

Improving refining efficiency with deflocculation

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ABSTRACT: The ability to load a refiner requires the formation of a fiber mat between opposing refiner bars. One of the consequences of this is the formation of flocs that persist through the refiner grooves and exit the refiner. These flocs interfere with sheet strength, requiring additional energy to make up the strength deficit. In addition, flocs can initiate string formation, resulting in machine efficiency issues such as cross-machine profile deterioration and the downtime required to correct it.

Novel refiner plate modifications have been shown to improve refining efficiency in otherwise identical refiner plates. Energy savings are typically around 15% of gross refining energy on the basis of the treated stock, although much higher reductions have also been seen. Addressing this previously underappreciated flaw in conventional refining enables greenhouse gas reduction and other benefits related to sheet strength and machine efficiency.

Application: Conventional refining of softwood and old corrugated containers (OCC) is compromised by the creation of flocs. A novel refiner plate modification counteracts this, making refining more energy efficient. The improvement in refining efficiency is typically greater than can be achieved through no-load reduction. Additional research could yield further optimization.

Refining of low consistency stock continuously forms flocs in the gap between the rotor and the stator. The fate of these flocs is different, depending partly on fiber morphology. Hardwood flocs, for example, are easily broken during refining, but softwood flocs are stronger and do not break as easily with refining [1]. Floc formation in the gap between opposing refiner bars is necessary to accomplish refiner loading. This gap is typically a few tenths of millimeters, which is several times the width of individual fibers. El-Sharkawy et al. [2] used the onset of net power application in refining as the indication of when fibers were trapped in the refining gap and therefore susceptible to refining action. They showed how pulp properties affect floc formation and how flocs interact with the refiner plate design and rotational speed to affect the onset of refining and the development of fibrillation and fiber shortening during refining. El-Sharkawy et al. also measured the size and stability of flocs moving through a flow channel similar to a refiner groove. They found that flocs are temporarily elongated in the direction of flow, but flocs made of long, coarse fibers are larger and retain their size, while flocs of shorter, less coarse fibers had their size eroded through a flow channel. Lundin et al. [3] further quantified the effect of the thickness of the fiber mat trapped between the opposing refiner bars and showed how it depends on consistency and refiner speed. It is one of the two critical parameters in their model, the other being the fraction of the bar that traps fibers.

Flocs strong enough to survive refining have the potential to affect sheet properties. The strength of flocs can vary

widely. Van de Ven differentiates between coherent flocs and incoherent flocs [4]. Coherent flocs are so strong that they are permanent, while incoherent flocs are weaker and are broken up in the papermaking process. Van de Ven points out that coherent flocs are susceptible to growing as they come into contact with individual fibers, and they are detrimental to paper properties. It is also known that shives are detrimental to paper strength [5]. Shives are similar to coherent flocs in that they present a nonuniformity in a sheet. A difference, however, is that shives can consist of uncooked wood, for example, because shives are defined as the mass reject fraction of a screening process. A floc, on the other hand, is defined by its morphology as being composed of individual fibers that are mechanically and/or chemically bonded with each other. We might expect coherent flocs and shives to decrease sheet strength through a similar mechanism, since they both present a nonuniformity in the sheet.

MILL ANALYSIS OF SHIVE AND FLOC MORPHOLOGY

A mill with two uncoated freesheet machines was equipped with a Valmet MAP fiber analyzer (Valmet; Espoo, Finland) that monitored freeness, fiber morphology, and shives. Both machines used a majority of hardwood, but they reinforced their sheets with softwood. During a paper machine performance audit, a multivariate analysis hinted that what the fiber analyzer described as “shives” played a significant role in refining performance and strength development. In particular, an entity designated on this apparatus

	Before Refiners, ppm	After Two Refiners, ppm
Paper Machine #1	24	7048
Paper Machine #2	24	8988

1. Softwood floc quantification before and after two stages of refining on each paper machine.

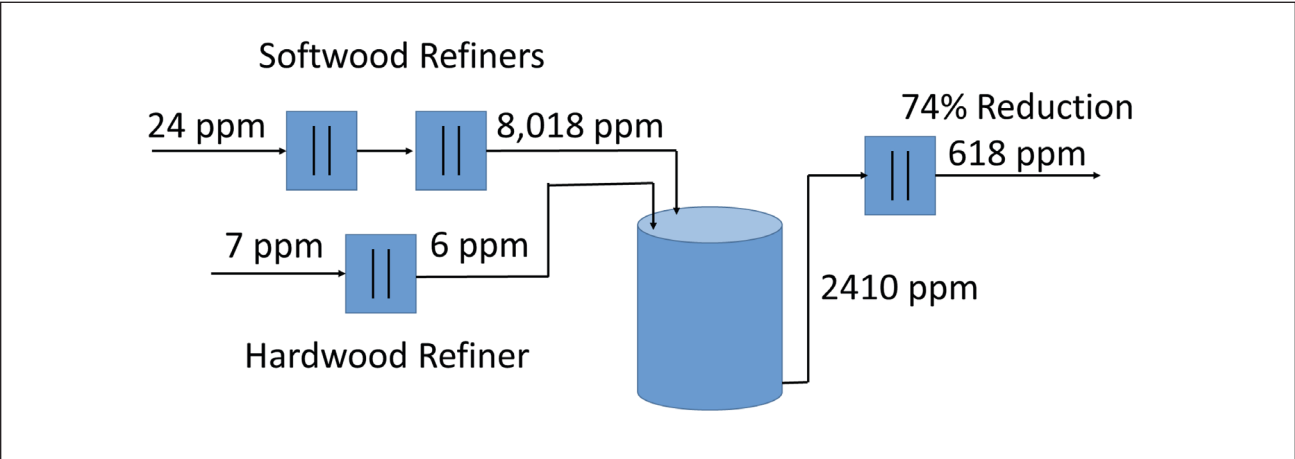
as a “wide shive” was prominent in differentiating performance. A “wide shive” was classified as having a width greater than 150 µm and a length from 0.3 mm to 40 mm. The “shive” designation in this term is appropriate in the sense that the fiber analyzer prepared the sample with dilution and agitation, mimicking what could have been done in a screening step such as is done in shive measurements. As it turns out, however, the “wide shives” were in fact flocs: they were aggregates of individual fibers. We will refer to these as flocs from here on. They do not primarily come from the pulp mill. They are mostly generated during refining. **Table I** shows the quantification of flocs across the softwood refiners, and **Fig. 1** shows the average floc

