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The Effects of Variable Double Disk Refining Action on Sheet and Fiber Properties

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THE EFFECTS OF VARIABLE DOUBLE DISK REFINING ACTION ON SHEET AND FIBER PROPERTIES

by

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ABSTRACT

The purpose of this project was to evaluate several operating variables of the newly installed Western Michigan University Jones DD 3000 refiner. The operating variables were refiner load in amperes, throughput rate in gallons per minute, and disk speed in revolutions per minute.

On the fiber level, Canadian Standard Freeness was most dependent upon the load and somewhat less dependent upon the tonnage rate and speed. The tonnages used were 4.8, 9.6 and 14.4 T/D. At 9.6 T/D, the refiner used the least HPD/T per 100 ml C.S.F. drop throughout the 300-500 ml C.S.F. range. At 4.8 and 9.6 T/D, the HPD/T increased per 100 ml C.S.F. drop over the same freeness range.

Lower refiner speeds produced similar C.S.F. results at higher tonnage rates at the same intensity, where less disk speed required a substantial increase in the power used over the higher tonnage rate.

Maximum sheet quality was developed in the mullen, tensile, and fold tests at high loads and low C.S.F. The tear test remained almost constant under varied loads. Sheet strength was highest at low and medium throughput rates, where the medium throughput developed nearly the same strength as the low throughput with a large savings in HPD/T.

In the optical tests, brightness dropped while opacity increased at greater values of HPD/T. The opacity results were opposite to the normally expected drop at higher HPD/T.

Further evaluation of the Western Michigan University DD 3000 was suggested with respect to Mono-Flo and Duo-Flo, consistency changes, pulp mixtures, disk configurations, and speed changes.

TABLE OF CONTENTS

INTRODUCTION

Refining is the treatment given to cellulose fibers by mechanical and hydraulic pressure for the purpose of altering fiber characteristics to develop certain sheet properties while maintaining control over the degradation of others. Stock refining in paper mills occurs between the hydrapulper and headbox, and is one of the more important parts of the papermaking process.

Unfortunately, with the complexity of the process and its many variations, stock refining finds itself in a state of flux and controversy, and appears to be one of the least understood. This controversy extends itself to the evaluation of recent progress because there is little common agreement on the basic effects of refiner operating variables.

As a example, we see that Canadian Standard Freeness has been and still is the credited way of determining the degree of beating or refining a stock. In contrast, more direct methods such as sheet characteristics are used including tear, tensile, burst, fiber length, bulk and optical properties. Other methods used in conjunction with continuous refiner control are the Delta-T method, wet end drainage, paper formation, porosity, and specific energy consumption.

The capability of these control parameters and sheets characteristics to adequately obtain refining at different levels using variable pulp types is often restricted to a given unit and to those applications and conditions which have been declared successful. The purpose of this study, therefore, is to analyze Double Disk Refining where the most important operating and

refiner variables are described in relation to sheet and fiber characteristics. These variables will be better understood when the refiner's operating parameters have been compared to the response obtained with different control mediums.

HISTORICAL BACKGROUND

Presently three basic types of refining equipment are being used for the preparation of fibrous plant materials. These are the beater, the conical plug-type refiner, and the disk refiner.

The beater, because of its multipass nature, is still the most flexible type of refining device and is best suited to perform extreme hydration and fibrillation with minimum cutting. However, beaters are rarely found in modern stock preparation systems except where bast fibers are used, as in high quality condensor papers.

The conical plug-type refiner is known for its cutting characteristic and is used in the control or tickler position. Its main disadvantage is uneven wear of the filling along the longitudinal edge. Also, reduced throughput results in a build up of a pressure head, thrusting the plug against the shell. This thrusting action decreases the draft thereby increasing the load and readjustment is essential to prevent overworking the stock at the lower throughput rate.

The conical and disk were developed for use in continuous operations. The disk became more popular where precise action on the stock flow was desired. Technical advances in materials, tooling, and assembly made this possible through more accurate parallel disk positioning and extended plate life.

The disk refiner is either single or double disk. Early single disk gravity discharge units developed into pressurized single and double disk types. Double disk design allows two methods of piping and operation.

In Mono-Flo, the total flow of a stock is passed through each set of disks, simulating two units in series. Mono-Flo with recirculation may be installed to compensate for normal variations in throughput with balanced refining. The advantages of Mono-Flo are shive removal, fiber length retention, and strength below 250 ml C.S.F. (1).

In 1960 Sprout Waldon introduced a new deisgn utilizing the floating disk principal where stock enters under pump pressure on both sides of the rotating disk. The floating principal is accomplished by connecting the rotating shaft to the drive motor with a coupling that permits lateral movement of the rotating disk. This design is referred to as three-pipe Duo-Flo where a header splits the pulp flow to the stationary inlet and sliding outlet of the refiner. The discharge line is connected to the top center opening in the refiner cavity. This method of operation is also used where the stock will support the horsepower, but the hydraulic capacity of the machine is not great enough to allow passing all of the tonnage through both sets of disks and still obtain the refining desired (2).

Two-pipe Duo-Flo is similar except the inlet through the sliding head is sealed off and pulp input is piped to the stationary inlet. The solid driven rotor is now exchanged with a ported rotor. Here the pulp flow is split internally, where half passes through the ports and exits at the common outlet. With this pipe and spoked rotor arrangement, there is less chance of plugging one inlet at low throughput rates. In Duo-Flo operation, the unit will act as an inefficient pump and also simulate two disk refiners in parallel. Apart from these comparisons of refiner effects, the disk type has several operating

advantages over the conical.

1. Ease of maintenance and accessability of disks.
2. Greater capacity permits greater range of flow and refining levels.
3. Addition of hydraulic control for either operator or computer.

One advantage of two pipe Duo-Flo over three pipe Duo-Flo is no piping to disconnect at the sliding head when changing disks and the flexible connector is omitted, therefore making maintenance simple and straightforward.

The big advantage of the Sprout floating disk principal is that of uniform stock treatment with flow changes. Mono-Flo operation requires a pressure drop of 5-15 psi from inlet to outlet (3). This pressure drop is essential because the stock is centrifugally thrown or pumped towards the periphery on the inlet side and must be pumped against the centrifugal force on the output side. Therefore, the pressure drop is used to maintain a uniform stock film on both sides of the rotor. In Mono-Flo, recirculation is used to adjust for small flow rate changes, where the stock can recirculate when less demand is initiated. In Duo-Flo operation the pressure drop is not critical. This arises because stock travel is from the eye of the disk towards the periphery throughout the refining chamber. The rotor pumps the stock in a spiral flow, eliminating the possibility of cavitation and recirculation. Therefore, Duo-Flo operation greatly facilitates the disk refiners increased capacity and wide range of flow rates.

In automatic control, valving back on the discharge, thereby reducing throughput, results in a build up of a pressure head, which is directly transmitted to the hydraulic cylinders releasing refining pressure on the disks, and resulting in virtually the same stock quality at the lower throughput rate. In manual control, throughput fluctuations are balanced by adjusting the hand wheel to obtain the desired power level.

Refiner Operation Parameters

One of the most common means to describe refiner operation is specific energy consumption, normally expressed as the number of horsepower days per ton of moisture free pulp. In any continuous unit, it has been defined as the gross horsepower divided by the stock flow in tons per day.

Refining power is defined as net horsepower per ton per day, where net horsepower is the gross applied horsepower less the backed-off or no-load horsepower (4).

The intensity of refining as defined by the Jones Division of Beloit Corporation is the net refining power divided by the inch contacts per minute (IC/M).

$$ICM = TLR \times TLS \times RPM$$

The inch contacts per minute equals the total length of Rotor bars times total length of Stator bars times refiner speed in RPM.

The intensity can be increased by using a greater number of bars in the filling or a greater RPM. It was found that at any level of C.S.F., higher physical properties (bulk, burst, tear, breaking length) resulted

as the applied load was lowered (5). This follows the idea that if a refiner is designed with a high number of IC/M, then the net hp per inch contact becomes low resulting in less cutting and more brushing.

The number of inch contacts per minute is a function of RPM, where more bar edge contacts received by the pulp results in less intense treatment to each fiber. Lester E. Reid (6) showed that less length reduction occurred at higher speeds. Physical tests have also shown that higher speed produces higher burst and breaking length with lower bulk at any level of C.S.F. (7). In other words, at higher refiner speeds, a given level of burst and breaking length is obtained at a higher freeness than at low speeds. The big advantage is that strength can be developed with a saving of certain amounts of freeness drop.

According to Danforth and Mladota most of the variables in the basic formulas become constants and only two variables are involved (8). They are:

1. The severity of impacts (S) varies directly as the net Hp; i.e., total hp applied minus no load Hp ("O" freeness drop Hp). $S = Hp_t - Hp_o$
2. Where the number of impacts per fiber (N) varies inversely as the throughput rate. $N = 1/T/D^{k1*}$

Results show that samples subjected to greater IC/M or impacts per fiber per unit time as a result of lowering the applied Hp from twenty to nine and the throughput rate in T/D from 2.3 to 0.5 developed a stronger

*k1 is a refiner constant used to associate any tonnage rate with a particular refiner.

pulp at a given level of C.S.F., but used twice the HPD/TON (9).

