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Title: A STUDY OF DESHIVE REFINING AND ITS EFFECTS ON HIGH YIELD KRAFT PULP

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High yield unbleached kraft pulp for linerboard and bag paper was deshived in a PFI mill and a Bauer model 187 double disk refiner. Levels of plate gap, specific energy consumption, throughput rate, and stock consistency were varied to control PFI mill and Bauer 187 deshive refining. Shive content reductions were accurately monitored with the von Alfthan shives analyzer. Mathematical models expressing post-treatment von Alfthan values in terms of the four control variables were proposed for both refining machines.

The PFI mill was an effective deshive refiner, but a poor modeling base due to the insensitive response of shive content to changes in processing conditions. The Bauer 187 performed well as a deshive refiner and model base. A strong relationship was found between post-treatment von Alfthan values and Bauer 187 control variables. A best model of Bauer 187 deshive refining was selected

by the total square error criterion. That model involves a complex relationship of plate gap, stock consistency, and throughput rate, but, in general, reducing plate gap and increasing stock consistency reduces post-treatment shive contents. Conditions which optimized the efficiency of Bauer 187 deshive refining depended upon the desired shive content of processed pulp. Shive contents typical of industrially deshived pulp were most efficiently obtained by Bauer 187 deshive refining at 1.5 mm plate gap, 1.2 kg/minute throughput rate, and 12 percent consistency.

The effects of deshive refining on pulp washing and strength development potential were also investigated. Chemical recovery from high yield kraft pulp was improved by Bauer 187 deshive refining. Washing improvements became more pronounced as pulp yield was increased. Pulp strength at common levels of CSF and sheet bulk generally benefited from Bauer 187 deshive refining. Strength differences between deshived and undeshived pulps were attributable to differences in the amount of strength development beating necessary to achieve specified bulks and freenesses.

A Study of Deshive Refining and Its Effects on High Yield Kraft Pulp

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TABLE OF CONTENTS

LIST OF FIGURES

A STUDY OF DESHIVE REFINING AND ITS EFFECTS ON HIGH YIELD KRAFT PULP

INTRODUCTION

Paper is a collection of fibers formed into a web. The nature of the fibers and the methods used in their manufacture and formation determine the properties of the resulting paper. Wood is the most common source of papermaking fibers, and the sulfate or kraft process is the most widely used chemical procedure for converting wood into wood fibers.

The kraft pulping process produces wood fibers by dissolving the lignin which holds those fibers together in solid wood. This dissolution is not highly selective, and some desirable fiber material as well as adhesive is dissolved. The percentage weight of dry fiber recovered from a given weight of wood is known as pulp yield. Conventional kraft pulp is prepared to a point where nearly all wood separates into individual fibers with little or no mechanical action. To reach this point of "fiber liberation" approximately 50 percent or more of the original wood material is dissolved causing typical kraft pulp yields to be 50 percent or less.

High yield kraft pulp (yields greater than 50 percent) is used extensively in the production of bag paper and linerboard. Efforts to produce it usually result in pulps having an unacceptably large number of incompletely fiberized fiber bundles. Larger fiber bundles are often known as rejects, and smaller ones are called shives. These fiber bundles are unsuitable for papermaking, but they can be made acceptable by further treatment. The manufacture of high yield kraft pulp depends on the successful reprocessing or fiberization of rejects and shives.

There are essentially two ways to deal with the fiber bundles present in high yield kraft pulp. One approach is to screen them out of the pulp flow and treat them separately. They ordinarily cannot simply be discarded as the resulting yield of acceptable fibers would frequently be less than that of a conventional kraft pulp. The two realistic options for handling screenings are to return them to the pulping process as though they were fresh wood, or mechanically fiberize them and blend them back into the pulp flow as acceptable fibers.

A second way of dealing with rejects and shives is to mechanically treat the entire pulp flow in a manner specifically designed to break apart fiber bundles. When pulp is subjected to this kind of treatment while still under digester pressure, it is known as blow-line refining. When the treatment occurs at atmospheric pressure and involves pulp containing the waste pulping liquors, it is called hot-stock refining. Blow-line and hot-stock refining are designed primarily to fiberize rejects, the larger fiber bundles. When mechanical treatment of the entire pulp flow occurs after some of the waste liquor has been washed out of the pulp, it is called deshive refining. As the name suggests, the main objective of deshive refining is the fiberization of shives, the smaller fiber bundles.

Blow-line and hot-stock refining have quietly taken their places in the scheme of high yield kraft pulp production. Deshive refining has taken its place also, but its inclusion in the high yield kraft production line has been surrounded by debate. Advocates of deshive refining tout it as a shive content reducer which does not adversely effect pulp drainage rates. They further claim that specific energy consumption of the process is low, that pulp strength potential is unchanged or improved, and that the potential for recovering chemicals from a pulp is improved if pulp washing follows deshive refining. Those who question the value of the process point out that while the deshive refiner does reduce the shive content of a high yield kraft pulp, it sometimes requires a higher specific energy than expected, reduces pulp strength potential in some cases, and modifies the pulp in a way that reduces the operating capacity of equipment downstream from its location.

Because of the controversy surrounding deshive refining, particularly in view of high yield kraft pulp's importance to the Pacific Northwest, a project was initiated to examine the fundamentals of the deshive refining process. Objectives of this project are:

1. Mathematically model deshive refining for the PFI mill, a laboratory refining machine, in terms of pulp weight, pulp consistency, specific energy consumption, blade gap, and beating pressure.
2. Mathematically model deshive refining for the Bauer 187 double disk refiner, a pilot plant scale refining machine, in terms of plate gap, pulp consistency, pulp throughput, specific energy consumption, and relative disk speed.
3. Compare and contrast the deshive refining capabilities of

the PFI mill and the Bauer double disk refiner with the capabilities of deshive refiners used industrially.

4. Examine secondary characteristics of deshive refining, with special emphasis on strength potential and chemical recovery.

LITERATURE REVIEW

The Shive

The Dictionary of Paper (1) defines a shive as "A bundle of incompletely separated fibers which may appear in the finished sheet as an imperfection." While this definition is quite general, researchers in the mechanical pulping industry are unable to agree on a more specific one (2), and better definitions for the chemical pulping industry were not found in the literature. Typically, authors define the shive exclusively for the purposes of their study and then only in terms of whatever procedure is being used for shive quantification. If, for example, screening techniques are used to measure shives, a shive will be defined as any debris retained on a screen of specified size (3). Shives may not be definable in a universally satisfactory manner, but their presence is troublesome for several reasons.

Sheet appearance is the most obvious and widespread problem associated with shives. Unless a shive is very small, a "bundle" of perhaps two fibers, it will cause a visible flaw in the paper web. Such flaws are known as dirt or specks. Dirt can be quantified (4), and customers often specify that the ratio of speck area to paper area may not exceed a stipulated amount. Shives detract from the appearance of all papers, whether made from mechanical pulp, or from bleached or unbleached chemical pulp.

Strength degradation as a result of shives is also of concern to papermakers. Sears, Tyler, and Denzer (5) found that shives in newsprint are poorly bonded to surrounding fibers, and that shives are the most common cause of web failure attributable to the paper itself. In a companion paper MacMillan, Ferrell, and Booth (6) substantiated these claims. The effect of shives on the strength of chemical pulps remains largely unexplored; however, unbleached kraft handsheets with high shive contents have lower burst and tensile strength than similar handsheets with low shive contents (7).

Chemical recovery in kraft mills may be affected by shives. Kurdin (8) claims that large shives generated during high yield kraft pulping reduce a mill's ability to remove chemicals at their brown stock washers. He states, "Insufficient defiberization prior to washing will reduce efficiency and will result in increased chemical loss." This decrease in washing efficiency is said to occur at yields above fifty-five percent. Hartler, Danielsson, and Ryrberg (9) have also observed this phenomenon.

Definition of Deshive Refining

Deshive refining, DSR, is a mechanical treatment of high yield kraft pulp occurring after the first, second, or third stage of brown stock washing. It is performed at a consistency of between 12 and 15 percent, specifically at the particular consistency of pulp departing a rotary drum washer. Disk refiners of large circumference and high peripheral speed are used to assure a low intensity refining action (8). Deshive refiners are usually operated at specific energy levels of approximately 60 kilowatt-hours per metric ton of dry pulp (10). Good deshive refining will not significantly affect a pulp's freeness or fiber length; it brushes out fiber bundles without fibrillating or cutting (9).

Consistency of Deshive Refining

The overwhelming majority of all pulp refining is accomplished at consistencies of less than six percent. Refining machines operating on low consistency pulps are well understood, and their effects on pulp have been reported by several researchers (11, 12, 13, 14, 15, 16). The predominant mechanical action of low consistency refining is one of fibers striking the leading edge of rotating metallic refiner bars. Refiners can be designed to emphasize fiber cutting or fibrillation. Low consistency refining in paper mills develops sheet strength and improves sheet formation, and is normally performed just before sheet manufacture.

The effects on fibers peculiar to high consistency refining become observable at consistencies above approximately ten percent (17), but consistencies of 20 percent or higher improve the efficiency of the process (18). Salient aspects of high consistency refining are reported as part of Fahey's (18) excellent review of the literature of refining. Early work in high consistency refining was performed by West (17) who suggests that the dominant mechanical action of the process is one of fibers rubbing fibers. He observed that fibrillation proceeds in an environment where fiber cutting is essentially nonexistent. Some fiber length reduction observed by Page (19) is a clear result of fiber compression. The foremost advantage of high consistency refining is that tear resistance, stretch, and especially toughness can be developed at higher freeness levels and lower specific energy consumptions than are possible with low consistency refining (17).

Unfortunately, the rates of burst and tensile strength development relative to freeness drop realized with high consistency refining do not differ markedly from those of low consistency refining, and at high consistencies more energy is required to achieve a given freeness than is the case at low consistencies (17). Thus in the manufacture of most paper grades, the extra refining energy is not considered worthwhile, and industrial applications of high consistency refining have been limited.

Fahey states:

> "Refiners which will handle pulp at intermediate consistency yield the most pronounced effects and greatest efficiency if operated at 20% consistency or higher. Thus, refining at 10-12% would offer no attraction and to some extent has been neglected." (18).

So it is that a paucity of literature exists in the area of medium consistency refining, those consistencies at which deshive refining takes place.

Deshive refining performed at consistencies above ten percent should exhibit some characteristics of high consistency refining. Despite its low specific energy inputs, approximately 60 kilowatt-hours per dry ton, Fahey's statement implies that some improvement in stretch, tear resistance, and toughness may be realized in the finished sheet by virtue of deshive refining. These properties would be beneficial to both linerboard and bag paper, which together represent nearly all paper made from deshive refined pulp. Fiber cutting should be minimal, or missing entirely. The absence of significant fiber length reduction is essential for successful deshive refining as fiber cutting would ruin the long-fibered character of softwood kraft pulps and result in reduced freeness properties.

Intensity of Deshive Refining

Deshive refining was described earlier as being low intensity refining. The intensity of refining, also known as severity of impact, refers to the way in which pulp absorbs energy, not to the amount of energy absorbed. A fiber absorbing a unit of energy after a large number of fiber-metal and fiber-fiber impacts has been refined at a lower intensity than a fiber which absorbs a unit of energy after a small number of such impacts. Studies of low consistency refining have been undertaken which relate refining machine parameters to the average number of impacts experienced by a fiber. The two studies addressed below both support Kurdin's opinion that deshive refiners should be large machines with high angular speeds.

Leider and Rihs (12) derived the following expression for low consistency refining in disk refiners:

$$N = k \frac{D_m^3 \, L \, R}{W_m^3 \, Q} (D_f L_f)$$

where: N = Average number of impacts per fiber during refining

k = Constant equal to $(\pi^3/4)$

D_m = Mean diameter of refining zone $(D_1 + D_2)/2$

W_m = (bar width + groove width)/2

L = Groove length

R = Revolutions per minute

Q = Volumetric flow rate

D_f = Average fiber diameter

L_f = Average fiber length

As the average number of impacts per fiber increases, the intensity of refining decreases. In the expression above the average number of impacts per fiber increases with increasing disk diameter, groove length, number of bars/grooves, and angular velocity; and with decreasing throughput. If conclusions based on low consistency refining can be extended to medium consistency refining, low intensity deshive refining should employ disk refiners of large diameter, having relatively closely spaced bar/groove patterns, turning at high angular speeds, and operating at low throughput rates.

Danforth (20) proposed the following relationship describing the number of impacts per fiber with the parameters of a low consistency conical refiner:

$$N = k \frac{L_r \, L_s \, (\mathrm{RPM}) \, (\mathrm{CONS})}{X \, T}$$

where: N = Number of impacts per fiber

k = Constant of proportionality

L_r = Total length of rotor bars

L_s = Total length of stator bars

RPM = Revolutions per minute

CONS = Stock consistency

X = Average bar contact length

T = Throughput rate

According to Danforth's expression an increase in angular velocity, length of rotor and stator bars, or consistency; or a decrease in average contact length or throughput rate increase the number of impacts per fiber. An increase in total length of rotor and stator bars could result from either a larger conical refiner, or an increased number of thinner, more closely spaced bars. More numerous rotor and stator bars would, if shorter, also reduce average bar contact length. Increasing consistency simply provides a higher probability of fiber-fiber impact and hence a higher number of impacts per fiber.

Again, if low consistency refining conclusions pertain to medium consistency refining, Danforth's study of conical refiners suggests that low intensity deshive refining should be accomplished in large, high speed machines having a closely spaced bar/groove pattern operating at low throughput rates. These conclusions are not unlike those suggested by Leider and Rihs' work, and in addition, Danforth identifies consistency as a factor effecting the average number of fiber impacts, ultimately influential to refining intensity.

Reported Effects of Deshive Refining

Deshive refining reduces the shive content of high yield kraft pulps (8, 9). Pulps of reduced shive content form sheets of improved appearance. Most manufacturers of linerboard have installed deshive refiners solely as a means of competing successfully in the appearance conscious marketplace (10).

Installation of deshive refiners allows mills to produce satisfactory linerboard and bag paper from pulps of higher yields than were possible before deshive refining, because DSR reduces the shive content of high yield pulps to acceptable commercial levels (8, 9). The promise of more efficient wood utilization and increased daily production are obvious incentives favoring DSR.

Judicious placement of a deshive refiner has reduced sodium losses in a Swedish high yield kraft mill (9). Using deshive refiners after washing not only controls shive contents, but also enables hot stock refiners to be adjusted for maximum washing efficiency. It is believed that deshive refining alone, if accomplished between the second and third stage of brown stock washing, will result in improved chemical recovery (10).

Although bleachable grade kraft pulp is of much lower kappa number and shive content than is high yield kraft pulp, DSR can reduce bleaching chemical costs by delivering cleaner pulps to the bleach plant (9). Extra quantities of bleaching chemicals are consumed when bleaching undeshived pulp. A Swedish mill producing bleached kraft market pulp observed a 50 percent reduction of shives into their bleach plant after installing a deshive refiner.

The effects of DSR on the strength of high yield kraft pulp remain largely unexplored. Kurdin (8) reported pulp strengths immediately after DSR at various energy consumption levels. His data show gradual strength improvements with increased DSR work, but he did not compare the strengths of deshived and undeshived pulps after refining stages beyond DSR. Bublitz (21) compared the strengths of deshived and undeshived pulps after PFI mill strength development refining (SDR). He found that DSR did not improve and may actually have impaired pulp strength.

EXPERIMENTAL

The following section contains experimental information of a general nature. Specific experimental considerations immediately precede discussions of results when that arrangement improves continuity.

Sample Collection and Preparation

Approximately 300 dry kilograms of undeshived, high yield pulp were obtained from Western Kraft Corporation, Albany, Oregon, for PFI mill and Bauer 187 double disk refiner modeling studies. This 76 Kappa pulp, normally used in the base layer of kraft linerboard, was gathered from the last of three rotary drum brownstock washers. The stock had been previously treated by a Morden fiberizer and screened through a knotter. No blow-line or hot-stock refining had been accomplished. Undeshived pulp was taken from location 1, Figure 1.

Approximately ten dry kilograms of deshived pulp were also collected. Except for deshive refining by Western Kraft this pulp was historically identical to the undeshived pulp described above. Deshived pulp was taken from location 2, Figure 1.

Pulp samples were also obtained from International Paper Company, Gardiner, Oregon. International Paper (IP) pulp was 100 Kappa and had received hot-stock refining at approximately 40 kilowatt hours per oven dry ton prior to deshive refining. Deshived and undeshived samples were taken from locations 2 and 1, respectively, Figure 2.

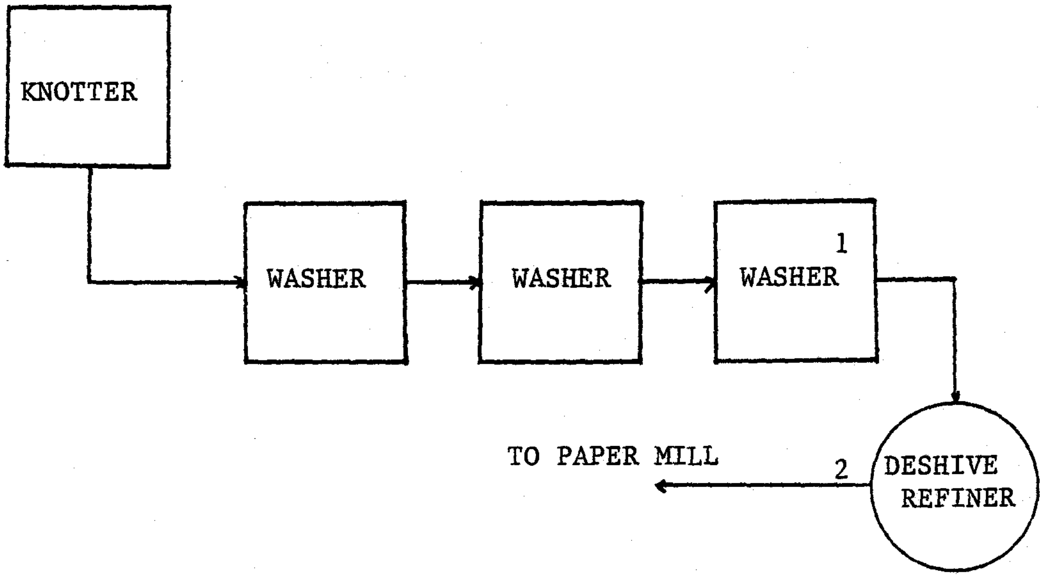


Figure 1. Pulp flow diagram for Western Kraft Corporation.

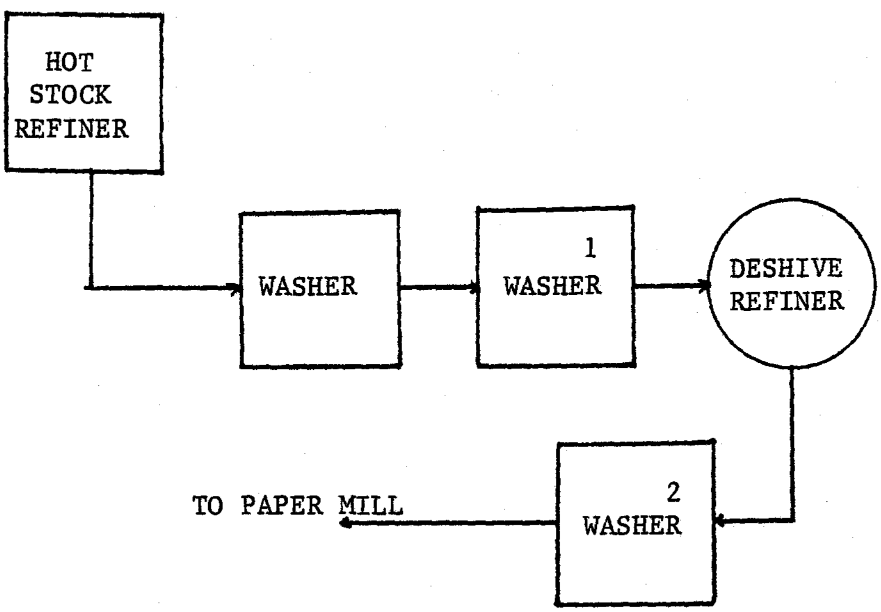


Figure 2. Pulp flow diagram for International Paper Company.

At the Forest Research Laboratory, barrels containing the Western Kraft (WK) and IP undeshived pulps were treated with 500 ml of 37 percent formaldehyde, sealed, and stored outdoors. Undeshived pulps were dewatered to 30 percent consistency as needed. Deshived pulps from both mills were immediately consolidated to 30 percent consistency and stored at 3° C in sealed bags. Before PFI mill or Bauer 187 DSR, or PFI mill strength development refining (SDR), all samples were diluted from 30 percent to appropriate consistencies with fresh water, and stabilized at ambient temperature.

Pulp Testing

The von Alfthan Shives Analyzer

The von Alfthan shives analyzer was used to evaluate pulp shive contents after deshive refining. The working principles of the instrument have been reported in detail by its inventor, Dr. von Alfthan of the Finnish Pulp and Paper Research Institute (22). The apparatus forces a pulp slurry to flow by gravity through a circular slit of adjustable width located at the bottom of a vertical tube (Fig. 3). Individual fibers pass easily through this slit, but shives having a smallest dimension larger than the chosen slit width are trapped. As shives clog the circular slit, the level of the slurry in the tube rises. Before the slurry can overflow the tube, a switch is activated that opens the slit, flushing away the trapped shives. In batch operation this process is repeated until all the pulp has passed through the slit (23). The number of flushings for a standard weight

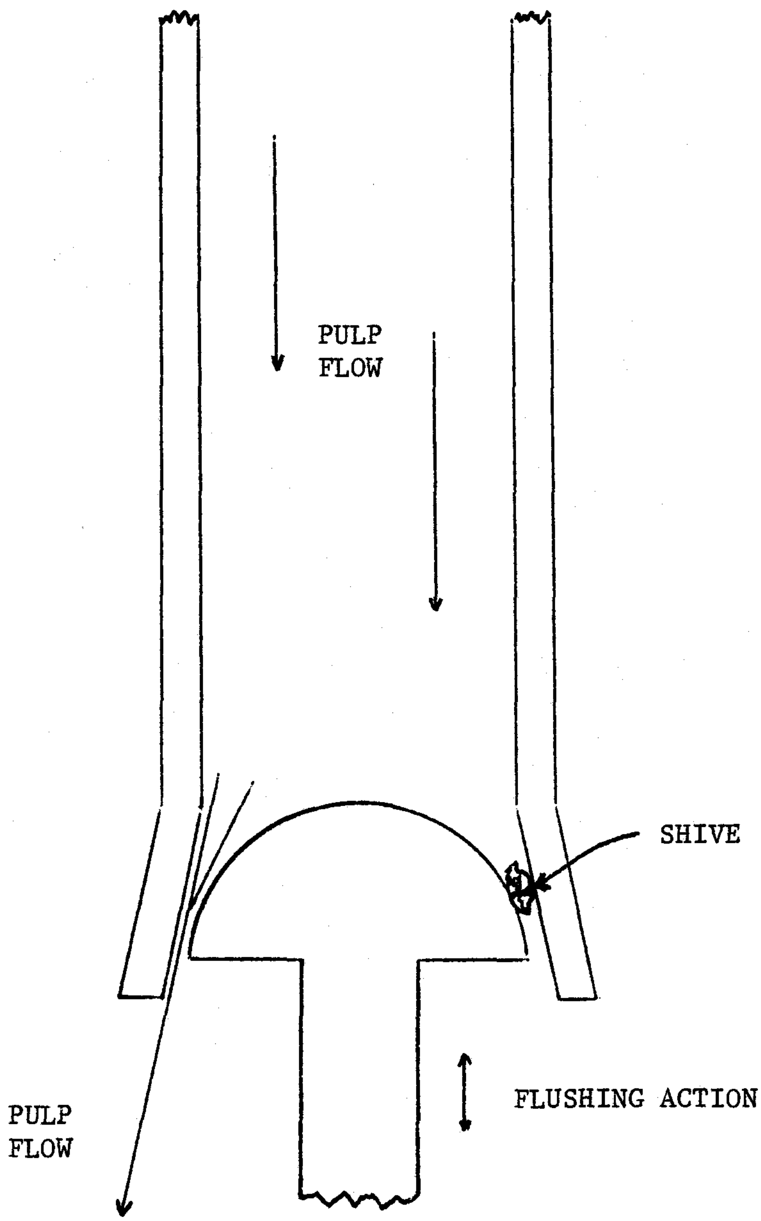


Figure 3. Von Alfthan shives analyzer - the circular slit with a trapped shive.

of dry pulp is that pulp's von Alfthan value at a given slit width. The von Alfthan operating manual recommends ten ODg of chemical pulp at 0.1% consistency be passed through a 0.18 mm slit opening, and all von Alfthan values for this study were obtained under those conditions.

A major advantage of this instrument is that shive contents are obtained from pulp slurries, obviating the sheet formation and human judgment involved with visual shive content determinations. The von Alfthan shives analyzer is faster than Bauer-McNett classification and has less potential for operator error than flat screening. Stevens, Pearson, and Chaffey (2), and a major American pulp and paper producer (24) report good correlation between von Alfthan values and other methods of evaluating shive content including appearance criteria. No method or means of shive content determination superior to the von Alfthan shives analyzer was found in the literature. The von Alfthan shives analyzer is assumed to accurately measure the true shive content of high yield kraft pulp, and the effectiveness of DSR will be judged solely on this measurement.

