THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

MINIMIZING REFINING ENERGY REQUIREMENTS FOR LINERBOARD BASE STOCK

Project 2926-8

Report One

A Progress Report

to

THE FOURDRINIER KRAFT BOARD GROUP

OF THE

AMERICAN PAPER INSTITUTE

March 1, 1985

TABLE OF CONTENTS

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

MINIMIZING REFINING ENERGY REQUIREMENTS FOR LINERBOARD BASE STOCK

SUMMARY

A study of the merits of operating at low speeds and low gaps to reduce the energy consumed for disk refining linerboard base stocks has been carried out. A specially instrumented, 12-inch Sprout-Waldron "twin-flo" disk refiner was used for the experiments. Using this system, a southern kraft linerboard stock was refined over a broad range of gaps, speeds, consistencies, flow rates, and refining amounts. Handsheets made from the refined stocks were tested for burst, breaking length, STFI compressive strength, ring crush compressive strength, and tear factor. Canadian Standard freeness values were determined for the pulp. Horsepower levels for refining were determined from separate torque and speed measurements. No-load or idling power values, all measured for a refiner gap of 0.030-inch, were measured for water, unrefined stock and refined stock.

Data from these experiments show that refiner losses vary as the cube of operating speed. Pulp property values, including Canadian Standard freeness, are strongly related to net specific power and only very weakly related to any of the other refining variables. Hence, from a property development point of view, the selection of a refiner operating condition can be arbitrary so long as the net specific power required for property development is satisfied. Such behavior affords the opportunity to refine at low speeds and low gaps to save large amounts of energy while maintaining property development. It should be possible to maintain refiner capacity for such operation so long as the required pumping horsepower is provided externally.

INTRODUCTION

Disk refiners consume large amounts of electrical energy. It is well recognized that only a fraction of the energy supplied is used in doing useful work on the fibers. Estimates vary from less than 0.1% to as much as 25% (1). The remaining energy is wasted at considerable expense to the papermaking process. The overall goal of this project was to develop design and operating strategies for reducing wasted energy and, therefore, the total energy cost of refining.

Of the wasted energy, most goes into hydraulic losses in the refiner (2). Motor inefficiency, bearing friction and pumping losses are relatively small contributors. Thus, to improve the efficiency of refiner energy use, it is necessary to reduce the hydraulic losses. These generally vary as the cube of refiner speed, so that even small reductions in speed lead to large decreases in energy consumption.

In earlier work at the Institute (3), a small, specially built laboratory refiner was used to investigate the concept of low-speed refining as a means of reducing energy consumption. Up to 40% energy reductions were obtained by operating at lower speeds to reduce hydraulic losses, and at smaller plate clearances to retain the desired refining action. Although highly encouraging, those experiments were carried out in a plastic-bodied refiner with a bleached kraft southern pine furnish at consistencies of 3% or less.

The basic purpose of this study was to verify similar energy reductions for the coarser unbleached stock used in linerboard base sheets, evaluated with more realistic consistencies and refining equipment. This work has been carried out over a two-year period with the first year devoted to equipment development and planning, the second to experimentation and reporting.

In a parallel and complementary study, Westman (4) examined the idling power losses in a 42-inch commercial refiner in an unbleached kraft linerboard mill.

EXPERIMENTAL

REFINING SYSTEM

A 12-inch Sprout-Waldron "twin-flo" disk refiner, shown schematically in Fig. 1, was equipped with special instrumentation for this study. A 75-hp variable speed dc motor was coupled to the refiner through a torque sensor. Speed was sensed by a digital tachometer, and horsepower to the refiner was calculated as the product of torque and speed. Two proximity sensors, externally mounted to avoid temperature and pressure distortion, were used to measure plate gap. The stock flow rate was measured with a magnetic flowmeter. A schematic diagram of the refining system is shown in Fig. 2.

The refiner was carefully trammed to bring the machined surfaces for plate positioning into parallel. Sprout-Waldron plates with patterns D5A011 and D5A012 were surface ground to obtain surface flatness within 0.0005-inch. Specifications for these plates are given in Appendix A. After installation, the plate surfaces were again indicated to confirm parallelism. Static indication of the rotor showed a runout of 0.0025-inch which, according to the supplier, is well within normal specifications. No attempt was made to measure dynamic runout.

The torque sensor was calibrated statically with a load arm and checked carefully after each of several initial tests. Both the calibration factor and the zero remained constant through repeated tests. Dial micrometers and feeler gages were used to calibrate the proximity sensors to within 0.001-inch. Periodic checks of the torque and proximity sensors were used to maintain the calibration of these measurements throughout the experimental program.

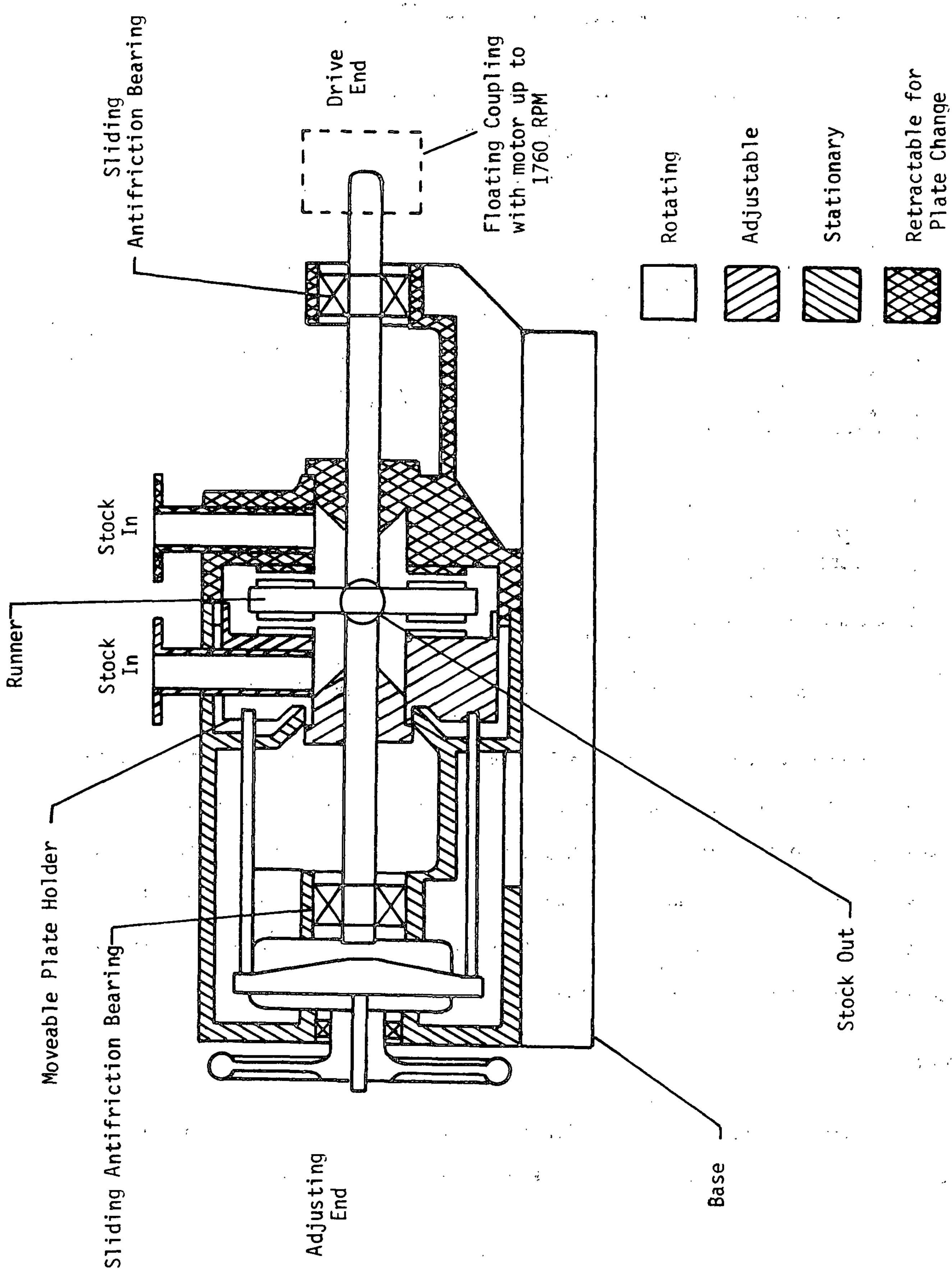


Figure 1. Simplified cross section of the "twin-flo" refiner.