Sample 1	Sample 2
20 HP/2.3 T/D = 8.7 HPD/TON	9 HP/0.ST/D = 18 HPD/TON

In Figure 1 the dotted lines are calculated by using the grid values of Hp applied/throughput rate in T/D. The darkened lines indicate the values of C.S.F. attained at relatively low severity (just above the no load Hp line) and those at higher Hp and T/D values. In Table II of Figure 1 the relative severity of impacts was figured from the ratio of applied Hp - no load Hp, for the lower load (sample 2) to the net horsepower of the higher load (sample 6).

$$\frac{9\ \text{Hp} - 7.5\ \text{Hp}}{20\ \text{Hp} - 7.5\ \text{Hp}} \quad 12 \text{ to } 100 = 12\%$$

And the relative number of impacts was figured from the throughput rate, where

$$\frac{2.3\ \text{T/D}}{.5\ \text{T/D}} = 4.6 \text{ to } 1.00$$

Sample 2 was subjected to a greater number (4.6 to 1.00) of gentler impacts (12 to 100). The test results at 400 C.S.F. indicate higher mullen, fold and tensile with less bulk, porosity and tear. The tear of sample 2 was predictably lower, showing that severe treatment reduced weighted average fiber length about twice as much as compared to the gentle treatment (9). Sample 2 was refined with emphasis on brushing while sample 6 produced the same level of C.S.F. with cutting. Both samples exhibit different test

Figure 1

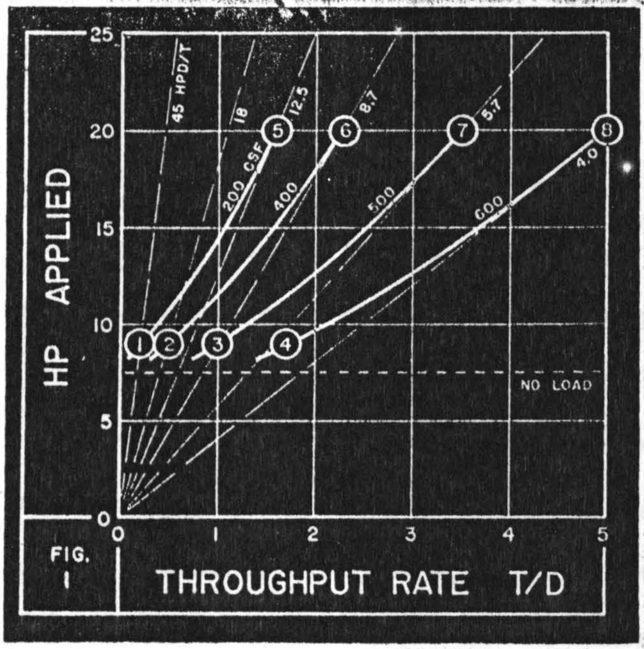


TABLE I—Fiber length classification

Screen mesh	Unrefined	Per cent retained Sample No. 2	Sample No. 6
14	39.6%	35.5%	32.0%
30	41.0	38.5	35.6
50	11.6	12.5	13.9
100	4.3	6.8	9.2
Fines	3.5	6.7	9.3

TABLE II—Operating conditions and test results

	Unrefined	Sample 2	Sample 6
HP applied	—	9.0	20.0
T/D rate	—	0.5	2.3
HPD/T	—	18.0	8.7
Consistency	3.0	3.0	3.0
Freeness (CSF)	690	400	400
Bulk	1.86	1.51	1.57
Mullen	22.9	70.0	57.3
Tear	219	154	178
Fold	25	1705	1075
Tensile	3360	9040	7880
Shrinkage	3.3	6.6	5.4
Air resistance	3	109	84
Stiffness	95	106	106
Severity of impacts (Relative)		12	100
Number of impacts (Relative)		460	100

All tests conducted in accordance with TAPPI Standard Procedures.

Source: Danforth, D.W., and Mladota, J., Pulp and Paper International, 9 (7): 50-52, (1967).

characteristics, with the freeness virtually equal, therefore, making many combinations of refiner variables suitable to develop different actions on each fiber with equal freeness.

Mead Corporation (10) obtained similar strength relationship in a detailed study of the Sprout disk refiner with regard to power consumption, throughput rate, freeness drop, and strength development. The results indicated that maximum mullen, fold, and tensile developed at high C.S.F. drops. Tear factor reached a peak and then decreased with high C.S.F. drops.

At any throughput rate, the Sprout required exactly twice the net HPD/T to double the freeness drop. Therefore, Canadian Standard Freeness is directly related to net refiner load, and is an accurate test of evaluating the severity of refining load. Other results indicate that greater throughputs cause a slight increase in net HPD/T, for a given freeness drop. This increase in load suggests that more severe impacts are necessary to produce the same level of refining. Although, generally speaking the strength properties were dependent upon the amount of C.S.F. drops, and independent of refiner throughput.

Refiner speed and throughput rate can be related by the number of IC/M. Greater throughput decreases the IC/M and lower RPM results in less IC/M. The number of IC/M is relative to a given speed and tonnage. If the tonnage is raised, the RPM must also be stepped up in the same proportion. This method of pre-determining the number of IC/M is only for calculation and reference purposes.

Disk refiners are currently monitored and controlled using HP or load in amperes. Results show that higher tonnage draws more net HPD/T for any freeness drop (11). Greater RPM results in more HPD/T at any freeness drop (12). Therefore, to produce the same freeness at a higher tonnage, we should increase the RPM. This increase in RPM should reproduce the same IC/M as imparted before the T/D increase. The increase in HPD/T from the RPM increase should also be equal to the added load from the higher throughput. Horsepower was shown to be directly proportional to C.S.F. drop. But in this case the Hp is used to either speed up the disk or to impart more severe action to the fibers because they receive less IC/M. This difference between refiner loads many constitute the relative effect produced when the IC/M is changed.

Few refiners have variable speed control and so little information has been gathered concerning the effects produced when RPM is varied along with throughput.

A summary will indicate that the major purpose of refiner control is to develop maximum sheet strength with the least drop in freeness. At higher levels of freeness, the drainage rate is greater providing increased speed on the machine. Generally, strength must be balanced with drainage for any given machine, because increased strength occurs at lower levels of freeness where the drainage rate is lower.

EXPERIMENTAL DESIGN

The design of this project was based on the following:

1. WMU Pilot Plant Jones DD 3000 refiner.
2. Important refiner variables.
3. Limitations cited in preliminary investigation.
4. Current usage of fiber types in pilot plant.

The WMU Jones DD 3000 refiner is a 12" double disk (DD) unit that is currently in the two pipe Duo-Flo arrangement. The DD 3000 employs a holding chest and stock pump with pressures gauges on inlet and outlet of refiner. A Fischer & Porter magnetic flowmeter and controller is used to activate a Saunders type valve on the output side of the refiner. Flows can be varied up to 120 gpm and can be recirculated or sent to the machine chest. Preliminary results indicate that the Saunders valve will plug at flows in the range of 0-40 gpm, especially if the consistency is high (4%). The refiner is coupled to a Westinghouse 200 Hp motor with a Fuller RT 910 - Exp. #1 transmission. The transmission is geared in high range and allows five forward speeds and one reverse.

Pilot plant layout allows beaters to be made and beaten to 675 ml C.S.F. The beater will then be pumped to the holding chest where consistency can be adjusted using dilution water from the beater. The chest has 86 useable inches of which 37 inches constitute a 220 lb. beater at 2% consistency. The chest will hold 2 X 220 lb beaters using only 74 inches.

Current operations in the pilot plant are strictly multipass conical refining from the beater. This method uses additional energy because the beater and conical both operate continuously to refine a batch of pulp. The conical refiner takes over an hour to drop to 300 ml C.S.F. for only one beater. Approximately 30 minutes are required to reach the Claflin standard of 500 ml C.S.F.This method is inefficient because when more stock is needed the beater is tied up with the conical refiner.

The disk refiner system allows two beaters to be refined at the same time. This system would also benefit the beater man because he need devote his attention to only the disk refiner and not both refiner and beater while refining. At 2% consistency 1 X 220 lb beater will give 1320 gallons of stock. The disk unit will refine the chest of stock faster than the conical with savings in beater wear and energy.

Disk Refiner

GPM	Refining Time for One Beater (one pass)
120	10.5 minutes
80	16.5 minutes
40	33 minutes

The 80 gpm flow is highly practical because it lessens the possibility of plugging the discharge line.

The Jones DD 3000 is designed for continous or one pass operation. Pretrial results show that multipass flow produces tremendous drops in CSF, using the time to empty the chest as the multipass limit, figuring that each fiber passes through the refiner once.

The pulp used was a 50/50 mixture of Port Hudson hardwood and Domtar Q-90 softwood. WMU uses this blend most often at refined freeness levels between 300 and 500 ml C.S.F.

The motor draws 58 amps at no load. Extreme refining action occurred at loads greater than 85 amps. From these data, a mid-operating point has been selected as 80 gpm flow, 70 amp load, and 5th gear speed.

The first trial compared various combinations of load and throughput in 5th gear speed. They were as follows:

5th Gear Speed	
40 gpm	60, 70, 80 amps
80 gpm	60, 70, 80 amps
120 gpm	60, 70, 80 amps

These combinations of load and throughput were selected to center the test data around the mid operating point. In the preliminary investigation, the 5th gear speed produced the most accurate loading at each flow rate.

Samples were taken in buckets at the machine chest. Freeness tests were run handsheets were made and tested for strength and optical development.

Freeness Tests	Strength Tests	Optical Tests
C.S.F.	Mullen	Brightness
	Tensile	Opacity
	Tear	
	Fold	

The second trial involved varying RPM and load at selected flow rates.

