

The effect of TMP refining using an adjustable-speed drive on energy consumption and pulp quality

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ABSTRACT: *An experimental investigation was conducted to study the effect of TMP refining using adjustable-speed drive (ASD) on energy consumption and pulp quality. The project is based on the studies of disc refiner models at high- and low-consistency refining. Our primary objective is to examine the potential energy efficiency improvement of a TMP system by evaluating the effect of TMP refining using ASD in pilot scale at the Center for High Yield Pulping Science. The pilot experimental results show that certain benefits of TMP refining using ASD can be obtained. Preliminary results demonstrate that increasing the first stage of refining speed reduces electrical energy at similar pulp quality.*

KEYWORDS: *Drives, energy consumption, mechanical pulps, pressurized refining, quality, refiner mechanical pulps, refining, thermomechanical pulps, variable speed drives.*

The manufacture of thermomechanical pulp (TMP) is an energy-intensive process requiring 1800-3600 k·Wh of electricity per ton of pulp produced. The increase in electrical power cost has reached the point where it causes U.S. pulp manufacturers to be at a competitive disadvantage relative to foreign competitors with access to lower-cost hydroelectric power. As a result, the

mechanical pulping sector of the U.S. pulp industry has not kept pace with the demand; the United States is a net importer of newsprint pulp.

Efficient use of energy enables commercial and industrial facilities to minimize production costs, increase profits, and stay competitive. The majority of energy consumed in a TMP mill is used to run electrical motors. One potential way to cut

TMP costs would be to reduce the electrical energy requirements of the disc refiner.

The disc refiner is a major electrical energy consumer in the TMP process. There were two basic refiner models proposed to express the relationship between total energy consumed and refiner configuration for low- and high-consistency refining. The model for low-consistency refining is described below (1, 2):

$$HP_T = K_d N^3 D_o^5 + K_e N D_i (D_o^2 - D_i^2) + K_p N^2 D_o^2 \quad (1)$$

where

HP_T = total brake horsepower applied to produce each ton of pulp, kW·h/ton

N = rate of revolution, rpm

D_o = outside diameter of the refiner plates, ft

D_i = inside diameter of the refiner plates, ft

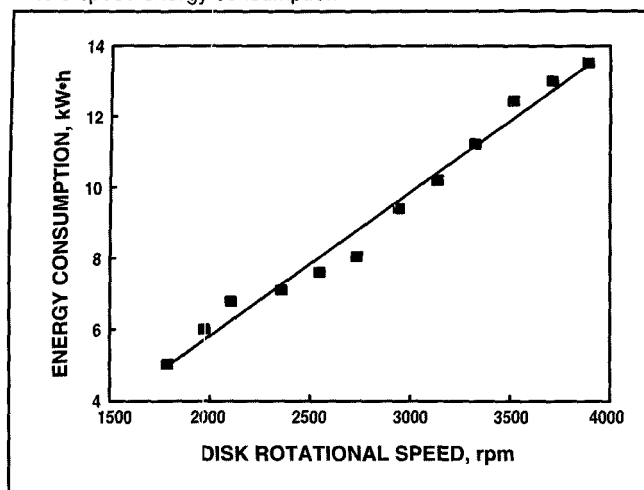
K_d = disc friction constant, which is directly proportional to the density of the pulp handled and varies with plate geometry

K_e = a constant that includes the coefficient of friction between fibers and between the plate and fiber, as well as the average separating pressure between plate-contacting surfaces

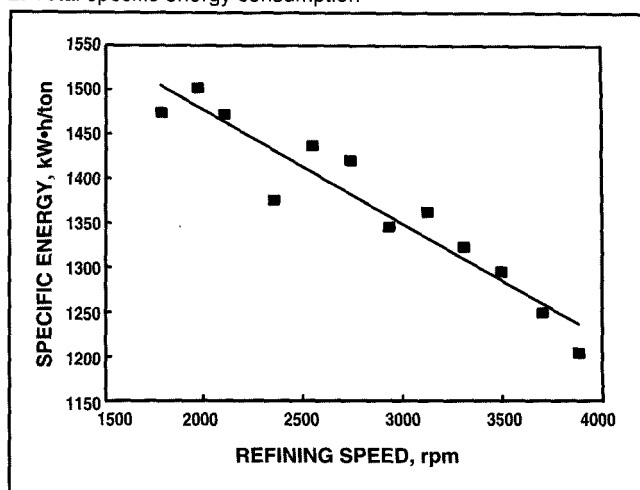
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Refining Energy

