Jorma Lumiainen describes a new theory of the mechanism of refining. Ultimately, it should allow paper mills to improve their existing refining systems and reduce energy costs.

New theory can improve practice

The most commonly used theory of refining - the "specific edge load theory" - takes into account cutting edge length, but ignores bar width. A new "specific surface load theory" has now been developed, in which the length of the refining impact across the bars is a critical factor. The theory permits a better understanding of existing refining systems, allows their subsequent optimization, and offers possible power savings.

Three measures are currently used to describe the refining effect. The first, the amount of the refining, is precisely described by the specific refining energy (net energy) in kWh/ton. The second measure, namely the cutting speed (km/s) indicates the number of refining impacts during refining. The third measure, the intensity of the fiber impacts, is the most difficult to evaluate. The term specific edge load is used, as well as other expressions, but they assume that all the energy is transferred to the fibers during the short period in which the leading edge of the bars cross each other. They ignore both the width of the bars and grooves, and also the flat bar surface area.

Specific edge load theory was developed years ago, when manufacturing techniques did not permit fine narrow bar type fillings, and proved a valuable tool. Today, fillings are much finer and the width of the bars plays a significant role.

Refining mechanism

Although the following description of the refining mechanism used to describe the new specific surface load theory considers only one fiber floc, it should be remembered that a coarse-fibered pulp such as southern pine (fiber length 3.5 mm) contains one million fibers/g of pulp. The equivalent figure for a finer pulp, such as eucalyptus (fiber length 1.0 mm) is 13 million fibers.

The refining mechanism can be divided into five different phases. In the first (Figure 1A), the rotor bar, being opposite to the stator groove, picks up the fiber floc for the refining action. At this point the power consumed is only the no-load power, whereas the subsequent phases consume active refining power. The fiber floc is hit hard along its length. Actual length of impact depends greatly on the sharpness of the edge (in this case 0.1 mm radius). The rounder the edge, the longer the length hit.

This edge-to-edge phase is then followed by the edge-to-surface phase (Figure 1B). The bars' leading edges now slide along the surface of the fiber floc, which is pressed against the flat bar surfaces. If the bar surfaces are sufficiently rough, the outside fibers slide gradually along the surfaces, creating sufficient movement for the inside fibers to glide. If the bar edges are sharp and their surface rough, the outer fibers move with the bars and the whole fiber floc is delaminated. Where both the bar edges and their surface are smooth, the fiber floc is only pressed without any longitudinal movement among the fibers.

The edge-to-surface phase continues until the leading bar edge reaches the trailing edge of the opposite bar (Figure 1C). The length of this refining phase is equal to the width of the bars, assuming that the intersecting angle is zero.

After the edge-to-surface phase, the fiber floc is still pressed between the flat bar surfaces (Figure 1D). This phase continues to work on the already refined area of the fiber floc, provided there is sufficient friction between the bar surfaces and the floc. The refining action is complete when the trailing edge of the rotor bar leaves the trailing edge of the stator bar (Figure 1E).

The above refining phases exert a single impact on the fiber floc. The length of this impact is equal to the width of the bars. All the above refining phases consume energy and most of it is transferred to the fiber floc. A profile of the intensity (in Watts) against time shows the highest and briefest intensity upon initial impact (edge-to-edge phase), followed by a high and longer intensity during the edge-to-surface phase. The intensity is markedly lower during the long surface treatment.
phases and gradually dwindles to the no-load power level.

Since the different phases occur simultaneously in the refiner, the total power absorbed remains at a constant level. However, the energy split between these phases, and thus the refining effect, depends on the disk plate pattern. In the refining mechanism just described, the fiber floc was longer than the width of the refiner bars. However, when the fiber floc is shorter than the bar width, the effective length of the refining impact no longer correlates with the width of the bars. This is because the third and fourth stages surface treat the complete length of the floc.

As in the case where the fiber floc was longer than the width of the refiner bars, the bulk of the energy input is during the edge-to-edge and edge-to-surface phase. The conventional specific edge load theory now applies, because the additional bar width contributes little in the way of treatment.

The total effective energy of one refining impact can thus be expressed as a combination of the intensity and the impact distance - the longer the distance, the lower the intensity for the same energy (Figure 2).

This demonstrates the inherent weakness of the specific edge load theory, namely, that it does not consider the distance of impact. The specific edge load value (in J/m or Ws/m) only indicates how much effective refining energy has been consumed for a given cutting length. Where this effective refining energy has been consumed during a short impact, the real intensity of the impact must be higher than during a longer impact.

If the conventional specific edge load value (SEL, in J/m or Ws/m) is divided by the distance of impact, we get a new value, the Specific Surface Load (SSL, in J/m² or Ws/m²), which also considers the distance of impact.

Thus, for a constant SEL of 2.4 J/m, an SSL of 800 J/m² is given by refining a floc length of 3 mm with 3 mm (or wider) bars. If the floc length is increased to 5 mm (or greater) and the bar width to 5 mm, then the SSL drops to 480 J/m². The smaller value of floc length and bar width (i.e., impact distance) determines the SSL.

Putting theory into practice

Comprehensive pilot plant trials were carried out on mill-scale refiners using bleached pine kraft pulp. The following conclusions were drawn for conical refiners with both narrow bar type short fiber fillings (which create low edge loads) and wide bar type long fiber fillings (which give high edge loads):

- Short fiber type fillings at low specific edge loads produce weaker fibers than the long fiber type fillings at higher edge loads;
- Short fiber type fillings require more refining energy than the long fiber type fillings to reach the same refining degree (SR);
- Long fiber type fillings can shorten fibers more and also produce more fines than short fiber type fillings without reducing strength properties;
- Short fiber type fillings result in significant fiber cutting at relatively low specific edge loads, whereas long fiber type fillings do less cutting and produce superior strength properties at a higher specific edge load.

From the traditional parameters specific refining energy (in kWh/ton) and specific edge load (in J/m), we can calculate "the number of applied refining impacts" by simply dividing the former by the latter. The result (in km/kg) tells us how many cuts or impacts the fibers have received. Alternatively, the applied cutting length or the number of impacts can be calculated by dividing the cutting speed (km/s) of the refining system by the throughput (kg/s).

The length of the refining impact across the bars depends on the width and the intersecting angle of the bars, according to the formula:

\[ \text{Impact length (mm)} = \frac{(W_r \times W_s)}{[2 \times (\cos + \frac{1}{2})]} \]

Where: \( W_r \) is the width of the rotor bars; \( W_s \) is the width of the stator bars; and \( \epsilon \) is the average intersecting angle of the opposite bars.

These new terms, specific surface load, impact length and applied cutting length indicate the real severity, length and number of refining impacts.

In terms of the specific edge load theory, one might expect a high number of mild impacts (expressed as specific edge load) to preserve the fibers and produce good strength properties, whereas a low number of high intensity impacts would do more cutting and produce lower strength values.

In fact, when refining long fibers with narrow bars there is a high probability that the refining impacts will be directed at the same spot, which is already well refined, while other parts of the floc are not treated at all. In contrast a low number of hits of long impact length can treat the entire length of the fiber bundle in one go. Reduced bar width greatly increases the cutting length and gives a high number of short impacts, whereas wide bars give a low number of long impacts.

Finally, Figure 3 shows a further weakness of the specific edge load theory. In this figure, all three plate patterns have equal cutting length according to the well-known formula:

\[ \text{Cutting length} = Z_r \times Z_s \times l \]

where \( Z_r \) is the number of rotor bars, \( Z_s \) is the number of stator bars and \( l \) is the contact length. The plate patterns have an

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