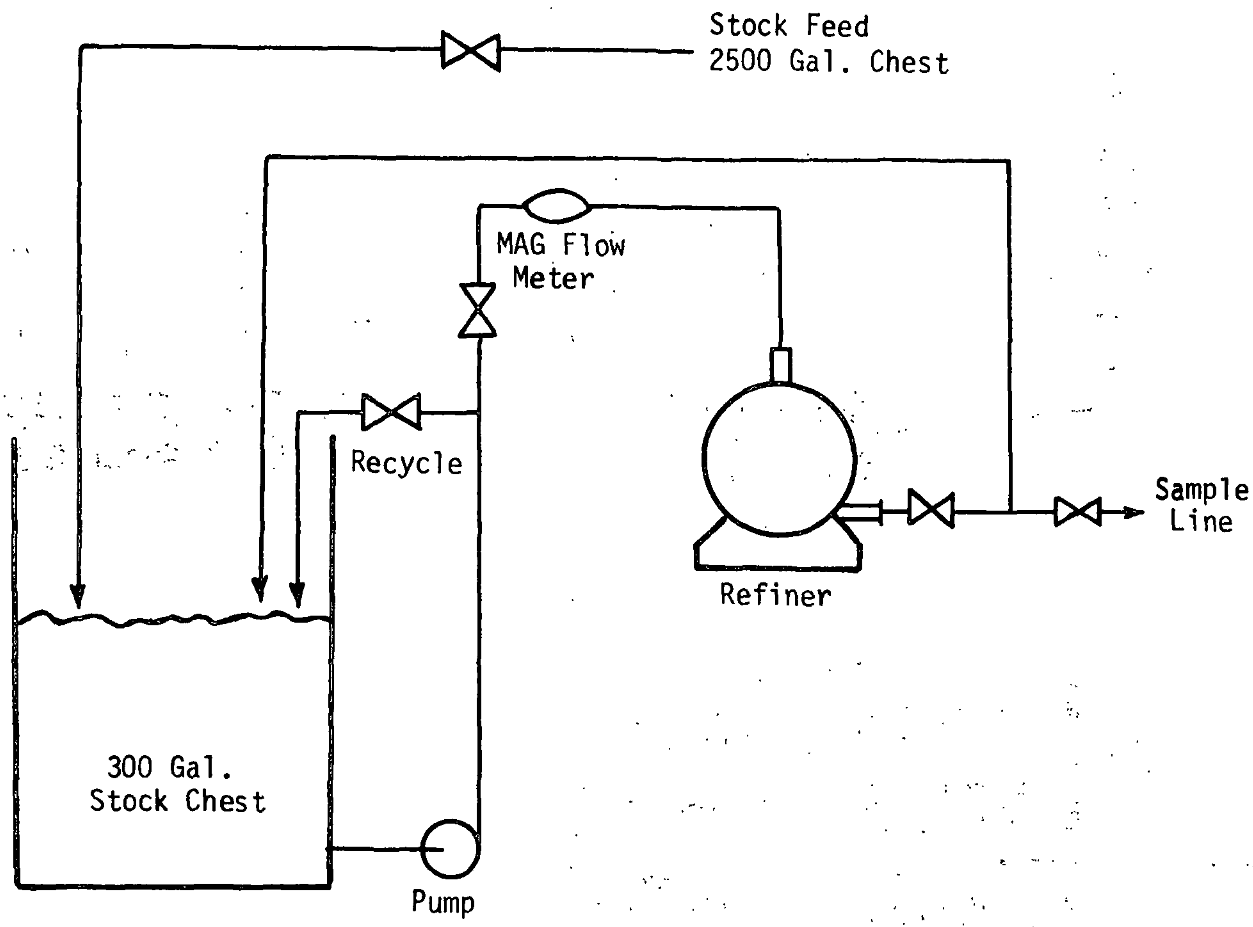


Figure 2. Schematic diagram of the refining flow loop.

A simplified cross sectional diagram of the "twin-flo" refiner is shown in Fig. 1. Each of the sliding anti-friction bearings has an end-to-end clearance of 0.010-0.015-inch which allows the runner to "float" between the two plates. A simple force balance centers the runner during normal operation. To hold the refining gap constant during a test, the rotor was first centered and then fixed by clamping the adjusting-end bearing.

STOCK

Approximately one ton of linerboard base stock was collected from the last stage washer in a southern linerboard mill. This southern pine kraft furnish had a yield of about 53% and a kappa number of 82. Following a high dilution wash and dewatering to about 20% solids in the presence of a preservative, the stock was placed in plastic lined fiber drums and stored at low temperature to reduce microbial degradation.

For each refining run, the stock was subjected to a single initial pass through the refiner at a gap of 0.020-inch for defiberizing. Lightweight handsheets, made before and after this processing step, showed fiber bundle counts per sheet of 480 and 60-65, respectively. Strength measurements, made on these "before" and "after" handsheets showed little difference, thus indicating that there was no significant refining during the defiberizing step.

REFINING

The experimental program was based on recirculation of small batches through the refiner. A large sample at the desired consistency was prepared in a 2500-gallon stirred tank. Smaller batches were withdrawn to a separate, small stock tank from which the refiner was fed in a recirculation mode as shown in Fig. 2.

Refining action due to pumping was checked by recirculating a small batch of pulp around the pump/tank system for an extended period of time. Heat generated in the closed loop system was removed by cooling the tank and pump. Final freeness values were within 5 cc of the initial value of 745 cc CSF. Handsheets made from pulp sampled before and after pumping showed no significant changes in fiber properties. This is in line with previous work at the Institute (5) which showed little, if any, pumping induced refining at consistencies below 5%.

Refiner no-load or idling power was measured with water only for a gap of 0.030 and a flow rate of 65 gpm. These data are shown in Fig. 3 as idling horsepower *versus* speed on log-log coordinates. A straight-line of the form

$$hp = 1.52 + 12.31\ (N/1000)^3 \qquad (1)$$

superimposed on the graph, shows that idling horsepower varies approximately as the cube of speed. The multiplying constant is approximately 1.23×10^{-8} for these data, but may vary with refiner size, plate pattern, and other factors.

EXPERIMENTAL PLAN

To establish the proper gap range for refining, the gap was set initially to 0.008-inch and the speed to an appropriate value between 800 and 1750 rpm. The gap was then reduced in 0.001-inch increments until a significant degree of refining, as indicated by a motor load increase, was observed. Based on these probing tests, gaps of 0.005-, 0.004-,and 0.003-inch were selected for the refining experiments. Because of the rotor runout of 0.0025-inch, mentioned earlier, the actual gap ranges may have been as follows:

	Center Value	Possible Range
Gap 1	0.003-inch	0.0005 to 0.0055-inch
Gap 2	0.004-inch	0.0015 to 0.0065-inch
Gap 3	0.005-inch	0.0025 to 0.0075-inch

Because of these wide ranges, the fiber may have been exposed to conditions overlapping all three ranges in a single test. Although the average value is used in this report to describe the gap setting, it is likely that runout introduced a band of gap values within a given run, thus obscuring, somewhat, the effect of gap. Nevertheless, such behavior is apparently typical of refiners,

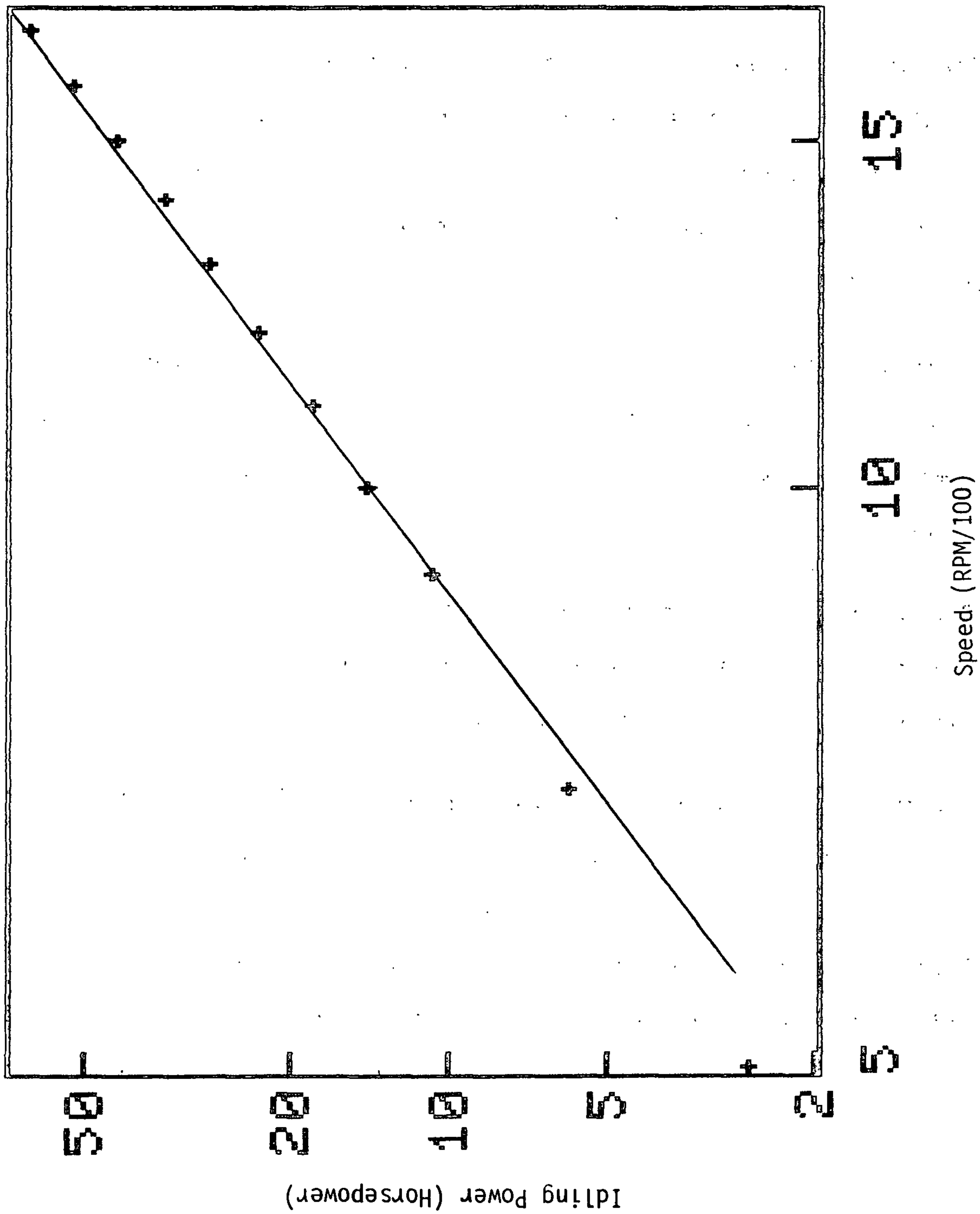


Figure 3. Idling losses for water flow through backed-off refiner (gap = 0.030-inch).

making the data representative, if not clean. Furthermore, operating at gaps large enough to dominate the runout would have precluded any refining action, and reducing the runout would have been expensive and unrealistic.