1. Idle speed energy consumption



2. Total specific energy consumption



K_p = a constant that includes the gravity constant and the density of the fluid.

The first term, representing the disc friction, is the energy required to turn the disc in a stock suspension. This power is proportional to the cube of the rotational speed. Among the three terms shown, the disc friction consumes the most energy during disc refining.

The second term represents the effective work, which is the power applied to the stock. Note that the power absorbed in useful attrition work is directly proportional to the speed of rotation. The last term represents the power consumed in accelerating the stock to rotational velocity. Power losses due to pumping effects are proportional to the square of the rotational speed and directly proportional to the flow quantity.

Compared to the first term, the second and third terms are normally small enough to be disregarded. The simplified model for low-consistency refining is then described below:

$$HP_T = K_p N^3 D_o^5 \quad (2)$$

In mechanical pulping with disc refiner processes for low-consistency refining, power consumption can be shown to have a direct relationship with the disc rotational speed and is always proportional to the disc refin-

I. Relationship between energy consumption and disc rotational speed

ASD change, %	Disc idle speed, rpm	Energy input, kW-h
45	1780	5.0
50	1970	6.0
55	2100	6.8
60	2350	7.1
65	2540	7.6
70	2730	8.7
75	2930	9.4
80	3120	10.2
85	3310	11.2
90	3500	12.4
95	3700	13.0
100	3880	13.5

ing speed. For example, higher disc rotational speeds consume more power than lower speeds.

For high-consistency refining, the relationship between disc speed and power consumption is opposite from that shown in Eqs. 1 and 2. Refining intensity has commonly been used to evaluate high-consistency refining (3). The model for high-consistency refining is described below:

$$RI = kN^2/C \quad (3)$$

where

RI = refining intensity, kW-h/ton

k = refiner configuration constant

N = rate of revolution, rpm

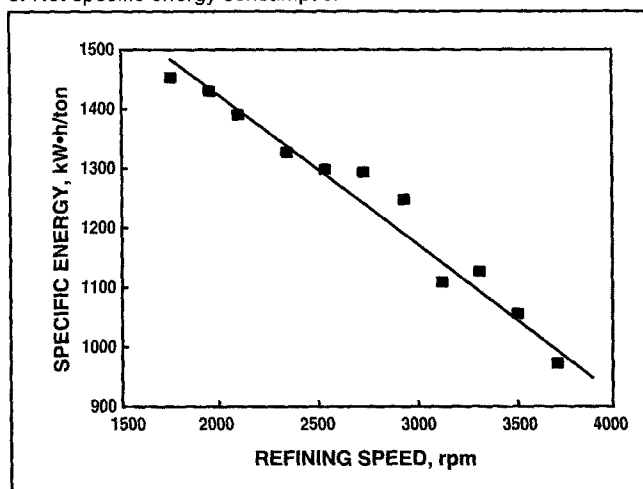
C = consistency, %.

Previous studies showed that, for two stages of disc refining, the use of high intensity in the first stage and low intensity in the second stage is the best strategy for reducing electrical energy consumption and producing high-quality pulp.