The Canadian Standard Freeness Test

Canadian standard freeness (25) was chosen as a means of monitoring drainage characteristics of pulp. Kurdin (8) and others claim that this test is somewhat insensitive at the freeness levels of deshived pulp, but alternatives were not available at the Forest Research Laboratory.

All other pulp testing was done in accordance with TAPPI standards or as documented in appendices.

Experimental Design

A second order, central composite, rotatable design in four variables was chosen to mathematically model PFI mill DSR, and Bauer 187 DSR was modeled with a non-rotatable but otherwise similar design in three variables. This type of design, commonly used in research, generates models in the form of response surfaces and is well described by Cochran and Cox (26), and Myers (27).

Second order rather than first order designs were selected to adequately describe any non-linear responses of DSR to changing independent variables. Central composite designs minimize the testing required to provide sufficient points for estimating the coefficients of a second order surface by adding points to a first order factorial design.

The rotatable nature of the PFI mill design insured that the variance of a predicted response was dependent only on the distance between its associated set of experimental conditions and the center of the experimental region. Rotatable designs can be thought of as treating with equal importance all sets of experimental conditions found a certain distance from the center of the experimental region. In addition to being rotatable, the PFI mill design was of the near-uniform precision type. The responses from near-uniform precision designs are of essentially uniform quality when estimated from within the limits of the factorial portion of the central composite design. The Bauer 187 design was not rotatable as throughput rates could not be precisely maintained at required levels. Both designs were well suited to exploratory modeling.

Data Analysis Techniques

The data from both DSR modeling studies was analyzed by multiple linear regression analysis. The resulting regressions were models of CSF and von Alfthan count after PFI mill or Bauer 187 DSR. The Forest Research Laboratory's HP9825 desk top calculator provided the computing power for these regressions.

The relative importance of a set of terms to a regression can be examined by the reduced model test. In that test a regression lacking the terms of interest (reduced model) is compared to a regression not lacking those terms (full model) in a manner which tests the hypothesis that the coefficients of all the eliminated terms are zero. Specifically:

Reduced Model Test (28)

H_0: $B_1 = B_2 =$ etc (of interest) $= 0$

H_A: At least one is not zero

$$F = \left[\frac{SSE(RM) - SSE(FM)}{DFE(RM) - DFE(FM)}\right] \div \frac{SSE(FM)}{DFE(FM)}$$

$$F_{critical} = F^{DFE(RM) - DFE(FM)}_{DFE(FM)}$$

Reject H_0 when $F > F_{critical}$, at the α level selected

The contribution of an independent variable to a model is readily checked by eliminating from a model of many independent variables (full model) all terms associated with the one independent variable of interest. The hypothesis that the coefficients of all terms thus eliminated are zero is tested with the reduced model test.

If the coefficients of all terms eliminated from the full model were nearly zero, the contribution of those terms to the model's prediction ability would be slight. Such small contributions occur when the independent variable associated with those terms has little or no effect on the process under consideration. Low values of F(reduced *vs* full) indicate relative insensitivity of the process to changes in the eliminated variable(s); high values indicate that the process is relatively sensitive to changes in associated variables.

Selection of a Best Model

The best way to control a process is to develop an equation which accurately relates some set of processing conditions to the response needing control. The regression model of von Alfthan count after Bauer 187 DSR is one such equation, but many of its terms are of limited consequence and may be eliminated from the full model. If the elimination of one such term resulted in a regression model having higher values of r^2 and F(regression/error), and a lower value of mean square error, the reduced model would be clearly superior to the full model. In practice the elimination of a term from a regression model results in a lower value of r^2, and it may increase the mean square error and reduce F(regression/error). Reduced models possess advantages and disadvantages compared to the full models of their origin, and various criteria, such as described by Netter and Wasserman (28) and summarized below, can be used to select the "best" model of a process.

Systems based on mean square error (MSE), coefficient of determination (r^2), and total square error (C_p) were used to select the best model of von Alfthan count after Bauer 187 DSR.

Under MSE criterion, the reduced model with the fewest terms having a MSE not significantly higher than the MSE of the full model is considered best. Likewise, the reduced model with the fewest terms having a r^2 not significantly lower than the r^2 of the full model is considered best under r^2 criterion. In both cases the selection of a best model is based on the arbitrary interpretation of whether or not the difference between MSE or r^2 values is significant.

A third method of choosing a best model involves values of C_p, an estimator of total square error. $C_p = (\frac{SSEp}{MSE}) - (n - 2p)$

where: p = number of regression parameters in the model of interest

n = number of trials (data points)

MSE = mean square error of full model

SSE_p = sum square error of the model of interest

Total square error is comprised of random error and bias components. It is assumed that the full model is without bias, and random error and bias components of smaller models are compared to those of the full model. Under the C_p criterion the model which minimizes C_p without significant bias is considered best. Like the significance of MSE and r^2 differences, the significance of a bias is determined arbitrarily. The total square error criterion does, however, result in a single lowest value of C_p, and may clearly identify a best model when other methods cannot.

PHASES OF DESHIVE REFINING RESEARCH

Mathematically modeling PFI mill DSR and Bauer 187 DSR, and assessing the effects of DSR on chemical recovery and pulp strength comprised three distinct phases of research. The individuality of these three phases overshadowed their similarities. For this reason specific experimental considerations, discussions of results, and conclusions associated with each phase have been grouped together in a single section of text.

PHASE I

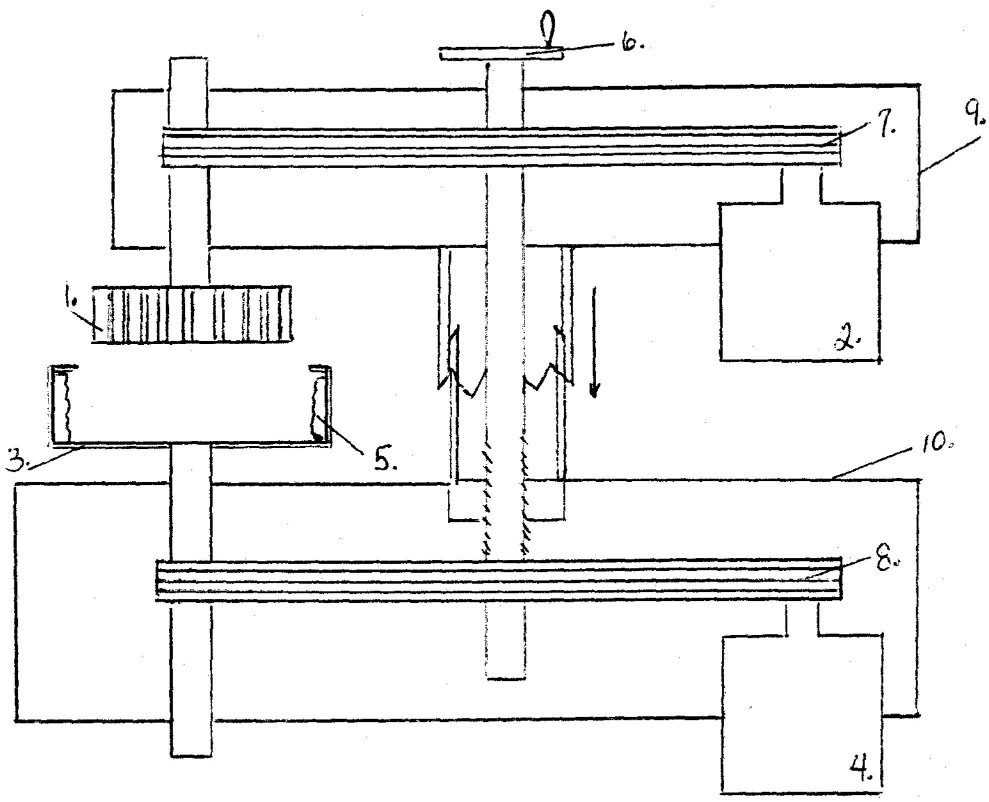
Deshive Refining with the PFI Mill

Experimental

Description

The PFI mill (Papirindustriens ForskningsInstitutt) is a laboratory pulp beating machine designed by the Norwegian Pulp and Paper Research Institute. It was chosen as the first machine for modeling DSR for several reasons. This beater is widely used in research laboratories, it is easily operated and controlled, its beating action is gentle and reproducible, and it processes small pulp batches of between five and 40 dry grams.

The knives of the PFI mill are mounted on a spindle which revolves within and against a turning bedplate bowl (Figure 4). The knife spindle and the bedplate bowl rotate in the same direction, but the knife spindle turns at a faster speed causing pulp fibers to be brushed out between the blunt knives and the smooth bedplate. The PFI mill at the Forest Research Laboratory operates at a peripheral speed differential of approximately eight meters per second at idle. This low speed differential in combination with wide blunt knives, a grooveless bedplate, and typical charges and consistencies results in predominately fiber-fiber interaction and low intensity, gentle refining.



1. Knife spindle
2. Knife spindle motor
3. Bedplate bowl
4. Bedplate bowl motor
5. Pulp mat
6. Lowering wheel
7. Knife spindle belt drive
8. Bedplate bowl belt drive
9. Upper housing
10. Lower housing

Figure 4. Representation of the PFI mill.

Independent Variables

There are six independent variables natural to the PFI mill. The minimum gap between the knives and bedplate (gap) is continuously adjustable from zero to over five mm. The dry weight of pulp processed in a single batch (charge) can be varied between 5 and 40 grams, and the consistency of that pulp can be varied upward from five percent. (Total weight of dry pulp and water may not exceed 450 g.). The pressure of the knives against the pulp mat can be set at either 18 or 33 newtons per cm bar height. The difference in peripheral speed between the knife spindle and the bedplate bowl can be adjusted by changing pulley on their belt drives. Finally, the duration of the process can be controlled in terms of number of knife spindle revolutions, time of processing, or energy (watt-sec/gram) consumed by the pulp.

The first four variables listed above are straightforward in nature and easily controlled. Their effects on deshive refining were investigated in this project. The effect of peripheral speed difference was not included in the study due to practical problems of changing pulleys and measuring actual speeds with accuracy.

Normal PFI mills are not equipped to measure power or energy consumption. The amount of PFI mill refining a pulp receives is usually expressed as the number of knife spindle revolutions (or time, since the rate of knife spindle revolutions is essentially constant) which occur during processing. The number of revolutions associated with a particular energy consumption may vary with the processing conditions of PFI mill refining, so pulp batches receiving the same amount of refining in terms of knife spindle revolutions may consume different amounts of energy. Knife spindle revolutions have meaning only for the PFI mill, but energy consumption, a more fundamental measure of refining, can be measured for all industrial and laboratory refiners, making it the preferred quantification for PFI mill DSR.

Since energy is the product of power and time, once the electrical power consumptions of the PFI mill motors were known time could be used to regulate energy consumption. Unfortunately, no description of PFI mill power consumption characteristics was found in the literature. Two YEW model 2105 wattmeters were obtained to measure, apparently for the first time, the power consumption characteristics of that machine. The choice of using energy consumption rather than the somewhat less descriptive but more easily measured revolution count or time uncovered some interesting PFI mill characteristics.

Experimental Design

The experimental design used was a second order, central composite, rotatable design in four variables (26), gap, pulp charge, pulp consistency, and throughput rate. Beating pressure, controllable only as high or low, was to be analyzed by comparing two complete replications of the chosen design.

RESULTS AND DISCUSSION

Power Use Measurements

After considerable preliminary trials the instrumentation to measure PFI mill power consumption was arranged as shown in Figure 5. One power meter measured power from the wall to the system of two motors, a second measured power drawn only by the knife spindle motor. The power load of the bedplate bowl motor was calculated as the difference between the power load of both motors and that of the knife spindle motor.

Of interest in this study was the measurement of the power (energy) actually consumed by the pulp, rather than merely the power (energy) used by the PFI mill. The efficiencies of electric motors vary with their output; highest efficiency usually occurs at or near full rated output. Nominal efficiency data for the PFI mill motors were obtained from the Baldor Electric Company, Fort Smith, Arkansas. This information was used to estimate each motor's mechanical power output from its electrical power consumption. Appendix I contains additional information regarding efficiencies of these induction motors.

It was originally assumed, since both motors apparently transfer power into the pulp slurry, that the sum of the mechanical power output of the two motors would equal the total power delivered to the pulp. The total power consumed by the pulp would then be calculated as follows:

$$P_T = P_1E_1 + P_2E_2 - P_I \qquad \text{Equation 1}$$

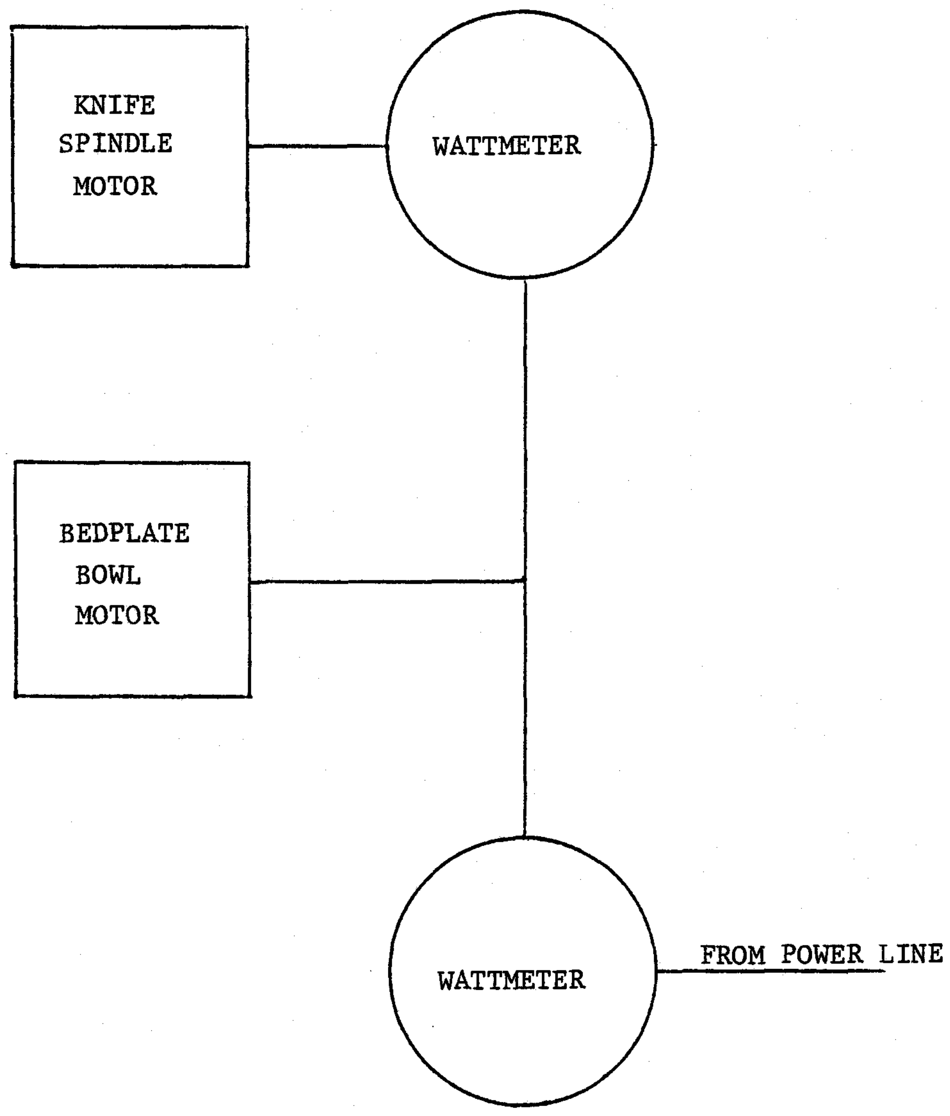


Figure 5. Wiring diagram for PFI mill wattmeters.

where: P_T is total power to the pulp in watts

P_1 is power drawn by the knife spindle motor in watts

E_1 is the efficiency of the knife spindle motor in percent

P_2 is the power drawn by the bedplate bowl motor in watts

E_2 is the efficiency of the bedplate motor in percent

P_I is the total power to refining area at idle in watts

This original assumption was quickly shown to be false for an operating PFI mill. Power consumed by the knife spindle motor alone exceeded power consumed by the two motors together. These results appeared to violate physical law, but they are easily explained. The beating action of the PFI mill is achieved by the knife spindle rotating at a higher angular (and peripheral) speed than the bedplate bowl. During PFI mill operation the knife spindle accelerates the bedplate bowl through the pulp mat to angular speeds above its idle speed, which in turn causes the bedplate bowl induction motor to be accelerated to speeds higher than idle and ultimately to speeds above synchronous. The bedplate bowl motor, like any induction motor, generates rather than consumes electrical power when operated above synchronous speed.

PFI mill power consumption is more complex than the additive description given in Equation 1. Electrical power is converted by the knife spindle motor into mechanical power. Part of that mechanical power refines the pulp slurry. Some power overcomes system friction arising from belt drives, bearings, air resistance, etc. The remainder drives the bedplate bowl motor to speeds above synchronous, and is re-converted into electrical power. Total power into the pulp slurry of an operating PFI mill is the mechanical power from the knife spindle motor less those losses associated with electrical power generation and friction. Equation 2 estimates the total power consumed by a pulp slurry during PFI mill DSR:

$$P_T = P_{M1}E_{M1} - P_{G2}\frac{1}{E_{G2}} - P_I \qquad \text{Equation 2}$$

Where: P_T is total power into the pulp in watts

P_{M1} is power drawn by the knife spindle motor in watts

E_{M1} is the efficiency of the knife spindle motor in percent

P_{G2} is power generated by the bedplate bowl motor in watts

E_{G2} is the efficiency of the bedplate bowl motor as a generator in percent

P_I is total power to the refining area at idle in watts

The product of power drawn by the knife spindle motor and its efficiency represents the mechanical power input to the PFI mill system. The power generated by the bedplate bowl motor divided by its efficiency as a generator represents the mechanical power consumed for electrical power generation. Actual speeds of the knife spindle and bedplate bowl change little, so friction losses are accounted for by the total power to the refining area at idle. The difference between mechanical power input at the knife spindle and drains due to electrical power generation and friction describes the power necessary to cut, fibrillate, fiberize, deform, and heat the pulp slurry in an operating PFI mill.

Appendix II outlines the development of equations used to estimate the efficiencies of the knife spindle and bedplate bowl motors under various loads of interest. The incorporation of estimated efficiencies under such loads permits Equation 2 to be rewritten:

$$P_T = -153.167 + 1.052P_{M1} - 0.000131P_{M1}^2 - (119.936 + 0.8611P_{G2} + 0.000402P_{G2}^2) - 52.0 \quad \text{Equation 3}$$

Where P_{M1} and P_{G2} are as defined previously, and P_T is in watts.

Specific work or specific energy consumption is the amount of energy consumed during refining by a unit weight of dry pulp. By measuring the duration of PFI mill treatment and the amount of dry pulp being processed specific energy consumption can be estimated by:

$$E_s = \frac{(P_T)(T)}{G} \quad \text{Equation 4}$$

Where: T = time in seconds

G = oven dry grams of pulp

E_s = specific energy consumption

Equation 4 can be rearranged:

$$T = \frac{(E_s)(G)}{P_T} \quad \text{Equation 5}$$

From Equation 5 processing time may be estimated for any selected level of specific energy consumption. This estimated processing time was used to deshive refine the pulp to the desired specific energy levels, thus meeting the objective of using energy to quantify PFI mill deshive refining.

The PFI Mill as a Modeling Tool

The process variables and test results of the PFI mill modeling study at low beating pressure only are presented in Table 1. These results encompass a range of von Alfthan count and Canadian Standard

TABLE 1. PFI MILL TESTING AT LOW BEATING PRESSURE

Coded Parameter Levels*				Results	
Specific Energy Consumption	Pulp Charge	Gap	Consistency	CSF ml	von Alfthan Count
3	3	3	3	692	52
3	3	3	3	694	48
3	3	3	3	690	55
3	3	3	3	690	59
3	3	3	3	690	50
3	3	3	3	690	57
3	3	3	3	695	53
2	2	2	2	706	60
4	2	2	2	686	42
2	4	2	2	706	60
4	4	2	2	694	50
2	2	4	2	710	69
4	2	4	2	698	55
2	4	4	2	696	68
4	4	4	2	692	60
2	2	2	4	686	58
4	2	2	4	692	63
2	4	2	4	708	66
4	4	2	4	698	64
2	2	4	4	702	66
4	2	4	4	707	63
2	4	4	4	710	63
4	4	4	4	696	60
1	3	3	3	715	67
5	3	3	3	690	58
3	1	3	3	695	61
3	5	3	3	690	59
3	3	1	3	692	62
3	3	5	3	700	69
3	3	3	1	716	104
3	3	3	5	696	54

*See Appendix III.

Freeness (CSF) values typical of pulp after industrial deshive refining. Statistical analysis of the CSF and von Alfthan data follow in the next sections.

The CSF Model at Low Beating Pressure

Table 2 summarizes a regression analysis of CSF at low beating pressure as a function of all variables, their squares, and their cross products. This full regression model of fourteen terms is a basis for several analytical techniques.

The natural log of CSF and the square root of CSF were also regressed against the full model of fourteen terms. Table 3 shows that regression quality was not improved by the transformations.

Table 4 shows that changes in specific energy consumption and stock consistency have relatively large effects on the regression equation of CSF after PFI mill DSR, while changes in minimum gap and pulp charge have lesser and possibly insignificant effects.

Increased refining reduces pulp freeness, so the large effect of specific energy consumption on post treatment CSF is not unexpected. As stock consistency in the PFI mill is reduced, an increased fraction of work is expended to stir and heat the associated water, which explains the sensitivity of CSF consistency variation.

Of less significance to CSF after low pressure PFI mill DSR were gap and pulp charge. The importance of pulp charge was reduced by its use as a normalizing factor in determining specific energy consumption. Desired minimum gap was not always achieved during the process, and

TABLE 2. CANADIAN STANDARD FREENESS AFTER PFI MILL DESHIVE REFINING

ANOVA $r^2 = 0.79$

Source	DF	SS	MS	F
Regression	14	1653	118.08	4.23
Error	16	447	27.91	
Total	30	2100		

Term*	Coefficient	t-value
Constant	789.05	
Energy	-26.02	2.85
Charge	6.48	0.71
Gap	-0.52	0.06
Consistency	-41.35	4.53
$(\text{Energy})^2$	2.72	2.75
$(\text{Charge})^2$	0.22	0.22
$(\text{Gap})^2$	1.10	1.11
$(\text{Consistency})^2$	3.60	3.64
Energy · Charge	-1.19	0.90
Energy · Gap	0.69	0.52
Energy · Consistency	2.19	1.66
Charge · Gap	-3.69	2.79
Charge · Consistency	2.31	1.75
Gap · Consistency	1.69	1.28

*Coded; see Appendix III.

TABLE 3. ANOVA TABLE - SQUARE ROOT AND NATURAL LOG OF CANADIAN STANDARD FREENESS AFTER PFI MILL DESHIVE REFINING

Square Root:

ANOVA $r^2 = 0.79$

Source	DF	SS	MS	F
Regression	14	0.590	0.042	4.23
Error	16	0.159	0.010	
Total	30	0.749		

Natural Log:

ANOVA $r^2 = 0.79$

Source	DF	SS	MS	F
Regression	14	$6.36\ (10)^{-4}$	$4.54\ (10)^{-5}$	4.24
Error	16	$1.71\ (10)^{-4}$	$1.07\ (10)^{-5}$	
Total	30	$8.07\ (10)^{-4}$		

TABLE 4. REDUCED MODEL TESTS FOR CANADIAN STANDARD FREENESS AFTER PFI MILL DESHIVE REFINING

Variable Eliminated	F (Reduced vs Full)
Specific Energy Consumption	6.02
Pulp Charge	2.35
Knife - Bedplate Gap	2.96
Stock Consistency	4.39

$F_{critical} = 2.85$ at $\alpha = 0.05$

only when pulp was sufficiently compressed by the knives was the minimum knife-bedplate gap attainable. At normal pulp charges the minimum gap setting was meaningful only above approximately 1.0 mm, while at lower settings the knives were supported by the pulp and operate at actual gaps larger than the minimum gap setting.

The von Alfthan Model

Table 5 lists a regression analysis at low beating pressure of von Alfthan count as a function of all independent variables, their squares, and their cross products. Table 6 summarizes regressions of log von Alfthan count and square root von Alfthan count as a function of all fourteen terms.

A strong relationship does not exist between von Alfthan count and the full fourteen term model, and transformations of von Alfthan count improve regression quality very little.

Reduced model tests (Table 7) show that von Alfthan count regression equation is quite insensitive to minimum gap, pulp charge, and specific energy consumption. Stock consistency was the most significant of the four variables tested, but still was not significant at the $\alpha = 0.05$ level. None of the four independent variables appears particularly important to the von Alfthan value of PFI mill DSR.