Refining experiments were carried out for gaps of 0.005-, 0.004-, and 0.003-inch and speeds ranging from 800 to 1600 rpm. Stock consistencies of 3.6 and 4.2% and throughput rates of 50 and 65 gpm were selected on the basis of available flow loop and pumping equipment. Refining capacity at 65 gpm and 3.6% consistency is 14.0 tons/day.

Up to six refining passes were used to adequately develop stock properties. The time for one pass was calculated from volumetric flow rate and total system volume. Stock returned from the refiner was reintroduced below the slurry surface.

The idling power with stock flowing through the refiner was measured before and after each refining experiment. A gap setting of 0.030-inch was used for these measurements to avoid additional refining action.

Handsheets were prepared from pulp samples obtained at selected refining intervals for physical testing to characterize the effect of the refining action. For most normal paper tests, 1.2 g handsheets were used; for ring crush and STFI compressive strength measurements, 6 g handsheets were used to avoid undue buckling during testing. TAPPI Standard procedures were used for handsheet preparation.

RESULTS AND DISCUSSION

IDLING POWER

In Fig. 4, idling horsepower *versus* speed data obtained with unrefined stock flowing through the refiner are indicated by the crosses. These data are described well by the formula

$$hp = 0.649 + 12.79\ (N/1000)^3 \qquad (2)$$

The straight line represented by this formula is superimposed on the idling power data shown in Fig. 4. Comparison of Eq. (2) with Eq. (1) shows that the idling power for water and for stock are nearly identical. These data are somewhat at odds with those obtained by Westman (4) which show slightly more idling power with stock flow. Aside from the obvious differences in the experimental setup, Westman measured power to the motor rather than power to the refiner, as in this study. In both studies, it is clear that idling power varies as the cube of speed and dominates total power consumption.

Idling losses for the refined stock (6 passes), also shown in Fig. 4, averaged about 7% less than for the unrefined stock. Apparently the friction level of the fiber suspension is reduced during refining. Similar results were obtained in recent laboratory experiments with an instrumented Valley beater for a bleached sulfite stock (6).

OPERATING CONDITIONS

Figure 5 shows a diagram of the refiner speed and gap operating states used in this study. Generally, data were collected at each of these operating states for two consistencies, 3.6 and 4.2%; for two flows, 50 and 65 gpm, and for approximately two, four, and six passes through the refiner.

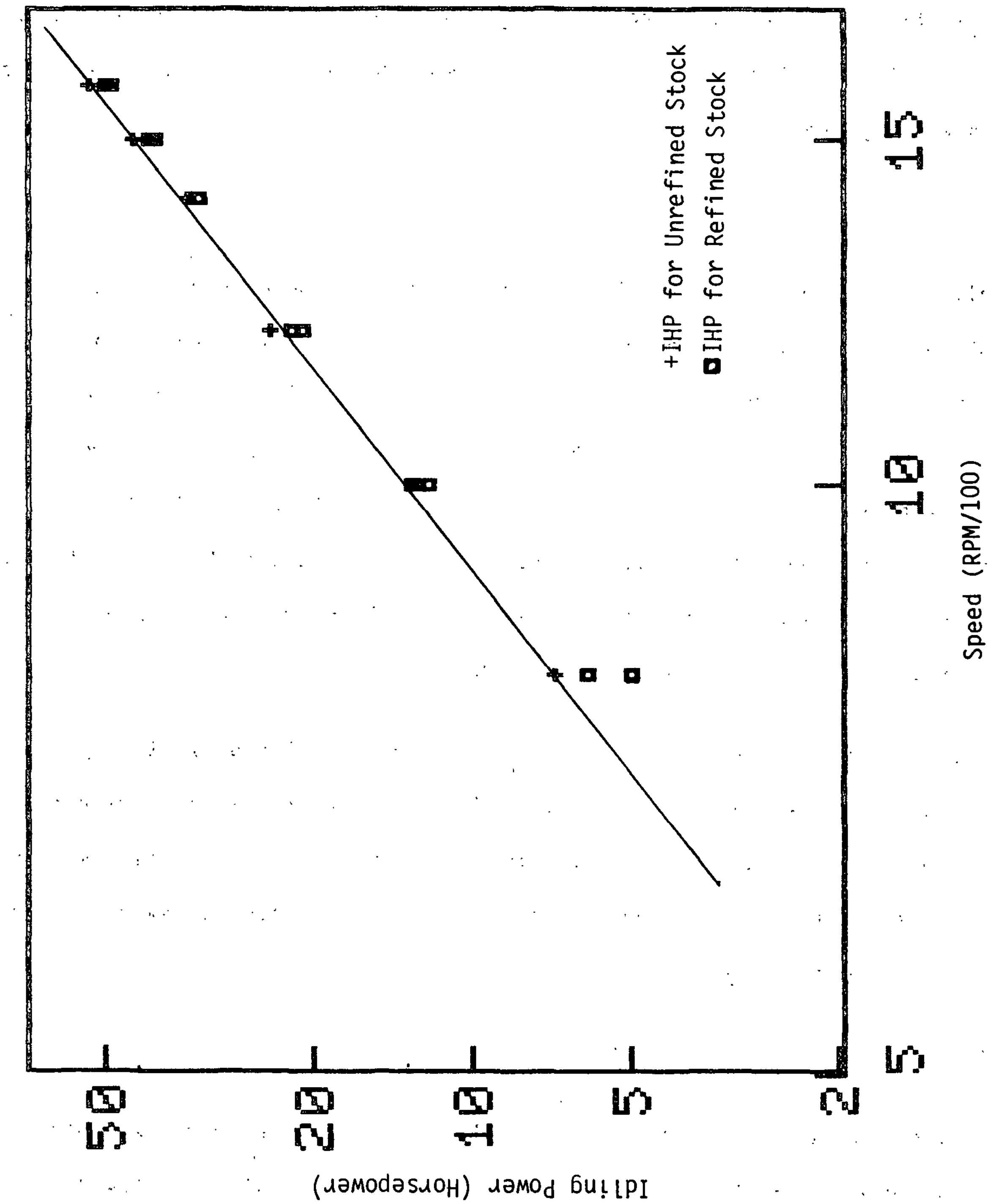


Figure 4. Idling losses for unrefined and refined stock flow through a backed-off refiner (gap = 0.030-inch).