Gear	Gear Ratio	Disk Speed (RPM)	Flow Rate
5	1.00	885	60 gpm
3	1.56	567	60 gpm
1	2.51	353	40 gpm

The same testing procedure was used in Trial 2.

Once the data were gathered, the Canadian Standard Freeness, strength, and optical tests were compared in tables and graphs. Tables were constructed to display all of the data. Graphs were plotted showing the general trends, and to generate new data between existing conditions. Some of the following questions were answered:

1. Does the higher flow rate draw additional load?
2. Will higher disk speed draw more load?
3. What effects are produced at different flow rates with respect to the following:

   Canadian Standard Freeness

   Strength Tests

   Optical Tests

EXPERIMENTAL PROCEDURE

The experimental procedure involved making 220 pound beaters of 50 percent Port Hudson hardwood and 50 percent Domtar Q-90 softwood. The intitial moisture was 11% for both pulps. The beater was then charged with 247 pounds of moist baled pulp and beaten for one half hour to 675 ml Canadian Standard Freeness. The beater was then pumped to the storage chest using 700 gallons of hard water. The water softener system was out of order, therefore the experiments were all run with partially softened dilution water. The final consistency was 2%.

The agitator was started and flow valves were set to allow sampling the refined stock at the machine chest. A portable ampere meter was clamped around the center conductor wire inside the refiner power breaker box. The breaker switch was closed and the handwheel was backed out (clockwise) fully.

The Fischer & Porter flow controller scale reads one half of actual throughput. The initial flow was set at 20 to produce a 40 gpm flow. Initially the flow controller was set to automatic control. Later, it was discovered that the response time was two minutes for a flow rate to change from 40 gpm to 80 gpm. Therefore, the flow controller was used in manual control during set point changes, and then switched back to automatic to maintain steady flows at various loads.

Refiner startup was actuated by switching on the stock pump. The handwheel was turned in to the desired load of 80 amperes, and the corresponding kilowatt reading was taken, while the stock was traveling

through the piping network to the machine chest. Once the refined stock reached the chest, a sample was taken in a three gallon pail. A new level of refining was set by one clockwise turn of the handwheel. Flow changes were made with the controller in manual, and the handwheel fully clockwise to allow the higher tonnage enough disk clearance to pass freely.

In subsequent refiner trials, the 120 gpm flow was used first with loads ranging from small to large. This procedure was more effective because the load setup was reached more quickly and steadily by turning the handwheel counterclockwise.

The procedure used in changing the gear ratio with various loads and flows was quite similar to the one above. The only difference was that the stock pump was shut off to stop the refiner motor during gear ratio changes. The refiner must be in a stopped position for changing gears.

The refiner cavity required flushing with fresh water immediately after shutdown. The two inch draincock was opened until clear water spouted from the pipe. The breaker switch was closed and the storage chest was cleaned out.

Testing Procedure

On the fiber level, Canadian Standard Freeness was the dependent test used to evaluate the stock sample with respect to various loads, throughput and speeds. Duplicate C.S.F. tests were run to ensure accuracy and uniformity of the stock sample. Corrections were made for consistency and temperature. Four Noble and Wood handsheets were made from each stock sample. Each handsheet weighed 3.0grams dry. Handsheets were immediately placed in the constant humidity test room.

Paper testing was run according to Tappi Standard Procedures. Three brightness and opacity tests were run for each sample, where felt side only was tested. The mullen test was an average of both wire and felt side data. In the tensile test, the same return position and sample length was used, making elongation directly readable from the graph. The tear test required four sheets per sample. MIT fold test was under 1 Kg force.

DISCUSSION OF RESULTS

An unusually high Canadian Standard Freeness of 525 ml C.S.F. resulted in one sample taken at the 40 gpm flow at high loads. In the other samples the freeness was nearly 200 ml less, indicating that the refined pulp was still mixing with unrefined pulp in the pipes leading from the refiner to the machine chest. Therefore, in subsequent tests at low flow rates, at least two minutes were allowed for the unrefined pulp to pass out of the system. This problem of lag time and mixing in the pipes was lessened at the higher flow rates where the pipe was more completely filled and mixing was minimal.

Canadian Standard Freeness, the dependent variable, was inversely related to refiner power and load at any throughput. The resolution of the kilowatt scale was better than the load scale. The inaccuracy of the ampere load measurement was due to unsteady meter readings and high to full scale meter deflections. The measurement technique was also quite variable because of the portability of the meter. Therefore, in subsequent runs, power in kilowatts was used as the independent loading unit.

From Figure 2 and 3, the drop in C.S.F. increased with an increase in kilowatts and HPD/T. The lowest tonnage rate had the steepest slope in Figure 2 and the flattest slope in Figure 3. The mid tonnage rate had a medium slope in both Figures 2 and 3. The greatest tonnage had the flattest slope in Figure 2 and the steepest slope in Figure 3.

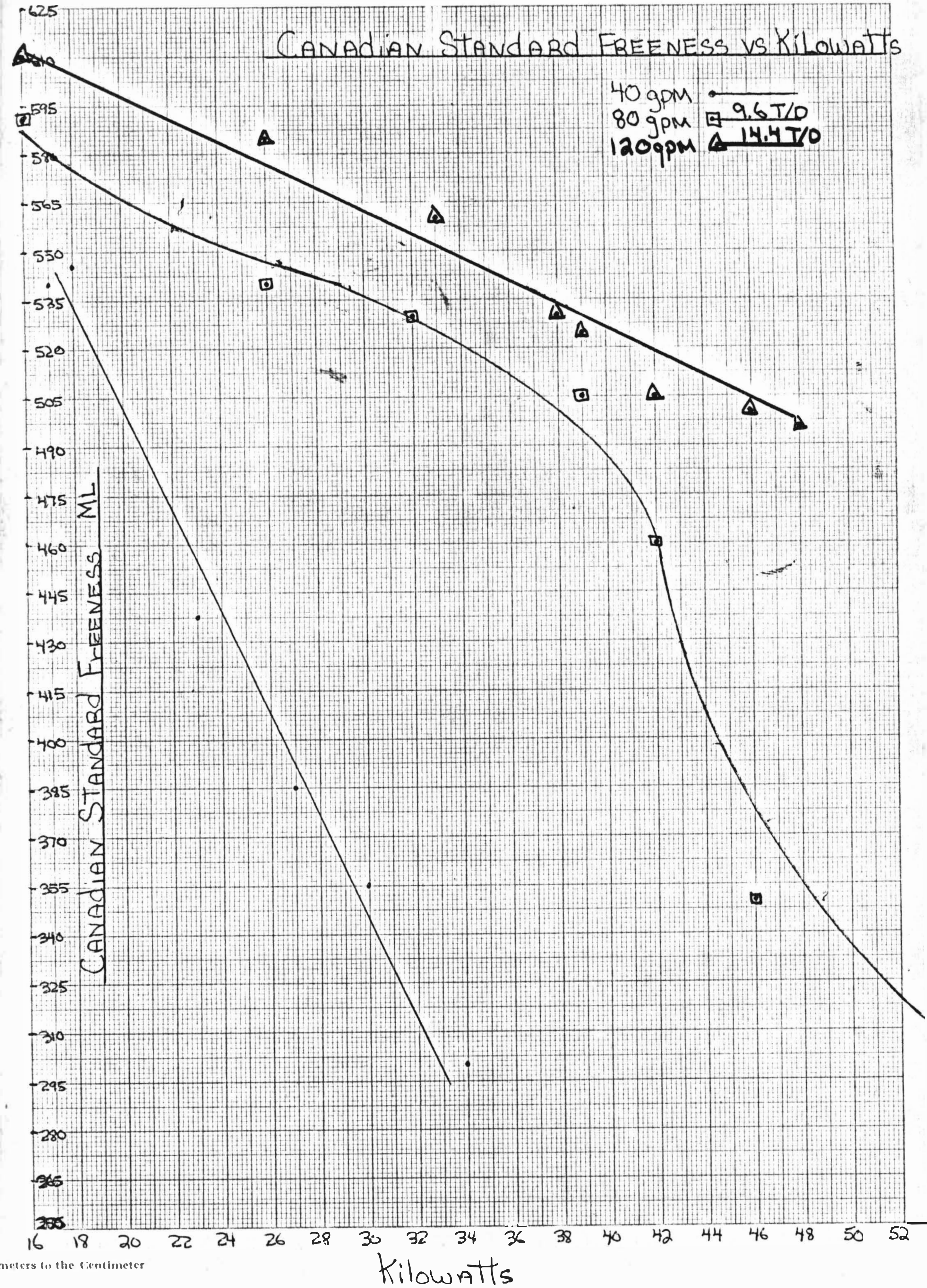
At loads approaching 50 KW and 4 HPD/T, the 120 gpm flow produced almost no drop in C.S.F. with increased power and specific energy consumption. The refiner shut down automatically at loads exceeding 50 KW and 100 ampers. When this occurred, the handwheel was turned out and the breaker box reset.

The mid flow produced almost the same magnitude of C.S.F. drop as the low flow. On Figure 3, the mid flow produced the same C.S.F. as the low flow using less HPD/T per 100 ml C.S.F. drop. For the mid flow rate, the difference in the line slope was smaller in Figure 3 with respect to the slope in Figure 2. Therefore, for a given drop in C.S.F., the 9.6 T/D rate responded best with respect to the load required for a given C.S.F. drop.

The higher tonnage would also show this trend of increased efficiency over the mid and lower tonnage rates, except that the C.S.F. range produced in the 14.4 T/D rate was very small due to refiner shutdown at high loads.