level throughout the two machines. The machines have the same overall schematic and very similar floc profiles.

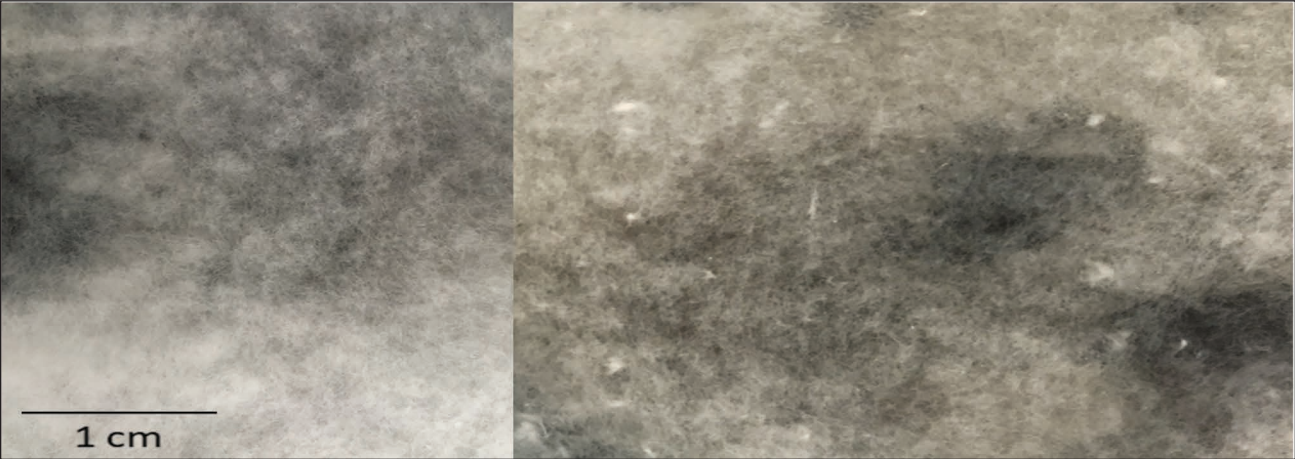
The bleached hardwood pulp was lower than the softwood pulp in flocs before refining, and flocs did not increase after hardwood refining. Although the softwood flocs after refining only appear to constitute approximately 8000 ppm of the softwood pulp, the actual floc content could be greater. The floc definition used by the fiber analyzer does not count all flocs that might affect strength development, such as roughly spherical flocs of 150 µm or less.

Figure 2 shows stock samples before and after the first and second stages of softwood refining on Paper Machine #2. The samples must be diluted to approximately 0.1% to 0.2% consistency to see the flocs clearly, and that process of dilution breaks up the looser flocs. The remaining flocs, however, appear to be dense and roughly spherical.

The last refiner on each of these machines was a Beloit SA400 conical refiner. The last refining position in a machine is commonly known as a “tickler” refiner because it is the final means to apply refining energy before the machine. A tickler typically applies a moderate amount of power. These refiners, however, were almost always un-



1. Schematic of each paper machine showing average levels of flocs.



2. Bleached softwood pulp before (left) and after (right) two stages of refining.

	Flocs Into Tickler*, ppm	Flocs Out of Tickler, ppm	Floc Reduction (%)
Paper Machine #1	2118	395	81%
Paper Machine #2	2701	842	69%
* Estimated from softwood/hardwood stock blend.			

