, the bursting strength obtained depended on the average fiber length of the beaten pulp; the tear was less affected by the fiber length than by the bulk of the sheet.

When pulps were dried beyond the fiber saturation point, whether air-dried or machine-dried, they developed less bursting strength, slightly higher tear, and gave a bulkier sheet on subsequent beating. Very little of the loss in bursting strength could be accounted for by the fact that, when beaten to a certain freeness, the dried pulp gave a bulkier sheet, but the loss could be accounted for by the fact that the fiber had been cut more than when the same pulp in the slush or wet-lap form was beaten to this freeness. The slightly higher tear was due to an increase in the bulk of the sheet and not to any differences in the fiber length.

Although not investigated very extensively, the hygroscopic materials which were added to the pulps before drying did not in any way prevent the changes which ordinarily take place when pulps are dried.

When used as a beater, the rod mill developed the same sheet properties at a given freeness as a laboratory beater giving the same amount of fiber cutting at that freeness. From the standpoint of power consumption, however, it was entirely too inefficient to be practical for its beating action alone. As stated above, its advantage consisted in the disintegration of lap pulp before refining in equipment that tended to cut rather than to defiber the laps.

LITERATURE CITED

1. Rue, John D., and Wells, Sidney D., Paper Trade J. 83, no. 12: 53-54(Sept. 16, 1926).

2. Wells, Sidney D., Paper Mill 62, no. 7:16-18, 24(Feb. 18, 1939).

3. Cross, C. F., and Bevan, E. J. "A text-book of paper-making." 5th edition, especially p. 206-208. New York, Spon and Chamberlain, 1920. 527 p.

4. Schwalbe, C. G., and Becker, E., Z. angew. Chem. 33:58-59(1920).

5. Strachan, James, Proc. Tech. Sect. Paper Makers' Assoc. Gt. Brit. & Ireland 6:139-167(1925-26).

6. Mark, H., and Meyer, K. H., Cellulosechem. 11:91-100(1930).

7. Lüdtke, M., Cellulosechem. 13:169-175, 191-195(1932); 14:1-9 (1933).

8. Strachan, James, World's Paper Trade Rev. 97:576-582(even pages), 667-668, 671-672, 675, 755-756, 759, 760, 762, 764, 800, 802, 805 (1932).

9. Kress, O., and Bialkowsky, H., Paper Trade J. 93, no. 20:35-44 (Nov. 12, 1931).

10. Campbell, W. Boyd, "The cellulose-water relationship in paper-making." Canada, Dept. of the Interior, Forest Service, Bulletin 84. Ottawa, F. A. Acland, 1933. 52 p.

11. Smith, Sigurd, "The action of the beater." London, Tech. Sect. Paper Makers' Assoc. Gt. Brit. & Ireland, 1923. 212 p.

12. Grund, E., Papier-Fabr. 36:141-148(1938).

13. Steinschneider, M., and Grund, E., Papier-Fabr. 36:1-21(1938).

14. Shlick, Leo, Paper-Maker 97:TS1-13(1939).

15. Simmonds, F. A., Paper Trade J. 96, no. 20:31-35(May 18, 1933).

16. Swartz, J. N., Pulp Paper Mag. Can. 40:582-586(1939).

17. Babbitt, J. S., Pulp Paper Mag. Can. 31:813-816, 830-831, 842, 844(1931).

18. Müller, F., and Trenschel, R., Wochbl. Papierfabr. 62, no. 23A (Sondernummer):25-35(June 6, 1931).

19. Kehoe, R. D., Paper Trade J. 104, no. 24:32, 34, 36, 39(June 17, 1937).

20. Alsted, Lewis L., U. S. patent 1,847,326(March 1, 1932).

21. Wells, Sidney D., U. S. patent 1,962,164(June 12, 1934).

22. Wells, Sidney D., U. S. patent 1,654,624(Jan. 3, 1928).

23. Schmid, W., Zellstoff u. Papier 9:756-757(1929).

24. Rue, John D., Paper Trade J. 83, no. 24:43-44(Dec. 9, 1926).

25. Chidester, G. H., Paper Trade J. 86, no. 25:51-64(June 21, 1928).

26. Wells, Sidney D., Paper Trade J. 85, no. 17:115-116(Oct. 27, 1927).

27. Wells, Sidney D., Pulp Paper Mag. Can. 26:301-303(1928).

28. Wells, Sidney D. "The use of the rod mill in the beating of kraft pulp." In Baird, P. K., "The use of the rod mill for fiber processing." p. 76-80. Madison, Wisconsin, U. S. Forest Products Laboratory, 1931. 80 p.

29. Graff, John H. "Pulp and paper microscopy." p. 3-10. Appleton, Wisconsin, The Institute of Paper Chemistry, 1936. 132 p.

30. Dixson, H. P., Doctor's Thesis, especially p. 76, The Institute of Paper Chemistry, 1939.