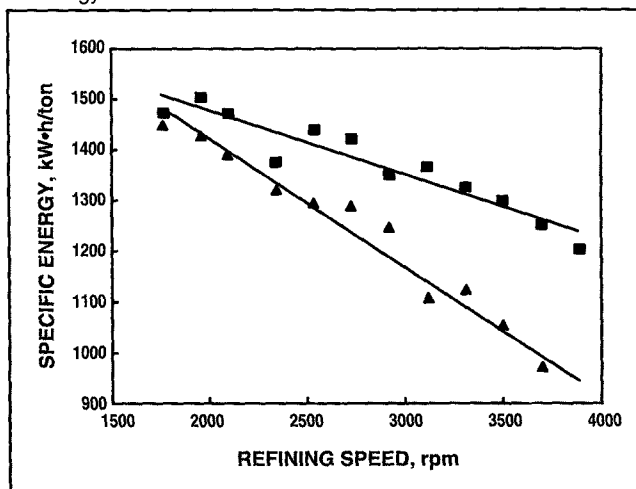
Experimental design

A Center for High Yield Pulping Science (CHYPS) was established by the Georgia Institute of Technology in collaboration with the Institute of Paper Science and Technology and the Herty Foundation. The Center, formed to promote research and development in high-yield mechanical pulping, offers a relatively inexpen-

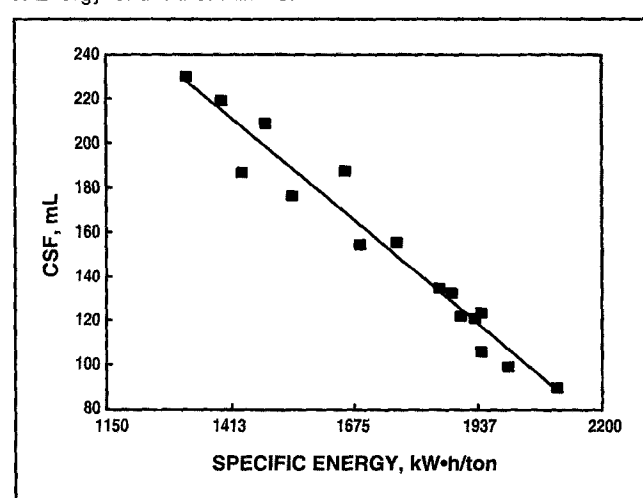
3. Net specific energy consumption



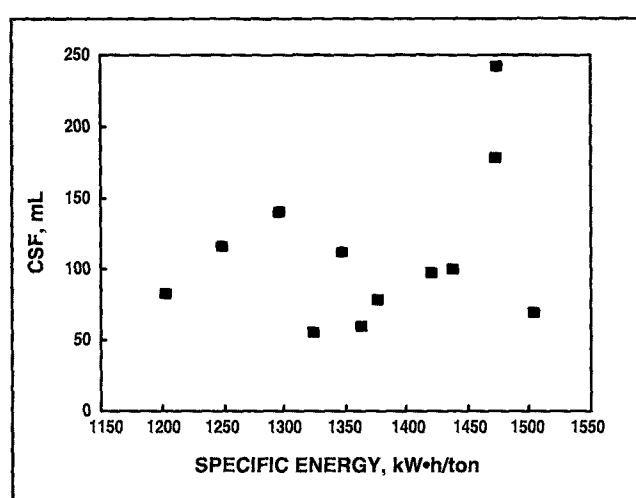
4. Energy load



5. Energy load without an ASD



6. Freeness results



sive way for commercial enterprises to conduct pilot-scale research.

The pilot system operated by the CHYPS is located at the Georgia Power Technology Application Center in Atlanta. The process equipment for the CHYPS is comprised of a two-stage Sunds Defibrator refining system with chemical pretreatment and interstage washing. The continuous pilot refining system, which uses a CD-300 pressurized first-stage and a Defibrator ROP-20 atmospheric second-stage refiner, is designed to handle 1-5 lb of chips per minute at a maximum pressure of 250 psi. Retention time can vary from 1 min to 60 min, and specific energy inputs to 2500 kW·h/ton are possible.

The unit consists of two screw feeders, an atmospheric impregnator, a vertical preheater with a built-in "PREX" impregnator, and a KMW chip classifier for screening the chips. The CD-300 refiner is equipped with 12-in. discs and a 200-hp motor capable of operating at 0-3880 rpm using the current adjustable-speed drive (ASD). The second-stage ROP-20 refiner is equipped with 20-in. discs and a 200-hp motor.