The Effects of Beating Pressure

In Table 8 the factorial portion of processing conditions and test results after low pressure beating, taken from Table 1, are compared

TABLE 5. MULTIPLE REGRESSION ANALYSIS OF VON ALFTHAN VALUES AFTER PFI MILL DESHIVE REFINING

ANOVA $r^2 = 0.54$

Source	DF	SS	MS	F
Regression	14	1793	128.09	1.33
Error	16	1543	96.43	
Total	30	3336		

Term*	Coefficient	t-value
Constant	146.12	
Energy	-21.96	1.29
Charge	-1.29	0.08
Gap	-0.21	0.01
Consistency	-36.54	2.15
$(\text{Energy})^2$	1.57	0.86
$(\text{Charge})^2$	0.95	0.52
$(\text{Gap})^2$	2.32	1.26
$(\text{Consistency})^2$	5.70	3.10
Energy · Charge	0.44	0.18
Energy · Gap	-0.19	0.08
Energy · Consistency	2.94	1.20
Charge · Gap	-1.19	0.48
Charge · Consistency	-0.56	0.23
Gap · Consistency	-2.44	0.99

*Coded; see Appendix III.

TABLE 6. ANOVA TABLE - SQUARE ROOT AND NATURAL LOG OF VON ALFTHAN VALUE AFTER PFI MILL DESHIVE REFINING

Square Root:

ANOVA $r^2 = 0.55$

Source	DF	SS	MS	F
Regression	14	6.74	0.482	1.40
Error	16	5.50	0.344	
Total	30	12.25		

Natural Log:

ANOVA $r^2 = 0.57$

Source	DF	SS	MS	F
Regression	14	$7.99\ (10)^{-2}$	$5.71\ (10)^{-3}$	1.49
Error	16	$6.14\ (10)^{-2}$	$3.84\ (10)^{-3}$	
Total	30	$14.13\ (10)^{-2}$		

TABLE 7. REDUCED MODEL TESTS OF VON ALFTHAN VALUE AFTER PFI MILL DESHIVE REFINING

Variable Eliminated	F (Reduced vs Full)
Specific Energy Consumption	0.88
Pulp Charge	0.13
Knife - Bedplate Gap	0.83
Stock Consistency	2.74

$F_{critical} = 2.85$ at $\alpha = 0.05$

TABLE 8. CANADIAN STANDARD FREENESS AND VON ALFTHAN VALUES AFTER HIGH AND LOW PRESSURE PFI MILL DESHIVE REFINING

Coded Parameter Levels*				Canadian Standard Freeness Results		von Alfthan Results	
Specific Energy Consumption	Charge	Gap	Consistency	Low Pressure	High Pressure	Low Pressure	High Pressure
2	2	2	2	706	713	60	52
4	2	2	2	686	672	42	50
2	4	2	2	706	696	60	55
4	4	2	2	694	686	50	60
2	2	4	2	710	690	69	70
4	2	4	2	698	685	55	62
2	4	4	2	696	708	68	69
4	4	4	2	692	686	60	60
2	2	2	4	686	696	58	64
4	2	2	4	692	672	63	47
2	4	2	4	708	684	66	55
4	4	2	4	698	696	64	54
2	2	4	4	702	702	66	58
4	2	4	4	707	700	63	55
2	4	4	4	710	708	63	59
4	4	4	4	696	704	60	58

Paired difference t value for Canadian Standard Freeness = 2.00
Paired difference t value for von Alfthan = 1.28
Critical value of t for $\alpha = 0.05$, 15 degrees of freedom = 2.13

with test results after high pressure beating performed under otherwise identical processing conditions. The paired difference t-tests summarized in that table show that beating at high rather than low pressure does not consistently lower von Alfthan or CSF values by a significant amount. High pressure beating thus displayed no practical advantage over low pressure beating, and the remaining trials needed to complete the experimental design within the high beating pressure block were omitted. Although the effects of PFI mill beating pressure on CSF and von Alfthan values were incompletely analyzed, the superiority of the Bauer 187 refiner for DSR research (Phase II of this DSR research) made those effects matters of little interest.

CONCLUSIONS

1. The PFI mill has complex power use characteristics. Its knife spindle motor converts electrical power to mechanical power, but its bedplate bowl motor generates rather than consumes electrical power.

2. PFI mill DSR can be used to achieve CSF and von Alfthan values similar to those of typical pulp mill DSR.

3. A mathematical relationship ($r^2 = 0.79$) exists between the processing conditions of PFI mill DSR and the CSF of deshived pulp. Specific energy consumption and stock consistency were especially influential.

4. The processing conditions of PFI mill DSR have very little effect on the von Alfthan count regression equation of deshived pulp ($r^2 = 0.54$). For this reason the PFI mill was a poor modeling base for deshive refining.

PHASE II

THE BAUER DOUBLE DISK REFINER MODEL OF DESHIVE REFINING

Experimental

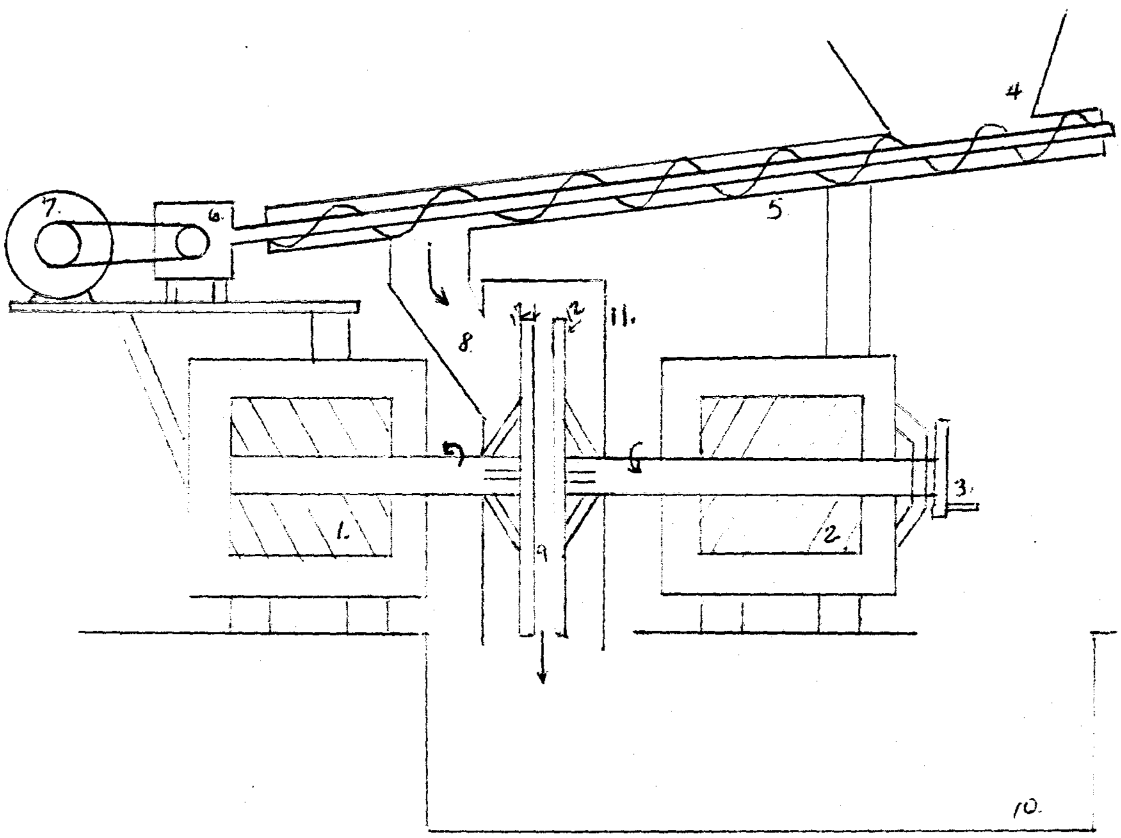
Description

The double disk refiner used to model DSR was the Bauer model 187 (Figure 6). The Bauer 187 is an open discharge, non-pressurized refiner, with two 610 mm diameter refining elements driven in opposite directions by 37 kilowatt induction motors. The nominal speed of each disk is 1800 rpm, or 1700 meters per minute at the perimeter. Steam can be injected into the housing which contains the rotating disks. The disk plates used were recommended by Bauer (30) as being well suited to DSR in this machine.

The Bauer 187 was designed for continuous operation. At the Forest Research Laboratory minor modifications have adapted this machine to the small, batchlike trials typical of a research laboratory. In particular, inlet and outlet plumbing have been replaced respectively by a controllable auger feeding system and a large holding pit for discharge collection, but the refining action of the Bauer 187 has not been altered.

Independent Variables

Three processing variables, plate gap, stock consistency, and throughput rate, are natural to the Bauer 187 double disk refiner. The gap between the counter-rotating plates is continuously adjustable from



1. 37 kilowatt motor
2. 37 kilowatt motor
3. gap adjustment wheel
4. sample hopper
5. auger (sample delivery)
6. auger gear box
7. auger motor
8. sample delivery chute
9. refining area
10. sample holding pit
11. disk housing
12. refining disks

Figure 6. Representation of the Bauer 187 refining system.

zero clearance to one of several centimeters. Pulp throughput is continuously controllable between approximately 0.5 and 2.0 dry kilograms per minute. All stock consistencies below approximately 30% can be processed.

A fourth variable, peripheral speed of the disks, cannot be altered, but one disk can be immobilized. By holding one disk motionless the effect of relative disk speed can be examined at two levels.

Pulp refining is characterized by a combination of effects on fibers, such as fiber cutting, fiber fibrillation, and in the present case, separation of fiber bundles (deshiving). Work is necessary to accomplish these effects and the amount of work actually absorbed by the pulp is the most fundamental measure of the extent of the refining process. The amount of work is a complex function of such variables as machine geometry, plate pattern, refining time, plate gap, and pulp consistency, to name a few. Of all possible variables, only four were selected for study in this section, plate gap, stock consistency, throughput rate, and number of rotating disks, and the others were held constant. The work per ovendry ton of pulp, specific energy consumption, was readily measured for each trial with electrical devices. Specific energy consumption was studied as a function of the primary Bauer 187 variables, and secondarily as a quantitative measure of the extent of pulp refining.

Because of its fundamental significance to refining action, specific energy consumption is the best single measure of refining when studying other refining variables, such as machine design or plate pattern. Its greatest value here involves the efficiency of refining:

the effects of different machine variables on deshive refining efficiency can best be quantified by measuring the specific energy consumptions associated with the planned variable changes. Refining conditions which deshive a pulp to a given shive content with the least work input are the most efficient.

In many refining machines hydraulic control systems continuously vary plate gaps to achieve desired power loads. In those constant power load refiners, plate gap is not a control variable, and specific energy consumption is of primary, not secondary interest. Specific energy consumption was included as a fifth variable which permitted DSR descriptions in terms applicable to both constant gap machines and constant power load machines.

Experimental Design

A second order, central composite design in three variables, plate gap, consistency, and throughput rate, was used to study Bauer 187 DSR. Specific energy consumptions associated with each set of conditions were recorded and included in the analysis as a fourth variable. The experimental design was completed in two blocks, corresponding to one and two disks operating, so that the effects of the number of powered disks could be analyzed.

Bauer 187 Power Use Measurements

Bauer 187 energy consumption was measured with a GE V63A kilowatt-hour meter. Irregular power consumption characteristics of the Bauer 187 made calculating motor efficiencies impractical. The difference between energy consumption during DSR and energy consumption at idle was divided by the dry weight of pulp processed to yield specific energy consumption in kilowatt-hours per oven dry ton.

Results and Discussion

The Canadian Standard Freeness Model

Table 9 contains the processing conditions and test results of Bauer 187 DSR.

TABLE 9. PROCESSING CONDITIONS AND TEST RESULTS OF BAUER 187 DESHIVE REFINING

Coded Parameter Levels*				Specific Energy Consumption (kwh/ton)	Test Results	
Plate Gap	Stock Consistency	Through-put Rate	Number of Plates		CSF (ml)	von Alfthan Count
3.00	3.00	3.18	2	1.24	718.00	78
3.00	3.00	2.29	2	1.73	715.00	72
3.00	3.00	3.18	2	2.08	719.00	80
3.00	3.00	2.82	2	1.86	720.00	72
3.00	3.00	2.43	2	2.00	719.00	78
3.00	3.00	3.84	2	1.81	716.00	76
2.00	2.00	2.56	2	2.65	723.00	63
4.00	2.00	2.65	2	1.78	716.00	77
2.00	4.00	2.60	2	5.66	722.00	51
4.00	4.00	2.51	2	1.75	718.00	90
2.00	2.00	5.87	2	2.65	723.00	53
4.00	2.00	5.25	2	1.44	718.00	77
2.00	4.00	5.74	2	4.32	716.00	48
4.00	4.00	4.94	2	1.34	718.00	88
1.14	3.00	3.31	2	6.77	716.00	36
4.86	3.00	4.68	2	0.89	740.00	96
3.00	1.13	3.00	2	3.00	718.00	69
3.00	4.87	3.00	2	4.73	722.00	61
3.00	3.00	1.99	2	1.82	722.00	78
3.00	3.00	8.47	2	1.35	716.00	74
3.00	3.00	10.63	2	1.26	712.00	79
3.00	3.00	67.50	2	0.59	715.00	85
2.00	3.00	76.30	2	3.10	710.00	74
1.50	3.00	63.50	2	5.84	723.00	64
3.00	4.00	63.50	2	3.39	728.00	72

TABLE 9, continued:

Coded Parameter Levels*				Specific Energy Consumption (kwh/ton)	Test Results	
Plate Gap	Stock Consistency	Throughput Rate	Number of Plates		CSF (ml)	von Alfthan Count
2.00	4.00	45.00	2	8.75	716.00	56
3.00	2.00	53.80	2	1.82	732.00	81
1.14	2.00	52.90	2	5.14	720.00	62
3.00	3.00	4.72	1	0.65	736.00	112
3.00	3.00	4.59	1	0.74	731.00	109
3.00	3.00	4.63	1	0.74	724.00	113
3.00	3.00	4.59	1	0.74	724.00	113
3.00	3.00	4.68	1	0.93	710.00	115
3.00	3.00	4.09	1	1.02	718.00	110
2.00	2.00	2.26	1	1.12	716.00	114
4.00	2.00	4.59	1	0.84	722.00	120
2.00	4.00	2.68	1	3.63	714.00	95
4.00	4.00	4.00	1	0.37	716.00	112
2.00	2.00	5.91	1	1.21	712.00	112
4.00	2.00	4.99	1	0.84	724.00	112
2.00	4.00	4.41	1	4.84	714.00	82
4.00	4.00	5.12	1	0.84	718.00	123
1.14	3.00	4.81	1	4.95	726.00	82
4.86	3.00	4.94	1	0.56	725.00	122
3.00	1.13	4.72	1	1.60	715.00	97
3.00	4.87	4.32	1	2.53	720.00	102
3.00	3.00	2.26	1	1.12	716.00	117
3.00	3.00	7.06	1	0.65	722.00	113
0.75	2.00	4.85	1	1.60	718.00	101
1.14	4.00	4.31	1	10.50	702.00	73

*Coded; see Appendix IV.

Table 10 summarizes the regression of CSF after Bauer 187 DSR as a function of 19 terms representing five variables, plate gap, consistency, throughput rate, specific energy consumption, and number of disks operating. Low values of r^2 and F(regression/error), 0.46 and 1.39, indicate that a significant relationship does not exist between the five variables and CSF after Bauer 187 DSR.

TABLE 10. REGRESSION OF CANADIAN STANDARD FREENESS AFTER BAUER 187 DESHIVE REFINING

ANOVA $r^2 = 0.46$

Source	DF	SS	MS	F
Regression	19	960.48	50.55	1.39
Error	30	1139.50	36.47	
Total	49	2100.00		

Term*	Coefficient	t-Value
Constant	726.08	
Gap	0.06	0.01
Consistency	-8.13	0.59
Throughput	2.41	0.93
Energy	2.25	0.45
$(\text{Gap})^2$	-2.03	0.96
$(\text{Consistency})^2$	-0.95	0.51
$(\text{Throughput})^2$	0.00	0.43
$(\text{Energy})^2$	-1.34	2.21
Gap · Consistency	4.20	1.15
Gap · Throughput	0.32	1.45
Gap · Energy	-5.60	1.70
Consistency · Throughput	-0.13	0.87
Consistency · Energy	3.97	1.42
Throughput · Energy	0.10	1.18
Plates	-5.72	0.36
Plates · Gap	7.23	1.71
Plates · Consistency	-5.14	1.29
Plates · Throughput	-1.65	1.19
Plates · Energy	3.83	1.83

*Coded; see Appendix IV.

Dropping the five terms associated with number of rotating disks results in the regression summarized in Table 11. The low value of F for the reduced model test, 0.98, indicates that the number of powered disks was not significant to the regression of CSF after Bauer 187 DSR. Relative disk speed is halved by holding one disk motionless, so presumably that property is also not significant to post-treatment CSF.

TABLE 11. ANOVA TABLE - CSF AFTER BAUER 187 DESHIVE REFINING WITH NUMBER OF PLATES ELIMINATED FROM THE FULL REGRESSION

	ANOVA	$r^2 = 0.37$		
Source	DF	SS	MS	F
Regression	14	774.79	55.34	1.51
Error	35	1325.20	36.56	
Total	49	2100.00		

The CSF regression was not sensitive to number of rotating disks, and in normal Bauer 187 operation both disks are powered and are rotating in opposite directions. Table 12 thus contains the regression ANOVA only for double disk trials. The r^2 and F(regression/error) values of the regression for double disk operation are improved somewhat from those of combined single and double disk operation (Table 13). However, with $r^2 = 0.74$ and F(regression/error) = 2.63 for the double disk regression, a strong relationship cannot be said to exist. Table 13 shows with reduced model tests that only gap and specific energy consumption were significant variables in the regression of CSF after double disk DSR.

TABLE 12. ANOVA TABLE - CSF AFTER BAUER 187 DESHIVE REFINING - DOUBLE DISK OPERATION ONLY

	ANOVA	$r^2 = 0.74$		
Source	DF	SS	MS	F
Regression	14	721.33	51.52	2.63
Error	13	254.78	19.60	
Total	27	976.11		

TABLE 13. REDUCED MODEL TESTS FOR CSF AFTER BAUER 187 DESHIVE REFINING - DOUBLE DISK OPERATION ONLY

Variable Eliminated	F(Reduced vs Full)
Plate Gap	5.90
Stock Consistency	1.61
Throughput Rate	2.28
Specific Energy Consumption	3.61

$F_{critical} = 3.03$ at $\alpha = 0.05$

All values of CSF, regardless of Bauer 187 operating conditions, are acceptably high for deshive refined pulp. This agrees with Kurdin's claim that DSR has no major effect on pulp freeness (8), since a natural extension of his argument is that processing conditions of DSR should have little or no effect on pulp freeness. Thus, the absence of a strong relationship between the variables of Bauer 187 DSR operation and a deshived pulp's CSF is neither troublesome nor unexpected.

The von Alfthan Model

Table 14 contains the regression of von Alfthan count after Bauer 187 DSR on the terms associated with five variables, plate gap, stock consistency, throughput rate, specific energy consumption, and number of operating disks. The r^2 and F(regression/error) values, 0.98 and 68.8 respectively, indicate a strong relationship exists between Bauer 187 operating conditions and the resulting shive content of processed pulp. This unwieldy model of 19 terms and a constant was reduced to a model of fewer terms that still has excellent prediction ability.

TABLE 14. REGRESSION OF VON ALFTHAN COUNT AFTER BAUER 187 DESHIVE REFINING

ANOVA $r^2 = 0.98$

Source	DF	SS	MS	F
Regression	19	23,930	1259.50	68.83
Error	30	549	18.30	
Total	49	24,479		

Term*	Coefficient	t-Value
Constant	169.75	
Gap	-13.07	2.16
Consistency	9.98	1.02
Throughput	-1.57	0.85
Energy	-9.54	2.68
$(Gap)^2$	0.74	0.50
$(Consistency)^2$	-2.72	2.06
$(Throughput)^2$	0.00	0.72
$(Energy)^2$	0.84	1.96
Gap · Consistency	2.11	0.81
Gap · Throughput	-0.04	0.26
Gap · Energy	3.66	1.57
Consistency · Throughput	-0.15	1.41
Consistency · Energy	-1.76	0.89
Throughput · Energy	0.02	0.40
Plates	-58.95	5.21
Plates · Gap	3.48	1.16
Plates · Consistency	2.89	1.02
Plates · Throughput	0.96	0.97
Plates · Energy	-0.46	0.31

*Coded; see Appendix IV.

Table 15 contains the regression ANOVA of post-treatment von Alfthan count with the number of rotating disks having been dropped from the model. A reduced model test, F(reduced vs full) = 39.61, indicates that the number of rotating disks was highly significant to the regression of von Alfthan count after Bauer 187 DSR.

TABLE 15. ANOVA TABLE - VON ALFTHAN VALUE AFTER BAUER 187 DESHIVE REFINING WITH NUMBER OF PLATES ELIMINATED FROM THE FULL REGRESSION

ANOVA $r^2 = 0.83$

Source	DF	SS	MS	F
Regression	14	20,309	1451.6	12.17
Error	35	4,170	119.2	
Total	49	24,479		

To evaluate the merits of deshiving with one or two operating disks, all von Alfthan count values were plotted as a function of specific energy consumption for both arrangements (Figure 7). Regardless of refining conditions less energy to reach a given von Alfthan level was needed with two disks operating than with one. The Bauer model 187 is thus a more efficient deshive refiner with both disks powered than with only one disk powered. These data suggest that deshive refining machines should be double disk refiners or at least employ high relative disk speeds to profit from improved power use efficiencies available under such conditions. Therefore, the importance of the remaining four variables (gap, consistency, throughput, and specific energy consumption) will be assessed only for the trials with both disks operating, the Bauer 187's designed and most efficient refining mode.

Table 16 contains a regression analysis of von Alfthan count after Bauer 187 deshiving as a function of the three processing variables and specific energy consumption for double disk operation only. Values of

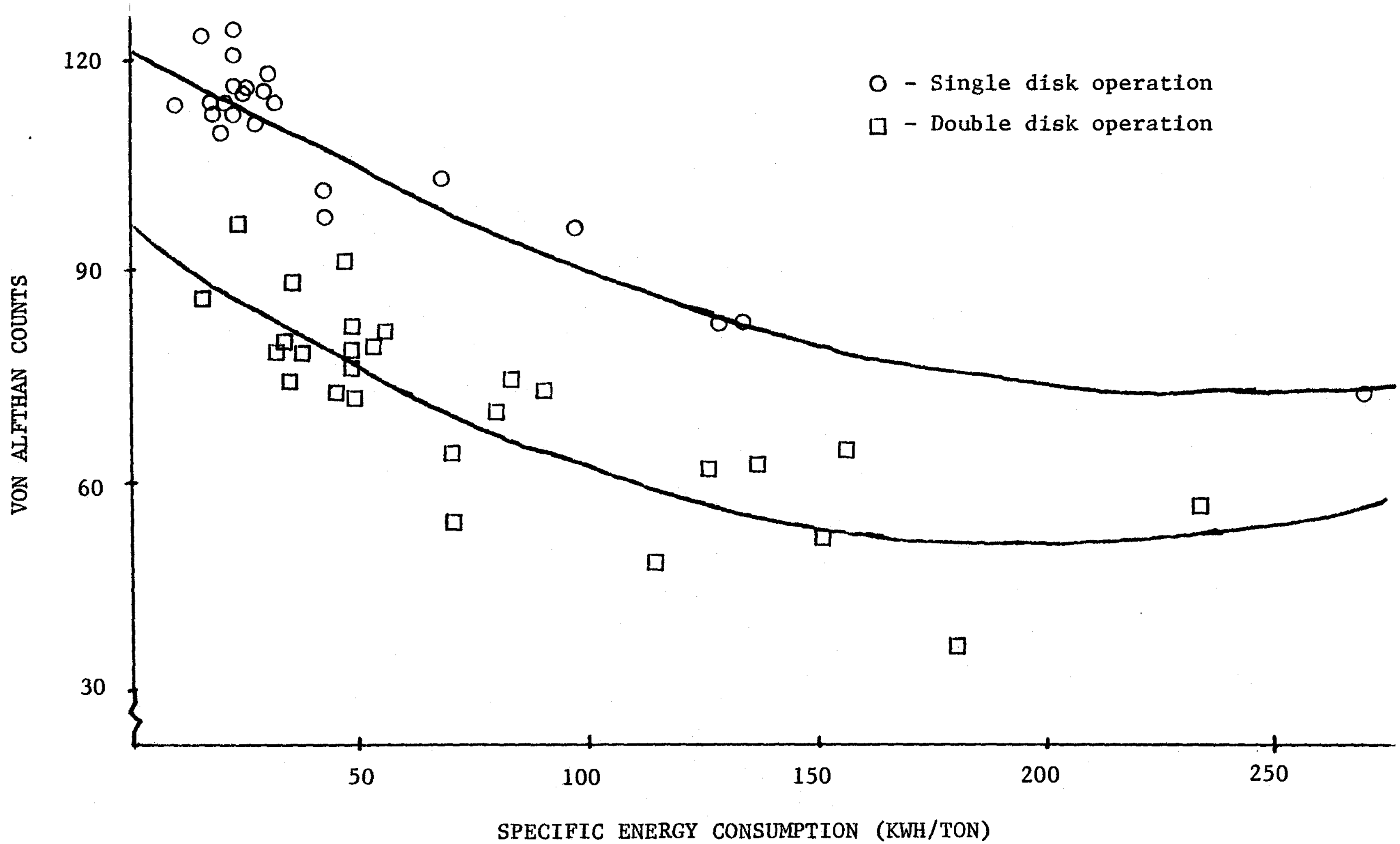


Figure 7. Von Alfthan values as a function of specific energy consumption.

r^2, 0.96, and F(regression/error), 25.0, reflect the major impact of these four variables on the von Alfthan count after Bauer 187 DSR.