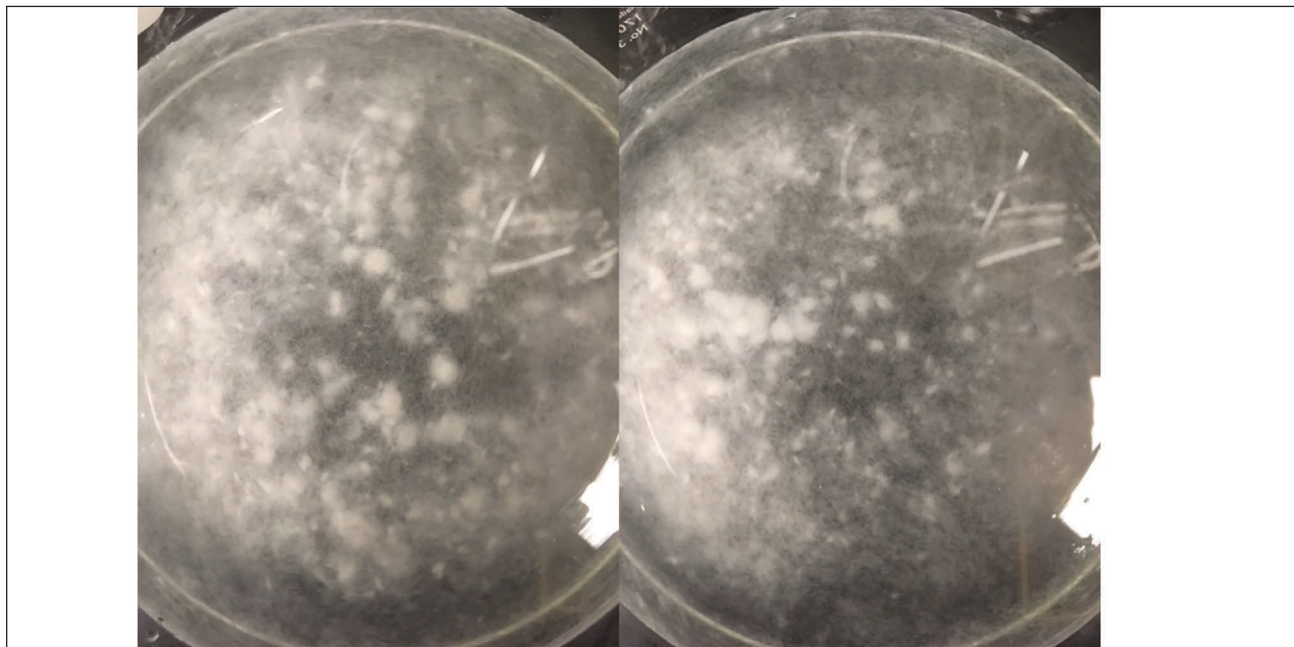
II. Floc reduction across unloaded tickler refiners.

loaded. Even unloaded, these refiners operated at a significant energy cost. It turns out this cost was easily justified. Whenever the operators turned the ticklers off, the sheet quality would suffer from poor formation. Could this formation be related to the flocs made during softwood refining? A measurement of flocs going into the tickler refiners was not available, but it could be estimated from the flocs in the outlets of the softwood and hardwood refiners on the basis of the 30% softwood/70% hardwood flow ratio, assuming minimal changes in an intermediate chest. Given this assumption, the unloaded tickler refiner reduced flocs by 74% on average between the two machines. **Table II** compares the flocs at the inlets and outlets of the tickler refiners. In both cases, the tickler refiners were being operated near their no-load power.

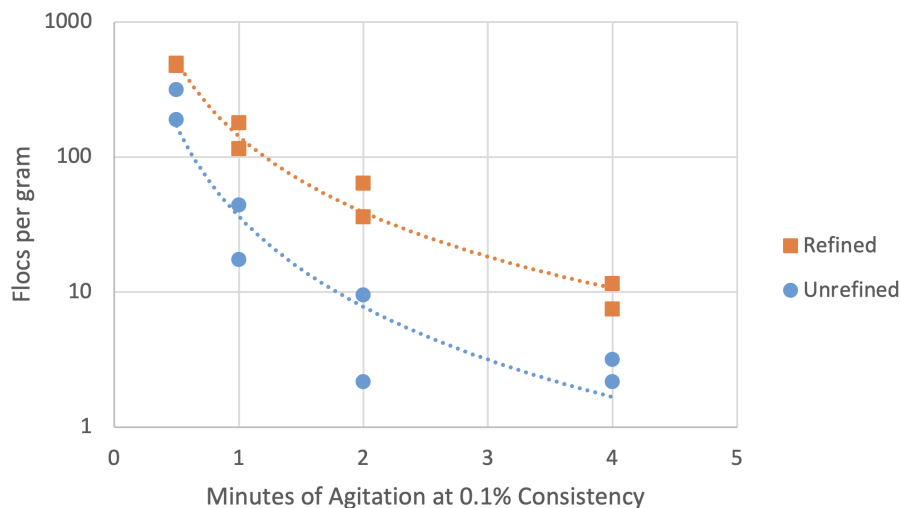
The floc reduction in Table II assumes there is no significant change in flocculation in the thick stock system after the refiners. This seems reasonable to expect. A quick check was done with another mill's uncoated freesheet machine with a semi-quantitative method to assess the relative amount and strength of flocculation. Approximately 0.5 o.d.

grams of never-dried fiber were added to 500 mL of water in a 7-3/8 in. diameter flat-bottom bowl and agitated at slow speed with a magnetic stir bar. Stirring was paused after 30 s, 1 min, 2 min, and 4 min so that manual counts could be made of flocs visible to the unaided eye. **Figure 3** compares the blend chest and machine chest samples after 30 s of agitation with this protocol. It was necessary to do some agitation to begin to see the structure of the flocs and differentiate them from the well-dispersed or loosely flocculated fibers. The ideal amount of agitation would represent the subsequent mixing of the thin stock system. We do not know what amount of mixing this would be, but some point within the 4-min protocol should be close to this. Very little difference between these two chests is visually apparent, even though the machine chest sample represents one more stage of mixing and pumping at nominally 4% consistency. We see no reason to doubt that the flocculation of 4% consistency stock after the refiners is somewhat stable.