From Figure 3, the relative refining efficiency for each flow rate was seen at the smallest value of HPD/T per 100 ml C.S.F. drop. The 120 gpm flow reached its maximum C.S.F. drop and efficiency at 3.9 HPD/T. The 80 gpm flow produced great drops in C.S.F. in the 350-500 ml C.S.F. range per unit HPD/T. The 40 gpm flow produced good refining throughout the 80 gpm range and seemed to produce further C.S.F. drop without refiner shutdown below the 350 ml C.S.F. range. The 120 gpm flow reached a maximum

Figure 2



CANADIAN STANDARD FREENESS VS KILOWATTS
40 gpm
80 gpm 9.6 T/D
120 gpm 14.4 T/D
CANADIAN STANDARD FREENESS ML
625
595
565
550
535
520
505
490
475
460
445
430
415
400
385
370
355
340
325
310
295
280
16
18
20
22
24
26
28
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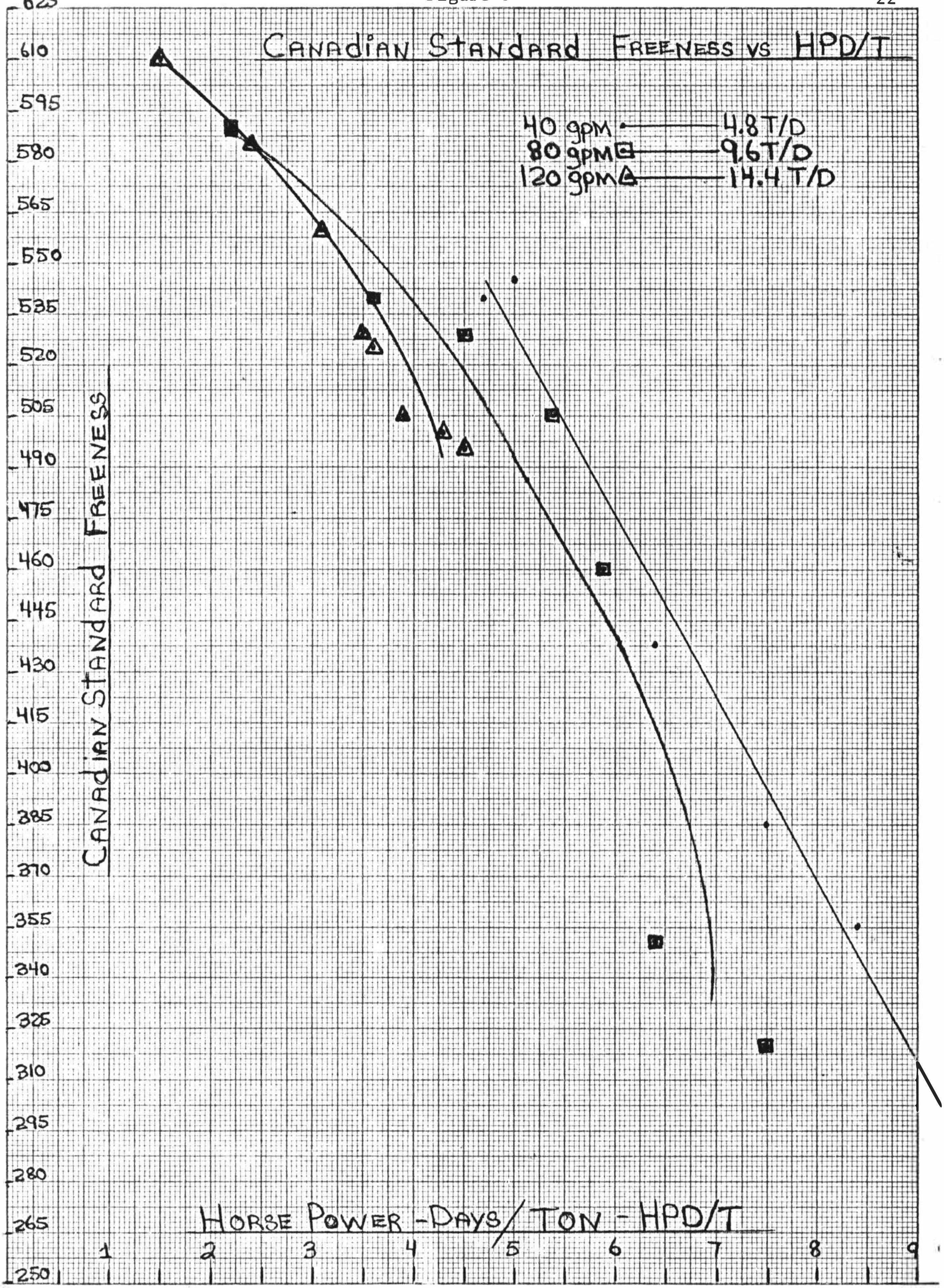
38
40
42
44
46
48
50
52
KILOWATTS
meters to the Centimeter

Figure 3


CANADIAN STANDARD FREENESS VS HPD/T
40 gpm • 4.8 T/D
80 gpm ▣ 9.6 T/D
120 gpm △ 14.4 T/D
CANADIAN STANDARD FREENESS
HORSE POWER - DAYS/TON - HPD/T
625
610
595
580
565
550
535
520
505
490
475
460
445
430
415
400
385
370
355
340
325
310
295
280
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4
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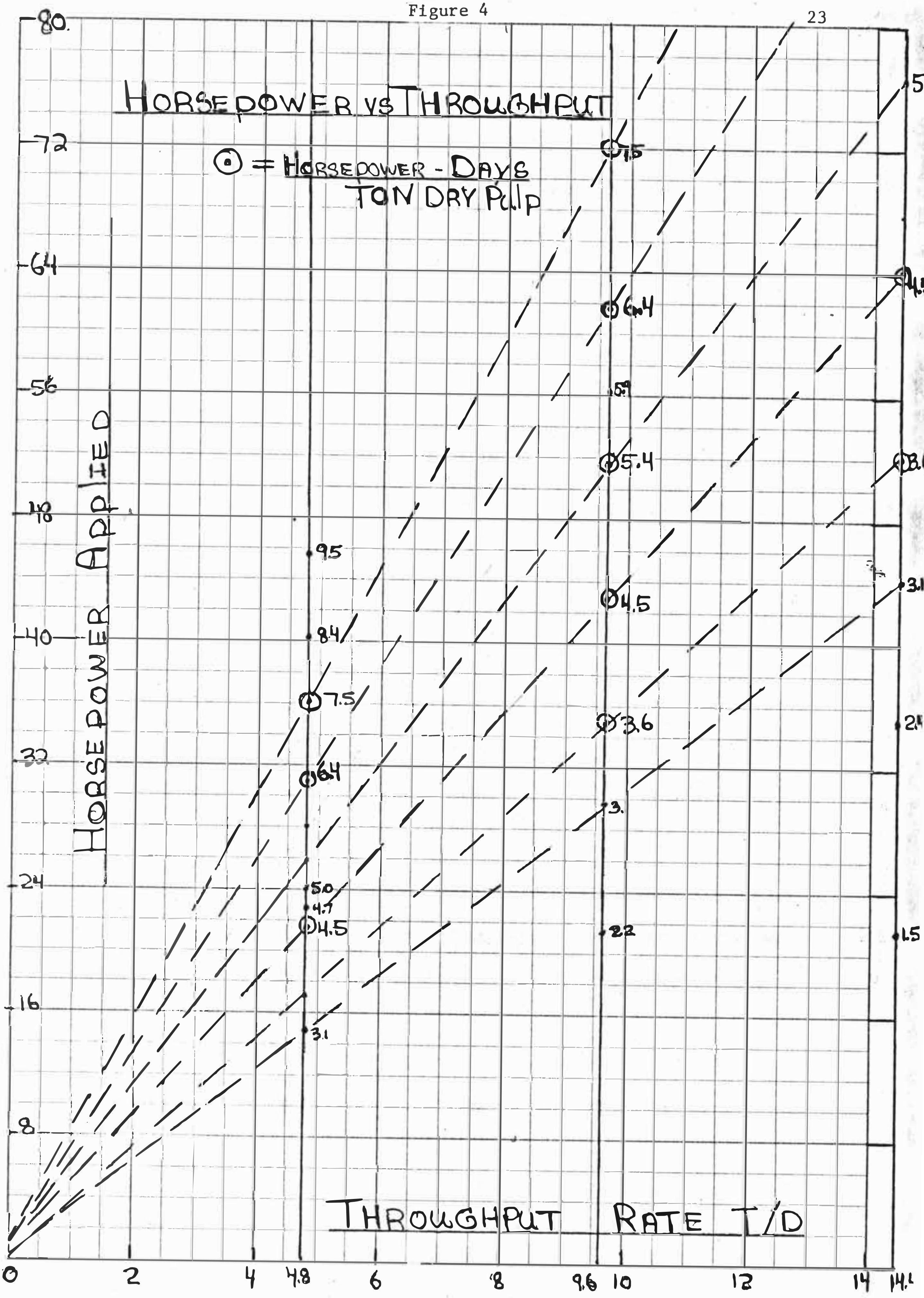
6
7
8
9

Figure 4



HORSEPOWER VS THROUGHPUT
⊙ = HORSEPOWER - DAYS / TON DRY PULP
HORSEPOWER APPLIED
THROUGHPUT RATE T/D
80
72
64
56
48
40
32
24
16
8
0
2
4
4.8
6
8
9.6
10
12
14
9.5
8.4
7.5
6.4
5.0
4.7
4.5
3.1
6.4
5.9
5.4
4.5
3.6
3.
2.2
1.5

C.S.F. drop at 500 ml C.S.F. At larger values of HPD/T the C.S.F. dropped very little and the refiner became more and more inefficient. The 80 gpm flow responded quite well to increased loads in the 300-350 ml C.S.F. range. Projection of the existing data indicated that the 40 gpm flow became more and more efficient as the 80 gpm flow became less and less efficient. The efficiency of the refiner is best achieved by matching the magnitude of the C.S.F. drop desired to the proper flow rate. The beat means of making this comparison is by HPD/T vs. C.S.F. drop at various flows as shown in Figure 3.