TABLE 16. REGRESSION OF VON ALFTHAN COUNT AFTER BAUER 187 DESHIVE REFINING - DOUBLE DISK OPERATION ONLY

ANOVA $r^2 = 0.96$

Source	DF	SS	MS	F
Regression	14	4803	343.1	24.98
Error	13	179	13.74	
Total	27	4982		

Term*	Coefficient	t-Value
Constant	13.75	
Gap	7.80	0.28
Consistency	19.90	0.91
Throughput	0.39	0.52
Energy	-3.62	0.43
$(\text{Gap})^2$	-0.97	0.23
$(\text{Consistency})^2$	-3.00	1.30
$(\text{Throughput})^2$	0.00	0.62
$(\text{Energy})^2$	0.73	1.00
Gap · Consistency	2.06	0.51
Gap · Throughput	-0.04	0.24
Gap · Energy	2.83	0.63
Consistency · Throughput	-0.15	1.27
Consistency · Energy	-2.66	0.95
Throughput · Energy	0.02	0.27

*Coded; see Appendix IV.

Table 17 summarizes reduced model tests which evaluate the importance of the four variables to the regression analysis of Table 16. Throughput rate and plate gap are significant to the regression, each having associated terms which cannot be eliminated as a set from the full model under reduced model test rules. Consistency and specific energy consumption are not significant to the full regression. Dropping all terms associated with consistency results in a borderline value of F(reduced vs full), but the small value for dropping specific energy consumption terms, 0.42, reflects a minimal contribution of specific energy consumption to the full regression.

TABLE 17. REDUCED MODEL TESTS FOR VON ALFTHAN VALUE AFTER BAUER 187 DESHIVE REFINING - DOUBLE DISK OPERATION ONLY

Variable Eliminated	F(Reduced vs Full)
Plate Gap	5.30
Stock Consistency	2.87
Throughput Rate	7.74
Specific Energy Consumption	0.42

$F_{critical} = 3.03$ at $\alpha = 0.05$

TABLE 18. REGRESSION OF SPECIFIC ENERGY CONSUMPTION AGAINST BAUER 187 PROCESSING CONDITIONS - DOUBLE DISK OPERATION ONLY

ANOVA $r^2 = 0.94$

Source	DF	SS	MS	F
Regression	9	101.00	1.12	28.54
Error	18	7.08	0.39	
Total	27	108.08		

Term*	Coefficient	t-Value
Constant	7.39	
Gap	-2.24	2.30
Consistency	-0.97	0.98
Throughput	0.07	1.74
$(Gap)^2$	0.56	4.19
$(Consistency)^2$	0.64	4.84
$(Throughput)^2$	-0.00	3.13
Gap · Consistency	-0.80	4.07
Gap · Throughput	-0.01	1.96
Consistency · Throughput	0.02	2.68

*Coded; see Appendix IV.

TABLE 19. REGRESSION OF VON ALFTHAN COUNT AFTER BAUER 187 DESHIVE REFINING AGAINST PLATE GAP, STOCK CONSISTENCY, AND THROUGHPUT RATE - DOUBLE DISK OPERATION ONLY

ANOVA $r^2 = 0.96$

Source	DF	SS	MS	F
Regression	9	4774	530.50	46.05
Error	18	207	11.52	
Total	27	4982		

Term*	Coefficient	t-Value
Constant	13.24	
Gap	20.03	3.80
Consistency	6.21	1.17
Throughput	0.63	2.93
$(\text{Gap})^2$	-3.14	4.35
$(\text{Consistency})^2$	-3.51	4.90
$(\text{Throughput})^2$	0.00	0.39
Gap · Consistency	4.86	4.56
Gap · Throughput	-0.12	2.95
Consistency · Throughput	-0.07	1.73

*Coded; see Appendix IV.

In the Bauer 187 specific energy consumption is altered by changing levels of the three processing variables. Table 18 reflects the high accuracy ($r^2 = 0.94$) with which specific energy consumption can be estimated from known values of plate gap, stock consistency, and throughput rate. Since specific energy consumption is highly correlated with the three processing variables, its low F(reduced *vs* full) value in Table 17 is expected from regression theory.

Specific energy consumption is unnecessary to the von Alfthan model only because it is accounted for by processing variables. It is still a fundamental measurement of refining, and increased energy consumption during DSR, caused by a changing process variable(s), should reduce the shive content of processed pulp.

At constant levels of stock consistency and throughput rate reduced plate gaps increase the internal shear and turbulence between refining elements which increases specific energy consumption and lowers von Alfthan count. At constant levels of plate gap and throughput rate, increased consistency reduces the fraction of the refining machine's energy expended to heat and pump water which increases specific energy consumption and lowers von Alfthan count. Changes in throughput rate at constant plate gap and consistency levels do not follow this increased specific energy consumption - decreased von Alfthan count pattern, but in a later section it will be shown that changes in throughput rates, while statistically significant in regression models, have virtually no practical effect on von Alfthan values.

Changes in plate gap and stock consistency thus affect post treatment von Alfthan count because those changes affect specific energy consumption, a fundamental measure of refining.

Specific energy consumption was to be used to apply Bauer 187 DSR results to refining machines which operate at constant power loads rather than constant plate gaps. The value of specific energy consumption as a substitute for Bauer 187 plate gap is questionable. If plate gap and specific energy consumption were redundant, either could be eliminated from the full regression model with little or no loss in regression quality. Table 17 shows that specific energy consumption fits that criterion, but plate gap does not.

In the Bauer 187, plate gap and specific energy consumption are not interchangeable, and caution is required when applying Bauer 187 DSR models to constant power load refiners. Research with constant power load deshive refiners is needed to examine the effects of processing variables on their operation.

The Best von Alfthan Model

Deshive refining is controllable if an equation can be found which accurately relates some set of DSR processing conditions to subsequent von Alfthan count. Table 19 contains an equation of one constant and nine terms which accurately relates Bauer 187 processing conditions to subsequent von Alfthan count. Specific energy consumption is not included because it is not an independently controllable variable of Bauer 187 processing. Some of these terms are of limited consequence to von Alfthan count prediction and may be eliminated from the full model.

Unlimited access to a HP9825 desk top calculator permitted the regression of post-treatment von Alfthan count against all possible combinations of two through eight of the nine terms. The regression of a given number of terms having the lowest MSE values were used to select the best constant plate gap model of von Alfthan count. Such models of three through nine estimated parameters (two through eight terms) are listed in Appendix V.

Best Constant Plate Gap von Alfthan Count Model

Values of r^2, MSE, and C_p for the models in Appendix V are compared in Table 20 and plotted in Figure 8 (a-c). For C_p calculations smaller models were compared to the full model of nine terms. All three bases of comparison indicate that the greatest improvement in model quality is realized by adding a fourth parameter (third term). As model size increases to beyond one constant and three terms, improvements in model quality still occur, but are less pronounced. When six parameters have been estimated, one of the model's five terms cannot be shown to have a non-zero coefficient by the "t" or reduced model test at $\alpha = 0.05$. Based on r^2 and MSE values, all models containing eight or more parameters are nearly as significant as the full model of ten parameters. Also, the minimum value of C_p occurs for the model of eight estimated parameters. For these reasons a model of seven terms and a constant, given below, is considered the best model of von Alfthan count as a function of coded Bauer 187 control parameters.

$$\begin{aligned}\text{von Alfthan} = {} & 25.28 + 17.93\,(G) + 0.64\,(T) - 3.16\,(G)^2 \\ & - 2.89\,(C)^2 + 5.60\,(G \cdot C) \\ & - 0.12\,(G \cdot T) - 0.06\,(C \cdot T)\end{aligned} \qquad \text{Equation 6}$$

where: G = coded plate gap

C = coded stock consistency

T = coded throughput

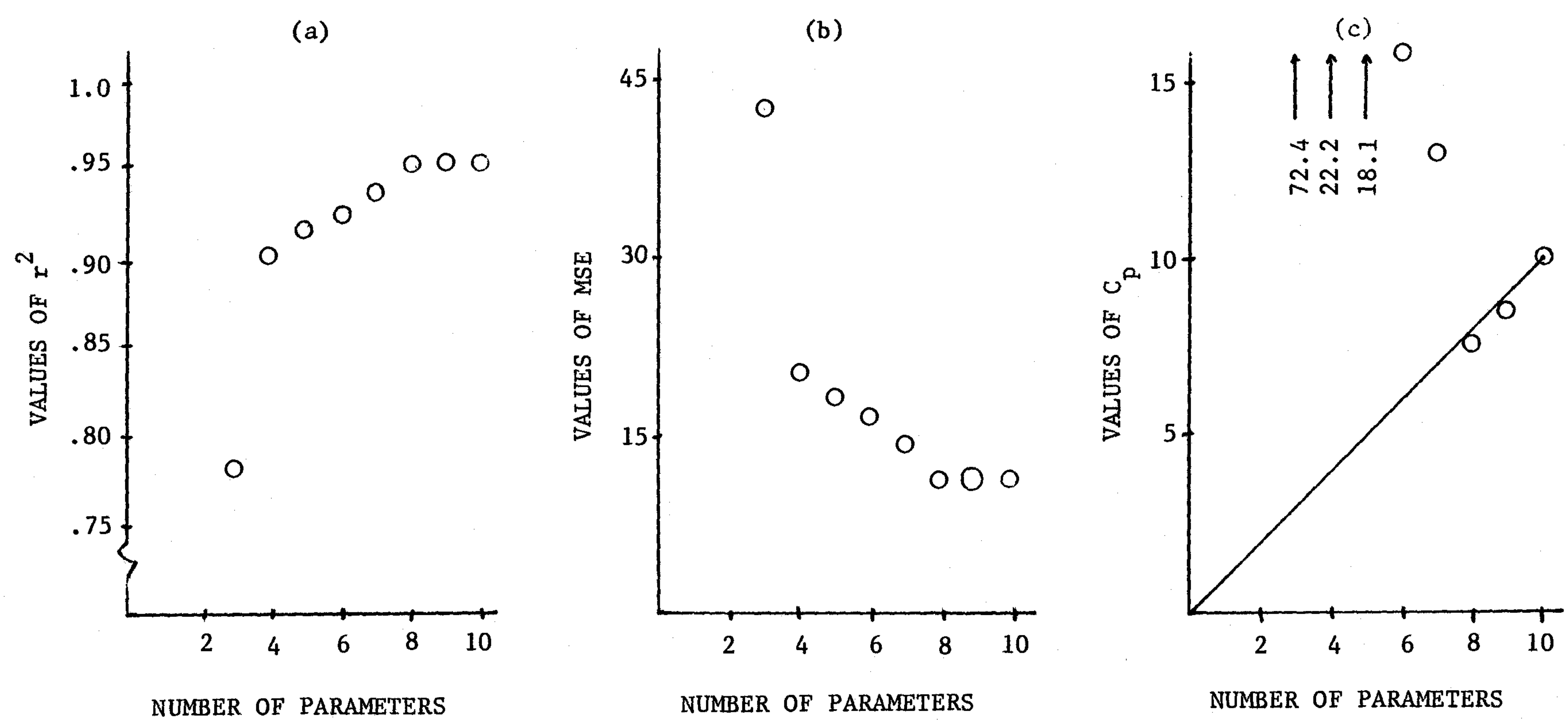


Figure 8(a-c). Values of r^2, MSE, and C_p for constant gap models plotted against number of regression parameters estimated.

TABLE 20. r^2, MSE, AND C_p VALUES FOR LOWEST MSE MODELS OF VON ALFTHAN COUNT APPROPRIATE TO CONSTANT PLATE GAP DESHIVE REFINERS - BASED ON BAUER 187 DATA

Number of Terms	r^2	MSE	C_p
2	0.782	43.5	72.4
3	0.902	20.2	22.2
4	0.917	18.1	18.1
5	0.926	16.7	15.9
6	0.938	14.8	13.0
7	0.955	11.3	7.6
8	0.958	11.0	8.5
9	0.958	11.5	10.0

It is possible for a variable or term which is significant to the regression model to be of limited practical concern. In Figure 9, Equation 6 is used to plot predicted von Alfthan count against changing plate gap, stock consistency or throughput rate. Predicted von Alfthan counts were plotted at the central and factorial levels of the changing variable, levels encompassing industrial ranges of plate gap and stock consistency, while the remaining two variables were held constant at their central point levels. Figure 9 shows for these conditions that changes in plate gap had the largest effect on predicted von Alfthan count. Stock consistency had a smaller but still noticeable effect on predicted von Alfthan count. Changes in throughput rate, the variable having the largest value of F(reduced *vs* full) in Table 17, caused no practical change in predicted von Alfthan count. Since the Bauer 187 is much smaller and less powerful than commercial refiners, and because high throughput rates are impossible with the stock delivery system of our installation, throughput rate could not be varied within

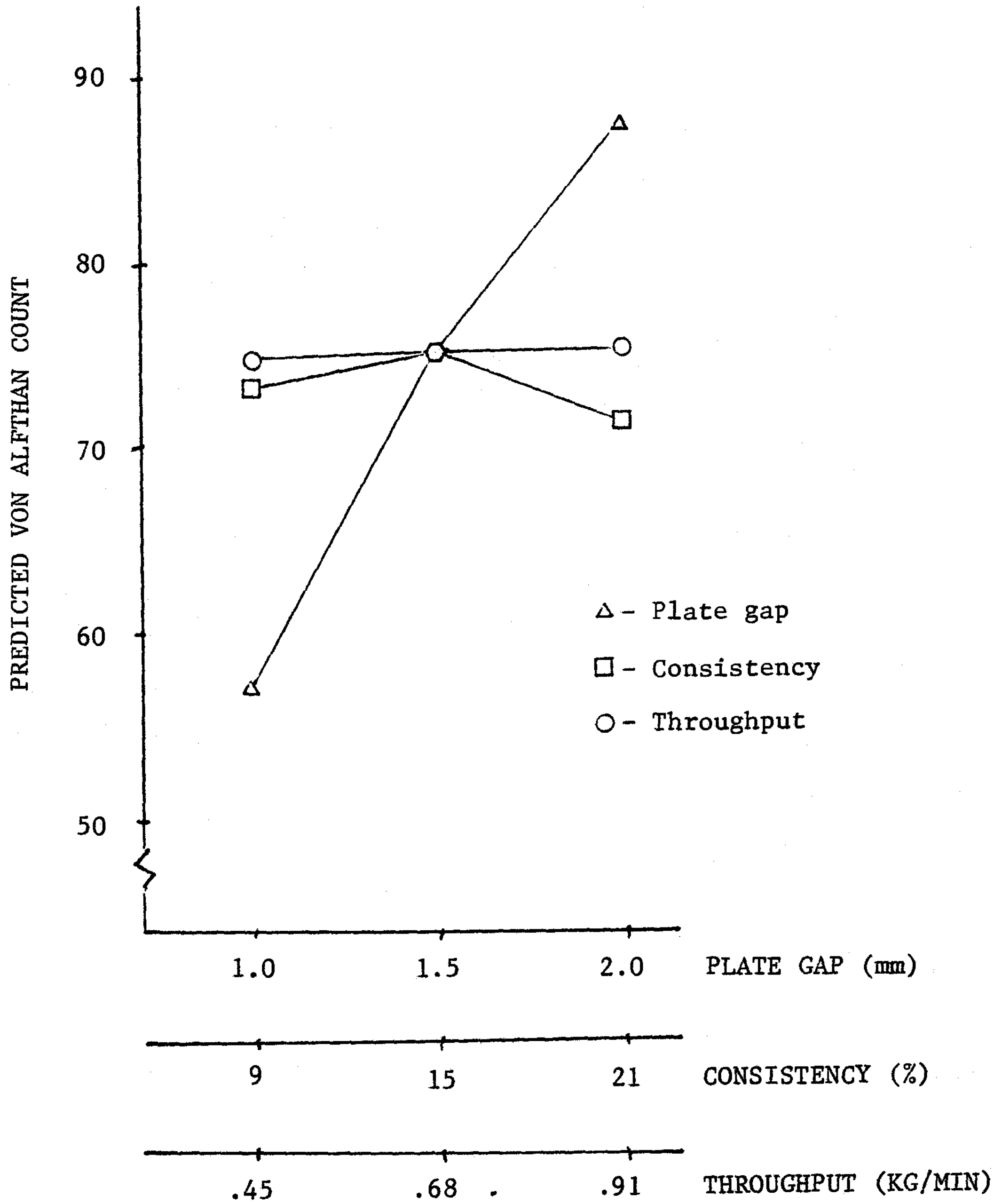


Figure 9. Predicted practical effects of changing one processing variable with the remaining two constant at their central values. (Prediction from equation 6.)

industrial ranges. Thus, in practice, the von Alfthan count of Bauer 187 deshived pulp is influenced most strongly by plate gap, less strongly but noticeably by stock consistency, and, within the range tested, unaffected by throughput rate.

The effects of plate gap, consistency, and, within a limited range, throughput rate on the von Alfthan count of deshived pulp were established for a single high yield kraft pulp processed exclusively in the Bauer 187. The influences of pulp quality and refiner design were not investigated. Extrapolation of these results to other DSR processes or high yield kraft pulps is speculation. While it is not unreasonable to suspect that other high yield kraft pulp undergoing DSR in constant plate gap machines might be characterized by similar relationships, additional research is necessary to verify that suspicion.

Best Constant Power Load von Alfthan Count Model

Plate gap and specific energy consumption were shown not to be interchangeable variables of Bauer 187 DSR. Nevertheless, specific energy consumption terms were substituted for plate gap terms of the Table 19 regression equation in an attempt to represent constant power load deshive refiners with Bauer 187 (constant plate gap) data. Table 21 contains the resulting regression of von Alfthan count as a function of specific energy consumption, stock consistency, and throughput rate. The best constant power load von Alfthan count model was selected in the same way as was the best constant plate gap model. Models of two through nine terms having lowest MSE values are summarized in Appendix VI, and values of r^2, MSE, and C_p for those models are listed in Table 22 and plotted in Figure 10 (a-c).

TABLE 21. REGRESSION OF VON ALFTHAN COUNT AFTER BAUER 187 DESHIVE REFINING AGAINST SPECIFIC ENERGY CONSUMPTION, STOCK CONSISTENCY, AND THROUGHPUT RATE - DOUBLE DISK OPERATION ONLY

ANOVA $r^2 = 0.89$

Source	DF	SS	MS	F
Regression	9	4439	493.27	16.37
Error	18	542	30.14	
Total	27	4982		

Term*	Coefficient	t-Value
Constant	118.32	
Energy	-15.22	4.23
Consistency	-15.78	1.96
Throughput	-0.35	0.98
$(\text{Energy})^2$	1.12	3.29
$(\text{Consistency})^2$	3.86	2.67
$(\text{Throughput})^2$	0.01	1.50
Energy · Consistency	-0.94	0.89
Energy · Throughput	0.10	3.93
Consistency · Throughput	-0.11	1.56

*Coded; see Appendix IV.

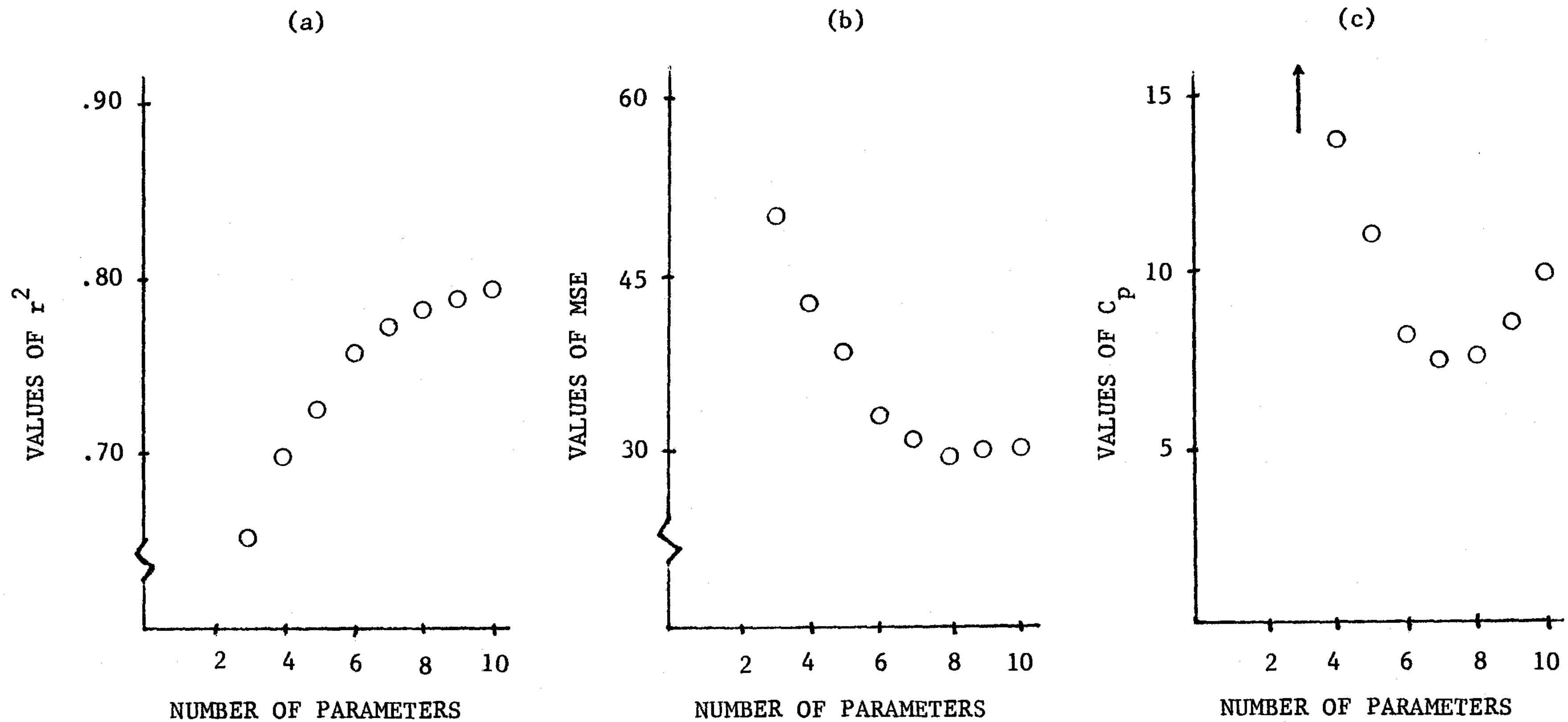


Figure 10(a–c). Values of r^2, MSE, and C_p for constant power load models plotted against number of regression parameters estimated.