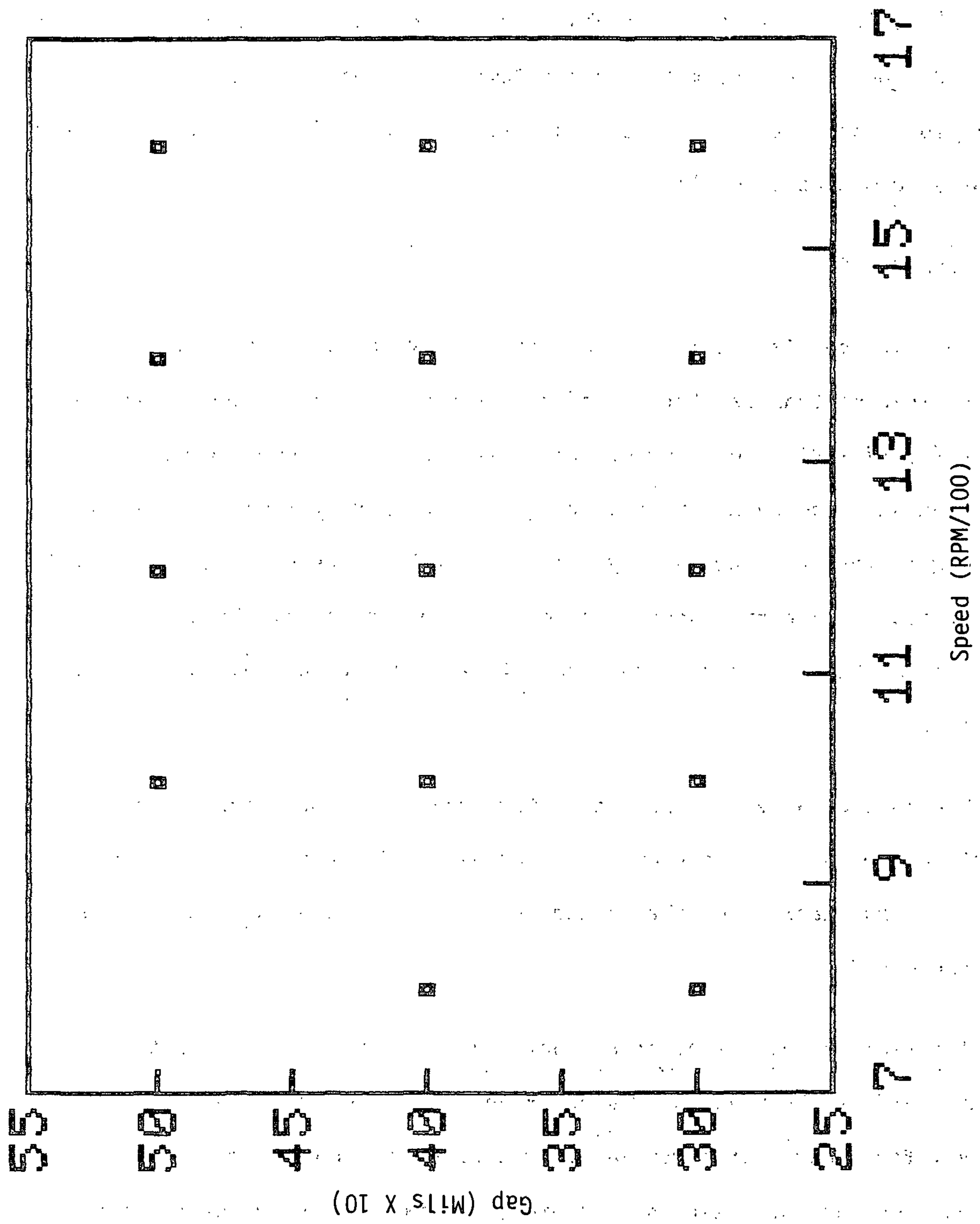


Figure 5. Operating range for the refining tests.

Figure 6 shows the actual net horsepower days/ton (NHPD/T) values achieved in the refining experiments. At 800 rpm, the maximum NHPD/T was about 4, which is just sufficient to develop the linerboard stock to commercial strength levels. The smaller gaps (<0.003-inch) required to achieve higher net horsepower levels at 800 rpm are not workable in the "twin-flo" refiner. At all other speeds, maximum net horsepower levels were sufficient to develop the stock well beyond normal commercial levels.

PROPERTY DEVELOPMENT

As noted earlier, compressive properties were measured on 6 g handsheets (61.5#/MSF) whereas tensile, burst, and tear properties were measured on 1.2 g handsheets (12.3#/MSF). For convenience of reference and comparison, these data have all been adjusted to a new basis weight of 42#/MSF by linear projection. While strength properties are strong functions of basis weight, the relationships are not necessarily linear. Hence, these adjusted data should be interpreted in terms of the relative effects of various refining conditions and not in terms of absolute values.

The data obtained in these refining experiments were carefully examined for the effects of stock consistency and throughput (flow rate). These effects were not distinguishable over the ranges tested, so all the data were pooled for further treatment.

The basic objective of this study was to show that equivalent stock properties could be obtained for a wide range of refiner operating conditions. If so, then, for a given property level, the refiner can be operated at the condition that consumes the least total energy, consistent with other constraints.

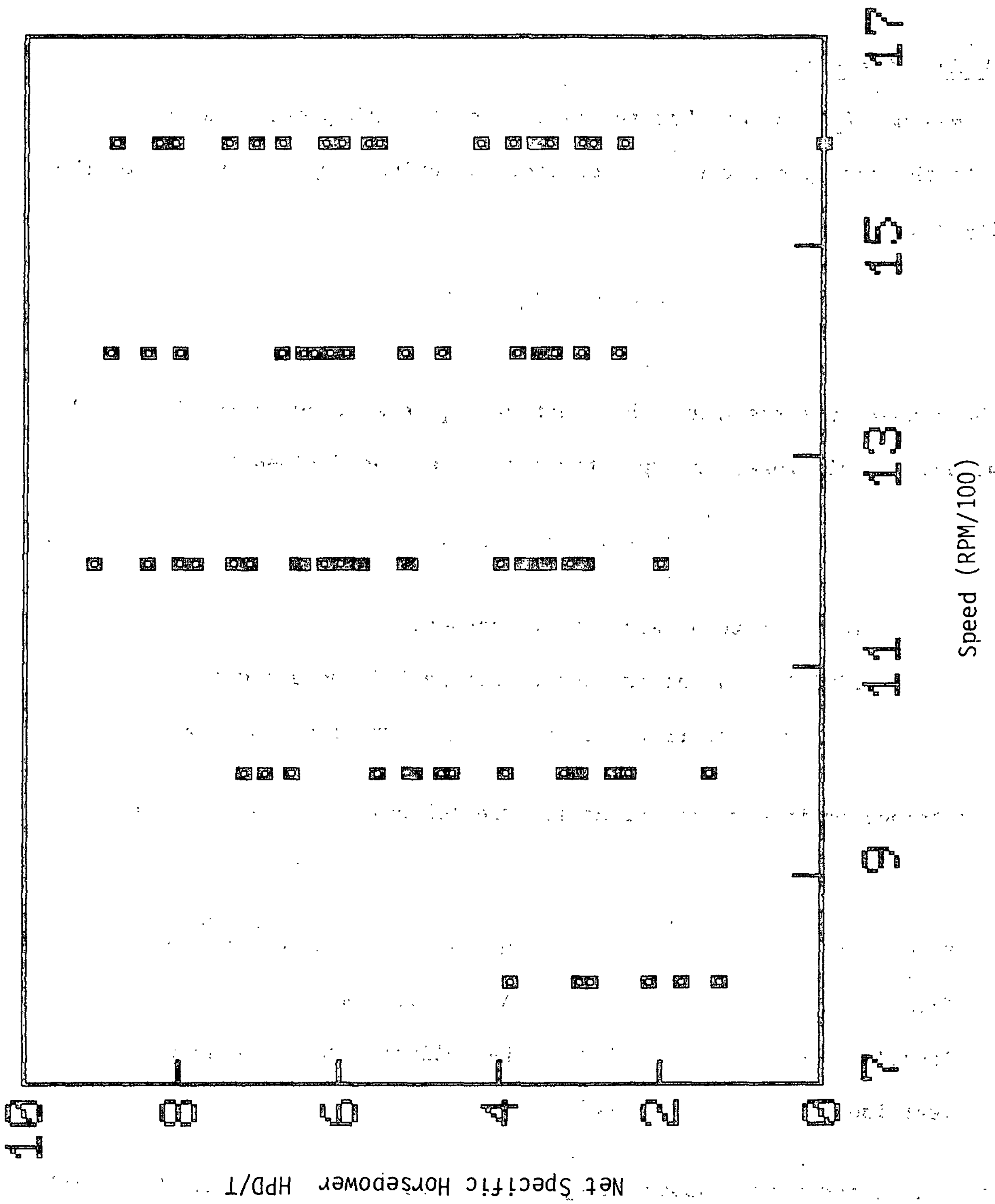


Figure 6. Operating range for the refining tests.

Stock properties of interest are those that relate to end-use performance such as burst, compressive strength, tensile strength and tear, and to machine runnability, often measured in terms of Canadian Standard freeness.

Strength Relationships

Westman (4) showed that the important strength properties could be related to the net specific horsepower used in refining by an equation of the following form

$$P = \sum_{i=1}^{N} a_i (NHPD/T)^i \quad (3)$$

where the number of terms N and the constants a_i were selected to give the best correlation. In his work, net specific horsepower was defined by

$$NHPD/T = THPD/T - k(IHPD/T) \quad (4)$$

where THPD/T = total specific horsepower

IHPD/T = idling or backed-off specific horsepower

k = constant selected to give the best correlation

Westman obtained optimum correlations for the following parameter values:

	N	k	
Burst index	3	1.2	N=3 slightly better than N=2
°MSR	3	1.2	N=1 almost as good
Tensile index	2	1.2	N=3 slightly better than N=2
Tear index	2	1.2	

where °MSR is a modified Schopper-Riegler variable. In all cases, the correlation coefficients r^2 exceeded 0.9, thus showing that the property variations were closely related to changes in net specific horsepower.

Pulp strength properties tend to vary linearly with net specific horsepower until the fiber approaches full development. At this point, the property-power curve bends or "hooks," and additional specific power produces little or no additional property development. Westman's experiments were conducted for a net specific horsepower range from 3 to about 13, the upper limit being sufficient to cause appreciable curvature in the power-property relationship. To adequately describe these curves, either second or third order polynomials were necessary, as evidenced by the values for N in the above table. Westman also found that the best correlations were obtained by setting k=1.2. This suggests that the effective losses in the 42-inch refiner were 20% higher than the backed-off power levels.