Rotational speed is not a variable on conventional refiners, but it could be with an ASD unit. An ASD, in general, permits optimum operation of a refining system and can drive the refiner along an operating curve that closely matches the desired sys-

tem requirements. It also maintains the efficiencies of the refiner. These features result in a tangible reduction in the power required to operate the refiner. Additional benefits, realized in extended bearing life and disc lives, result from variable-speed operation.

Adjustable-frequency drives, commonly called inverters, are also available in a size range from fractional to 2000 hp. Often sold separately, they are designed to operate a standard induction motor, allowing them to be easily added to an existing system. The basic drive consists of the inverter itself, which converts the 60-Hz incoming power to a variable frequency and variable voltage. The

II. Effect of refining speed on energy consumption

ASD, %	Speed, rpm	First stage		Second stage		Total load, kW-h/ton	Net load, kW-h/ton
		Consistency, %	CSF, mL	Consistency, %	CSF, mL		
45	1780	14.1	750	14.3	240	1475	1450
50	1970	14.6	791	17.0	68	1504	1427
55	2100	16.1	750	16.6	177	1474	1388
60	2350	16.9	765	16.6	77	1376	1321
65	2540	17.7	750	15.7	99	1438	1293
70	2730	18.2	642	16.6	96	1421	1287
75	2930	20.3	815	18.8	111	1347	1244
80	3120	19.4	770	18.8	59	1364	1107
85	3310	20.0	774	17.9	54	1323	1122
90	3500	19.2	750	17.4	139	1296	1052
95	3700	21.5	747	18.4	117	1249	968
100	3880	23.2	787	19.3	83	1203	897

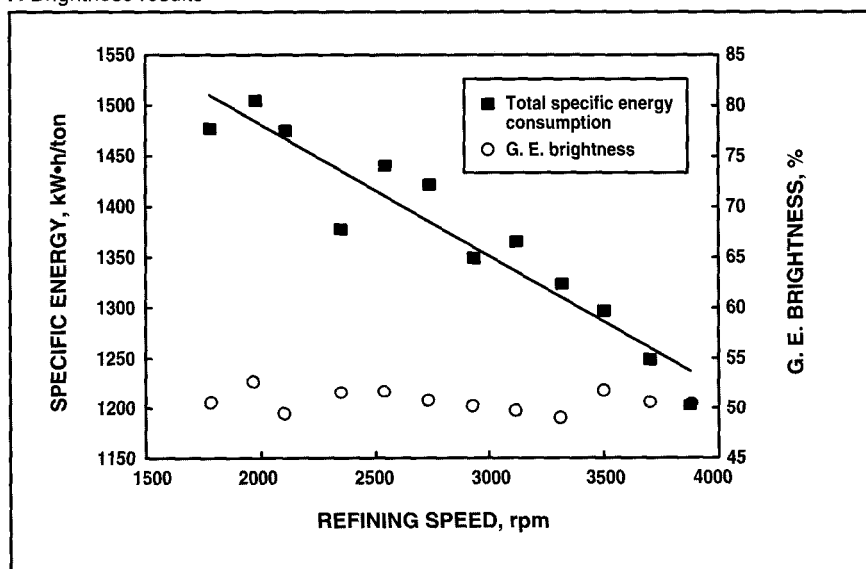
variable frequency is the requirement that controls the motor speed.

In creating the pilot experimental design, we assumed a linear relationship between energy consumption and disc rotational speed. The experimental factors were varied one at a time, with the remaining factors held constant. It was difficult to achieve both energy reduction and high pulp quality, because more than one important parameter often affects disc refining; the other parameters may act additively. Our experiments were conducted by varying disc rotational speed and comparing specific energy consumption at similar pulp qualities.

Results of pilot experiments

TMP quality highly depends on the refining conditions, the refining process, and the raw materials. The key refining condition factors are the refining consistency and pressure. Previous studies conducted at the CHYPS showed that (a) the freeness and the shives content decreased as the primary refining consistency increased; (b) the handsheet physical properties, the opacity, and the specific energy consumption of primary refining increased as the primary refining consistency increased; and (c) the brightnesses are similar through the entire consistency range. In addition,

7. Brightness results



tion, the pulp produced from high preheater pressures has slightly better quality than the that from low preheater pressures (4).