TABLE 22. r^2, MSE, AND C_p VALUES FOR LOWEST MSE MODELS OF VON ALFTHAN COUNT APPROPRIATE TO CONSTANT POWER LOAD DESHIVE REFINERS - BASED ON BAUER 187 DATA

Number of Terms	r^2	MSE	C_p
2	0.749	50.0	19.5
3	0.795	42.6	13.9
4	0.824	38.1	11.1
5	0.854	33.1	8.1
6	0.870	30.9	7.5
7	0.881	29.6	7.6
8	0.886	30.0	8.8
9	0.891	30.1	10.0

The model which resulted in the minimum value of C_p was chosen as the best constant power load model of von Alfthan count:

$$\text{von Alfthan} = 113.13 - 12.44\,(C) - 15.04\,(SEC) + 2.73\,(C)^2 + 0.71\,(SEC)^2 - 0.05\,(C \cdot T) + 0.10\,(T \cdot SEC) \qquad \text{Equation 7}$$

where: C = coded stock consistency

SEC = coded specific energy consumption

T = coded throughput rate

In Figure 11, Equation 7 is used to plot predicted von Alfthan count against specific energy consumption, stock consistency, and throughput rate. The levels of each variable were varied with levels of the other two held constant at central values. Specific energy consumption and stock consistency were varied across industrial ranges, but, as before, throughput rate remained well below commercial levels. Within these ranges Figure 11 shows that varying specific energy

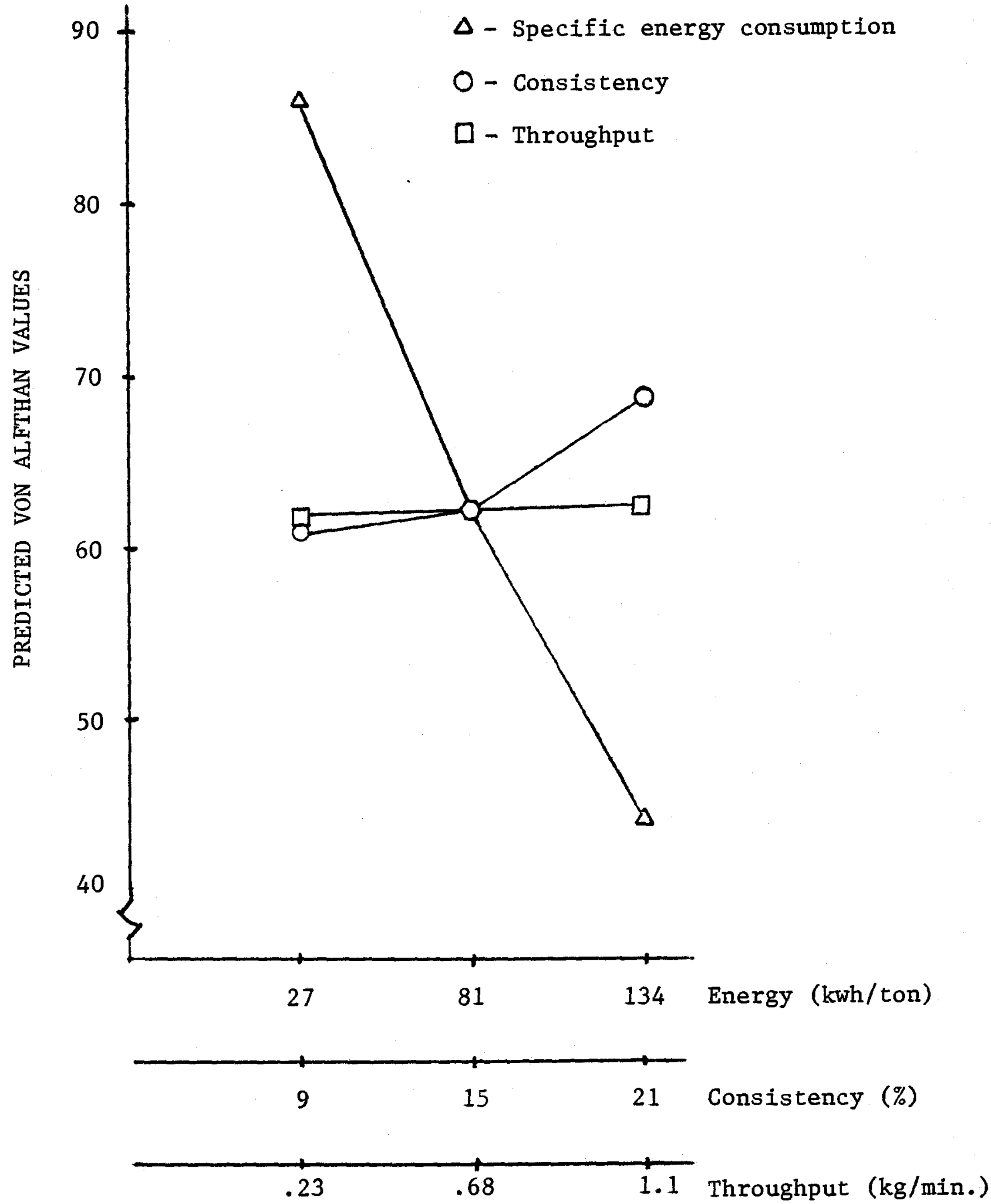


Figure 11. Predicted effects of changing one processing variable with the remaining two constant at their central values. (Prediction from equation 7.)

consumption causes the largest changes in predicted von Alfthan count. Changing stock consistency had a smaller but noticeable effect on stock consistency and the various throughput rates tested had no practical effect on predicted von Alfthan count. Thus, Bauer 187 (constant plate gap) data suggests that von Alfthan count after DSR in constant power load refiners is influenced most strongly by specific energy consumption, less strongly but noticeably by stock consistency, and is virtually unaffected by throughput rates.

Applications of Best Models

Deshive refining in terms of von Alfthan count has been predicted from process variables for one pulp deshived in one refiner. Operators of deshive refiners can expect to find relationships between the independent variables of their particular process and the shive content of their deshived pulp. Once established, such relationships could be quite useful in controlling a deshive refiner. Extended plate life and reduced specific energy consumption are two benefits which might be realized from a better understanding of a specific machine. Some operators will wish to predict the nature as well as the quantity of shives contained in pulp deshived by their refiner. Other operators will wish to predict the effects of "swinging" their digesters through various Kappa number ranges. Equations 6 and 7 are certainly not the ultimate models of deshive refining. They are valuable evidence that pulp shive contents after deshive refining can be mathematically predicted, and they form a basis for continued studies.

The Efficiency of Deshive Refining

Deshive refining results in a pulp of reduced shive content through electrical power consumption. It is desirable that shive content reduction be accomplished as efficiently as possible. A regression based on Bauer 187 DSR data was used to determine if various levels of plate gap, consistency, and throughput rates had noticeable effects on DSR efficiency. Figure 12 plots deshive refining efficiencies, expressed as change in von Alfthan count divided by specific energy consumption, as a function of consistency for three different plate gaps. (Throughput rate has been shown to have little practical effect on von Alfthan count and was not included in efficiency considerations.) Optimum consistency for deshive refining is seen to vary from eight percent to 16 percent, depending on plate gap.

In Figure 13 the regressions of Tables 18 and 19 were used to plot von Alfthan count and specific energy consumption as a function of stock consistency at constant plate gaps. That figure illustrates that a shive content of 75 to 78 von Alfthan counts, found desirable by Western Kraft Corporation, can be attained with minimum energy consumption by operating the Bauer 187 at approximately 12 percent consistency using a 1.5 mm plate gap (at intermediate throughput rates). Because of the nature of brownstock washers, industrial DSR is usually performed at consistencies in the neighborhood of 12 percent. Bauer 187 data thus suggests that pulp mills are operating their DSR systems at or near consistencies appropriate for optimum efficiency.

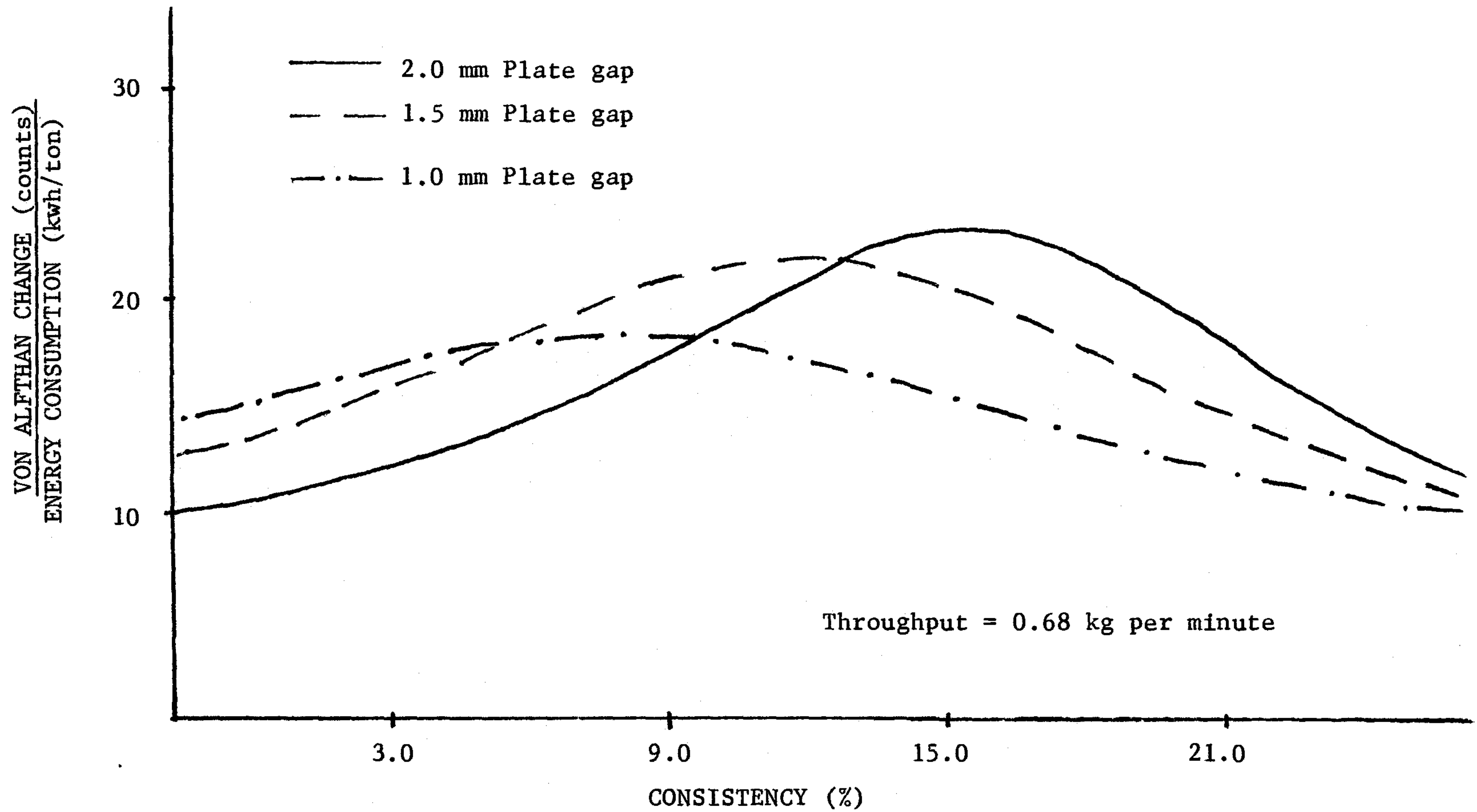


Figure 12. Efficiency of Baure 187 deshive refining as a function of consistency at three plate gap levels.

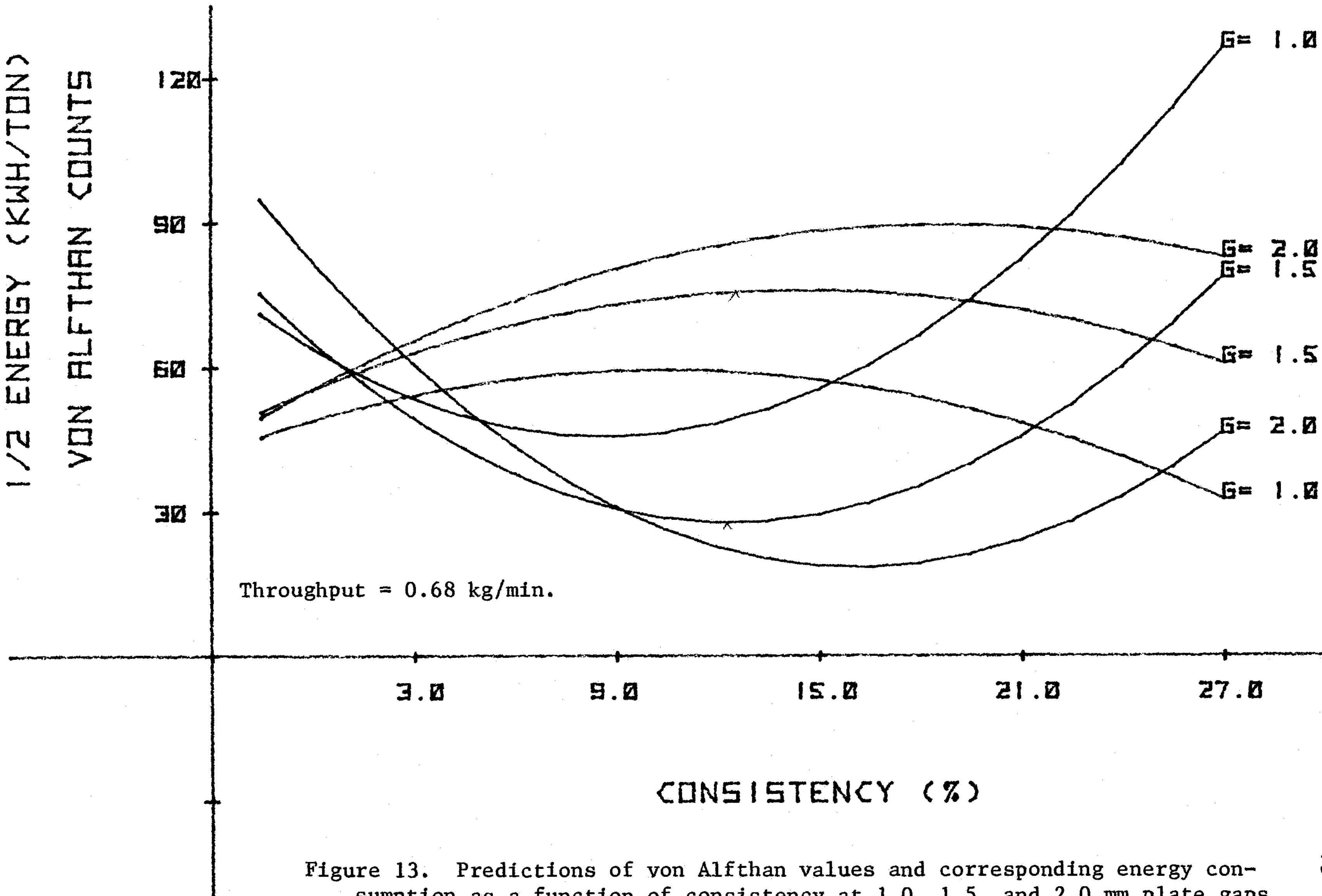


Figure 13. Predictions of von Alfthan values and corresponding energy consumption as a function of consistency at 1.0, 1.5, and 2.0 mm plate gaps.

Testing the Bauer 187 Model

The model given by Equation 6 was tested by deshive refining in the Bauer 187 at a 1.52 mm plate gap, 12 percent consistency, and approximately a 1.2 kg per minute throughput rate. These conditions were chosen from Figure 13 because regression equations (Tables 18 and 19) predicted that they would minimize the energy required to produce pulp having a von Alfthan value between 75 and 78. The expected von Alfthan value, 75, and the expected specific energy consumption, 47 kwh/ODT, are similar to values achieved by Western Kraft Corporation after in-house DSR of this particular high yield kraft pulp (10).

Table 23 summarizes the results of Canadian standard freeness, von Alfthan count, flat screening, and Bauer-McNett classification tests, performed to compare the general properties of Western Kraft (WK) deshived pulp to those of laboratory deshived pulp. The measured von Alfthan value of 76 is very near 75, the value predicted by Equation 6. Despite having a lower specific energy consumption, values of von Alfthan count, CSF, flatscreen rejects, and Bauer-McNett fractions of Bauer 187 deshived pulp compare favorably with corresponding values for pulp after DSR by WK. High yield kraft pulp can be deshived to realistic specifications in the Forest Research Laboratory's Bauer 187 refiner, and the laboratory process appears more efficient than DSR at Western Kraft Corporation.

TABLE 23. COMPARISON OF THE GENERAL PROPERTIES OF WESTERN KRAFT PULP AFTER MILL DESHIVE REFINING AND BAUER 187 DESHIVE REFINING

Property	Pulp Mill Deshive Refining	Bauer 187 Deshive Refining*
von Alfthan Count	78	76 (75)
Canadian Standard Freeness	735	730 (717)
0.20 mm Flat Screen Retains	1.9%	1.2%
Bauer-McNett Retains		
14 mesh	66%	64%
35 mesh	14%	14%
65 mesh	12%	10%
150 mesh	4%	4%
Specific Energy Consumption	est. 60 kwh/ODT	appx. 42 kwh/ODT

*(Value predicted from regression equations)

Explanations of the efficiency differences for the two machines would require consideration of differences in refiner design (Table 24), making them well beyond the scope of this study. Refining efficiency, being energy related, is of considerable importance and worthy of extensive research.

TABLE 24. DESIGN FACTORS OF THE BAUER 187 (LABORATORY) AND SPROUT-WALDRON 45-1B (WK) REFINERS

Property	Bauer 187	Sprout-Waldron 45-1B
Throughput Rate (kg/min)	1.2	210
Disks Rotating	2	1
Disk Diameter (mm)	610	1140
Plate Pattern	# 24301/24302	A031
	Constant plate gap	Constant power load

Bauer 187 Model - Conclusions

1. The variables of Bauer 187 operation have little influence on the CSF regression equation of processed pulp ($r^2 = 0.46$). All DSR trials included in this study resulted in deshived pulp of acceptably high CSF, 700 ml or higher.

2. The Bauer 187 is a more efficient deshive refiner with both disks operating than with one disk operating. Single disk operation would require three to five times higher energy consumptions for a given von Alfthan value than double disk operation.

3. A mathematical relationship ($r^2 = 0.95$) exists between plate gap, stock consistency, and to a lesser extent throughput rate, and the von Alfthan count value of Bauer 187 deshived pulp. Increasing plate gaps decrease von Alfthan count and a maximum von Alfthan count occurs at a stock consistency of approximately 12%. That mathematical

relationship is a model which can be used to control the shive content of a pulp treated by this DSR machine.

4. The energy efficiency of Bauer 187 deshive refining can be optimized. Stock consistencies in the neighborhood of 12 percent minimize the energy needed to achieve typical post-treatment von Alfthan values.

5. Constant plate gap refiners and constant power load refiners do not possess identical processing variables. Bauer 187 von Alfthan count regression models lose considerable prediction power ($r^2 = 0.95$ vs $r^2 = 0.87$) when specific energy consumption terms are substituted for plate gap terms.

PHASE III

SECONDARY EFFECTS OF DESHIVE REFINING

The Effects of Deshive Refining on Chemical Recovery

Background

Kraft pulping chemicals are extracted from wood pulp by water washings. Those chemicals not recovered must be made up by purchasing additional chemicals (primarily Na_2SO_4). Efficient pulp washing minimizes chemical losses. Shives are believed to impair this washing process.

Kurdin (8) claims that mechanical fiberization before washing is essential for kraft pulps at yields above 55 percent. Hartler, et. al. (9) describes using hot stock refining (refining at atmospheric pressure before washing) to optimize chemical recovery followed by deshive refining to satisfy shive content requirements. Both Kurdin and Hartler consider DSR only as a treatment for fully washed pulp. Technical personnel at local linerboard mills believe that deshive refining before the final washing stage will reduce chemical losses by making wash water more accessible to areas which otherwise would be fiber bundle cores (30). The effects on chemical recovery of DSR prior to final washing (for example, after the second brownstock washer) has not been documented in the literature, so an investigation was conducted to examine those effects.

Experimental

If deshive refining improves chemical recovery, it will reduce the amount of sodium ion remaining in pulp after washing. Two methods were investigated as a means of measuring sodium content of pulp. The two methods employed the same hot acid extraction of sodium ions from washed pulp (Appendix VII), followed by measurements of the extract's sodium ion concentration using different instruments, a sodium specific ion electrode and a flame spectrometer. Table 25 (fully explained in a later section) shows that the sodium specific ion electrode was unable to resolve differences between sodium ion concentrations of deshived and undeshived pulp which were readily detected with the flame spectrometer. For this reason work with the specific ion electrode was discontinued, and the flame spectrometer was used exclusively for measuring sodium ion concentrations.

TABLE 25. SODIUM ION CONCENTRATIONS IN PULP HAVING REINTRODUCED SODIUM IONS

Undeshived Pulp - 1.85 G

Flame Spectrometer Readings (units)	Sodium Specific Ion Electrode Reading (mV)
19.8	47
19.5	46
20.1	47
18.7	48
18.0	48
$\bar{X}$ = 19.22	$\bar{X}$ = 47
S = 0.86	S = 0.84
Sodium ion concentration ≈ 2.2 $(10)^{-4}$ M	Sodium ion concentration ≈ 1.5 $(10)^{-4}$ M
Pulp sodium ion content ≈ 126 moles/ton	Pulp sodium ion content ≈ 81 moles/ton

TABLE 25, continued:

Deshived Pulp - 1.75 g

Flame Spectrometer Readings (units)	Sodium Specific Ion Electrode Reading (mV)
16.4	46
16.2	47
14.8	47
12.3	46
11.5	46
$\overline{X}$ = 14.24	$\overline{X}$ = 46
S = 2.24	S = 0.55
Sodium ion concentration ≈ 1.3 $(10)^{-4}$ M	Sodium ion concentration ≈ 1.3 $(10)^{-4}$ M
Pulp sodium ion content ≈ 70 moles/ton	Pulp sodium ion content ≈ 74 moles/ton

Pulp from Western Kraft Corporation's third brown stock washer was taken to the laboratory, dewatered in a large centrifuge, and diluted with fresh water to achieve deshive refining consistencies. After this thorough washing, sodium ion concentrations were very low, much lower than would be typical of pulp after the second stage of brownstock washing. To increase its sodium ion concentration a 2.0 O.D.kg undeshived, dewatered pulp sample was diluted to 12 percent consistency with 2 M NaCl solution and allowed to stand at 3° C for three days. After this soaking period half the pulp received Bauer 187 DSR (1.52 mm, 12%, 1.2 kg/min) and half was set aside as a control.

Washing was accomplished by individually stirring approximately 50 wet grams of "salty" deshived and "salty" undeshived pulp with 200 ml boiling distilled water for 30 seconds, filtering with #410 filter paper via Buchner funnel, and further washing on the Buchner funnel with 600 ml of boiling distilled water. To determine sodium ion content, 10.0 wet grams of deshived and undeshived pulp were taken from the appropriate washed pads and subjected to the extraction procedure outlined in Appendix IV.

Results and Discussion

Table 25 lists the flame spectrometry (and sodium specific ion electrode) results for the pulps containing re-introduced sodium ions. This table shows that the flame spectrometer was much more sensitive to small changes in sodium ion concentration than was the sodium specific ion electrode. The ratio of sodium content of undeshived pulp to sodium content of deshived pulp was formed based on flame spectrometer measurements, and its high value of 1.80 indicates that after replicate washing procedures, undeshived pulp contained approximately 80 percent more sodium than pulp deshived before washing. Deshive refining thus had a noticeable and positive effect on chemical recovery under these conditions.

After DSR was shown to improve the recovery of artificially reintroduced sodium ions efforts were directed toward examining DSR's effect on washing high yield kraft pulp containing high concentrations of black liquor borne sodium salts. Table 26 summarizes the pulping conditions of two laboratory cooks which produced pulps of that description.

TABLE 26. KRAFT PULPING CONDITIONS FOR TWO LABORATORY COOKS

Property	Cook #1	Cook #2
Wood Charge (dry grams)	1088	1137
Active Alkali as Na_2O (%)	26.1	26.1
Sulfidity (%)	24.5	24.5
Liquor to Wood Ratio	8.0:1	8.0:1
Time to Temperature (minutes)	45	45
Time at Temperature (minutes)	30	50
Final Temperature (°C)	171	171
Grams of Pulp Fiberized	542	460
Yield (%)	56	49
Kappa	88	60

After blowing the digester, 8.5 kg of water were added to the cooked chips to facilitate gentle fibration with a TAPPI stirrer. Pulp was then dewatered to approximately 25 percent consistency and diluted with fresh water to 12 percent consistency for deshive refining. Half of the pulp from each cook was deshived in the Bauer 187 (1.52 mm plate gap, 12 percent consistency, 1.2 kg per minute throughput rate), and the remaining half was set aside as a control.

Bauer 187 deshived pulps and the control pulps were washed and evaluated for sodium ion content by the same procedures used on the salt-water soaked pulp. Table 27 summarizes the results of sodium ion measurements for both pulps of each cook.

TABLE 27. CHEMICAL RECOVERY TEST RESULTS OF LABORATORY PRODUCED PULP

Yield (%)	Treatment	0.20 mm Flat Screen Retains (%)	von Alfthan Count	Sodium Content (moles/ ton)	Sodium Content Ratio (undeshived/ deshived)
56	Undeshived	36	*	235	1.51
56	Deshived	3.2	112	156	
49	Undeshived	7.0	*	106	1.14
49	Deshived	1.0	72	93	

*Numerous large fiber bundles made von Alfthan count determination impossible.

Washing data from laboratory cooks after Bauer 187 DSR suggest that DSR's effects on chemical recovery during washing are positive and increase with increasing pulp yield. The results seen in Table 27 support Kurdin's claim that fibration prior to washing is necessary when dealing with pulp yields above 55 percent.

Conclusions

Deshive refining has a positive effect on chemical recovery potential. The effect increases with increasing yields of pulp being washed. At 49 percent yields deshived pulp contained 88 percent as much residual sodium as undeshived pulp, and at 56 percent yield deshived pulp contained only 66 percent as much residual sodium as undeshived pulp.

The Effects of Deshive Refining on Pulp Strength

Background

Linerboard and bag paper, the principal products made from high yield kraft pulp, must be strong sheets to successfully serve their intended purposes. Bursting strength, tensile strength, and tensile energy absorption (TEA) are three strength properties important to these products. Deshive refining has been shown to significantly reduce the shive content of high yield kraft pulp, but its effects on such pulp's strength potential remains largely unexplored. Bublitz (21) found for one deshive refiner that increased deshive refining prior to laboratory beating adversely affected pulp strength. Data published by Kurdin (8) describes pulp strength immediately after deshive refining at various levels of specific energy consumption. Kurdin's data show gradual strength improvement with increased DSR work, but he does not examine deshive refining's effects on the strength of pulp after subsequent strength development refining.

Experimental

The sheet strengths of undeshived, pulp mill deshived, and laboratory deshived high yield kraft pulps from Western Kraft Corporation, Albany, Oregon, were studied. The three 76 Kappa pulps, virtually identical except for deshive refining, were washed and consolidated to approximately 30 percent consistency in a laboratory centrifuge. A PFI mill was used to develop strength in each pulp. For strength development refining (SDR), the PFI mill was charged with

24 oven dry grams of pulp at ten percent consistency, zero knife-bedplate clearance, and high beating pressure. Four sets of TAPPI standard handsheets corresponding to 0, 4000, 8000, and 12,000 PFI mill revolutions were prepared for TAPPI standard strength tests. Table 28 lists these strength test results.