For the twin-flo refiner, net specific power was calculated from

$$\text{NHPD/T} = \frac{C(Z)(N)(H)}{(M)} - k\,(\text{IHP})$$

where Z = torque - ft-lb_f

N = refiner speed - rpm

H = refining time - min.

M = total weight of fiber being processed - tons

IHP = idling power for unrefined stock = $0.649 + 12.79\,(N/1000)^3$

C = constant determined from the units of Z, N, H, and M

k = constant selected to give the best correlations

STFI compressive strength, burst, and breaking length are plotted versus net specific horsepower in Fig. 7-9. Linear correlations, based on k=1.0, are superimposed on these plots. For the range of net specific power used in these experiments, 1-9 NHPD/T, there is very little curvature in the property relationships even at the extreme upper level of energy input. As a result,

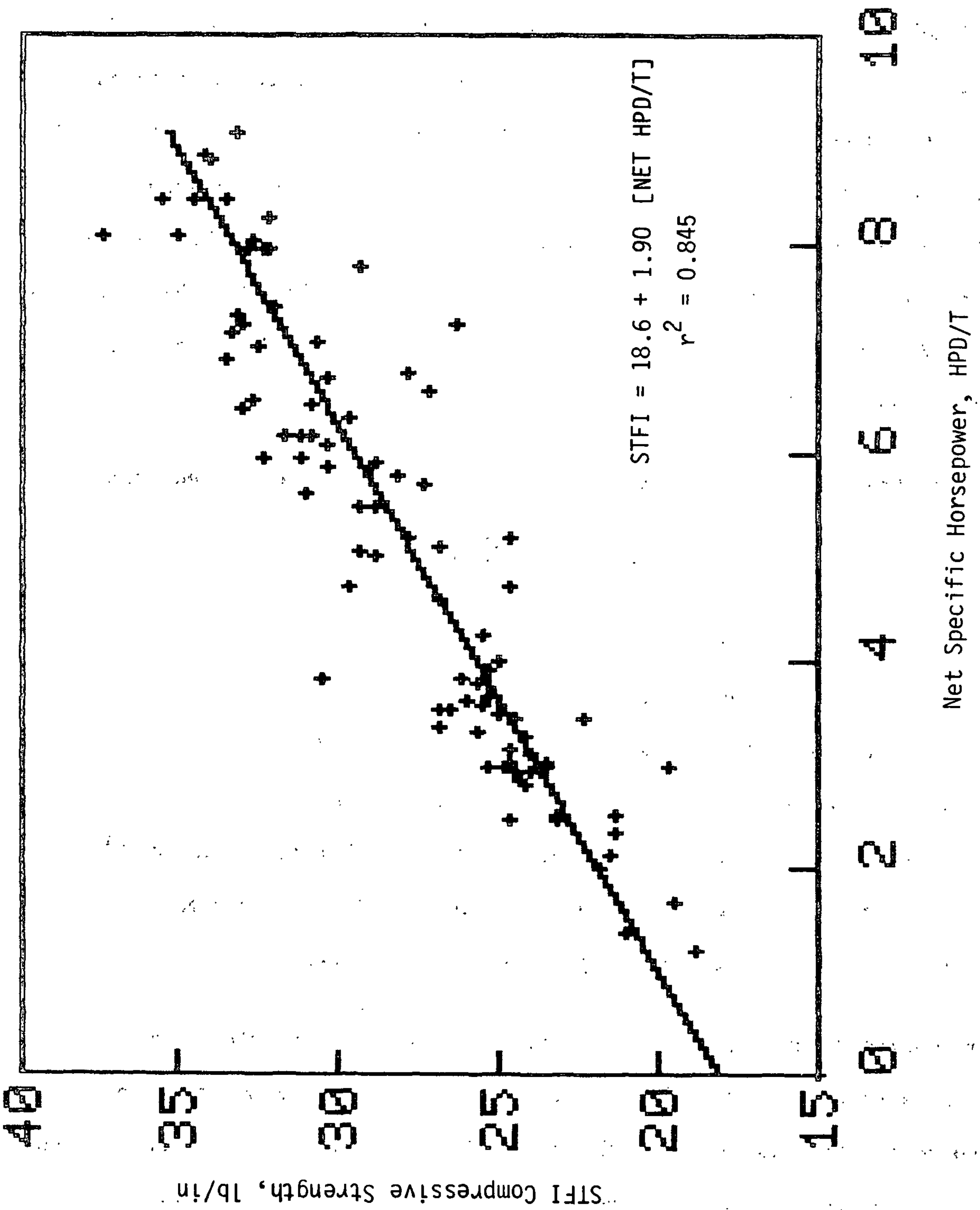


Figure 7. Compressive strength as a function of net specific horsepower.

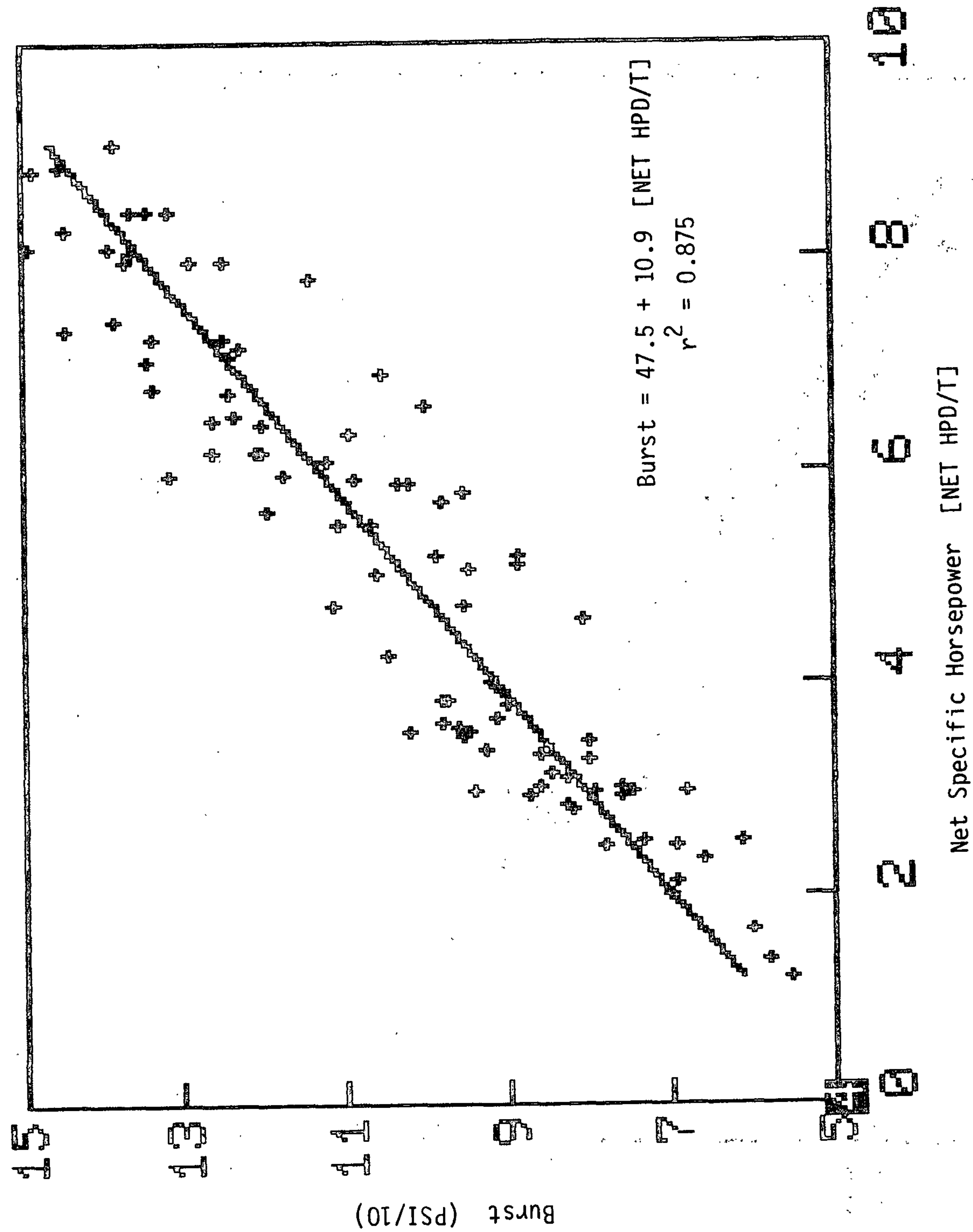


Figure 8. Burst as a function of net specific horsepower.