TABLE III

Selected Operating Conditions that Produced Equal C.S.F.

Samples	Flow Rates	HPD/T	HPD/T Differences	C.S.F.
2, 8	40, 80	8.4,6.4	2.0	355
5, 12	40, 80	4.7,3.6	1.1	540
5, 18	40,120	4.7,3.5	1.2	535
10, 16	80,120	5.4,3.9	1.5	505
11, 17	80,120	4.5,3.6	.9	527

The samples shown in Table III were refined to the same C.S.F. under different flows and loads. The specific energy consumption in horsepower days per ton of bone dry pulp, indicated that the relative refining efficiency was highest at the greater flow. The difference in HPD/T was highest where the greater tonnages produced the lower C.S.F. Samples 8 and 12 both produced the same C.S.F. as samples 2 and 5 respectively, but sample

8 did so with a larger savings in HPD/T than did sample 2. At higher tonnages, the ratio of the horsepower increase to the tons per day increase was less than the HPD/T at the lower tonnages. The difference in HPD/T at higher flow rates is because a greater percentage of the gross applied horsepower is actually used to refine the stock.

TABLE IV

Selecting Operating Conditions that Produced Equal HPD/T

Sample	Flow Rates	C.S.F.(ml)	Difference (ml)	HPD/T
3, 7	40, 80	385,320	65	7.5
4, 8	40, 80	437,350	87	6.4
11, 14	80,120	530,495	35	4.5
12, 17	80,120	540,525	15	3.6

The samples in Table IV were refined at various combinations of load and throughput that produced equal horsepower-days per ton. The difference in C.S.F. produced was due to the decreased number of bar edge inch contacts received by the fibers at the greater tonnages. At the higher tonnage, the ratio of the horsepower increase to tons per day increase was less than the HPD/T at the lower of the two throughputs. Accordingly the higher flow received more intense fiber treatment because each fiber was hit with more bar edge horsepower per contact. As mentioned earlier, the higher flow was more efficient because a greater percentage of the gross HPD/T was used to refine the pulp. The greater net horsepower, at the higher tonnage,had a marked effect on the severity of each contact. The relative difference in C.S.F. produced at the various flows did show that

as less horsepower was used at the 500-range of C.S.F. the C.S.F. difference was smaller due to the decreased proportion of net horsepower available to do work on the stock.

TABLE V

Disk RPM vs HPD/T

Sample	GPM	Gear	RPM	HPD/T	C.S.F.	IC/M (Relative)
23	60	3	576	8.4	510	64
24	60	5	885	4.1	537	100

The two samples produced nearly the same C.S.F. at different loads and speed. Third gear used twice the power at only 64 IC/M relative to fifth gear. Therefore as the IC/M was decreased, the net horsepower required to obtain the same C.S.F. increased. The strength produced in sample 23, was consistently lower than the strength results of sample 24. The strength tests have shown that higher speed produces higher mullen and tensile at a given level of C.S.F.

Strength Test Results

The mullen, tensile and fold tests responded linearly with increased kilowatts. The lower tonnage produced the highest results. The middle tonnage developed almost the same results as the lower tonnage requiring additional power. Specifically, all the tests drew lines with the same general slope. However, the test data lines drawn at the various tonnages were displaced from each other in proportions equal to the differences in gpm flow. This trend of line displacement was best explained by the relative number of IC/M, where the 80 gpm flow was twice removed from 40 gpm as it

was from the 120 gpm flow. A smaller line displacement was expected between 80 and 120 because only 50% less IC/M are developed by the 120 gpm flow.

TABLE VI

7.5 HPD/T

Sample	GPM	Mullen	Tensile	Tear	Fold	C.S.F.	IC/M Relative
3	40	34.0	9.7	85	107	385	100
7	80	30.9	10.0	68	84	320	50

TABLE VII

350 C.S.F.

Sample	GPM	Mullen	Tensile	Tear	Fold	HPD/T	IC/M Relative
2	40	33.0	10.8	85	164	8.4	100
8	80	32.6	9.3	72	108	6.4	50

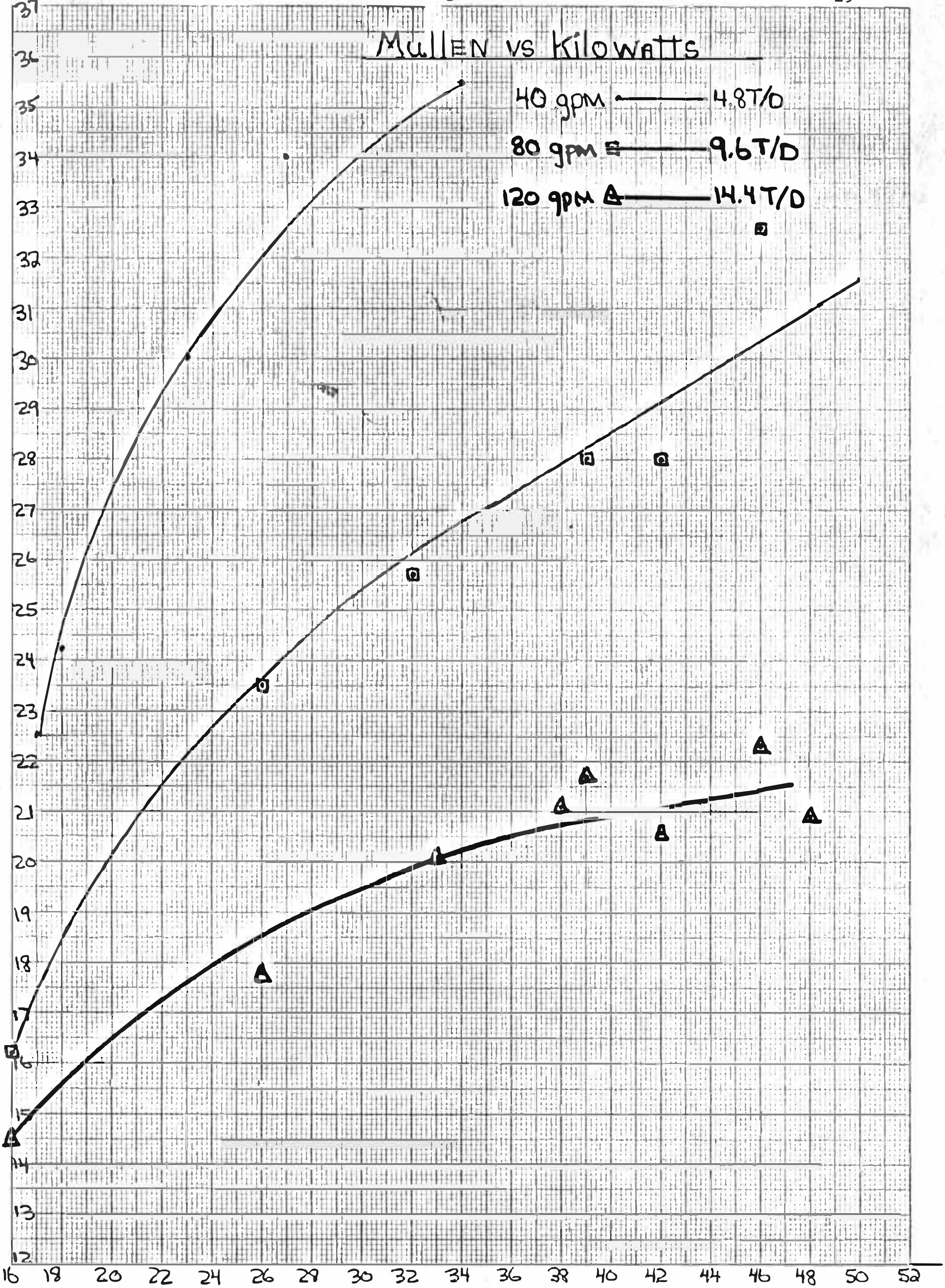
At 7.5 HPD/T, strength was highest for the 40 gpm flow. Again, the lower tonnage showed the best results at the same HPD/T. Strength was equally dependent upon both the flow rate (IC/M) and the load. It was shown earlier, that changing the IC/M by dropping the rpm, required twice the additional HPD/T to produce the same C.S.F. range. The strength dropped quite substantially with less rpm and required additional HPD/T. Therefore, strength should be developed at a given rpm for the refiner, by varying the load and throughput rate. At 350 C.S.F. the HPD/T decrease, was only 25% for the 80 gpm flow which produced lower strength in every test.

Generally, the comparison of gear vs HPD/T must be run at higher loads, where the refiner efficiency is greater. This difference in efficiency at high and low loads and resulting C.S.F. does constitute the factor needed to compare the efficiency of developing strength by varied rpm (IC/M) vs throughput (IC/M).