TABLE 28. STRENGTH PROPERTIES OF WK PULP AFTER PFI MILL SDR AT CONSTANT BEATING

Undeshived	PFI Mill Revolutions			
Property	0 rev	4000 rev	8000 rev	12,000 rev
CSF (ml)	751	686	572	326
Bulk (cm^3/g)	3.09	1.92	1.75	1.64
Burst Factor	9.0	49.5	57.3	65.4
Brk length (meters)	1880	7180	8470	8930
TEA ($kg\text{-}m/m^2$)	0.59	5.51	7.67	9.36
Pulp Mill Deshived				
Property	0	4000	8000	12,000
CSF (ml)	742	691	520	330
Bulk (cm^3/g)	2.76	1.93	1.79	1.69
Burst Factor	13.6	51.9	62.2	68.7
Brk length (meters)	2970	7570	8570	9220
TEA ($kg\text{-}m/m^2$)	1.49	6.66	7.95	9.82
FRL Deshived				
Property	0	4000	8000	12,000
CSF (ml)	731	700	542	316
Bulk (cm^3/g)	2.97	1.89	1.73	1.62
Burst Factor	12.1	47.6	61.7	68.4
Brk length (meters)	3080	7700	8540	9410
TEA ($kg\text{-}m/m^2$)	1.54	6.12	8.46	10.71

Results and Discussion

Linear interpolations enabled burst, tensile, and TEA values of the three pulps to be compared at common levels of Canadian standard freeness. Table 29 and Figures 14, 15, and 16 present these interpolations in tabular and graphic form.

TABLE 29. STRENGTH OF WK PULP AFTER PFI MILL SDR AT CONSTANT FREENESS

Undeshived	CSF Levels		
Property	700 ml	600 ml	500 ml
Beating (revs)	3140	7020	9170
Burst Factor	40.8	55.4	59.7
Brk length (m)	6040	8150	8600
TEA (kg-m/m^2)	4.45	7.14	8.17
Pulp Mill Deshived*			
Property	700 ml	600 ml	500 ml
Beating (revs)	3290	6130	8420
Burst Factor	45.1 (1.11)	57.3 (1.03)	62.8 (1.05)
Brk length (m)	6760 (1.12)	8100 (0.99)	8630 (1.00)
TEA (kg-m/m^2)	5.75 (1.29)	7.35 (1.03)	8.15 (1.00)
FRL Deshived*			
Property	700 ml	600 ml	500 ml
Beating (revs)	4000	6530	8740
Burst Factor	47.6 (1.17)	56.5 (1.02)	62.9 (1.05)
Brk length (m)	7700 (1.27)	8230 (1.01)	8710 (1.01)
TEA (kg-m/m^2)	6.12 (1.38)	7.60 (1.06)	8.88 (1.09)

(*) is ratio of: $\left(\frac{\text{Deshived Property}}{\text{Undeshived Property}}\right)$

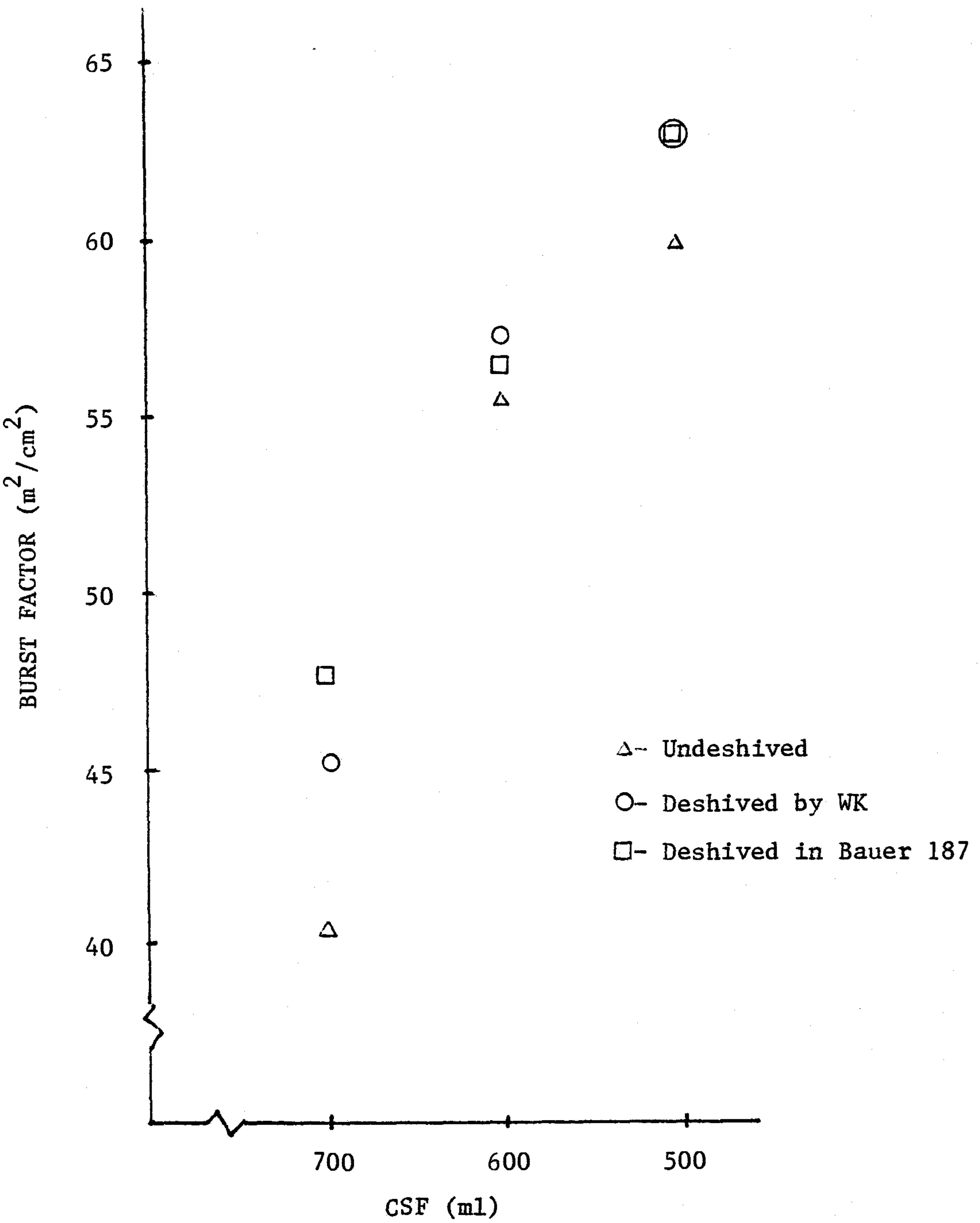


Figure 14. Burst factor of WK pulp at constant CSF.

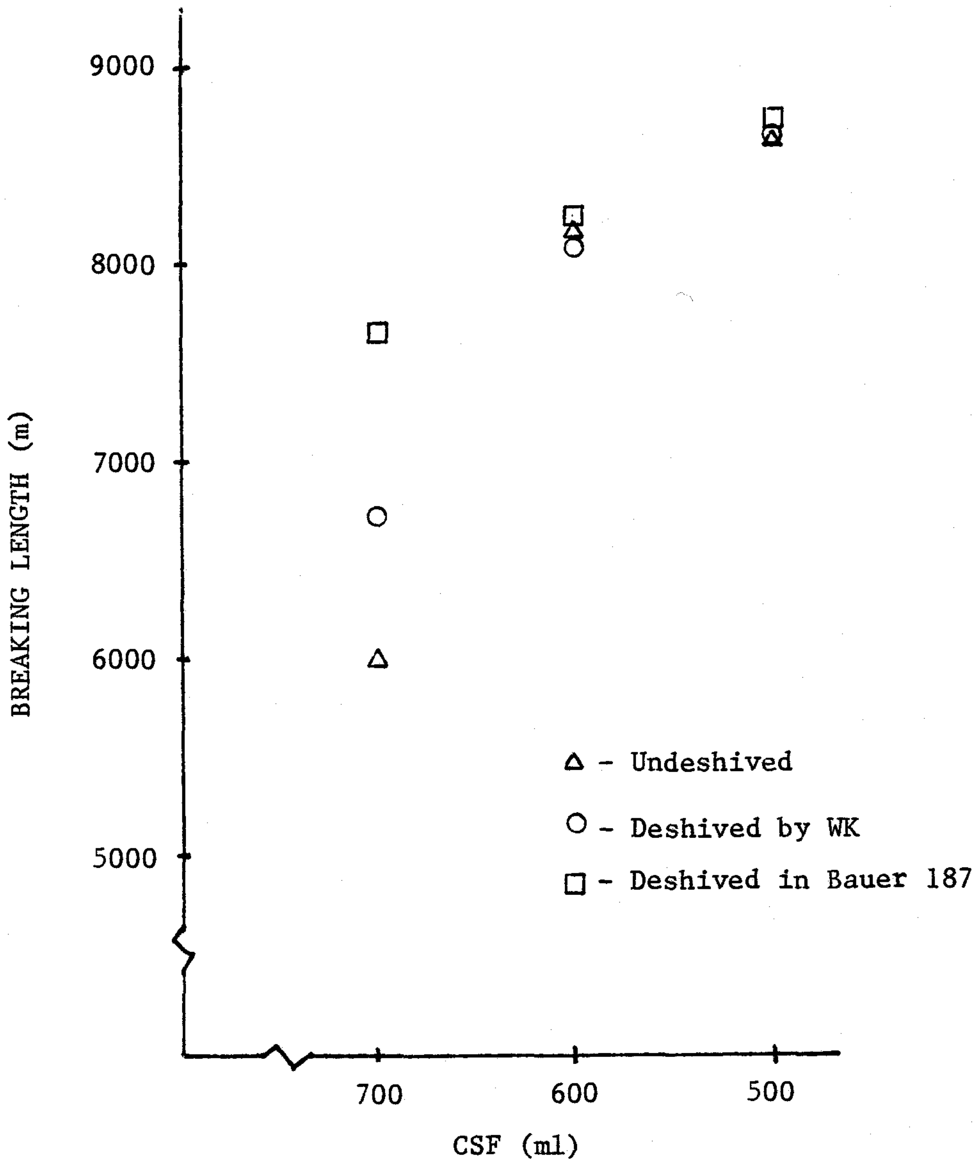


Figure 15. Breaking length of WK pulp at constant CSF.

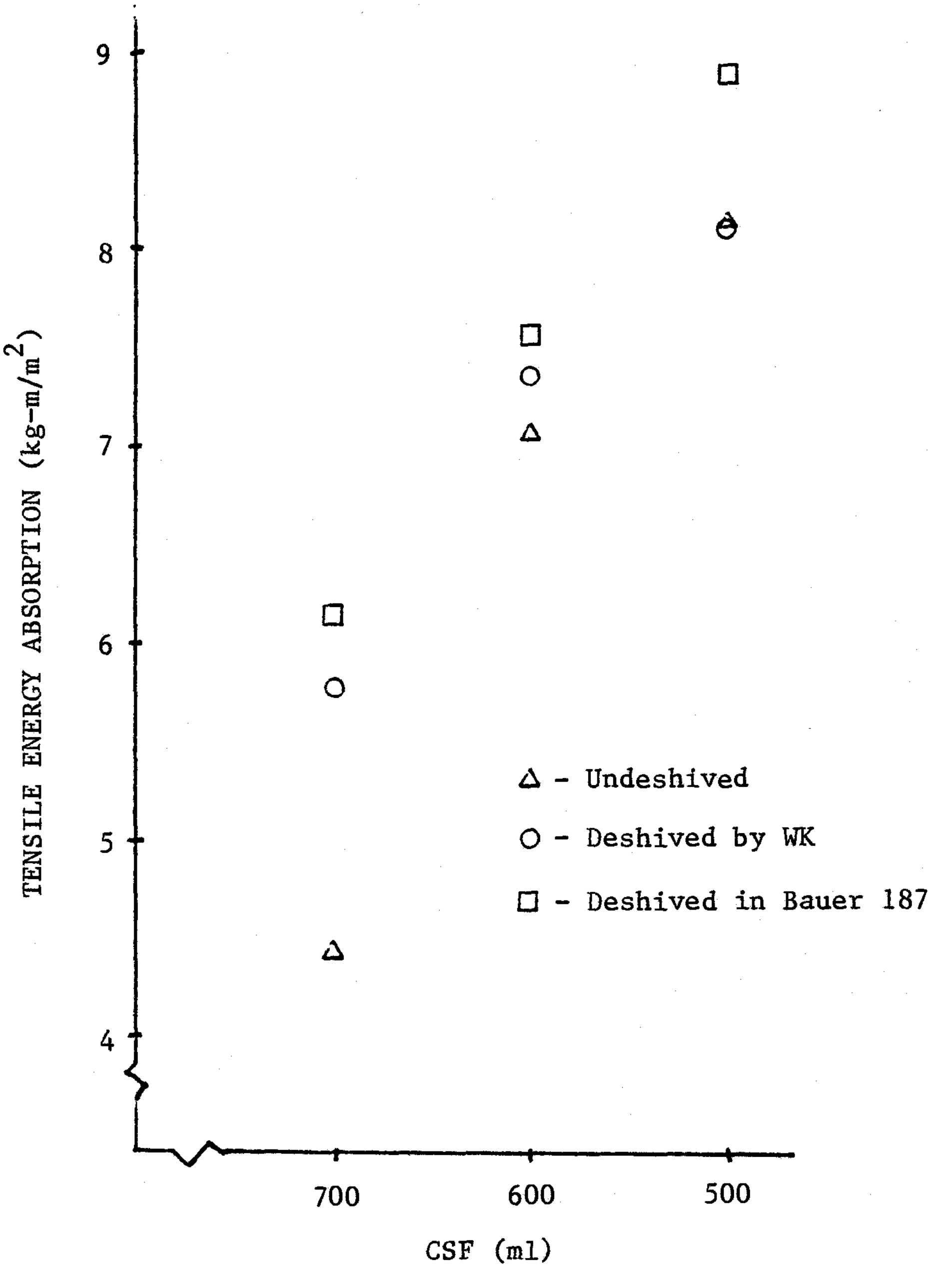


Figure 16. Tensile energy absorption of WK pulp at constant CSF.

At approximately 700 ml CSF deshived pulp was noticeably stronger than undeshived pulp. This may be attributable to the negative effect of shives on sheet strength, or to the characteristic that pulps refined at medium or high consistency have higher strength at given freenesses than pulps refined at low consistency. A more probable explanation is found in Table 29, which indicates that deshived pulp required more SDR (more PFI mill beating revolutions) to achieve a 700 ml CSF than did undeshived pulp. It is reasonable that deshived pulp subjected to more SDR than undeshived pulp would be stronger.

Here and elsewhere in this section the amount of strength development refining required to reach a given level of CSF (or sheet bulk) accounts for differences in pulp strengths. In some cases deshived pulp requires more SDR, and in other cases undeshived pulp requires more SDR. No explanation was found of why one pulp required more SDR than another.

As CSF was reduced to 600 ml and below the differences between deshived and undeshived pulps were essentially negligible. Increased PFI mill SDR caused the strength properties of undeshived pulps to resemble those of deshived pulps by two actions: Undeshived pulp was deshive refined, and the effects of DSR were made less influential. The PFI mill was shown earlier to be an effective deshive refiner within a wide range of control conditions including the conditions corresponding to SDR. Undeshived pulp was thus deshived in the PFI mill during SDR. The effects of DSR on pulp strength were reduced because as PFI mill SDR continued the portion of work done by the deshive refiner represented progressively smaller fractions of the total work absorbed by the pulp.

Table 30 and Figures 17, 18, and 19 summarize the three pulps' burst factor, breaking length, and TEA values as a function of sheet bulk. The strength properties of high bulk sheets were adversely affected by pulp mill DSR and positively affected or unaffected by Bauer 187 DSR. At sheet bulk levels of 2.1 cm^3/g and below both pulp mill and laboratory DSR had neutral or positive effects on strength properties. These characteristics resulted from the effects of PFI mill SDR on the pulps in question.

TABLE 30. STRENGTH OF WK PULP AFTER PFI MILL SDR AT CONSTANT BULK

Undeshived	Handsheet Bulk, cm^3/gm			
Property	2.4	2.1	1.8	1.5
Beating (revs)	320	1410	6190	27,300
Burst Factor	34.2	45.4	56.5	67.6
Brk Length (m)	5180	6620	8060	9510
TEA ($kg\text{-}m/m^2$)	4.14	5.79	7.43	9.08
Pulp Mill DSR*				
Property	2.4	2.1	1.8	1.5
Beating (revs)	123	938	7160	54,700
Burst Factor	31.1 (0.91)	46.1 (1.02)	61.2 (1.08)	76.2 (1.13)
Brk Length (m)	5010 (0.97)	6740 (1.02)	8470 (1.05)	10,200 (1.07)
TEA ($kg\text{-}m/m^2$)	3.90 (0.94)	6.06 (1.05)	8.21 (1.10)	10.36 (1.14)
FRL DSR*				
Property	2.4	2.1	1.8	1.5
Beating (revs)	219	1090	5460	27,200
Burst Factor	33.6 (0.98)	45.6 (1.00)	57.6 (1.02)	69.5 (1.03)
Brk Length (m)	5610 (1.08)	6970 (1.05)	8340 (1.03)	9700 (1.02)
TEA ($kg\text{-}m/m^2$)	4.63 (1.12)	6.43 (1.11)	8.23 (1.11)	10.03 (1.10)

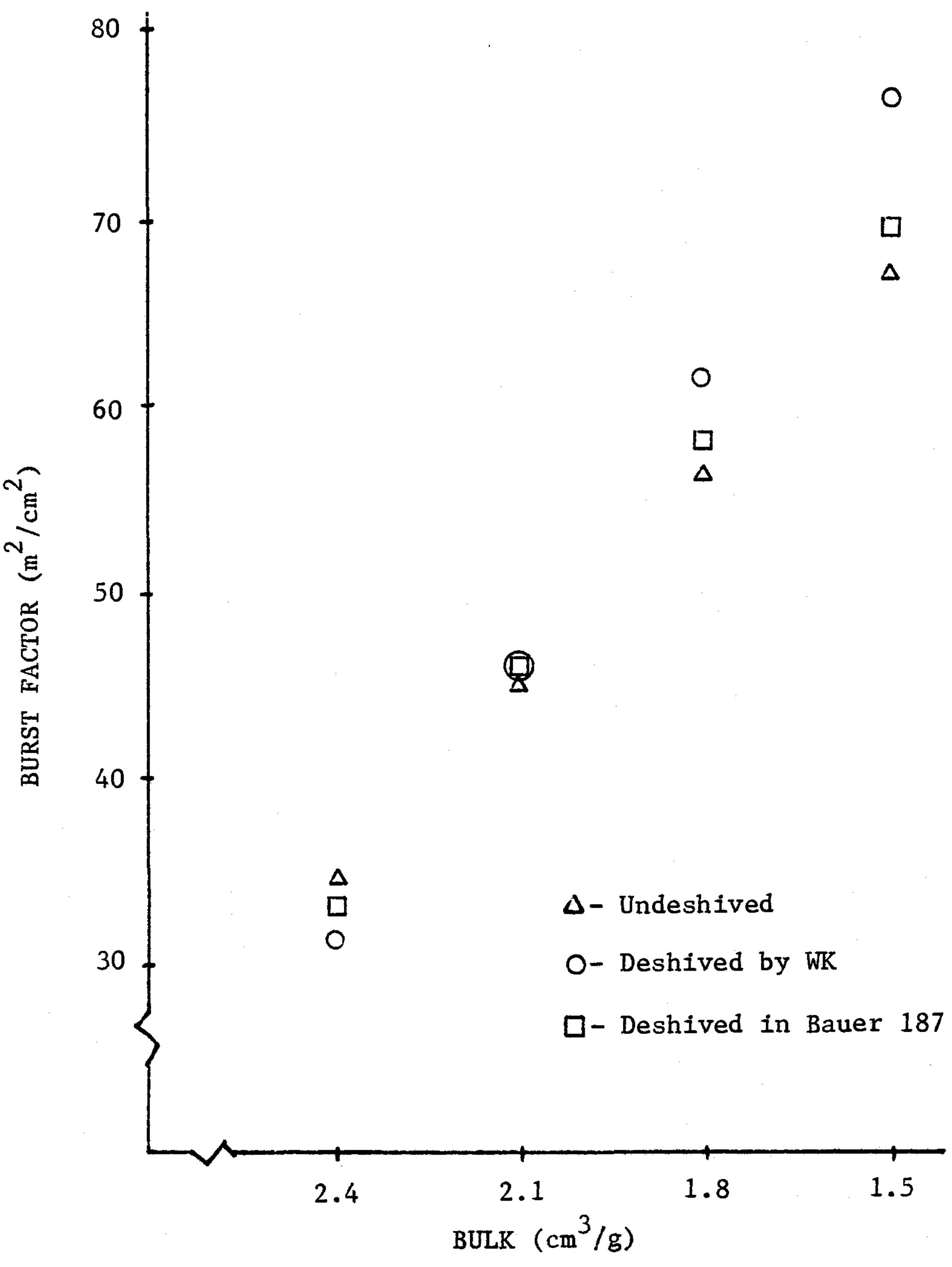


Figure 17. Burst factor of WK pulp at constant bulk.

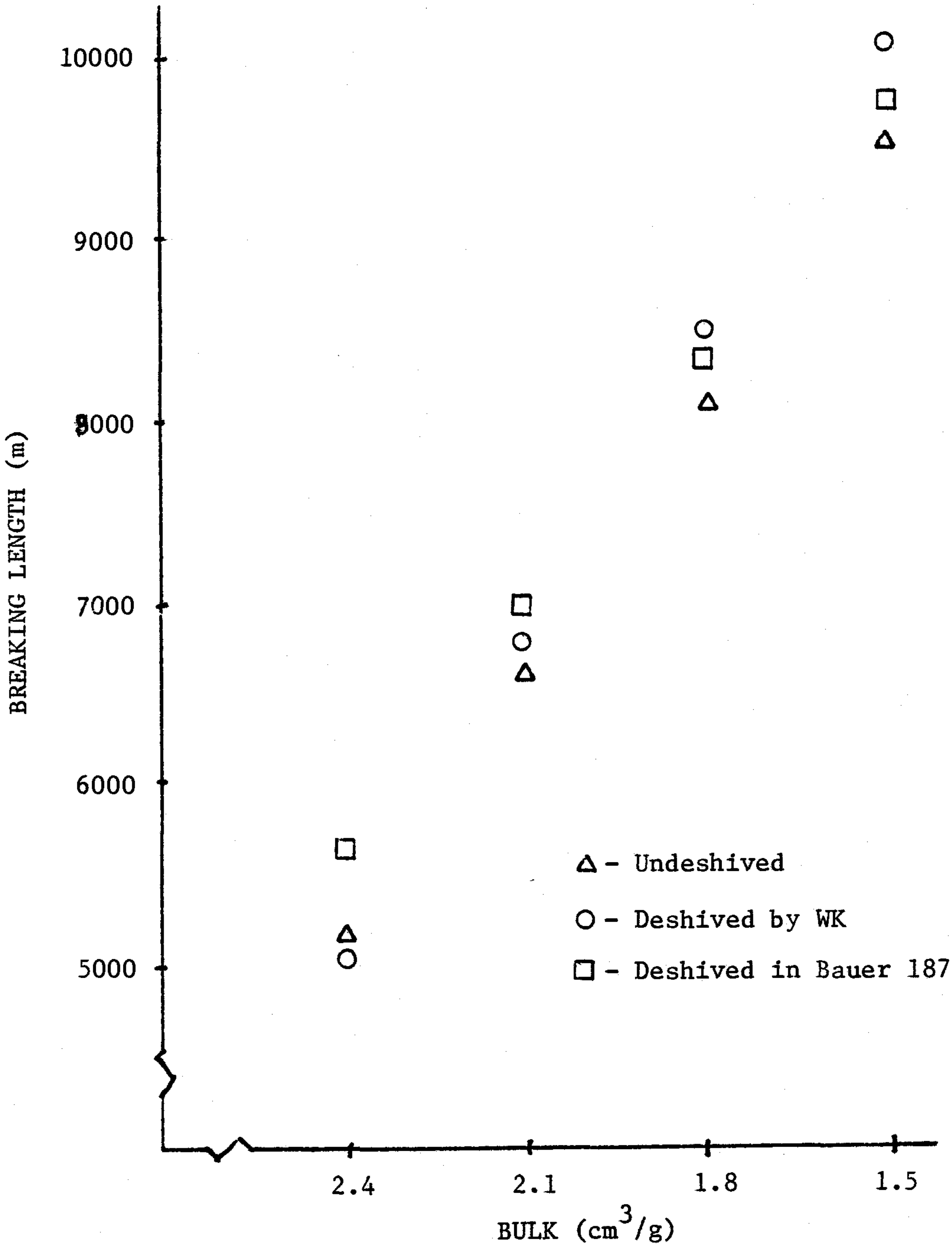


Figure 18. Breaking length of WK pulp at constant bulk.