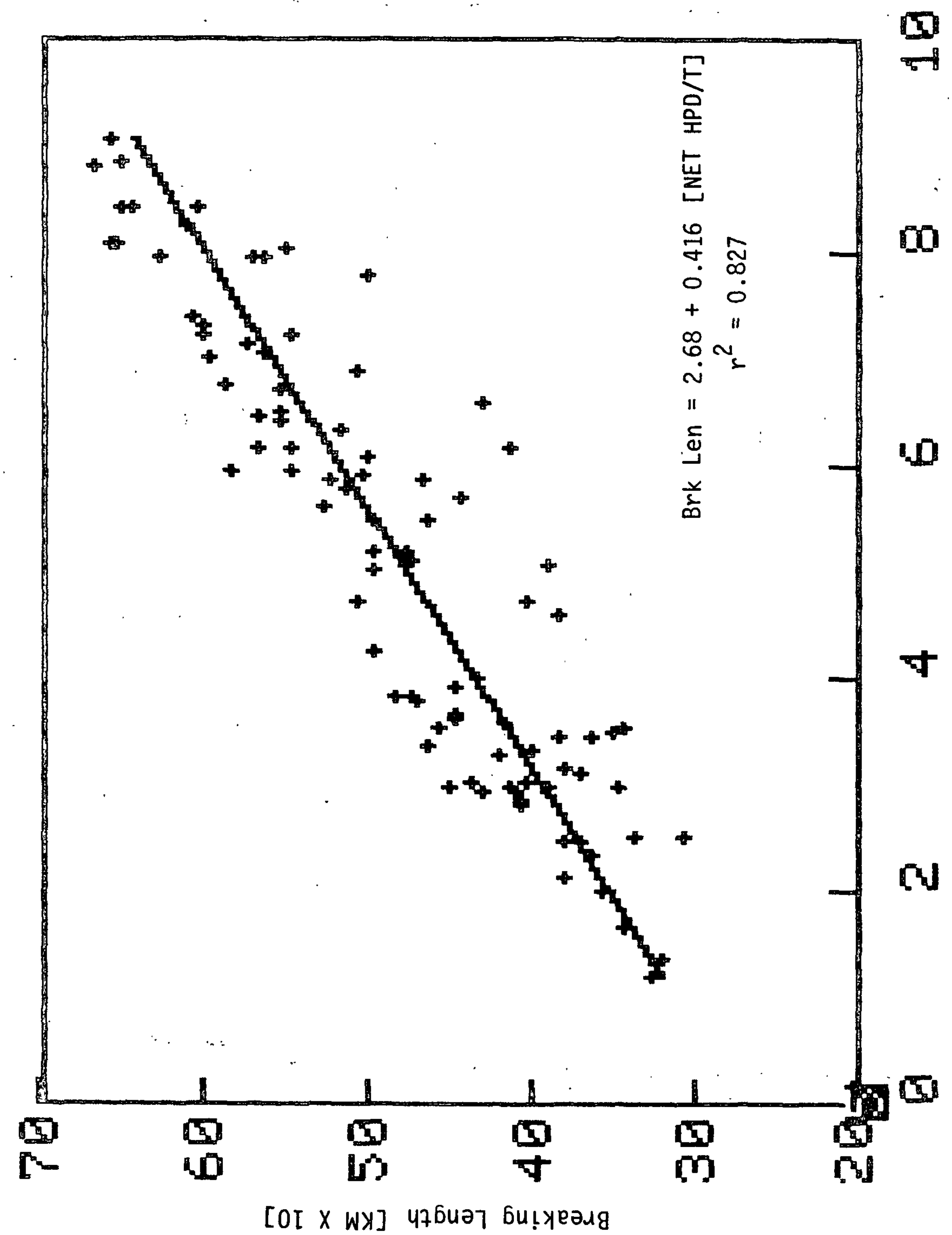


Figure 9. Breaking length as a function of net horsepower.

using higher power terms, N=2 or 3 in Eq. (3), did not improve the correlations significantly. Also, correlations for k other than 1.0 were not significantly better, thus suggesting that IHP is a good measure of the effective losses in the refiner. The specific correlation equations and r^2 values are listed on the figures. For completeness, STFI compressive stength is plotted versus ring crush (RCT) in Fig. 10. These variables are well related by a straight line having $r^2 = 0.90$. Tear-tensile data are shown in Fig. 11.

From these data, it is evident that end-use properties are well-related to net specific horsepower for the twin-flo refiner. It is also evident that there is considerable scatter in the data. Despite the scatter, simple linear relationships to NHPD/T account for about 85-90% of the variability in properties. These data were also fitted with correlations which included specific edge load, speed, gap, and several other variables, in addition to net specific horsepower as noted in Table 1. Some of these gave slightly higher correlation coefficients, but the improvements were slight and not worth the extra complexity.

Fiber property development, at least from an end-use performance point of view, is not significantly sensitive to any refining variable other than net specific power. This is consistent with Levlin (7), whose work showed that coarse kraft pulps are not sensitive to specific edge load. Hence, the choice of refining speed and gap for a given net specific power level is dictated by other considerations such as energy consumption, general refiner operation and so on. Figure 12 shows STFI compressive strength versus total specific energy, plotted separately for each of three distinct operating speeds. For a given STFI level, say 30 lb/inch the corresponding total horsepower varies from 8 at 800 rpm to 27 at 1600 rpm. Analyses based on burst or breaking length would show similar dependence on speed and total specific horsepower.

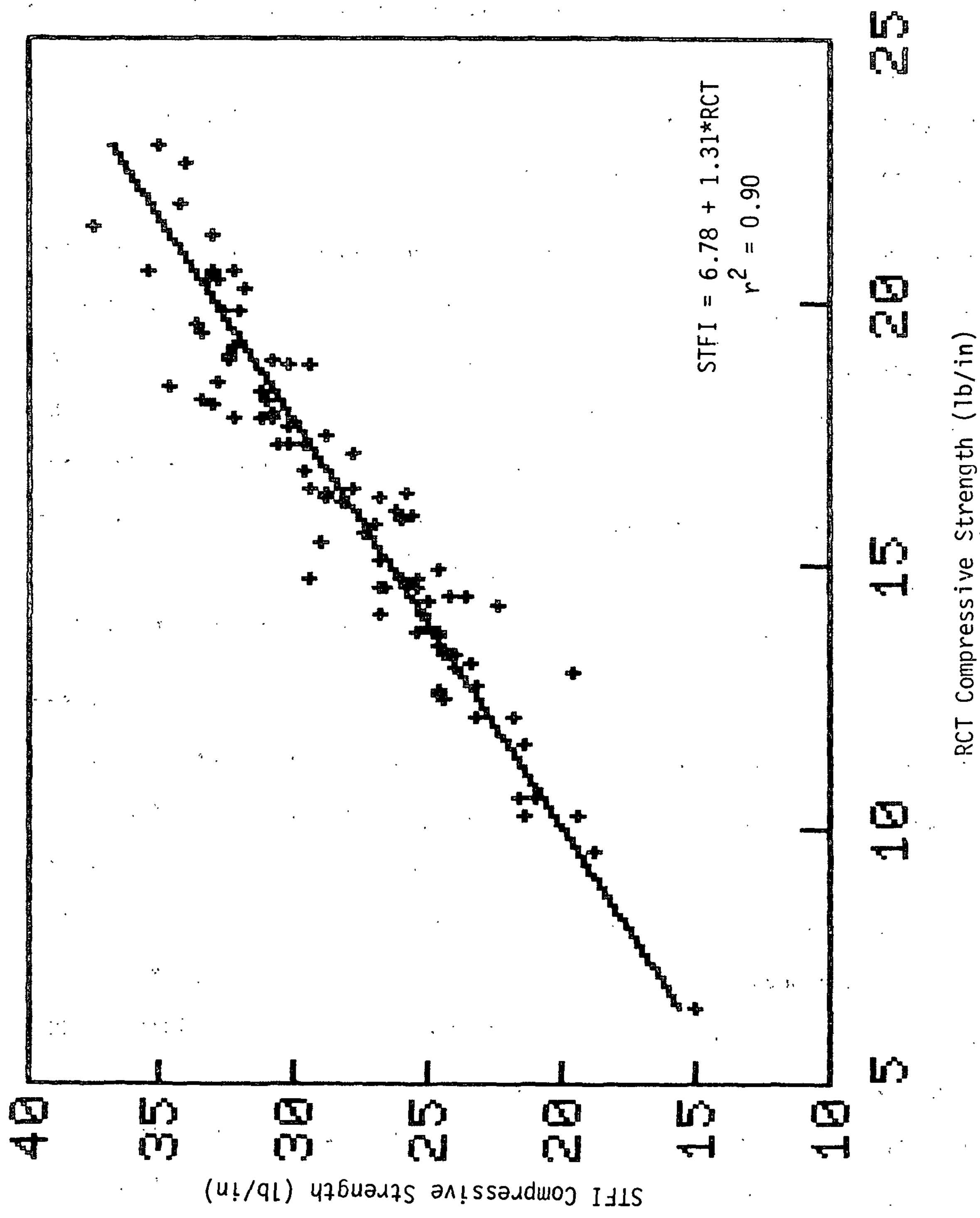


Figure 10. The relationship between STFI and RCT compressive strength values.

