Vapor-phase chemimechanical pulping of aspen—explosion vs. no explosion

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ABSTRACT *This work examines the effect of steam explosion on the refining characteristics as well as the mechanical and optical properties of chemimechanical pulps. Results obtained from a pilot-plant trial show no evidence that explosive discharge of steamed chips reduces consumption of specific refining energy or improves strength properties and bleachability. It appears that, at least in the case of aspen chips, the explosive discharge serves no purpose other than to empty the digester.*

KEYWORDS
Batch digesters
Chemimechanical pulping
Digestion
Energy
Fiber bonding
Pulp properties
Refining
Steam

Explosion pulping—high-temperature, vapor-phase cooking of pre-impregnated chips followed by explosive discharge into an atmospheric environment—has been the focus of renewed attention in recent years. It is an interesting high-yield pulping process because of its high cooking temperatures and consequently short reaction time.

The explosion process is said to produce a very high yield (90%+) pulp with excellent strength properties and substantially reduced energy requirements for refining (*1-7*). Despite these reported successes of the explosion-pulping process, there is little information explaining how or why this process provides such exceptional results. In a study of exploded and unexploded black spruce chips, Law and Bi (*8*) found that the sudden decompression of steamed chips did not improve pulp properties or reduce refining energy. In fact, the force of the explosive discharge and the resultant impact of the steamed chips against the walls of a blow vessel may damage the fibers and reduce the mechanical properties of the pulp.

The argument that fibers are liberated from the steamed chips when they are explosively discharged is open to debate. Law and Valade (*9*) recently demonstrated that explosive discharge following high-yield explosion pulping does not liberate fibers from steamed chips. This means that there should be little or no fibrillation on the fiber surface as a result of the explosive release. Thus it is questionable whether the explosive discharge serves any purpose other than to empty the digester.

In low-yield explosion pulping (e.g., sulfate and sulfite), which dissolves and removes most of the lignin bonding the fibers, the explosive force of the discharge can promote fiber liberation. However, Chornet and Overend (*10*) showed that explosive discharge of steamed chips (i.e., chips subjected to lignin- and hemicellulose-degrading high temperatures) did not fibrillate the individual fibers. Fibrillar structure on fiber surfaces was apparent when the chips were treated at a greater severity.

Explosion pulping

Explosion pulps are discharged by the sudden decompression that occurs when the digester is vented following a vapor-phase cook of pre-impregnated chips. Pulping at temperatures above 170°C could severely reduce pulp yield as well as the sulfonate and carboxylate contents of pulps made from aspen chips (*11*). Thus at comparable pulp yield, explosion pulps have lower sulfonate and carboxylate groups than a conventional liquid-phase chemimechanical pulp (CMP). Consequently, explosion pulps have lower fiber bonding strength (*11*).

Brownell and Saddler (*12*) recently studied the phenomenological aspects of steam pretreatment of aspen chips at temperatures ranging from 190°C to 240°C. They concluded that explosive discharge of the pulp contributed little or nothing to enzymatic hydrolysis (i.e., simultaneous saccharification and fermentation with residual pentosan). Water washing of unexploded steam-treated aspen wood is at least as efficient as that of exploded wood.

Explosive release is the main characteristic of a steamexplosion pulping process. Its effects on pulp properties can be difficult to isolate in actual production lines, where mechanical compression during feeding, impregnation, and pressing are involved. In laboratory studies, however, the mechanical effects can be reduced by using a blow valve that minimizes the physical impact of the exploded chips. This specially designed valve creates a circular movement of the exploded chips within the blow vessel.

The purpose of this study was to examine how the explosive discharge following a vapor-phase cook influences the characteristics of exploded pulps. The study was carried out using an explosion unit that minimizes the physical impact on the chips during explosion. Pressure within the explosion unit also could be bled off slowly, thus providing a means of producing an unexploded pulp for comparison. The pulped chips were then refined in a pilot-plant refiner.

Most of the recent works on explosion pulping processes have been carried out on a laboratory scale using blenders and PFI mills to refine the pulp. Unfortunately, these devices cannot reproduce conditions inside a commercial refiner. For the sake of comparison, the CMPs prepared by vapor-phase cooking (exploded and unexploded) in this study were also "refined" in a blender.