Counting both the larger, looser flocs and the smaller, denser flocs is tedious and imprecise, but it does seem to



3. Blend chest (left) and machine chest (right) outlet samples, diluted to 0.1% and agitated for 30 s. There is little apparent difference in the flocculation in spite of the machine chest being a subsequent chest.



4. Manual floc counts after dilute agitation.

be capable of differentiating between refined and unrefined samples. Unrefined softwood samples have lower flocs than the refined softwood samples at all levels of agitation, often by nearly an order of magnitude as seen in **Fig. 4**. This also illustrates that these flocs are capable of being dispersed with a few minutes of agitation at 0.1% consistency. This consistency is lower and the duration is longer than the time a floc spends in a headbox, but the degree of turbulence in a headbox is typically greater. The survival rate of the flocs through the papermaking process is therefore uncertain.

REMOVING FLOCS

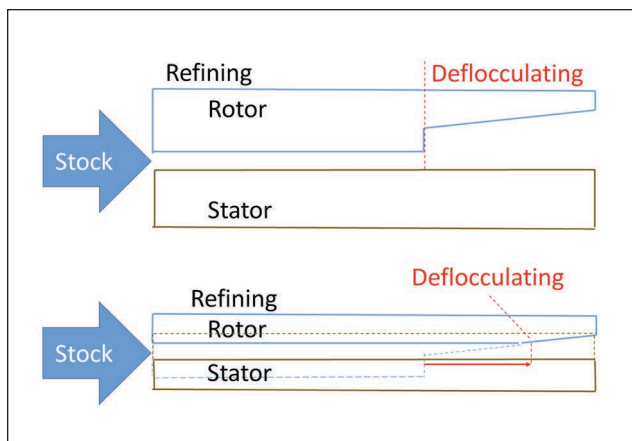
Deflocculating concept

We have demonstrated that just as softwood flocs are created faster than they are destroyed during refining, they are destroyed faster than they are created (if they are created at all) in an unloaded refiner. The shear forces of an unloaded refiner must therefore be suited to reducing flocculation. Following each refiner with an unloaded refiner would be a costly proposition. It would also allow only one plate gap for deflocculating, whereas it might be that different plate gaps are suitable for deflocculating different sizes and types of flocs. As was seen in Fig. 3, there is a large range of sizes, from large flocs a few millimeters in diameter, to small dense flocs just over 150 μm in diameter, and possibly smaller flocs that are not visually apparent without magnification. Refiner parameters such as bar width can influence floc size, but the size range in Fig. 3 was generated with a single set of refining conditions. The floc size distribution represents a degree of randomness inherent to the formation and release of flocs from the refining bar gap.

A refiner plate modification (D-Floc-It™ technology) [6] has been disclosed elsewhere [7,8] that provides for a range

of shear forces to be applied at the exit of a disc or conical refiner for the purpose of deflocculating the pulp as it emerges from a refiner. It is advantageous to deflocculate as soon as possible after refining for several reasons. First, it is possible that dense flocs could seed the formation of strings or larger flocs [4]. The mill where the flocs were quantified had significant stringing in the screens, with strings that were more than a centimeter in length. While strings might primarily form around screens, their tendency to form could be influenced by the presence of dense flocs. Second, when flocs are disrupted prior to entering another refiner, the stock is free to form new flocs between the bars of the subsequent refiner. Work on compression refining indicated that if a handsheet is not re-formed between successive compressive impacts, multiple impacts had little effect on the strength [9]. If, however, the handsheet is formed again between impacts, each successive impact contributes to the strength of the handsheet. In the same way, if a floc formed in a refiner enters a subsequent refiner bar gap intact, that impact would be analogous to a repeated compression on a handsheet that is not re-formed. Deflocculation at the refiner outlet, however, would be analogous to re-forming the handsheet in the compression refining study, thus enabling further strength development. Third, deflocculating in the refiner with a refiner plate modification can be done without capital and without the energy burden of additional unit operations. In fact, as we shall see, refining energy efficiency increases when deflocculation is incorporated into refining.

The new deflocculation zone concept typically occurs on the outer 1 to 2 in. (0.025 to 0.051 m) of circumference of a refiner plate. It consists of a gradually widening plate gap towards the outer circumference, as shown in **Fig. 5**. The expanding gap imparts a range of shear forces intended to disrupt flocs. As the plates wear and bar heights de-



5. Sketch (not to scale) of the modified bar geometry at the outlet of the rotor that constitutes a deflocculating zone. When the plates are new (top), the step in rotor bar height that initiates the deflocculating zone is enough to ensure no more refining occurs. As the bars wear (bottom), the bar height decreases, increasing the length of the refining zone and decreasing the length of the deflocculating zone.

crease, the beginning of the deflocculation zone moves radially outward over the life of the plate, as shown in the bottom of Fig. 5. In doing so, the refining intensity decreases slightly as the cutting edge length increases. If the refining intensity is close to the optimum level, this is immaterial. If, however, the refining intensity is far from optimum, a refiner plate with this kind of a deflocculation zone has the added benefit of being able to indicate the direction of change in intensity needed.