Optical Results

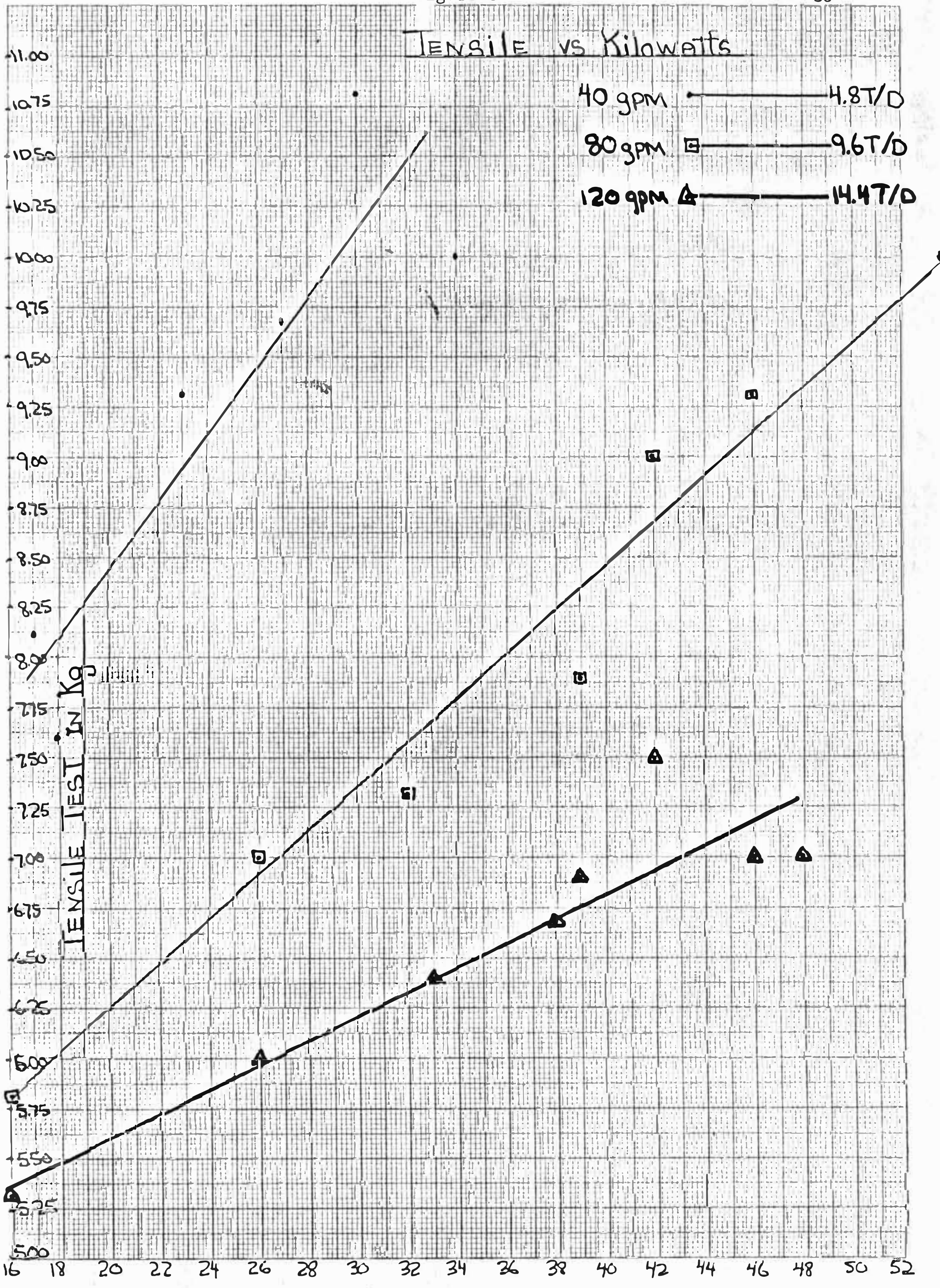
Brightness and opacity both remained constant until the higher loads were reached. Brightness dropped at the 40 and 80 gpm ranges with an unusually steep slope. The highest tonnage showed almost no drop in brightness. Opacity was definitely the least defined test results, where the perspective flow data points were quite scattered among the others. Although, the opacity did increase as the power did, other tests have shown these results to be incorrect. The opacity will normally drop at greater loads and lower C.S.F. values.