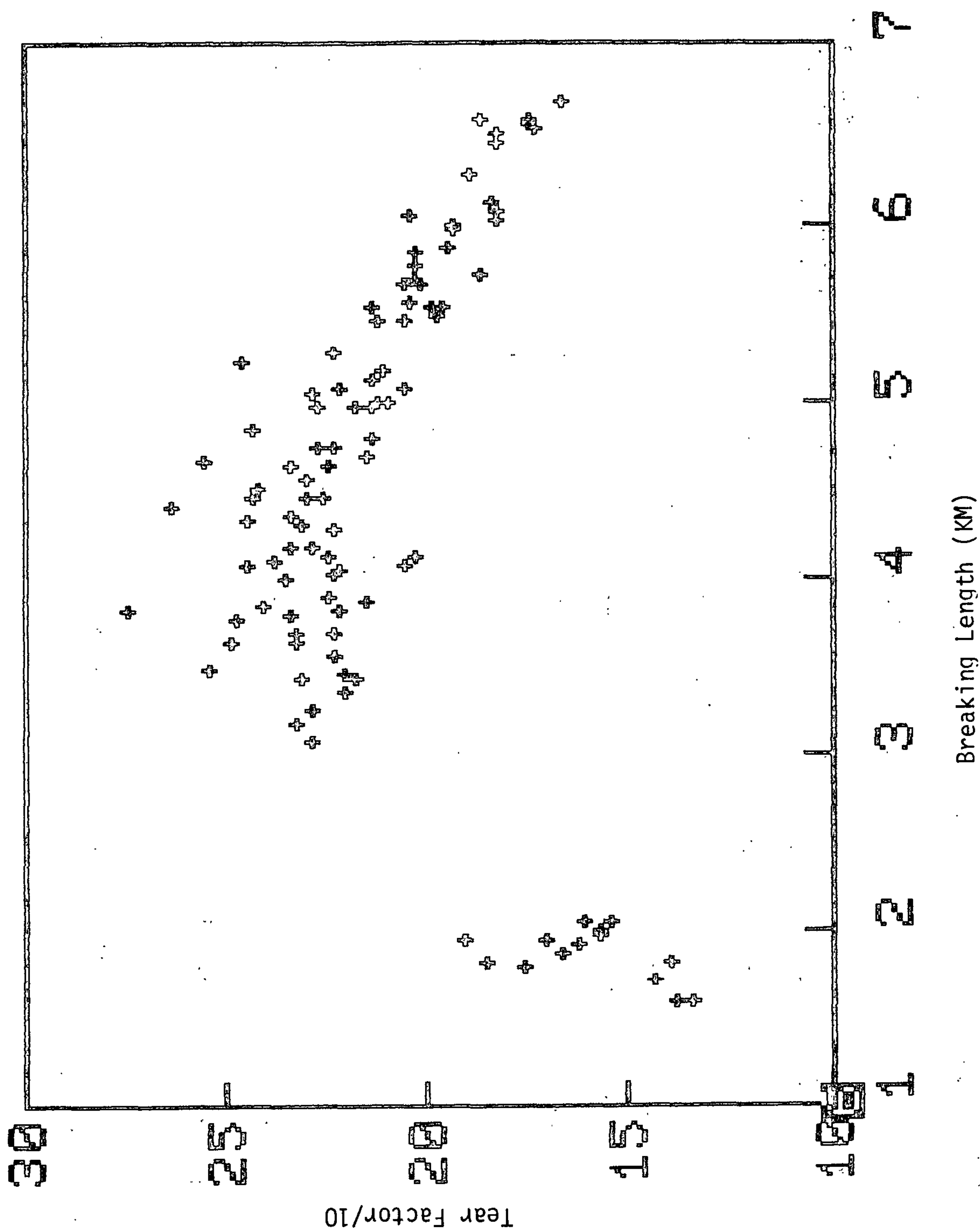


Figure 11. The tear-tensile relationship.

Table 1. Correlation equation multiplying and correlation coefficients for STFI compressive strength and refiner operating conditions.

Correlation Coefficient, r^2	Net Specific Horsepower, NHPD/T	$(NHPD/T)^2$	Gap, mils	Speed, rpm	Number of Passes	Consistency, %	Flow, gpm	Consistency x Flow	Specific[a] Edge Load WS/M	Constant
	Multiplying Coefficients for									
0.870	1.82	--	-0.996	0.000746	--	-0.0364	-0.00489	--	-0.731	22.8
0.867	1.81	--	-0.882	0.000884	--	--	--	--	--	20.8
0.865	1.84	--	-0.845	--	--	--	--	--	--	21.6
0.857	2.95	-0.103	--	--	--	--	--	--	--	--
0.850	1.90	--	--	--	--	1.24	-0.0162	-0.00846	--	16.4
0.850	1.90	--	--	--	--	0.695	-0.0467	--	--	18.4
0.846	1.88	--	--	0.000553	--	--	--	--	--	17.6
0.846	1.90	--	--	--	--	--	--	-0.00414	--	19.1
0.845	1.91	--	--	--	-0.00718	--	--	--	--	18.2
0.845	1.90	--	--	--	--	--	--	--	0.0645	18.1
0.845	1.90	--	--	--	--	--	--	--	--	18.2

[a] Specific edge load (SEL) $= \frac{110\ [\text{NET HP}]}{\text{rpm}}$

Note: These correlations all use STFI compressive strength as the dependent variable. Similar results would be obtained with BURST, BREAKING LENGTH, or DENSITY.

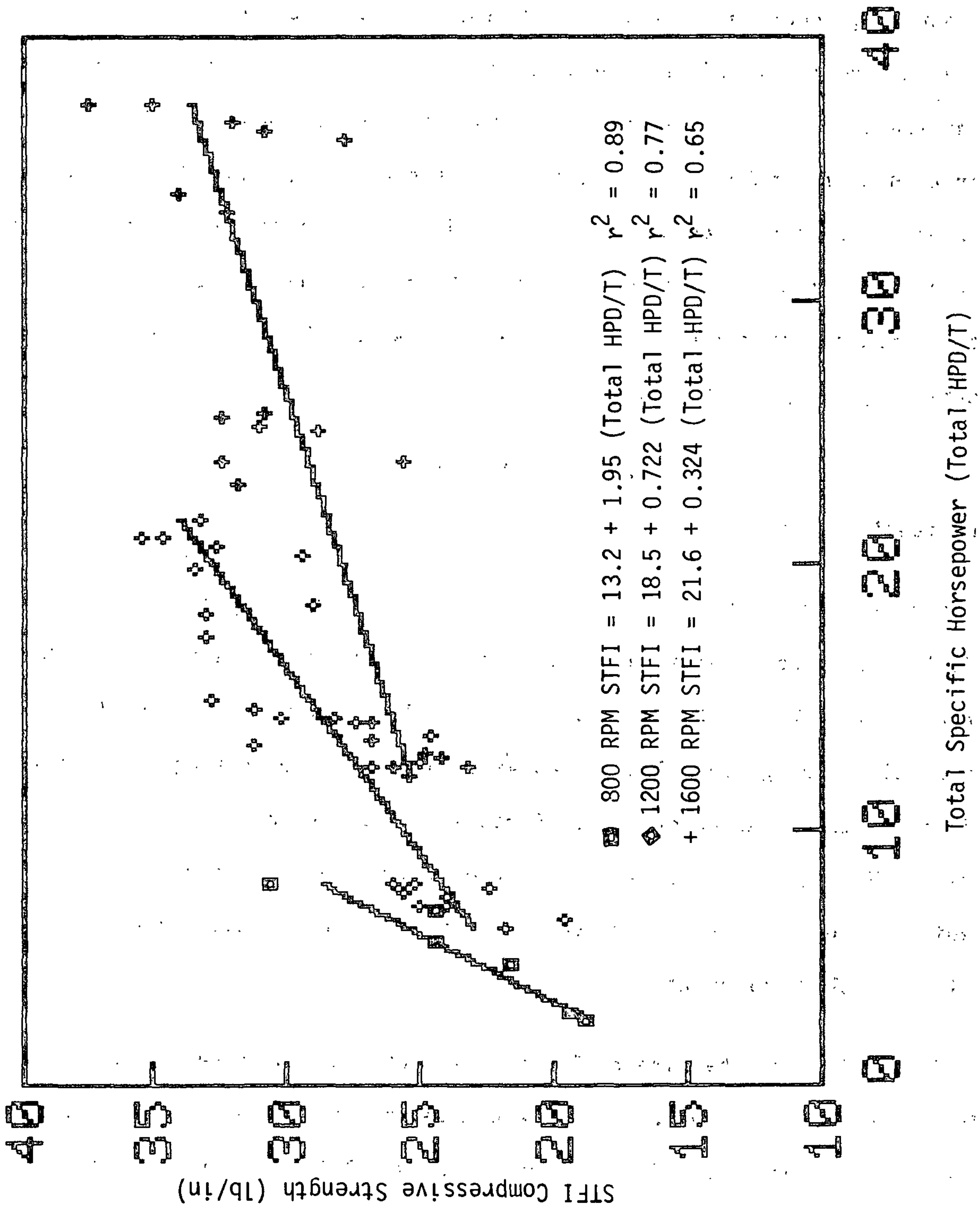


Figure 12. The relationship between compressive strength and total specific horsepower for various refiner operating speeds.

Paper Machine Runnability

Refining also affects pulp drainage and dewatering and, hence, machine runnability. Pulp properties affecting strength tend to remain constant as refiner operating conditions are varied at a given net specific horsepower level, thus affording significant opportunities to save energy by operating at low speeds and low gaps. It is important, however, to evaluate the effect of such operation on the pulp factors that affect runnability, e.g., Canadian Standard freeness. Canadian Standard freeness tends to be a very nonlinear function of almost all refining or other property variables and, thus, does not lend itself to simple linear correlations. However, most of these relationships can be linearized by using a new variable

$$LINCSF = 750-CSF$$

on a logarithmic scale.