First mill results

The first mill trial of a deflocculating refiner plate (also known as a “deflocer”) was performed on a linerboard machine in the southeastern United States. This machine typically operates two 54 in. (1.372 m) double disc refiners in parallel for the base ply, and refines 100% pine kraft pulp at about 105 kappa number. The top ply typically operates a single 42 in. (1.067 m) double disc refiner on the same furnish. The floc content of this high-yield pulp appeared much lower than the bleached pulps we had previously seen, but this particular machine was a good candidate for deflocculation because it had a longstanding problem of strings plugging the base headbox tubes. Every nine to twelve days, the cross-machine direction profiles would deteriorate to the point that the machine would need to be taken down to flush the headbox tubes that were filled with strings such as shown in **Fig. 6**.

The trial was done in two steps. First, one of the parallel base refiners had the legacy 54 in. (1.372 m) refiner plate replaced with an underhung 50 in. (1.270 m) refiner plate that did not have a deflocculating zone. In doing this, the bar width decreased from 0.119 in. (3.02 mm) to 0.095 in. (2.41 mm), and the cutting edge length was similar. There was some perception that this decreased the degree of the

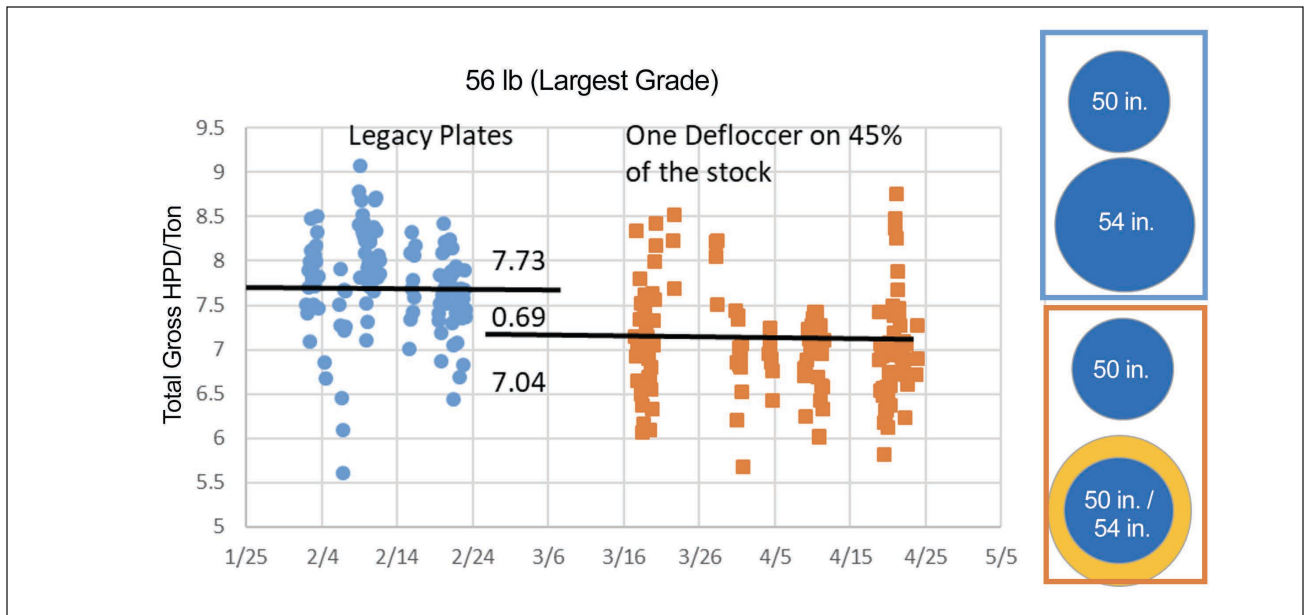


6. Strings removed from the base headbox.

headbox plugging somewhat, but it was still necessary to shut down to clean out the headbox as before. After three months of operating this way, the trial deflocer replaced the other parallel legacy 54 in. (1.372 m) plate set. The trial deflocer was a 54 in. (1.372 m) plate consisting of a refining zone identical to the 50 in. (1.270 m) plate in the parallel refiner, plus a two inch (0.051 m) circumferential outer radius designed to deflocculate the stock. The stator had full height bars for all 54 in. (1.372 m) of the plate diameter, but the rotor had a deflocculating zone that began at a radius of 25 in. (0.635 m) from the center of the plate, at which point the bar height stepped down by 0.7 mm. From this point outward, the bars were tapered with a decreasing bar height with a 3° angle to the full 27 in. (0.686 m) radius of the plate.

This first deflocer eliminated a long-standing machine liability. Since putting it in, the mill went from about twelve days to over a year and a half without needing to shut down to clean the headbox, and it is not certain that something else did not cause that rare plugging event. In spite of the less visible flocs in high-yield pine pulp, the deflocer is effective at reducing string formation. The 50 in. conventional plate operating in parallel with the trial plate was changed to the same 54 in. defloccing pattern at the midpoint of the original deflocer’s life, and both refiners have had deflocers ever since.