Figure 5



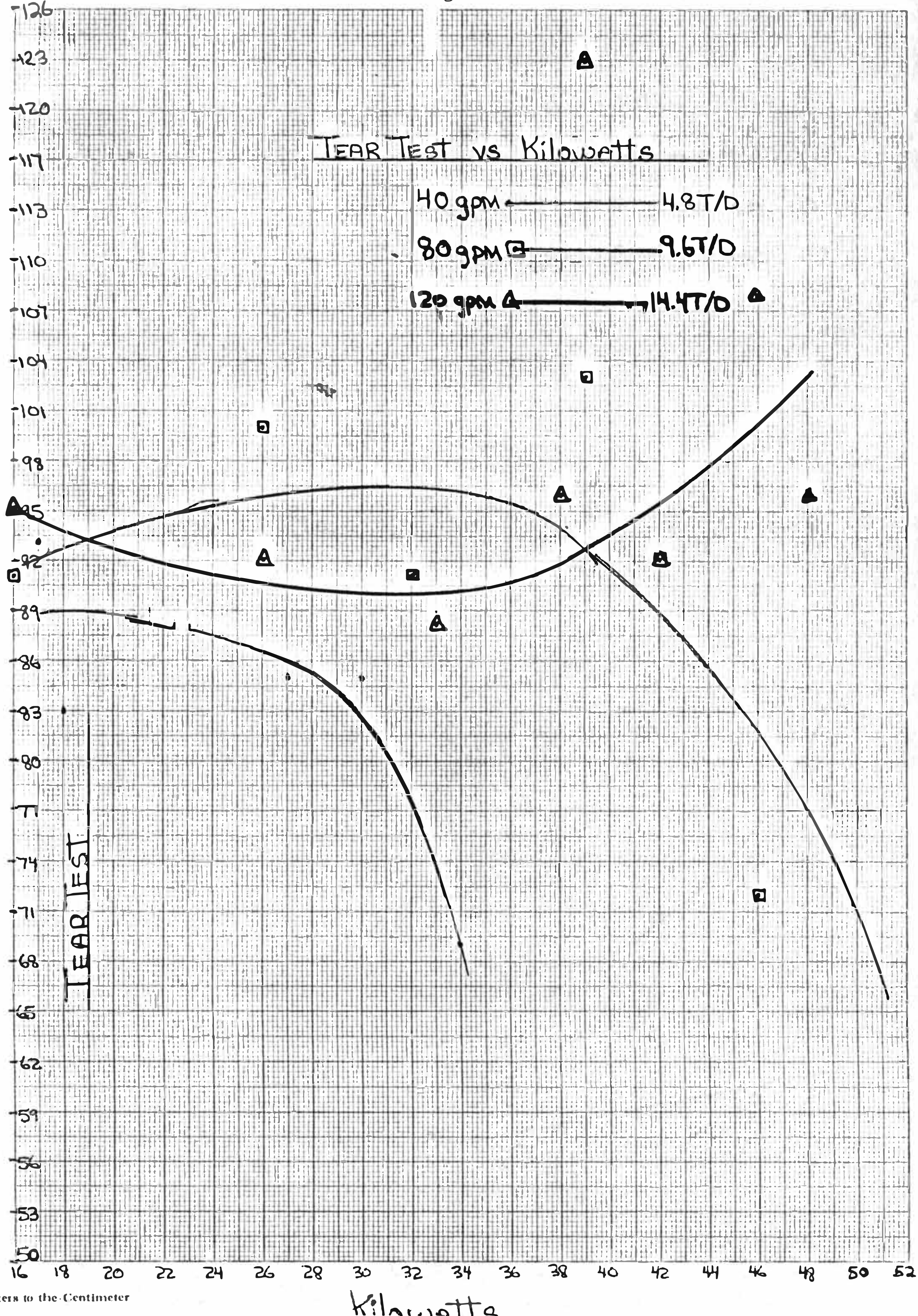
meters to the Centimeter

Figure 6



eters to the Centimeter

Figure 7



meters to the Centimeter

Figure 8

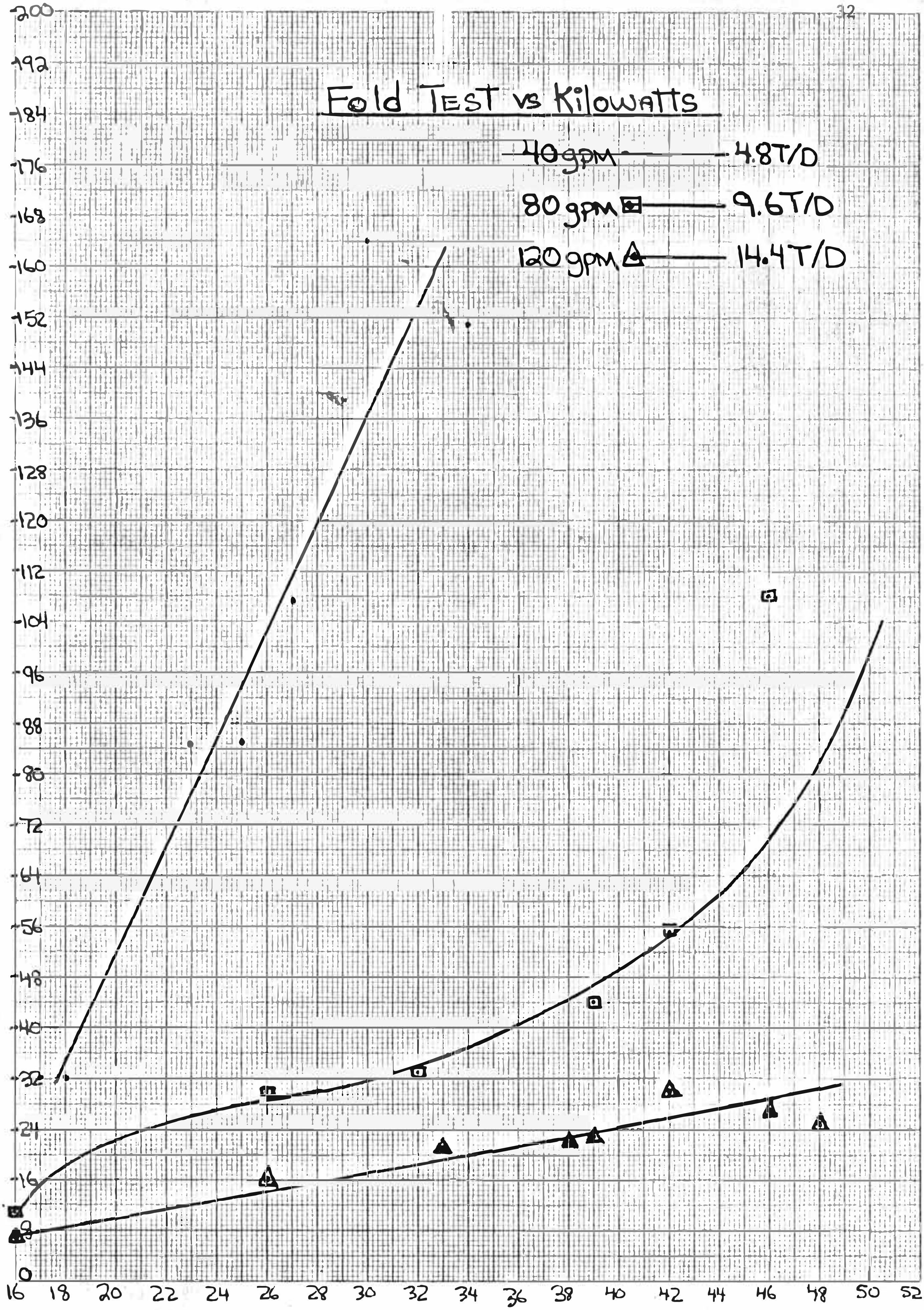

Fold Test vs Kilowatts
40 gpm — 4.8 T/D
80 gpm — 9.6 T/D
120 gpm — 14.4 T/D
200
192
184
176
168
160
152
144
136
128
120
112
104
96
88
80
72
64
56
48
40
32
24
16
8
0
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52

Figure 9

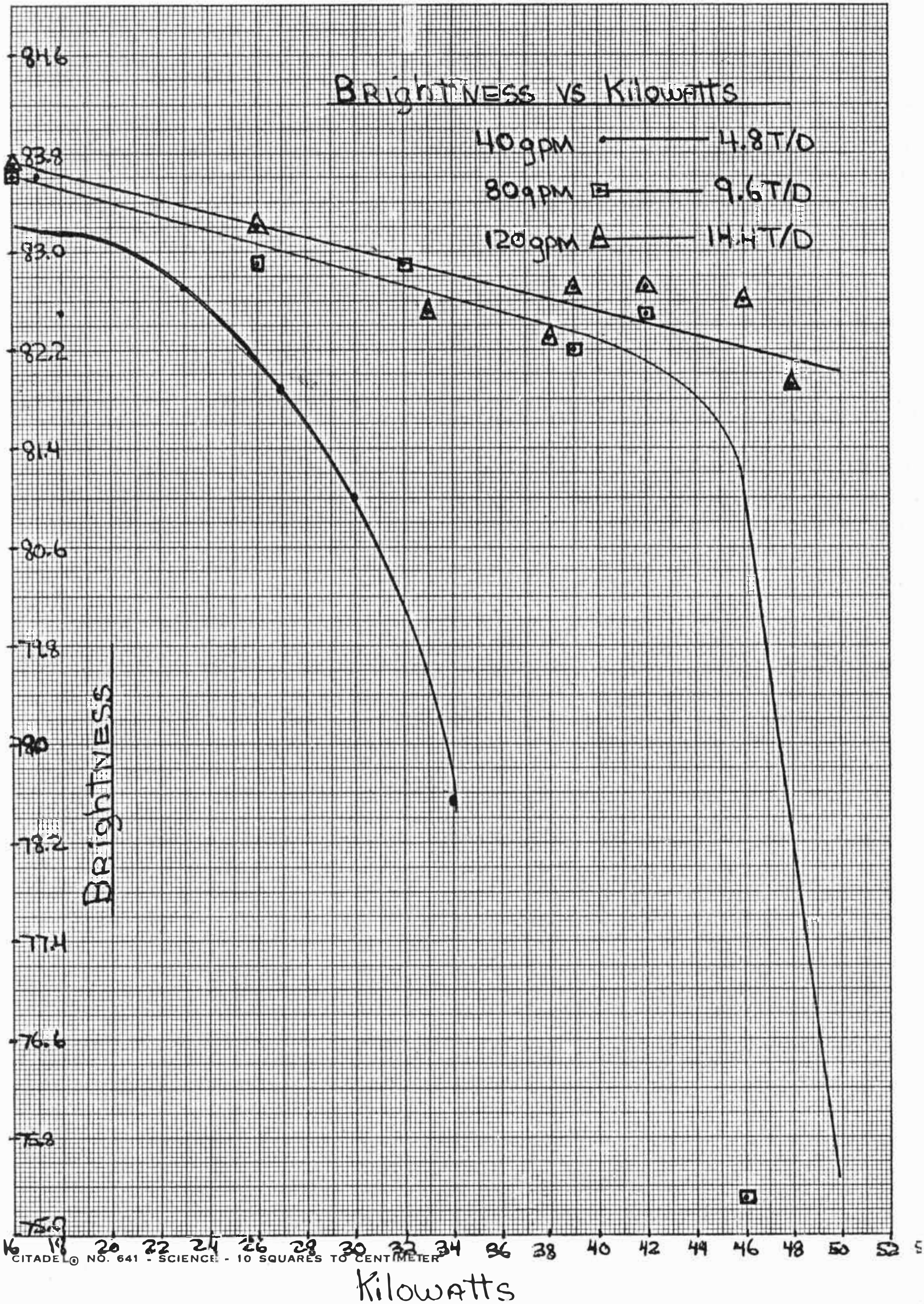
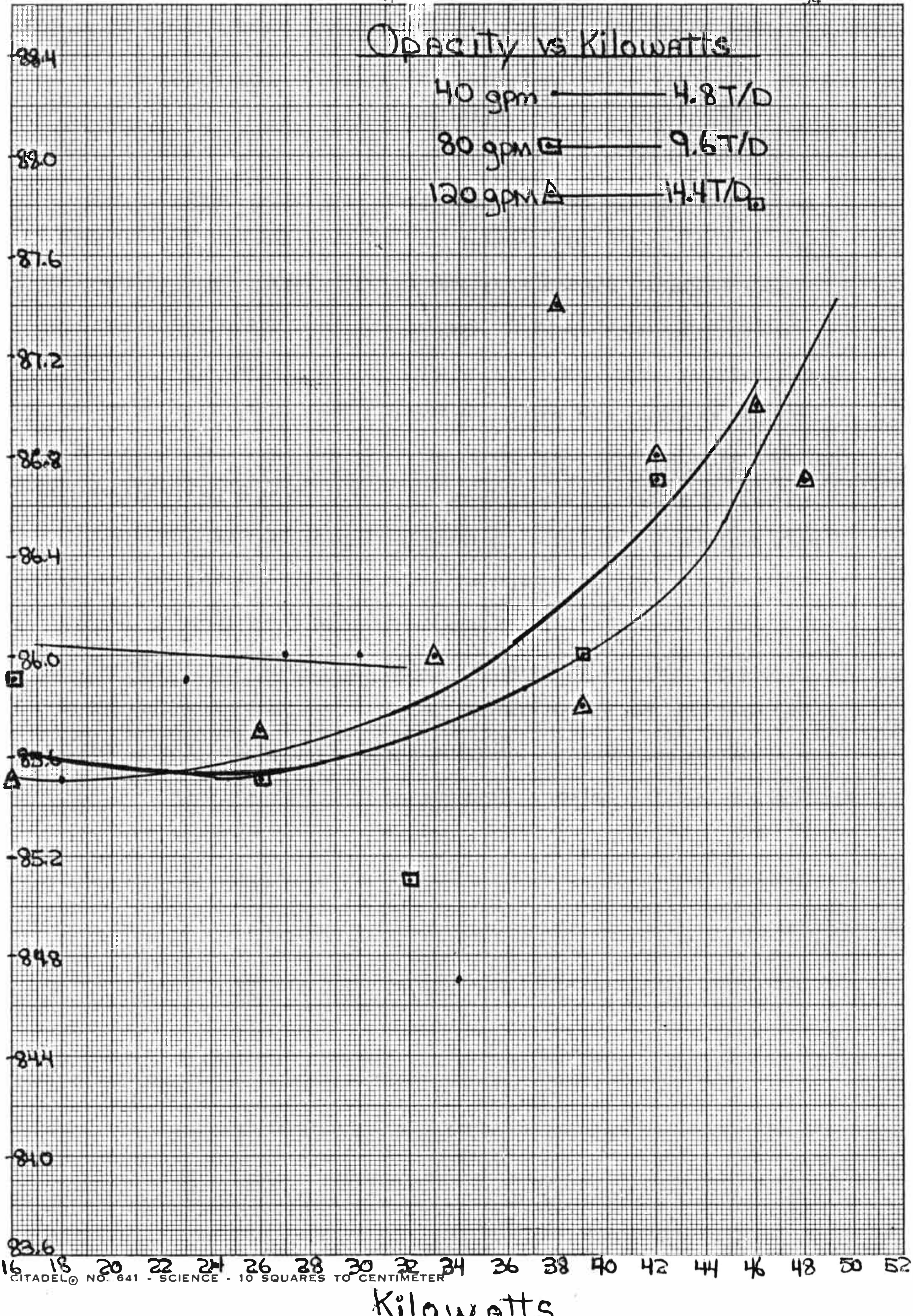