Based on those previous studies, the basic operating conditions for TMP are as follows:

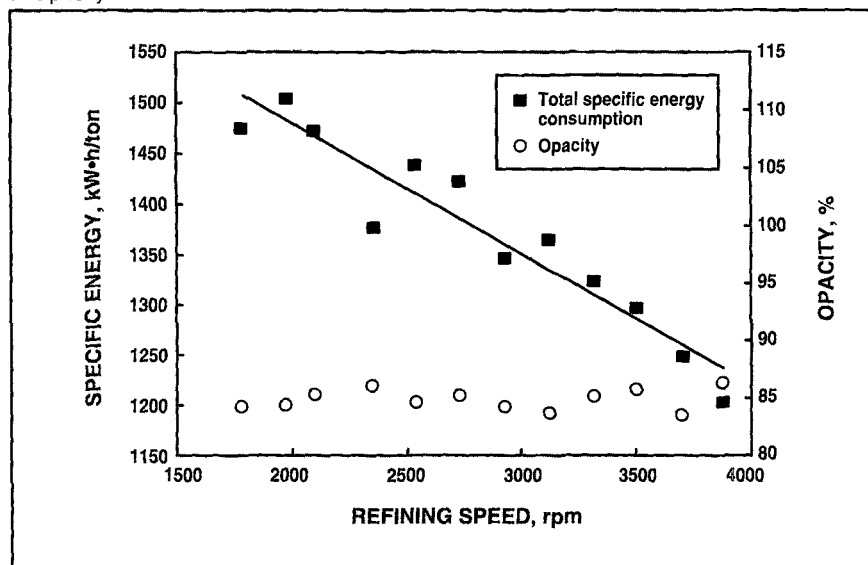
- The optimum consistency range is 15–35% for primary refining and 12–30% for secondary refining.
- The optimum preheater pressure for the pilot-plant process is 10–20 psi.
- Southern pine was chosen as the wood species.

Table I shows the relationship between energy consumption and disc idle speed using an ASD when there are no chips in operation. The data clearly show that higher rotational speeds consume more electrical energy than lower speeds. The preliminary results of the pilot trials are shown in **Tables II and III**. Table II shows the effect of refining speed on energy consumption; a refining speed change results in a net specific energy change and a total specific energy change. Total specific energy consumption is the net specific energy consumption plus the electrical power consumed by the

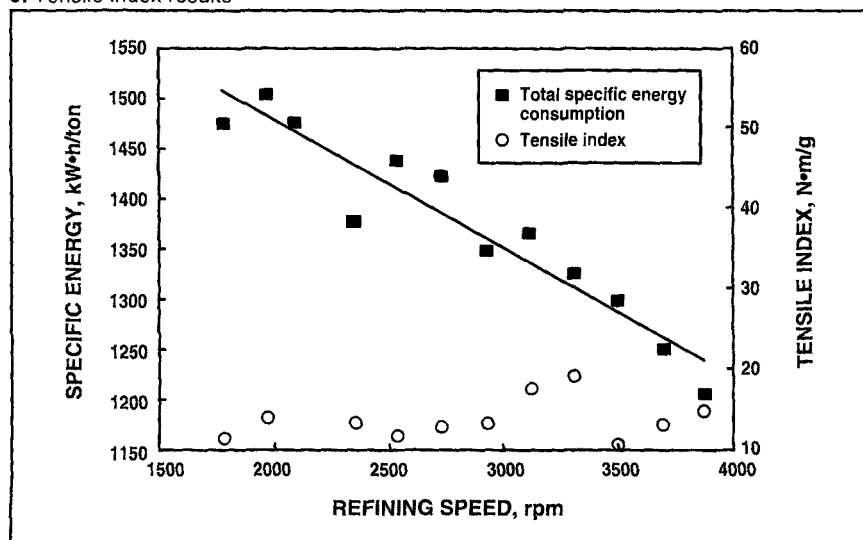
III. Effect of refining speed on pulp properties