Figure 13 shows STFI compressive strength plotted versus log (750-CSF) with refining speed as a parameter. All three speed curves intersect at a CSF value of about 725 mL (750-CSF = 25). For CSF values below 725, (750-CSF above 25), low speed refining gives less freeness loss per unit of strength gain than higher speed refining, although the differences are modest and, perhaps, not significant. Hence, for linerboard base stocks, low speed refining leads to both significant energy savings and constant or improved runnability at given levels of strength development.

In a more comprehensive analysis, which will not be detailed here, about 91% of the variability in CSF was accounted for by net specific energy. Of the remaining 9% of variability, almost none is related to gap or specific edge load or any other refiner operating variable. Including both total specific energy and net specific energy improves the correlation to about 92.5%.

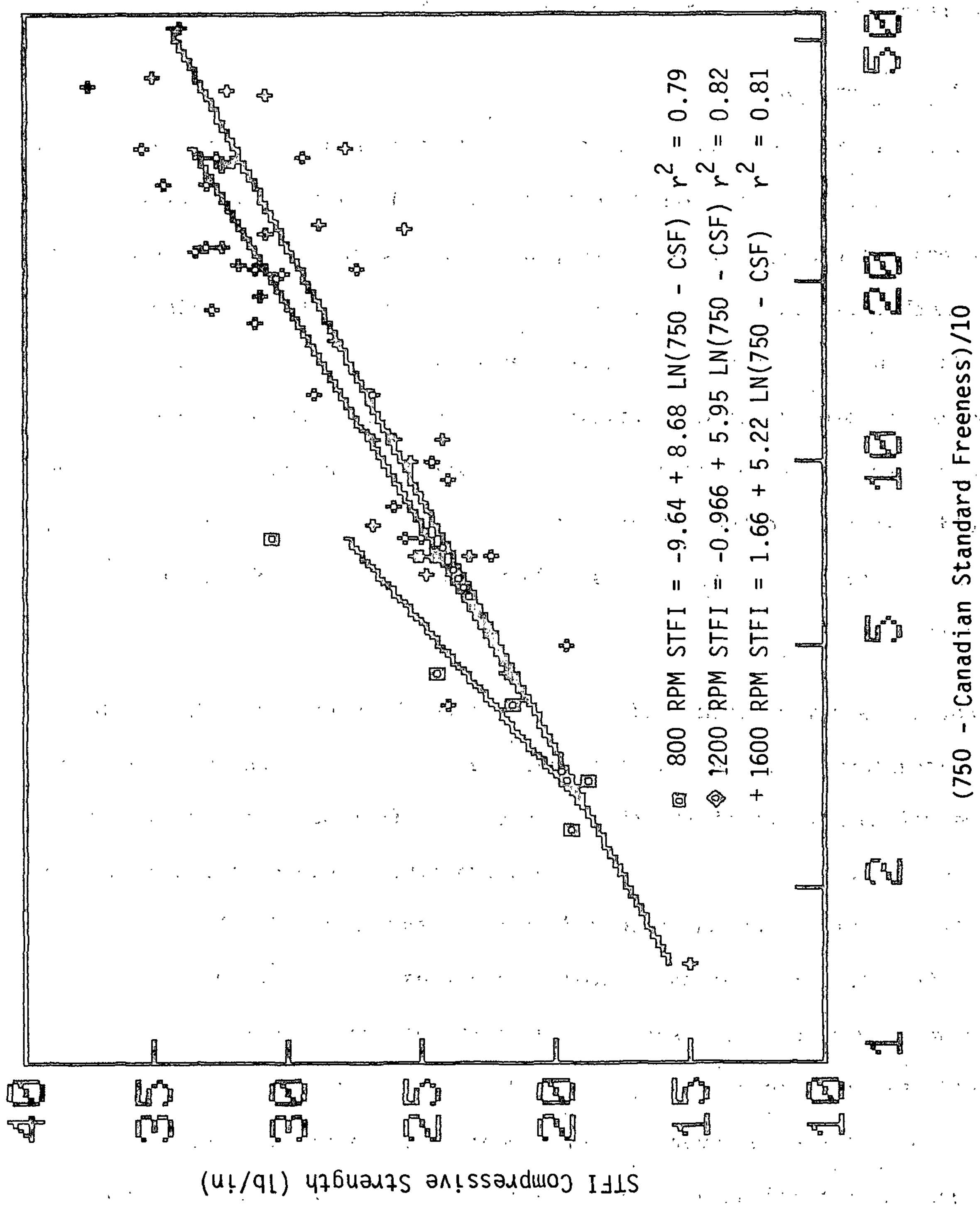


Figure 13. The relationship between compressive strength and 750-CSF for various refiner operating speeds.

Hence, CSF decreases very slightly as total specific horsepower increases at a given net specific horsepower. This is consistent with the data in Fig. 13 which suggest that refining should be carried out at the lowest possible speed, which also means the lowest total specific energy level.

Operating Considerations

It is clear, from the foregoing data and analyses, that the refining of linerboard base stock can be carried out over a broad range of operating conditions to produce nearly equivalent pulp strength and drainage properties. At low speeds much less total energy is required to carry out the refining process. Lower speeds require lower gaps to achieve an equivalent net specific horsepower, the key to proper property development. To achieve these conditions, gear boxes or variable speed drives will be required. The capital cost of these items should be quickly offset if significantly lower gaps are possible. This, in turn, will be determined by the basic design and operating characteristics of a given refiner.

For the studies documented in this report throughput was changed by only a modest amount. However, it was never necessary to reduce throughput to operate the refiner at any of the chosen conditions (a range much broader than is typical of commercial refiners), and pulp properties development was not sensitive to throughput. Westman collected data for throughput levels of 1.3, 1.8, and 2.5 m^3/min. for a refiner that normally operates at 1.7 m^3/min. None of his results showed any significant sensitivity to throughput. Limited earlier studies at the Institute also showed that property development does not depend on throughput (for a given net specific horsepower). Collectively, these data strongly suggest that refining capacity need not decrease as speed and gap (and total specific horsepower) decrease.

CONCLUSIONS

1. For disk refining of linerboard base stock, pulp strength and runnability properties depend largely on net specific horsepower and show little sensitivity to all other operating parameters including specific edge load, speed, gap, consistency, and throughput.

2. Lower speed refining with attendant smaller plate gaps develops properties equivalent to higher speed refining but at substantially lower total refining energy levels.

3. Refining capacity can be maintained at lower speeds and gaps.

LITERATURE CITED

1. Atalla, R.; Wahren, D. Energy Requirement in Refining. Tappi 63(6):121-2 (1980).

2. Arjas, A.; Huuskonen, J.; Ryti, N. Paperi Puu 52(4):269(1970).

3. Higgins, B. Energy Considerations for the Disk Refiner. 1981 Executives' Conference Proceedings, The Institute of Paper Chemistry.

4. Westman, L. Idling Losses in the Low-consistency Refining of Chemical Pulp. Svensk Papperstid. 3/1984:R8-13.

5. Unpublished work at The Institute of Paper Chemistry.

6. Sinkey, J. Refining of Chemical Pulps for Improved Properties. Status Reports to the Engineering Project Advisory Committee, Oct. 24-25, 1984.

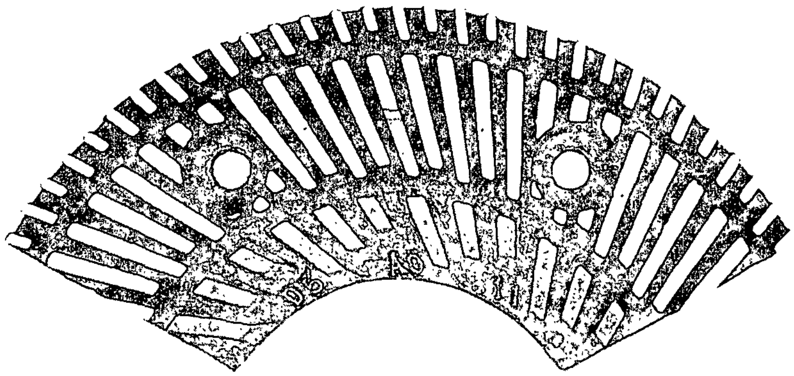
7. Levlin, J.-E. Characterization of the Beating Result. International Symposium on Fundamental Concepts of Refining, The Institute of Paper Chemistry, Appleton, Wisconsin, 1983. 127 p.

THE INSTITUTE OF PAPER CHEMISTRY

Clyde H. Sprague

Clyde H. Sprague
Director
Engineering Division

APPENDIX A



PATTERN	CODE	MATERIAL	PERIPHERY	DAMS	REMARKS
D5A011	B	Ni-Hard		None	15° Bar Angle
D5A012	B	Ni-Hard		None	Same as above
D5B011	B	440-C		None	Same as above
D5B012	B	440-C		None	Same as above
D5C011	C	Hi-C		None	Same as above
D5C012	C	Hi-C		None	Same as above

Sprout-Waldron 12-inch Twin-Flow Refiner Plate