Since this first trial, two machines in two other mills have also reported improved headbox cleanliness with deflocers. The headbox plugging reduction is interesting because it demonstrates something significant is happening, but refining efficiency is relevant to all machines. We can measure refining efficiency as energy reduction with all other variables held constant. Energy reduction is the most conservative valuation. Depending on bottlenecks and needs, it can be exchanged for more valuable properties, such as reduced basis weight, reduced chemical additives, higher yield, lower cost fiber, or higher speed, for example. Taken as an energy benefit, however, the reduc-



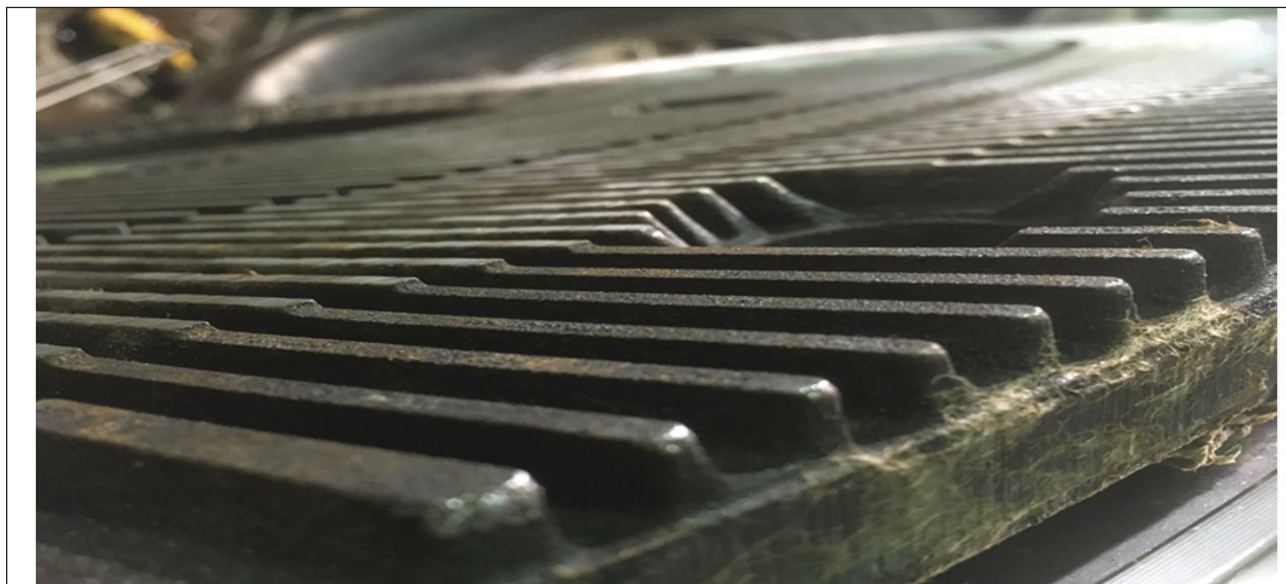
7. Energy savings on the largest grade with the first set of deflocculating refiner plates (deflocers) indicates 9% gross energy reduction on the whole sheet with only one deflocer refining 45% of the stock. The previous plates were a 50 in. underhung and 54 in. full size plate shown in the blue box on the right. The orange box on the right shows the deflocer replaced the 54 in. refiner with a 50 in. refining diameter and a 54 in. total diameter plate that included a 2-in.-wide circumferential defloccing zone.

tion in purchased electricity also contributes toward Class 2 emission reduction.

Based on comparisons made around the times of the plate changes, the conventional underhung 50 in. plate appears to have not saved refining energy and in fact might have increased energy demand slightly by 0.07 horsepower days per short ton (hpd/ton) on the whole sheet compared to the legacy 54 in. plate it replaced. The 54 in. trial deflocer plate, however, when it replaced the 54 in. legacy plate, appears to have saved 0.69 hpd/ton on the whole

sheet on the largest grade, 56 lb., as shown in **Fig. 7**. This is ten times greater than the no-load reduction from applying the deflocculating zone to what was previously part of the refining zone. Results were similar on other grades.

Refining energy efficiency is conventionally improved by decreasing no-load energy or achieving a more optimal refining intensity. In these cases, the benefit achieved on one refiner manifests itself as an average energy reduction across the whole sheet. Conversely, the energy change in the whole sheet can be attributed to the im-



8. First experimental plate with a defloccing zone designed for only partial plate life for diagnostic purposes. This picture shows the step down and slightly sloped out 2 in. of the rotor after 8 days of run time.

		Total Gross HPD/Ton			
Basis Weight, lb/1000 ft ²	No. of Refiners	Zero Defloccers	One Deflocцер	Savings	Savings (if all refiners were defloccers)
33	2	3.41	3.36	0.05	3%
36	2	3.42	3.18	0.24	14%
40	2	2.2	1.85	0.35	32%
45	2	2.27	1.77	0.50	44%
33	3	3.96	3.75	0.21	16%
34	3	4.11	4.00	0.11	8%
35	3	8.12	7.76	0.36	13%
				Average:	19%

III. OCC refining benefit.

proved refiner, all else being equal. The improvement with the deflocцер, however, is not in the refining per se. The 50 in. refining zone was the same in the deflocцер and the 50 in. underhung plate. The improvement was also not from no-load. The no-load difference between a 54 in. conventional plate and a 54 in. deflocцер is an order of magnitude less than the energy savings observed. The efficiency must come from the interaction of the defloc-culated stock with the sheet. For this reason, the benefit of defloc-culating might not scale linearly with the proportion of stock treated. Nevertheless, it is informative to represent the energy reduction in this way to be able to compare results from different applications with different percentages of stock treated and to relate results to conventional methods of improving refining energy efficiency. Normalizing the 9% energy reduction by the 45% of the stock that was treated with the deflocцер results in a 20% energy reduction of the whole sheet, extrapolating the same results to 100% defloc-ced stock.