ASD, %	Speed, rpm	CSF, mL	GE brightness, %	Opacity, %	Tensile index, N·m/g	Tear index, mN·m ² /g	Burst index, kPa·m ² /g
45	1780	240	50.6	84.3	11.7	2.8	0.37
50	1970	68	52.7	84.5	14.1	3.0	0.46
55	2100	177	49.4	85.4	9.7	2.2	0.29
60	2350	77	51.6	86.2	13.4	2.9	0.41
65	2540	99	51.8	84.7	11.8	2.7	0.39
70	2730	96	50.9	85.3	12.7	2.9	0.41
75	2930	111	50.3	84.2	13.2	2.7	0.46
80	3120	59	49.9	83.7	17.5	3.3	0.71
85	3310	54	49.0	85.2	19.0	3.6	0.81
90	3500	139	51.9	85.7	10.6	1.9	0.37
95	3700	117	50.7	83.5	12.8	2.3	0.47
100	3880	83	50.4	86.4	14.5	2.6	0.56

8. Opacity results



9. Tensile index results



disc at idle speed. Table III shows the effect of refining speed on pulp properties. It also compares the properties of handsheets made from the experimental pulps.

Figure 1 shows the relationship between electrical energy load and disc idle speed; higher idle speeds consume more electrical energy. The relationship between electrical energy load and disc idle speed is proportional, but it is not clear if the relationship is linear.

Figures 2 and 3 show the specific energy consumption during chip refining using an ASD. Figure 2 shows the total specific energy consumption, i.e., the net specific energy consumption plus the energy load for idle speed during refining. Note that higher disc speeds consume less total specific energy during refining. The preliminary results show that increasing the disc speed from 1780 rpm to 3880 rpm results in an 18% total specific energy reduction. Figure 3 shows the net specific energy consumption during refining. When refining disc speed increases from 1780 rpm to 3880 rpm, a 35% net specific energy savings can be obtained. That outcome indicated that higher refining speeds resulted in higher net specific energy savings, because less refining time is needed for a given amount of pulp produced using the higher refining speed.

Refining Energy

Figure 4 combines Figs. 2 and 3. The two curves represent the total specific energy and net specific energy consumption during chip refining. It is clear that higher disc refining speeds consume less specific energy than lower speeds. Note that the slope of the net specific energy consumption curve is higher than that of the total specific energy consumption. Because the disc consumes energy at idle, a higher disc idle speed results in less total specific energy savings.

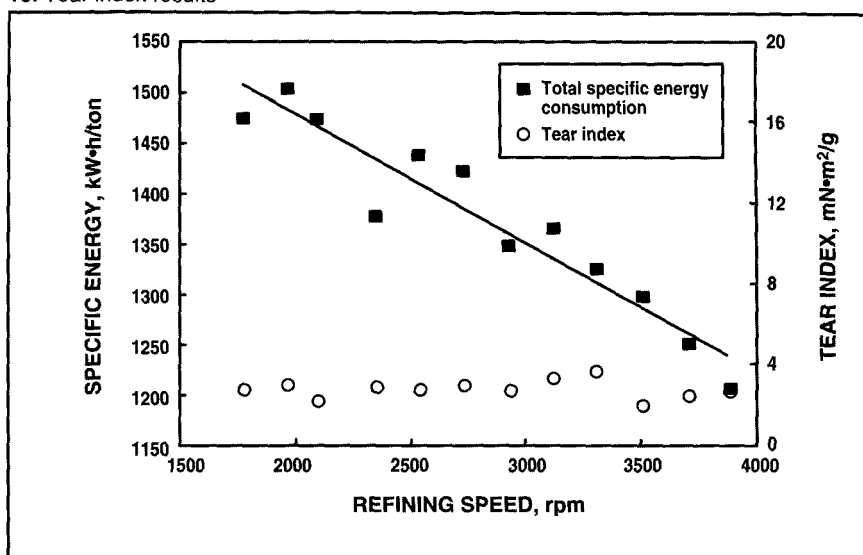
Figure 5 shows the results of previous experiments conducted at the CHYPS. These data show that, at 3600 rpm without the use of an ASD, higher specific energies produce lower pulp freenesses. This is consistent with other research conclusions.