Experimental

Impregnation of chips

Fresh, air-dried aspen (*Populus tremuloides* Michx.) chips were soaked at room temperature for about 16 h in a liquor containing 100 g Na_2SO_3/L (liquor-to-wood ratio = 6). Excess liquor was drained prior to steam treatment.

Steaming and explosion

Steaming and explosive discharge of the impregnated chips were carried out using the steam gun located at Forintek Corp. (Ottawa). The steam gun consists of a vertically mounted, insulated stainless steel pipe with a volume of 2 L. The top and bottom of the pipe are sealed by ball valves. Steam is introduced through a side arm fitted with a steam trap and steam purifier. This side arm is located immediately below the upper ball valve. Condensate could optionally be withdrawn through another side arm and steam trap located immediately above the lower ball valve.

The charge of wood chips (≅240 g) was loaded through the top ball valve, either directly into the preheated empty gun barrel or in a thin-walled, loosely capped, stainless-steel canister that was lowered into the gun. In the latter case, steam pressure after the treatment was reduced slowly by opening a bleed valve, enabling withdrawal of the canister without any explosion. When the canister was not used, the charge was exploded into a cyclone through the rapidly opened lower ball valve. The pipe between the lower ball valve and the cyclone or blow vessel is connected in such a way that a circular movement of the exploded chips is created inside the cyclone, minimizing the physical impact of the exploded chips.

The charge was steamed at 190°C for 3 min. For pulps that were not exploded, the time required to completely bleed down the pressure was about 3 min. The discharged chips, exploded or unexploded, were immediately washed in cold running water for at least 1 h and refined the next day.

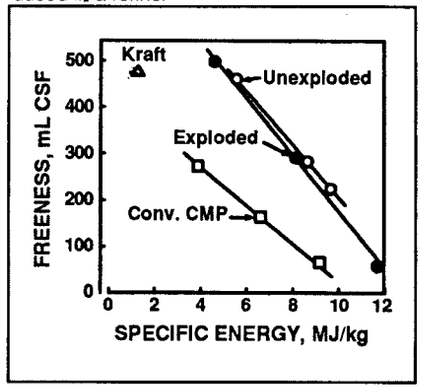
Sulfite and kraft cooking

For the sake of comparison, liquid-

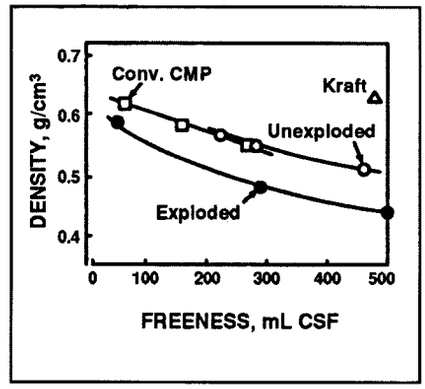
I. Pulp yield and chemical properties of aspen pulps

Pulp type	Yield, %	Sulfonate content, mmol/kg	Carboxylate content, mmol/kg	Kappa no.
Exploded	85.6	74	140	...
Unexploded	86.0	68	138	...
Conventional CMP	88.7	93	162	...
Kraft	55.6	...	...	10.7

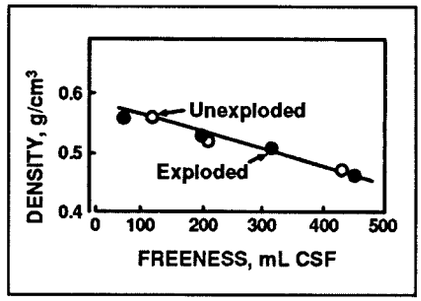
1. Pulp freeness as a function of specific refining energy consumption for pulps produced in a refiner



2. Handsheet density of refiner pulps as a function of freeness



3. Handsheet density of blender pulps as a function of freeness



II. Zero-span breaking length of never-dried webs made from exploded and unexploded pulps

	Freeness, mL CSF	Zero-span breaking length, km
Exploded	500	11.27
	292	11.38
Unexploded	457	11.81
	280	12.16

phase sulfite cooking of fresh aspen chips was carried out in a liquor containing 100 g Na_2SO_3/L (liquor-to-wood ratio = 5) for 60 min at 100°C and 15 min at 150°C.

Kraft cooking was carried out in a liquor with 18% active alkali (as Na_2O) and 30% sulfidity (as Na_2O) (liquor-to-wood ratio = 4.5) for 60 min at 100°C and 120 min at 170°C.