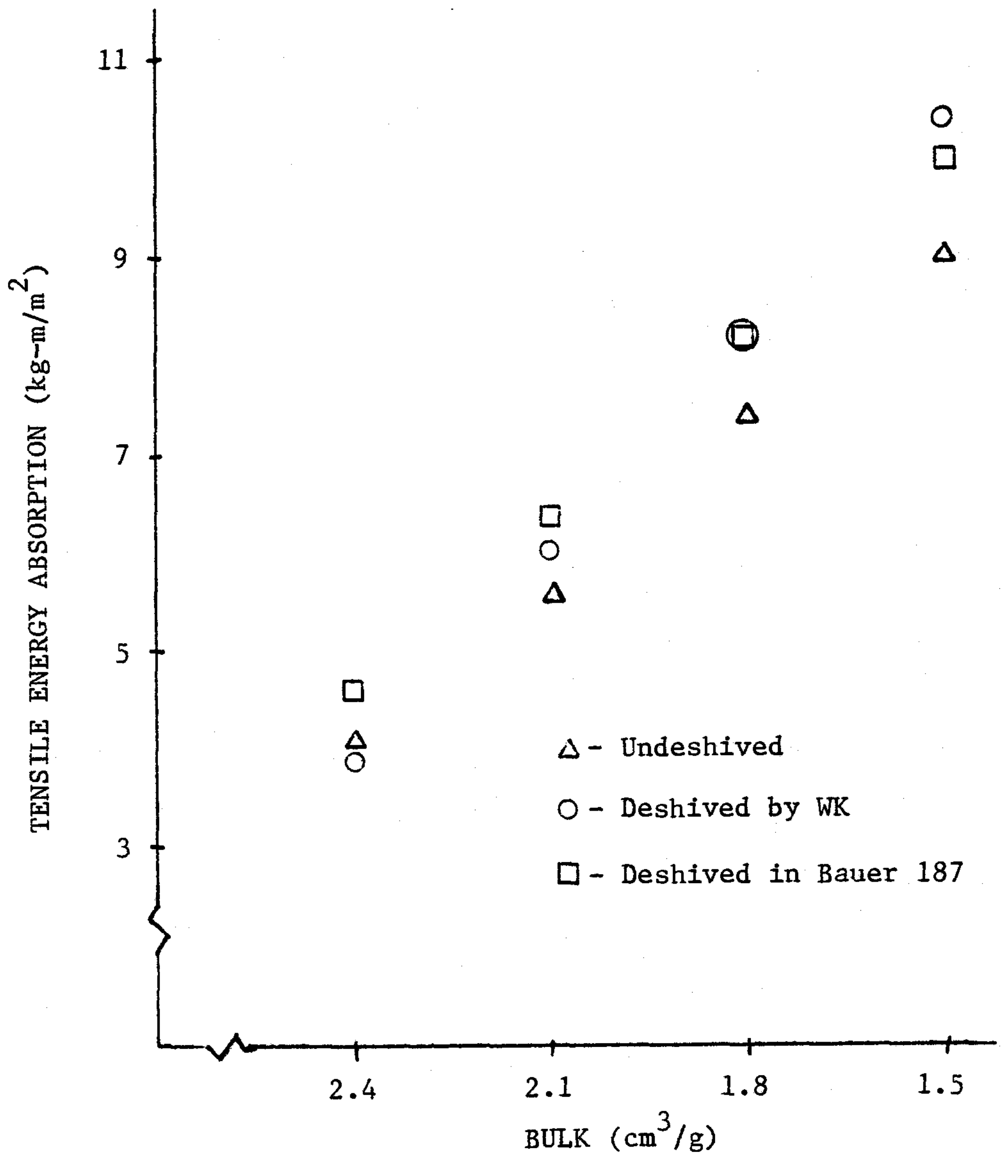


Figure 19. Tensile energy absorption of WK pulp at constant bulk

TABLE 30, continued:

(*) ratio of $\left(\frac{\text{Deshived Value}}{\text{Undeshived Value}}\right)$

Figure 20 plots the response of sheet bulk to PFI mill SDR. Pulp deshived at the mill entered SDR at a bulk noticeably lower than the bulk of either laboratory deshived or undeshived pulp, but after approximately 4000 PFI revolutions all three pulps had nearly identical sheet bulks. Mill deshived pulp will acquire a sheet bulk of 2.4 cm^3/g after less strength development beating than laboratory deshived or undeshived pulp. Having undergone less SDR it will be weaker than laboratory deshived or undeshived pulp.

Laboratory deshived pulp enters SDR at approximately the same value of sheet bulk as does undeshived pulp, and both pulps should acquire 2.4 cm^3/g sheet bulks after about the same amount of processing. After similar degrees of SDR the deshived pulp should be as strong as undeshived pulp or slightly stronger. The deshived pulp may be stronger because it has consumed more total work, DSR and SDR, and a greater fraction of its SDR energy is devoted to fibrillation than to deshiving, compared to undeshived pulp.

Figure 20 shows that sheet bulk values of 2.1 cm^3/g and below are attained by all pulps after nearly the same amount of SDR. By the reasoning of the proceeding paragraph it is expected that the two deshived pulps should be slightly stronger than the undeshived pulp by virtue of their having absorbed the energy of DSR as well as the energy of SDR.

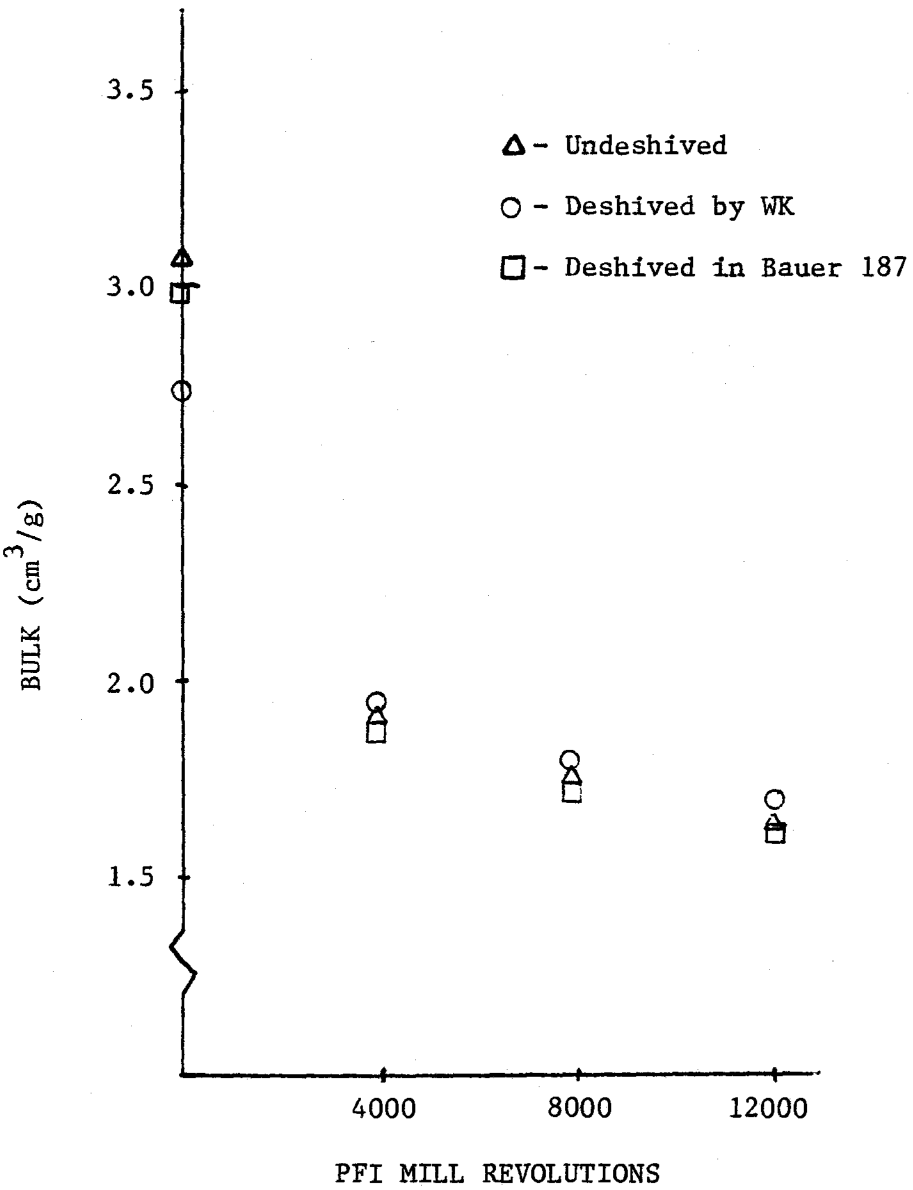


Figure 20. Bulk of WK pulp at constant beating

Whether based on common CSF levels or common sheet bulk levels, the effects of deshive refining are logical and explainable. The lack of pronounced DSR effects at CSF levels below 600 ml and at sheet bulk levels below 2.1 cm^3/g may indicate that no significant effects exist, that the effects may be small or that any effects present are quickly obscured by the gentle beating action of the PFI mill. During the course of SDR this machine brushes out shives which to some extent would be cut into cubical chunks by low consistency paper mill refiners (10). The PFI mill is inclined to cause high shive content pulps to compare favorably to low shive content pulps after each type has received PFI mill SDR. Developing strength with a single pass through a low consistency disk refiner should accentuate any differences in strength potential between deshived and undeshived high yield kraft pulp, and, by more closely simulating paper mill refining, may provide a more realistic assessment of these pulps' papermaking qualities than was possible with the equipment available at the Forest Research Laboratory.

Conclusions

Pulp mill and laboratory deshive refining had a generally positive albeit not necessarily profound effect on the strength of Western Kraft Corp. pulp. Burst, breaking length, and TEA values for deshived pulp were typically improved, but usually by no more than ten percent. There were exceptions: at 700 ml CSF laboratory deshive refining improved burst, breaking length, and TEA by 17, 27, and 38 percent, respectively, and pulp mill deshive refining improved those properties by 11, 12, and 29 percent, respectively. At high bulk (2-4 cm^3/g), pulp mill deshive refining reduced burst, breaking length, and TEA by 9, 3, and 6 percent, respectively, while laboratory deshive refining improved breaking length and TEA by 8 and 12 percent, respectively, and reduced burst by 2 percent.

The effects of deshive refining on pulp strength are a result of the amount of strength development refining consumed when preparing pulps to comparative levels of CSF or sheet bulk. Pulps, whether deshived or undeshived, requiring more strength development refining are stronger.

Investigations of a Second High Yield Kraft Pulp

Background

Pulp from the International Paper Company mill, Gardiner, Oregon, was collected to compare two substantially different industrial deshive refining processes. International Paper (IP) pulp differed from Western Kraft (WK) pulp in Kappa number and refining history. WK pulp was 76 Kappa and had previously received no significant mechanical treatment while IP pulp was 100 Kappa and had previously been subjected to hot stock refining at approximately 40 kilowatt-hours per oven dry ton. Table 31 contains deshive refining machine specifications for both Western Kraft Corporation and International Paper Company.

TABLE 31. CHARACTERISTICS OF WESTERN KRAFT AND INTERNATIONAL PAPER DESHIVE REFINERS

Property	WK Mill	IP Mill
Manufacturer	Sprout-Waldron	Sprout-Waldron
# powered disks	1	1
Disk rpm	1800	1800
Disk diameter (mm)	1140	1370
Plate pattern	A031	A031
Throughput rate (dry ton/day)	300	500
Nominal consistency (%)	11 (provided)	14 (measured)

Experimental

The effects of DSR on chemical recovery were not examined for IP pulp. Undeshived IP pulp, like undeshived WK pulp, was well washed before deshive refining occurred.

Undeshived IP pulp was deshive refined in the Bauer 187 at the same conditions used for laboratory DSR of WK pulp. Comparisons of different DSR processes on the same pulp and similar DSR processes on different pulps were possible.

All pulp testing was performed in accordance with procedures discussed earlier.

Results and Discussion

Table 32 summarizes the general properties of WK and IP pulp after in-house and Bauer 187 DSR. Found in that table are several aspects of IP pulp that are of particular interest. The von Alfthan value of laboratory deshived IP pulp was 75, exactly the value predicted by Equation 6, an equation developed for 76 Kappa pulp after no hot-stock refining. This 75 count von Alfthan value is significantly lower than 102, the von Alfthan value of pulp deshived by IP. Bauer-McNett data indicated that laboratory deshived pulp may contain a larger long fiber fraction and a smaller fines fraction than pulp deshived by IP. Flat screen retains of laboratory deshived pulp are considerably lower than those of IP deshived pulp. Finally, although each of the above comparisons favor laboratory deshive refining, such processing consumed only about 65 percent as much power as DSR by IP. Laboratory deshive refining is the more effective and efficient deshiving process for IP pulp.

TABLE 32. GENERAL PROPERTIES OF DESHIVED PULPS

Property	WK DSR	IP DSR	WK, DSR at FRL	IP, DSR at FRL
von Alfthan count	78	102	76	75
CSF (ml)	735	744	730	734
0.20 mm retains (%)	1.9	1.5	1.2	0.8
Bauer-McNett (%)				
14	66	63	64	67
35	14	15	14	15
65	12	8	10	8
150	4	3	4	2
-150	4	11	8	8
Specific Energy (kwh/ton)	≈ 50	≈ 60	42	38

Table 32 shows that the general properties of WK pulp are quite similar to those of IP pulp after both have been deshive refined under the same laboratory conditions. Unless this similarity is a coincidence, it suggests that raw material properties (pulp quality) are not critical to post-treatment von Alfthan count. When the general properties of the two pulps are compared after deshive refining at their respective mills, noticeable differences are observed in von Alfthan and fines (Bauer-McNett -150) values.

Consistency and specific energy consumption values, and relative values of throughput rate (coded as three for WK pulp and five for IP pulp) for the constant power load deshive refiners at each mill were substituted into Equation 7. That equation, devoid of refiner design considerations, predicted virtually identical von Alfthan counts, 74 and 70 for DSR by WK and IP, respectively. Observed values of post treatment von Alfthan count were 78 for Western Kraft DSR and 102 for International Paper DSR. A major discrepancy exists between the small von Alfthan count spread predicted by Equation 7, four counts, and the large observed spread, 24 counts. The large observed spread was not predicted from processing conditions (Equation 7) or pulp quality (von Alfthan count spread was small for the two pulps after comparable Bauer 187 DSR), which suggests that refiner design factors significantly influence von Alfthan count after DSR.

Effects of Deshive Refining on Strength Potential of IP Pulp

The effects of deshive refining on the strength potential of IP pulp were investigated by techniques used earlier for WK pulp, and the results are given in Table 33. Interpolated results for common levels of CSF and regressed results for common levels of sheet bulk are listed in Tables 34 and 35, respectively.

TABLE 33. STRENGTH PROPERTIES AT CONSTANT BEATING OF IP PULP AFTER PFI MILL SDR

	PFI Mill Revolutions			
Undeshived				
Property	0 rev	4000 rev	8000 rev	12,000 rev
CSF (ml)	762	711	625	432
Bulk (cm^3/g)	2.81	1.97	1.90	1.76
Burst Factor	16.5	50.5	54.6	64.7
Brk Length (m)	3830	8180	8170	8560
TEA ($kg\text{-}m/m^2$)	2.12	6.57	6.51	7.88
Pulp Mill DSR				
Property	0	4000	8000	12,000
CSF (ml)	744	683	574	378
Bulk (cm^3/g)	2.68	1.98	1.84	1.73
Burst Factor	23.5	47.5	56.0	63.6
Brk Length (m)	4790	7360	8780	8930
TEA ($kg\text{-}m/m^2$)	2.68	5.29	7.16	9.11
FRL DSR				
Property	0	4000	8000	12,000
CSF (ml)	734	704	608	391
Bulk (cm^3/g)	3.04	2.00	1.91	1.73
Burst Factor	23.9	48.4	55.0	66.5
Brk Length (m)	4630	7460	8190	9010
TEA ($kg\text{-}m/m^2$)	2.40	6.27	6.34	8.60

TABLE 34. STRENGTH PROPERTIES OF IP PULP AFTER PFI MILL SDR AT CONSTANT FREENESS

	CSF Levels		
Undeshived			
Property	700 ml	600 ml	500 ml
Beating (rev)	4510	8520	10,590
Burst Factor	51.0	55.9	61.1
Brk Length (m)	8180	8220	8420
TEA ($kg\text{-}m/m^2$)	6.56	6.69	7.40

TABLE 34, continued:

DSR at Mill #2*

Property	CSF Levels 700 ml	600 ml	500 ml
Beating (rev)	2890	7050	9510
Burst Factor	40.8 (0.80)	54.0 (0.97)	58.9 (0.96)
Brk Length (m)	6640 (0.81)	8440 (1.03)	8840 (1.05)
TEA (kg-m/m^2)	4.56 (0.70)	6.72 (1.00)	7.90 (1.07)

DSR at FRL*

Property	700 ml	600 ml	500 ml
Beating (rev)	4170	8150	9990
Burst Factor	48.7 (0.95)	55.4 (0.99)	60.7 (0.99)
Brk Length (m)	7480 (0.91)	8220 (1.00)	8600 (1.02)
TEA (kg-m/m^2)	6.28 (0.96)	6.43 (0.96)	7.47 (1.01)

(*) = ratio of $\left(\frac{\text{Deshived Value}}{\text{Undeshived Value}}\right)$

TABLE 35. STRENGTH PROPERTIES OF IP PULP AFTER PFI MILL SDR AT CONSTANT BULK

Undeshived

Property	Handsheet Bulk, cm^3/gm 2.4	2.1	1.8	1.5
Beating (revs)	186	1500	12,160	98,400
Burst Factor	33.9	47.0	60.1	73.2
Brk Length (m)	5830	7230	8640	10,000
TEA (kg-m/m^2)	4.25	5.82	7.40	8.97

DSR at IP*

Property	2.4	2.1	1.8	1.5
Beating (revs)	10	1000	10,300	106,000
Burst Factor	33.8 (1.00)	45.9 (0.98)	58.1 (0.97)	70.2 (0.96)
Brk Length (m)	5940 (1.02)	7280 (1.01)	8610 (1.00)	9940 (0.99)
TEA (kg-m/m^2)	3.99 (0.94)	5.80 (1.00)	7.61 (1.03)	9.42 (1.05)

TABLE 35, continued:

DSR at FRL*	Handsheet Bulk, cm^3/gm			
Property	2.4	2.1	1.8	1.5
Beating (revs)	383	2060	11,100	59,400
Burst Factor	41.7 (1.23)	50.5 (1.07)	59.4 (0.99)	68.2 (0.93)
Brk Length (m)	6590 (1.13)	7540 (1.04)	8490 (0.98)	9450 (0.95)
TEA ($kg\text{-}m/m^2$)	4.93 (1.16)	6.19 (1.06)	7.46 (1.01)	8.72 (0.97)

(*) = ratio of $\left(\frac{\text{Deshived Value}}{\text{Undeshived Value}}\right)$

Data in Table 34 (IP pulp strength at constant CSF) indicated that at high freeness levels DSR has a detrimental effect on IP pulp strength. This effect, opposite to that observed earlier for WK pulp, is more pronounced for pulp deshived by IP than for IP pulp deshived at the laboratory. A primary reason for the improvement in strength properties of WK pulp was that deshived pulp required more SDR enroute to 700 ml CSF than did undeshived pulp. Deshived IP pulp absorbed less SDR enroute to 700 ml CSF than did undeshived IP pulp. For this reason undeshived IP pulp was stronger than deshived IP pulp at 700 ml CSF.

After SDR to CSF levels of 600 ml and below DSR's effects on IP pulp's strength properties are generally negligible. As was true for WK pulp those effects may actually be insignificant, or they may be made so by the nature of the PFI mill beating action.

Table 35 summarizes data comparing strength properties of deshived IP pulp to those of undeshived IP pulp at common sheet bulks. With one exception, these differences were small. High bulk sheets made from IP pulp deshived in the Bauer 187 were stronger than high bulk sheets made from undeshived IP pulp or pulp deshived by IP. The same reasoning used to explain the weakness of WK mill deshived pulp compared to its companion pulps applies to the strength of IP pulp deshived in the laboratory compared to its companion pulps. Figure 21 shows that laboratory deshived IP pulp requires more SDR to achieve a sheet bulk of 2.4 cm^3/g than does either undeshived IP pulp or pulp deshived by IP. Having received more SDR the superior strength of Bauer 187 deshived IP pulp is expected.

Table 36 compares the strength properties of WK pulp after in-house deshive refining with those of IP pulp after in-house deshive refining. At common levels of CSF the high Kappa, hot stock refined IP pulp appears somewhat weaker in burst strength and toughness, and slightly stronger in tensile than the lower Kappa, previously unrefined WK pulp. Although the high Kappa pulp requires more SDR to arrive at the 600 ml and 500 ml CSF levels, once there its strength compares favorably with that of lower Kappa pulp.

TABLE 36. COMPARISON OF STRENGTH PROPERTIES AT CONSTANT FREENESS FOR WK AND IP PULP AFTER IN-HOUSE DESHIVE REFINING

WK DSR	CSF Levels		
Property	700 ml	600 ml	500 ml
Beating (revs)	3290	6130	8420
Burst Factor	45.1	57.3	62.8
Brk Length (m)	6760	8100	8630
TEA (kg-m/m^2)	5.75	7.35	8.15

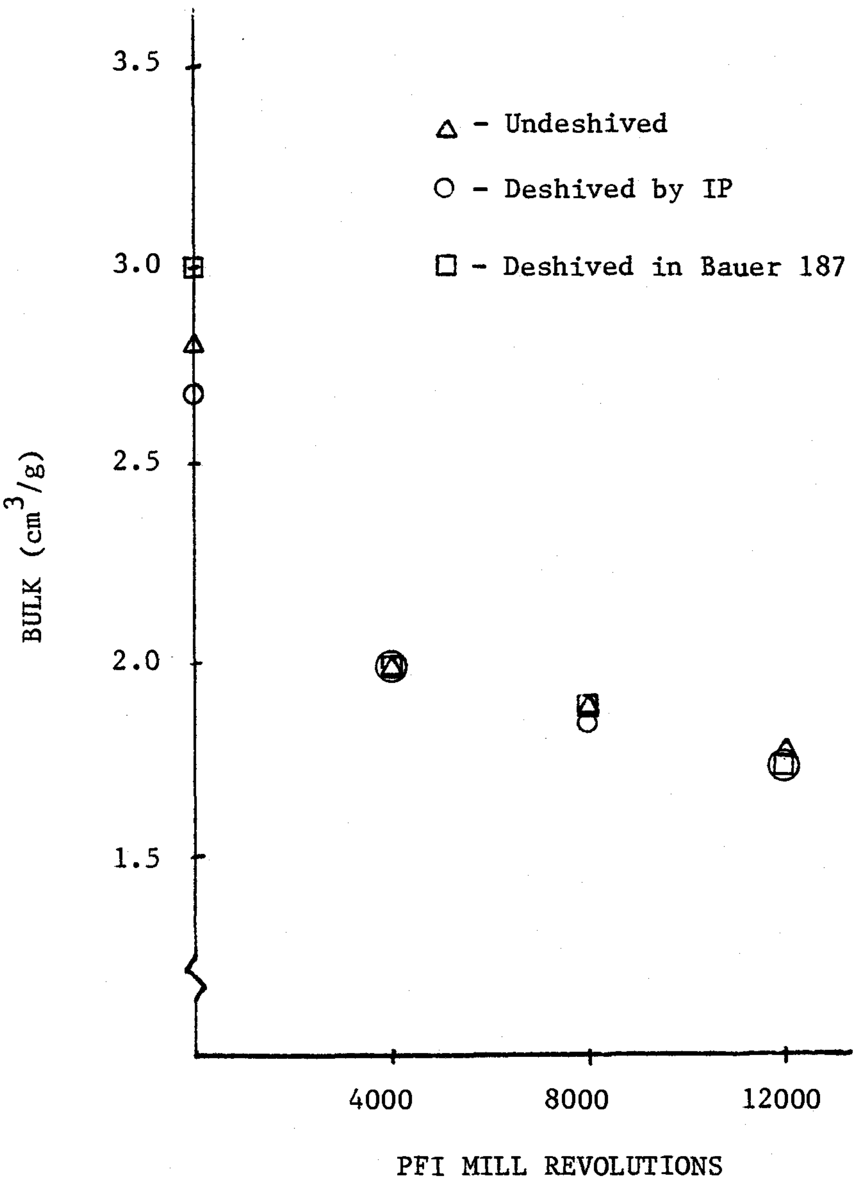


Figure 21. Bulk of IP pulp at constant beating.

TABLE 36, continued:

IP DSR	CSF Levels		
Property*	700 ml	600 ml	500 ml
Beating (revs)	2890	7050	9510
Burst Factor	40.8 (0.90)	54.0 (0.94)	58.9 (0.94)
Brk Length (m)	6640 (0.98)	8440 (1.04)	8840 (1.02)
TEA (kg-m/m^2)	4.56 (0.79)	6.72 (0.91)	7.90 (0.97)

* $\left(\frac{\text{IP value}}{\text{WK value}}\right)$

The preceding sections cited differences in strength development referring to DSR's effects on pulp strength. A particular deshived pulp was stronger or weaker than its undeshived counterpart because it absorbed more or less SDR. Unexplained are the fiber-process interactions at the deshive refiner which caused a deshived pulp to absorb more or less SDR than its undeshived relative. Additional research efforts should be directed in this area.

Conclusions

WK pulp and IP pulp had similar von Alfthan (76, 75) and CSF (730, 734) values after Bauer 187 deshive refining.

Refiner design variables, plate pattern, disk size and speed, stock delivery system, etc., appear relatively significant to von Alfthan count after DSR, and pulp quality appears relatively insignificant to von Alfthan count after DSR.