Brightness vs Kilowatts
40gpm 4.8T/D
80gpm 9.6T/D
120gpm 14.4T/D
84.6
83.8
83.0
82.2
81.4
80.6
79.8
79.0
78.2
77.4
76.6
75.8
75.0
Brightness
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Kilowatts

Figure 10


Opacity vs Kilowatts
40 gpm • 4.8T/D
80 gpm ⊡ 9.6T/D
120 gpm ⚠ 14.4T/D
88.4
88.0
87.6
87.2
86.8
86.4
86.0
85.6
85.2
84.8
84.4
84.0
83.6
16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
CITADEL® NO. 641 - SCIENCE - 10 SQUARES TO CENTIMETER
Kilowatts

CONCLUSION

The effects of refining on fiber freeness, sheet strength and optical properties were dependent upon the load induced. The effects of load were seen equally large as the effects of throughput changes throughout the load ranges used in the sheet strength and C.S.F. analysis. The effects of throughput changes on sheet strength were less pronounced than the effects produced by speed changes, and required many times less energy as the rpm speed decrease required. Therefore, decreased speed showed a major inability to maintain strength at the same power level as did increasing the tonnage.

Generally, the refiner produced large drops in C.S.F., excellent sheet strength, and maintained good optical properties at 80 gpm - 6.4 HPD/T and at 40 gpm - 8.4 HPD/T in the fifth gear speed.

However, it was noted, that in the evaluation of the refining effect, with the parameters used, the foregoing characteristics and relationships entailed rather extreme and complex conditions. Although, the evaluation was an excellent guide to both operation and project design criteria, and was used to implement a successful thesis program.

RECOMMENDATIONS

Further evaluation of the DD 3000 is necessary with respect to the following areas.

1. Speed vs load at C.S.F. between 300 and 500 ml C.S.F.
2. 100% hardwood or softwood furnish
3. Various disk types
4. Recycled fiber

More data is needed concerning the action produced at different speeds. Data lines should be constructed on graphs using the gear or disk speeds, and they should be compared more closely to the effects produced, with varied throughputs.

Various combinations of hardwood and softwood might also constitute a test useful to the pilot plant.

Recently, Jones Division has developed plastic disks that have a modulus of elasticity closer to that of the fiber. These disks would provide an accurate comparison to the results obtained in this experiment.

The WMU pilot plant is constructing a waste paper deinking system. Recycled fiber from the deinking cells could support many DD 3000 refiner trials at a substantial savings in virgin pulp cost.

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APPENDIX

Sample	Amps	Kw	C.S.F.	Mullen	Tensile Kg	Elongation	Tear	Fold	Brightness	Opacity
			40 GPM = 4.8 T/D 5th Gear							
1	70	34	300	35.5	10.0	3.5	69	151	78.5	84.7
2	72	30	355	33.0	10.8	2.4	85	164	81.0	86.0
3	71	27	385	34.0	9.7	2.3	85	107	81.9	86.0
4	68	23	437	30.0	9.3	2.0	88	85	82.7	85.9
5	64	17	540	22.5	8.1	1.9	93	32	83.6	86.8
6	60	18	545	24.2	7.6	2.6	83	32	82.5	85.5
			80 GPM = 9.6 T/D 5th Gear							
7	100	54	320	30.9	10.0	3.0	68	84	75.9	86.8
8	91	46	350	32.6	9.3	2.9	72	108	75.3	87.8
9	85	42	460	28.0	9.0	2.1	92	55	82.5	86.7
10	80	39	505	28.0	7.9	2.8	103	44	82.2	86.0
11	70	32	530	25.7	7.3	2.7	91	33	82.9	85.1
12	65	26	540	28.5	7.0	2.4	100	30	82.9	85.5
13	60	16	590	16.2	5.8	2.5	91	11	83.6	85.9
			120 GPM = 14.4 T/D 5th Gear							
14	92	48	495	20.9	7.0	2.5	96	25	81.9	86.7
15	90	46	500	22.3	7.0	2.5	108	27	82.6	87.0
16	85	42	505	20.6	7.5	2.6	92	30	82.7	86.8
17	80	39	525	21.7	6.9	2.7	123	23	82.7	85.8
18	78	38	530	21.1	6.7	2.5	96	22	82.3	87.4
19	70	33	560	20.1	6.4	2.5	88	21	82.5	86.0
20	66	26	585	17.8	6.0	2.5	92	16	83.2	85.7
21	60	16	610	14.5	5.3	2.5	95	7	83.7	85.5
Gear	GPM-Amps-Kw									
1 22	40GPM-64-	15	600	13.0	5.0	1.7	91	8	82.8	88.0
3 23	60GPM-85-	45	510	19.0	7.4	2.1	75	19	82.8	87.7
5 24	60GPM-66-	22	535	24.5	8.2	2.0	96	34	82.7	86.8

Sample	Gpm	Gear	Tons/Day	Kw	Hp	HPD/T	CSF
1	40	5	4.8	34	45.6	9.5	300
2	40	5	4.8	30	40.2	8.4	355
3	40	5	4.8	27	36.2	7.5	385
4	40	5	4.8	23	30.8	6.4	437
5	40	5	4.8	17	22.8	4.7	540
6	40	5	4.8	18	24.1	5.0	545
7	80	5	9.6	54	72.4	7.5	320
8	80	5	9.6	46	61.7	6.4	350
9	80	5	9.6	42	56.2	5.9	460
10	80	5	9.6	39	51.6	5.4	505
11	80	5	9.6	32	42.9	4.5	530
12	80	5	9.6	26	34.9	3.6	540
13	80	5	9.6	16	21.4	2.2	590
14	120	5	14.4	48	64.3	4.5	495
15	120	5	14.4	46	61.7	4.3	500
16	120	5	14.4	42	56.3	3.9	505
17	120	5	14.4	39	52.3	3.6	525
18	120	5	14.4	38	50.9	3.5	530
19	120	5	14.4	33	44.3	3.1	560
20	120	5	14.4	26	34.9	2.4	585
21	120	5	14.4	16	21.4	1.5	610
22	40	5	4.8	15	20.1	4.2	600
23	60	5	7.2	45	60.3	8.4	510
24	60	5	7.2	22	29.5	4.1	537

The refiner is automatically controlled via a pressure switch that is sensitive to stock line pressure. If the stock pump shuts down so does the refiner. The main power switch is closed and once the stock pump is started and a pressure is sensed, the refiner starts automatically.

Operation of DD 3000

Start-Up:

1. Before starting a project analysis of the refiner, the operator should check that equal spacing of 3/32" exists on both sides of the center power disk. This gap is usually kept small so that once started the stock can be refind with little adjustment time.
2. Turn on cooling and lubricating water to packing box 35 psi.
3. Open inlet valve.
4. Open outlet control valve at least 25%.
5. Connect main motor switch.
6. Connect stock pump.
7. Adjust head forward using handwheel.

Shut Down:

1. Back off refining disks using handwheel.
2. As the sliding head is backed off, it will activate the air limit switch which will engage the pneumatic locking assembly, fixing the rotating assembly in a locked position.
3. Stop stock flow, either valve or pump.
4. Flush out refiner and open 2" drain valve.

With each turn of the handwheel, the sliding head moves .004", allowing .002" inches per set of disks, therefore some 44 turns are required to set the limit switch and maintain 3/32" clearance between the disks.

W.M.U. 12" DD 3000 Refiner

Disk Configuration Data

	Disk Position	Bar Width	Groove Width	Groove Depth	Bar Angle
inlet	1	2	2	2	-5°
	2	2	2	2	+5°
	3	2	2	2	-5°
outlet	4	2	2	2	+5°

The disk configuration data shown above represents the three bar and groove dimensions in increments equal to 1/16" (inches). Therefore the three dimensions are 1/8 X 1/8 X 1/8 inches.

Mono-Flo - 20 psi Rise Between Inlet & Outlet

RPM	Nominal Flow		Furnish Factor		Duo-Flo Factor
1200	25 gpm	X	1.3	X	2
1500	30 gpm	X	1.3	X	2
1800	35 gpm	X	1.3	X	2

The data above was obtained from Beloit Jones Division. The flow rates produced were based on 4% consistency. The furnish factor converts the nominal flow when bleached hardwood kraft is used. The Duo-Flo factor converts Mono-Flo data into Duo-Flo data.