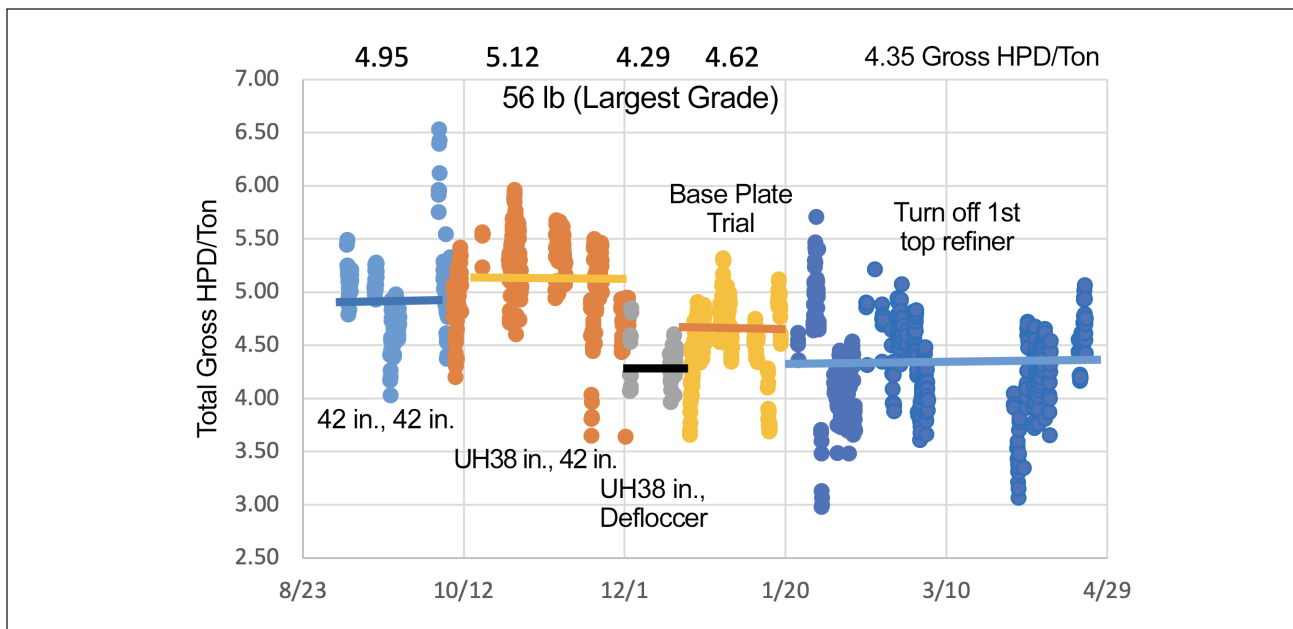
From our current perspective after having implemented dozens of deflocцers, this turns out to be fairly typical. The median energy savings we have seen in general is 15% of the gross refining energy on the total sheet, prorated by the percentage of defloc-culated stock. One of the features of the machine depicted in Fig. 7 is that refining is controlled by a vacuum box on the Fourdrinier. Thus, the refining energy reduction reflects the increased vacuum capability developed by the defloc-culated stock, perhaps as a result of liberating individual fibers from flocs. With defloc-culation, the refining energy is lowered to maintain the original vacuum setpoint.

The defloc-culating zone used in this first trial differs from later practice. **Figure 8** shows the first experimental plate after eight days of use. Notice the significant bar height at the outer edge. This was done on a trial basis so that the defloc-culating zone would wear away partway

through the plate life. Later versions have included a steeper taper that enables defloc-culating capability for the entire life of a plate. No loss of benefits has been detected with full-life deflocцers. For more than two years, this mill has run all low consistency refiner plates on both machines with full-life deflocцers.

Additional mill trials

The initial applications focused on softwood because long softwood fibers are most prone to make flocs. It turns out we also see a refining energy reduction on old corrugated containers (OCC). A 100% recycled container-board machine in the United States uses either two or three refiners at a time. The following analysis segregates comparisons by the number of refiners used. The mill has four refiners available, all of them being 42 in. (1.067 m) double disc refiners running plates with similar cutting edge lengths for both the baseline period and the trial period with the deflocцер. The deflocцер was installed on one of the two base refiners in parallel. Frequent sampling of the refiners in parallel suggested the deflocцер produced a lower CSF stock with less refining energy. As before, however, the most meaningful comparison is the grade-by-grade comparison of the gross specific energy on the total sheet. **Table III** shows this, comparing the full life performance of a single set of deflocцер refiner plates to over a month of data from the previous conventional plates. The average basis weights, machine speeds, and STFI short span compression test (STFI-SCT) were identical for the baseline period (zero deflocцers) and the trial period with one deflocцер. The average Mullen for the deflocцер trial increased 4%, however, and on corrugating medium grades, Concora increased 2%. If the refining had been run to constant net specific energy, it is likely that STFI-SCT would have been higher as well.