Figure 6 shows that, when using an ASD, a refining speed change results in an electrical energy change, with no effect on pulp freeness. This figure shows the random relationship between pulp freeness and specific energy. Compared to previous results without use of an ASD (Fig. 5), higher specific energy consumption during refining is not necessarily due to lower pulp freeness.

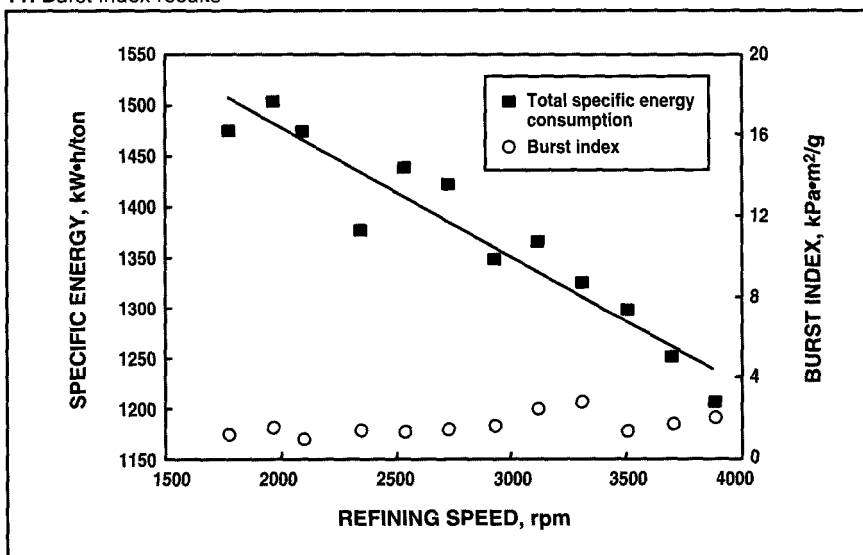
The data in Table III are plotted in Figs. 7–11. Figures 7 and 8 show the results of total specific energy consumption, brightness, and opacity using an ASD. These figures indicate certain relationships between total specific energy and refining speed; higher speeds result in lower total specific energy consumption, with no effect on brightness or opacity.

Figures 9–11 show strength properties of handsheets made using an ASD. The refining speed change resulted in a total specific energy consumption change, with little effect on tensile index, tear index, or burst index. Although a slight improvement in tensile index and burst index was seen, and tear index decreased slightly using an ASD at higher refining speeds, these minimal changes were ignored. Figures

10. Tear index results



11. Burst index results



7–11 indicate that using an ASD affects specific energy consumption, and total energy savings can be achieved by increasing the refining speed at similar pulp qualities.

Conclusions

The adjustable-frequency drive offers particular advantages for refiner application. It uses the standard induction motor, which permits easy installation and reliable operation. The drive readily accepts available control system signals and can con-

trol the motor without speed feedback. It can be located away from the motor, as available space dictates, and requires only three connections to the motor. Furthermore, it maintains the efficiency of the refiner system while itself operating at a generally high efficiency.

The pilot experimental results show that certain benefits of TMP refining using an ASD can be obtained. The preliminary results demonstrate that increasing the first stage of refining speed reduces specific energy during chip refining at a

similar pulp quality. An 18% total specific energy savings was achieved by increasing refining speed from 1780 rpm to 3880 rpm in the pilot plant.

Due to time and technique restraints, the effect of TMP refining using an ASD on pulp quality at similar specific energy inputs has not yet been studied. The results consist of the primary data, and future studies should investigate the impact of an ASD on TMP refining throughout the system. Two new ASDs will be installed on both the first and secondary refining stages at the CHYPS, and further experiments will be conducted soon. **□**

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