At CSF levels of 600 ml and below and sheet bulk levels of 2.1 cm^3/g and below, pulp mill and laboratory deshive refining randomly improved and degraded International Paper Company pulp strength by seven percent or less. Pulp mill deshive refining reduced burst, breaking length, and TEA of 700 ml CSF pulp by 20, 19, and 30 percent, respectively. Laboratory deshive refining reduced the burst, breaking length, and TEA of 700 ml CSF pulp by 5, 9, and 4 percent, respectively, but improved those properties by 23, 13, and 16 percent, respectively, for pulp of 2-4 cm^3/g bulk.

The effects of DSR on IP pulp strength were explainable in terms of the amount of strength development refining necessary to achieve common levels of CSF or sheet bulk.

After DSR, the strength of 100 Kappa IP pulp was, on the average, approximately seven percent lower in burst, one percent higher in breaking length, and eleven percent lower in TEA than that of 76 Kappa WK pulp.

SUMMARY

Deshive refining, while widely used in the high yield kraft pulping industry, has been an under-researched and sometimes controversial process. This project investigated the processing variables of DSR through mathematical modeling, evaluated the effects of DSR on chemical recovery and pulp strength potential, and compared two substantially different high yield kraft pulps and DSR processes.

The von Alfthan shives analyzer was assumed to accurately measure the shive content of high yield kraft pulp; it was the only measurement of shive content used in this study. Based on von Alfthan count values, the PFI mill was an effective deshive refiner capable of deshiving to industrial standards. It was poorly suited for modeling DSR because post-treatment shive contents did not respond to changes in processing conditions. The PFI mill can be used for laboratory DSR, but process control will be quite difficult.

The Bauer 187 double disk refiner simulated industrial DSR at a pilot plant scale. Bauer 187 DSR effectively reduced the shive content of high yield kraft pulp. Strong correlations were observed between Bauer 187 processing variables (plate gap, stock consistency, and throughput rate) and the von Alfthan value of deshived pulp. Conditions were found which minimized the energy expenditure for a specified post-treatment shive content. Bauer 187 data suggested that better controlled and more efficient industrial DSR is possible pending analyses of individual DSR systems.

One clue to optimum deshive refiner design was detected: The Bauer 187 was a more efficient deshive refiner with both disks operating than with one disk operating. The generalized implication is that double disk machines make better deshive refiners than single disk machines. Equipment limitations prohibited an examination of refiner design influences on deshive refining. Considerable research is warranted in this area.

Deshive refining high yield kraft pulps improved the potential recovery of pulping chemicals during washing by exposing chemicals in the core of undeshived fiber bundles to wash water. To realize improved chemical recovery, the drainage rate of pulp on a washer must not be significantly reduced by DSR, since getting more chemicals into the wash water is fruitless if the wash water cannot be readily extracted from the pulp mat. Research using apparatus such as the Ingmanson Filtration Resistance device and pilot plant scale rotary drum washers is required to analyze the practical effects of DSR on pulp washing.

Deshive refining generally improved the strengths of high shive content pulp, but improvements were small. Differences between strength properties of deshived and undeshived pulp resulted from the amount of PFI mill strength development refining each pulp absorbed to achieve the common levels of CSF or sheet bulk used for their comparison. Whether deshived or undeshived, the pulp receiving more PFI mill SDR was stronger.

Strength development refining in the PFI mill may have camouflaged the true effects of DSR on pulp strength regardless of differences in the initial shive content of the pulp or in the process control conditions of the machine. The effects of DSR on pulp strength may be small, or they may be camouflaged by the deshiving action of PFI mill SDR. Developing pulp strength by a single pass through a low consistency disk refiner might resolve this question by amplifying differences between the strengths of deshived and undeshived pulps.

Two substantially different pulps, hot-stock refined 100 Kappa International Paper Company pulp and unrefined 76 Kappa Western Kraft Corporation pulp, had similar general properties after Bauer 187 DSR at identical conditions. Both pulps were satisfactorily deshived. If raw material properties (pulp quality) were highly influential to DSR, IP and WK pulp would be expected to retain their markedly different properties. Their similarities after comparable Bauer 187 DSR may be coincidental, or it may indicate that within the range tested, shive content after DSR depends little on pulp quality and more on the conditions of DSR.

The two pulps possessed noticeably different general properties (especially von Alfthan count) after in-house DSR at the mills of their manufacture. Processing control conditions and pulp quality (the pulps were similar after comparable Bauer 187 DSR) did not account for such differences. Discrepancies between von Alfthan counts mathematically predicted from appropriate regression models and measured von Alfthan counts of in-house deshived pulp suggest that refining machine design variables influence DSR.

Deshive refining reduced the shive contents of high yield kraft pulp. It was a controllable process which generally improved pulp strength and chemical recovery and had no obvious adverse effects on pulp quality.

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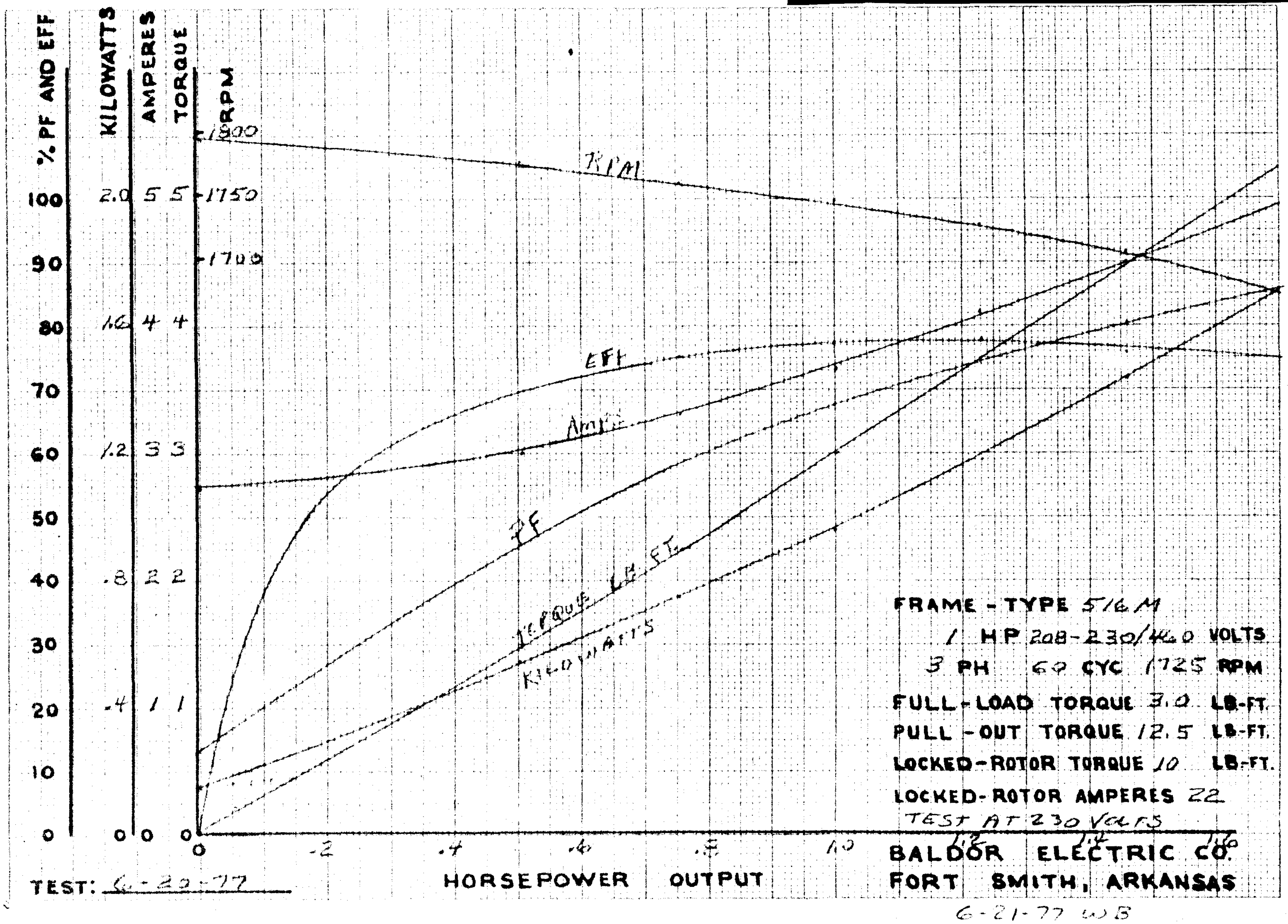
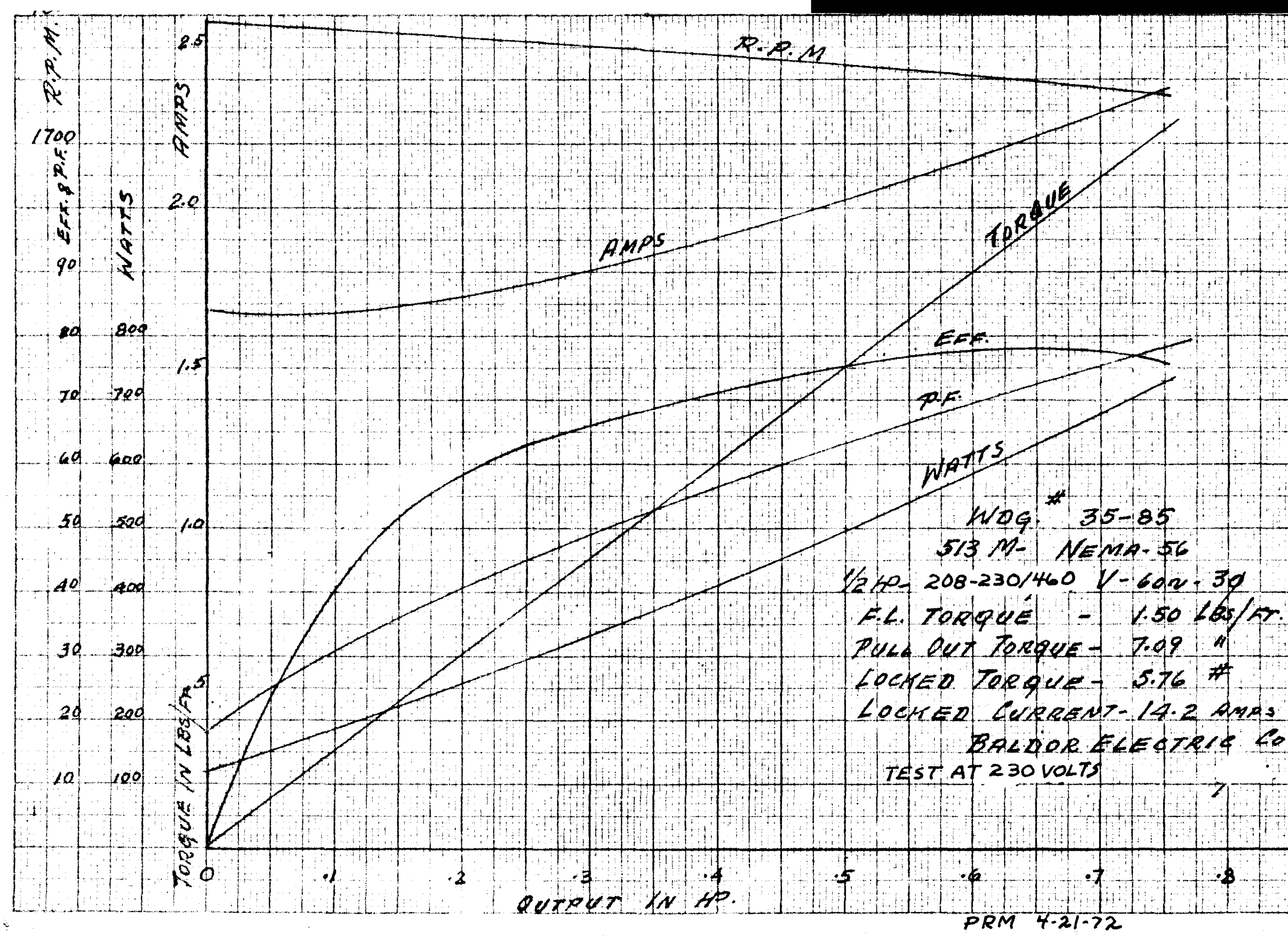
APPENDICES

APPENDIX I. KNIFE SPINDLE MOTOR TEST DATA.



APPENDIX I. BEDPLATE BOWL MOTOR TEST DATA



APPENDIX II. DEVELOPMENT OF EQUATIONS TO PREDICT EFFICIENCIES OF PFI MILL MOTORS

Mechanical power output of the knife spindle motor, Y_1 (watts), as a function of power drawn by that motor, P_{m1} (watts), was determined by fitting nominal data provided by Baldor Electric Company to a quadratic equation. The following regression equation predicts the mechanical power output of the knife spindle motor from its power consumption:

$$Y_1 = -153.166855 + 1.051618\ P_{m1} - 0.000131\ P_{m1}^2 \qquad r^2 = 0.999$$

During PFI mill operation sufficient mechanical power is available to drive the bedplate bowl motor to speeds beyond synchronous, causing it to generate electrical power. The assumption was made that this motor had the same nominal efficiency whether it was consuming or generating a given amount of electrical power. In other words, if 100 units of electrical power were converted at 50 percent efficiency to 50 units of mechanical power, then 200 units of mechanical power would be required to generate, at 50 percent efficiency, 100 units of electrical power. Curve fitting of mechanical power input, Y_2 (watts), as a function of electrical power output, P_{G2} (watts), resulted in the following expression:

$$Y_2 = 119.936144 + 0.861131\ P_{G2} + 0.000402\ P_{G2}^2 \qquad r^2 = 0.999$$

Under "no load" conditions, idle, both the bedplate bowl and knife spindle motors consume rather than generate electrical power. Baldor Electric Company test data was used to estimate the total mechanical power into the PFI mill refining area at idle, P_I. The value of P_I so obtained, 52 watts, did not change with variations of PFI mill processing variables.

The difference between mechanical power produced by the knife spindle motor and mechanical power consumed by the bedplate bowl motor (generator), $Y_1 - Y_2$, is a sound estimate of the mechanical power available in the refining zone to cut, fibrillate, heat up, and fiberize or deshive the pulp slurry. Fifty-two of the $(Y_1 - Y_2)$ watts are necessary to overcome machine friction. These 52 watts which do not contribute to pulp treatment are subtracted from $(Y_1 - Y_2)$ to yield total power to the pulp slurry, P_T.

$$P_T = Y_1 - Y_2 - 52$$

or

$$P_T = -153.167 + 1.051618\ P_{ml} - 0.000131\ P_{ml}^{\ 2} - (119.936144 + 0.861131\ P_{G2} + 0.000402\ P_{G2}^{\ 2}) - 52$$

The latter equation appears in the text as Equation 3.

APPENDIX III. TABLE OF ACTUAL PFI MILL VARIABLE LEVELS AND THEIR CORRESPONDING CODED LEVELS

Coded and Actual PFI Mill Variables

Variable	Coded Values				
	1	2	3	4	5
Specific Energy Consumption (watt-seconds/gram)	200	300	400	500	600
Pulp Weight (grams)	10	17.5	25	32.5	40
Knife-Bedplate Gap (millimeters)	0	0.5	1.0	1.5	2.0
Consistency (percent)	5	10	15	20	25

APPENDIX IV. EQUATIONS FOR DETERMINING ACTUAL VALUES OF BAUER 187 VARIABLES FROM CODED LEVELS

Actual		Coded
Plate Gap$_{(mm)}$	=	(Coded Plate Gap)(0.508)
Stock Consistency$_{(\%)}$	=	(Coded Consistency)(6.0) - 3.0
Throughput Rate$_{(kg/min)}$	=	(Coded Throughput)(0.227)
Specific Energy Consumption$_{(kwh/ton)}$	=	(Coded Specific Energy Consumption)(26.87)

APPENDIX V. MODELS OF VON ALFTHAN COUNT AFTER BAUER 187 DESHIVE REFINING HAVING NO SPECIFIC ENERGY CONSUMPTION TERMS

Two Term Model with Lowest MSE

ANOVA $r^2 = 0.782$

Source	DF	SS	MS	F
Regression	2	3894	1947	44.75
Error	25	1088	43.51	
Total	27	4982		

Term	Coefficient	t-Value
Constant	28.51	
Gap	14.22	9.45
Throughput	0.00	3.60

Three Term Model with Lowest MSE

ANOVA $r^2 = 0.902$

Source	DF	SS	MS	F
Regression	3	4496	1498	74.04
Error	24	486	20.24	
Total	27	4982		

Term	Coefficient	t-Value
Constant	52.78	
Consistency^2	-2.69	11.50
Throughput	0.00	4.92
Gap · Consistency	4.96	14.78

Four Term Model with Lowest MSE

ANOVA $r^2 = 0.917$

Source	DF	SS	MS	F
Regression	4	4566	1141	63.12
Error	23	416	18.08	
Total	27	4982		

Term	Coefficient	t-Value
Constant	54.62	
Gap^2	-1.00	1.97
$Consistency^2$	-3.54	7.32
$Throughput^2$	0.00	4.82
Gap · Consistency	6.75	6.99

Five Term Model with Lowest MSE

ANOVA $r^2 = 0.926$

Source	DF	SS	MS	F
Regression	5	4614	922.9	55.26
Error	22	367	16.70	
Total	27	4982		

Term	Coefficient	t-Value
Constant	42.26	
Gap	8.42	1.74
Throughput	0.17	5.20
Gap^2	-2.07	2.70
$Consistency^2$	-3.25	6.48
Gap · Consistency	6.08	5.91

Six Term Model with Lowest MSE

ANOVA $r^2 = 0.938$

Source	DF	SS	MS	F
Regression	6	4671	778.5	52.55
Error	21	311	14.81	
Total	27	4982		

Term	Coefficient	t-Value
Constant	37.00	
Gap	12.50	2.46
Gap^2	-2.48	-3.25
$Consistency^2$	-3.10	-6.49
$Throughput^2$	0.01	3.65
Gap · Consistency	5.78	5.91
Gap · Throughput	-0.08	-2.00

Seven Term Model with Lowest MSE

ANOVA $r^2 = 0.955$

Source	DF	SS	MS	F
Regression	7	4756	679.4	60.16
Error	20	226	11.29	
Total	27	4982		

Term	Coefficient	t-Value
Constant	25.28	
Gap	17.93	3.71
Throughput	0.64	4.41
Gap^2	-3.16	-4.46
$Consistency^2$	-2.89	-6.52
Gap · Consistency	5.60	6.49
Gap · Throughput	-0.12	-2.95
Consistency · Throughput	-0.06	-1.44

Eight Term Model with Lowest MSE

ANOVA $r^2 = 0.958$

Source	DF	SS	MS	F
Regression	8	4773	596.6	54.21
Error	19	209	11.01	
Total	27	4982		

Term	Coefficient	t-Value
Constant	12.41	
Gap	20.25	3.95
Consistency	6.40	1.23
Throughput	0.69	4.63
Gap^2	-3.18	-4.55
$Consistency^2$	-3.55	-5.13
Gap · Consistency	4.87	4.69
Gap · Throughput	-0.13	-3.06
Consistency · Throughput	-0.07	-1.74

Full Nine Term Model

ANOVA $r^2 = 0.958$

Source	DF	SS	MS	F
Regression	9	4774	530.5	46.05
Error	18	207	11.52	
Total	27	4982		

Term	Coefficient	t-Value
Constant	13.24	
Gap	20.03	3.80
Consistency	6.21	1.17
Throughput	0.63	2.93
Gap^2	-3.14	-4.35
$Consistency^2$	-3.51	-4.90
$Throughput^2$	0.00	0.39
Gap · Consistency	4.86	4.57
Gap · Throughput	-0.12	-2.95
Consistency · Throughput	-0.07	-1.73

APPENDIX VI. MODELS OF VON ALFTHAN COUNT AFTER BAUER 187 DESHIVE REFINING HAVING NO PLATE GAP TERMS

Two Term Model with Lowest MSE

ANOVA $r^2 = 0.749$

Source	DF	SS	MS	F
Regression	2	3731	1865	37.28
Error	25	1251	50.04	
Total	27	4982		

Term	Coefficient	t-Value
Constant	88.87	
Energy	-7.41	8.31
Throughput · Energy	0.05	3.57

Three Term Model with Lowest MSE

ANOVA $r^2 = 0.795$

Source	DF	SS	MS	F
Regression	3	3959	1320	30.98
Error	24	1022	42.60	
Total	27	4982		

Term	Coefficient	t-Value
Constant	84.68	
Energy	-8.12	9.24
Consistency^2	0.61	2.32
Throughput · Energy	0.06	4.20

Four Term Model with Lowest MSE

ANOVA $r^2 = 0.824$

Source	DF	SS	MS	F
Regression	4	4106	1026	26.96
Error	23	876	38.08	
Total	27	4982		

Term	Coefficient	t-Value
Constant	87.95	
Consistency	2.95	1.97
Energy	-12.60	5.45
$Energy^2$	0.59	2.15
Throughput · Energy	0.05	3.86

Five Term Model with Lowest MSE

ANOVA $r^2 = 0.854$

Source	DF	SS	MS	F
Regression	5	4254	850.9	25.73
Error	22	727	33.07	
Total	27	4982		

Term	Coefficient	t-Value
Constant	93.18	
Energy	-13.57	-6.22
$Consistency^2$	0.70	2.85
$Energy^2$	0:58	2.27
Consistency · Throughput	-0.05	-1.75
Throughput · Energy	0.09	3.72

Six Term Model with Lowest MSE

ANOVA $r^2 = 0.870$

Source	DF	SS	MS	F
Regression	6	4333	722.2	23.37
Error	21	649	30.90	
Total	27	4982		

Term	Coefficient	t-Value
Constant	113.13	
Consistency	-12.44	-1.59
Energy	-15.04	-6.54
Consistency^2	2.73	2.11
Energy^2	0.71	2.74
Consistency · Throughput	-0.05	-1.78
Throughput · Energy	0.10	3.98

Seven Term Model with Lowest MSE

ANOVA $r^2 = 0.881$

Source	DF	SS	MS	F
Regression	7	4391	627.2	21.22
Error	20	591	29.56	
Total	27	4982		

Term	Coefficient	t-Value
Constant	116.59	
Consistency	-13.94	-1.81
Energy	-16.55	-6.63
Consistency^2	3.14	2.41
Throughput^2	0.00	1.40
Energy^2	0.91	3.12
Consistency · Throughput	-0.13	-2.00
Throughput · Energy	0.10	4.14

Eight Term Model with Lowest MSE

ANOVA $r^2 = 0.886$

Source	DF	SS	MS	F
Regression	8	4416	552.0	18.53
Error	19	566	29.79	
Total	27	4982		

Term	Coefficient	t-Value
Constant	121.97	
Consistency	-15.74	-1.97
Throughput	-0.32	-0.92
Energy	-17.36	-6.54
Consistency^2	3.38	2.54
Throughput^2	0.01	1.54
Energy^2	0.99	3.24
Consistency · Throughput	-0.12	-1.82
Throughput · Energy	0.11	4.16

Full Nine Term Model

ANOVA $r^2 = 0.891$

Source	DF	SS	MS	F
Regression	9	4439	493.3	16.37
Error	18	542	30.14	
Total	27	4982		

Term	Coefficient	t-Value
Constant	118.32	
Consistency	-15.78	-1.97
Throughput	-0.35	-0.99
Energy	-15.22	-4.23
Consistency^2	3.87	2.67
Throughput^2	0.01	1.50
Energy^2	1.12	3.29
Consistency · Throughput	-0.11	-1.56
Consistency · Energy	-0.94	-0.89
Throughput · Energy	0.10	3.93

APPENDIX VII. A METHOD TO DETERMINE SODIUM ION CONCENTRATIONS IN KRAFT PULP

Materials

600 ml Beaker

Stirring rod

1 - liter volumetric flask

1 - liter suction flask

Büchner Funnel, Coors 07

#4 Whatman Filter Paper, 11 cm.

10% HCl

Distilled water

Atomic Absorption Spectrophotometer, P.E. Model 303

Sampling

Obtain approximately five dry grams of each pulp to be evaluated. When sampling from a brownstock washer take care that the entire thickness of the pulp mat is included in the sample.

Extraction Procedure

1. Transfer approximately 1.5 dry grams of the sample into a 600 ml. beaker containing 300 ml. (cold) HCl.

2. Heat to boiling. Stir several times with a clean stirring rod. Boil for about 5 minutes.

3. Filter through a #4 Whatman filter paper using a Büchner funnel.

4. Wash four times with 100 ml. cold distilled water.

5. Dry the pulp on the filter paper in the oven to a constant weight (about two hours).

6. Transfer the filtrate into a one-liter volumetric flask. Rinse the suction flask with the distilled water. Cool the solution to room temperature and dilute to the mark with distilled water. Shake well.

Sodium Ion Concentration from Flame Spectrometry

1. Generate flame spectrometer standard curve for sodium ion concentrations of 10^{-3}, $5(10)^{-4}$, 10^{-4}, $5(10)^{-5}$, and zero molar NaCl.

2. Record flame spectrometer readings for five specimens of each sample's washing filtrate (specimens taken from the one-liter volumetric flask).

3. Determine sodium ion concentration from flame spectrometer standard curve.

4. Calculate moles of Na^+ per dry ton of pulp:

$$\frac{[Na^+]\ 10^6}{G} = \text{moles } Na^+ \text{ per oven dry ton}$$

where: $[Na^+]$ = Sodium ion concentration in moles per liter

G = Oven dry grams of sample washed