9. Series of refiner trials shown for a grade that represents half of this paper machine's production.

Measuring refining energy differences from refiner trials with precision is often challenging because of variability in the process and the pulp, but the energy benefit in Table III is consistently favorable. The right column extrapolates the benefit to using deflocchers on all refiners. Interestingly, the 19% reduction in gross specific energy is about the same as for the softwood linerboard example mentioned previously.

One additional example is interesting, because it gives insight into the mechanism of the energy savings. A softwood linerboard machine in the southeastern United States was operating a top ply with two refiners in series. Each of these refiners operated at about 60% to 70% of full motor load. A defloccher was put in the second of these refiners. A series of plate changes was made in close consultation with a refiner plate supplier to contrast conventional ways of reducing refining energy to reducing energy with a defloccher. The baseline period, in September, had both top refiners with conventional 42 in. (1.067 m) plates, as shown in **Fig. 9**. This figure represents a single grade that constitutes approximately half of this machine's production. The first change, in October and November, was to put a 38 in. underhung plate into the first top refiner. We did not see an energy decrease from this, and in fact energy use increased from 4.95 to 5.12 gross hpd/ton. Next, a defloccher was added in the second top refiner. It had the same 38 in. refining zone as the underhung refiner, but a 2 in. circumferential deflocching zone was added. We averaged much lower, at 4.29 gross hpd/ton. While this was still running, a conventional trial plate was installed on the base ply, but the average energy use increased from 4.29 to 4.62 hpd/ton. In late January, the mill decided to turn off the underhung top refiner and only use

the defloccher in the top ply, resulting in a decrease to 4.35 gross hpd/ton on the whole sheet. All of the averages of the five periods noted in Fig. 9 are statistically different with 95% confidence, except for the third and fifth periods. These are not statistically different from each other, but they are lower than all other periods.

The defloccher is the only plate trialed that showed evidence of decreased energy use. The magnitude of energy reduction shows us that the defloccher on the top ply is affecting the sheet as a whole, not just the top ply refining energy. For example, look at the transition from the second to the third periods of trials, as the defloccher first went in. The total gross specific energy decreased by 0.83 hpd/ton (5.12 to 4.29) on the whole sheet, but the top ply refining itself actually increased slightly, from 15.06 to 15.42 gross hpd/ton. Half of the 15.42 gross hpd/ton being run on the top ply in the third period was due to the refiner with the defloccher. In other words, a defloccher operating at 7.7 gross hpd/ton on 10% of the total sheet (0.77 hpd/ton on the total sheet) reduced refining energy by 0.83 hpd/ton on the total sheet. The defloccher is effectively saving over 100% of the energy used by the deflocching refiner. Clearly, 100% energy reduction would not be possible on 100% of the sheet. This calculation demonstrates that the energy reduction mechanism is related to something that goes beyond the refiner itself. This defloccher must be building the sheet more efficiently. Even a small amount of deflocculated fiber can interact with the rest of the sheet to bring about a stronger sheet, thereby requiring less refining. A factor that might have supported this level of improvement could include a very high recirculation rate of 57% through the top ply refiner. Repeated passes through the refiner likely produced more flocs than is common.

CONCLUSIONS

Conventional refining of softwood, OCC, and perhaps other pulps results in the formation of flocs that are detrimental to strength and are therefore detrimental to refining efficiency. A refiner plate modification based on the ability of an unloaded tickler refiner to reduce flocs has been demonstrated to save nominally 15% of gross specific refining energy in the total sheet, prorated by the percentage of treated stock. This modification has also been demonstrated to improve headbox cleanliness by reducing the flocs that initiate fiber stringing.

Fiber morphology is most commonly measured on well-dispersed, dilute pulps so that single fibers can be isolated for measurement. The current work shows the importance of understanding the impact of flocs under the conditions they are present on a paper machine. Likewise, refining efficiency and the development of sheet strength on a paper machine are strongly affected by this phenomenon. While the solution investigated is straightforward and well-proven, a greater understanding of this phenomenon could lead to additional optimization in this nascent field. **TJ**

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ABOUT THE AUTHORS

Others have noted the formation of flocs in refining before, but not much attention has been given to its consequence or remedy. A confluence of fortuitous observations gave us insight into both of these.

Refining improvements are often focused on reducing no-load or optimizing fiber properties. Not much attention has been paid to the effect of flocculation in refining. To our knowledge, this is the first effort at identifying the effect of refiner-generated flocs and finding a remedy for them.

We found some interesting results with hand-sheets, but they were inconsistent. We have concluded that the handsheet making process itself, much like fiber morphology measurement, involves agitation and therefore degradation of flocs. Because of this, we have focused on the paper machine's response as our measure of success.

We discovered that, although we work in a mature industry, new opportunities can be found outside of existing paradigms. The elimination of headbox plugging with the very first trial set of plates was a pleasant surprise.

Almost any mill that is interested in saving refining energy or debottlenecking refiners could benefit

by implementing this technology. If the mill is happy with their current refiner plates, all the better. This can be added to most refiner plates without significantly affecting refining itself.

Although we are focused on completing replication in our company, further optimization might be possible with an improved fundamental understanding. We will look for opportunities to leverage research into this phenomenon.

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