Refining

All chips treated in the various pulping processes were refined in a Sunds Defibrator pilot refiner (CD300) at about 16% consistency. At least 4 kg of chips was used in each refining trial. For the sake of comparison, exploded and unexploded chips (10 g each batch) were "refined" at 2% consistency in a blender (Osterizer 8).

Pulp evaluation

Latency was removed from all pulps prior to preparation of handsheets. Pulp characteristics were evaluated following CPPA methods. Optical properties were measured with a Zeiss Elrepho photometer. Never-dried wet-web zero-span breaking length was determined at about 30% dryness using a Pulmac zero-span tester.

Results and discussion

Yield, acid groups, kappa number

Pulp yield, sulfonate and carboxylate contents, and kappa number of aspen pulps are presented in **Table I**. The CMPs prepared by vapor-phase cooking (exploded and unexploded) had lower sulfonate and carboxylate contents than the conventional CMP produced by liquid-phase cooking. This finding is in accordance with previous observations (*11*). It is proposed that the acidic groups within the fiber wall increase the swelling of pulp in water as a result of the osmotic pressure generated by their counterions (*13*, *14*). Thus it is expected that sheets produced from vapor-phase-cooked pulps would have lower bonding strength than sheets produced from liquid-phase-cooked pulps. Aspen kraft is included in Table I for the purpose of comparison.

Specific energy consumption

Figure 1 shows that the exploded aspen pulp had little or no advantage over unexploded pulp in regard to specific energy consumption for refining. On the other hand, the conventional CMP, which had higher acidic groups, consumed less refining energy than the steam-cooked pulps. Refining energy of an aspen kraft pulp is also illustrated for comparison.

Sheet density

Figure 2 shows handsheet density for pulps beaten in the pilot-plant refiner. The exploded pulp produced bulkier sheets than the unexploded pulp and the conventional CMP. This indicates that fiber bonding strength for the exploded pulp would likely be lower. Kraft pulp, despite its high freeness, produced high-density sheets.

Figure 3 shows density results for vapor-phase-cooked pulps refined in a blender. In this case, there was no difference in handsheet density for the exploded and unexploded CMPs. This implies that refining in a blender does not produce the same effect as a refiner.

Strength properties

Zero-span breaking length

Table II shows that the exploded and unexploded pulps had similar zero-span breaking lengths, indicating that explosive discharge had no effect on wet fiber strength.

Breaking length

Figure 4 shows that the breaking length of the unexploded pulp equaled or exceeded that of the exploded pulp, implying that the explosive discharge did not improve the bonding strength of the resulting fibers. As expected, the conventional CMP had much better interfiber bonding than the vapor-phase-cooked pulps. The tensile strength of the kraft pulp also was much higher than that of the vapor-phase CMPs.

Results obtained for vapor-phase-cooked pulps refined in a blender are presented in **Fig. 5**. The blender-refined exploded and unexploded pulps had almost identical breaking length.

Figure 6 shows that the breaking length for exploded pulp refined in a blender was in most cases inferior to that for pulps from either a refiner or a PFI mill (*11*). This is further evidence that data generated by a blender do not reflect the real pulp potential.

Burst index

Burst index of handsheets prepared from refiner pulps was reduced to some degree by the explosive discharge of the pulp, as demonstrated in **Fig. 7**. This may be attributable to the lower sheet density of the exploded pulp. There is no evidence that explosion pulp can match the kraft pulp in burst strength.

Burst resistance of vapor-phase pulps refined in a blender is presented in **Fig. 8**. The results showed no difference between the exploded and unexploded pulps.

Comparison of blender, PFI mill (*11*), and refiner pulps from exploded chips indicated that the refiner pulp had a slightly higher burst index than the other two pulps, as shown in **Fig. 9**.

Tear index

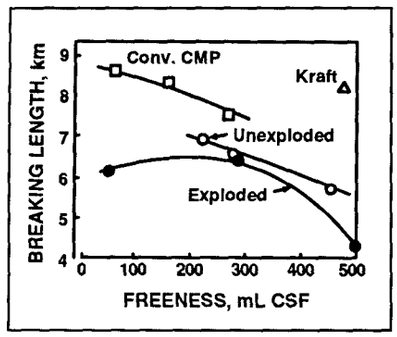
The conventional CMP is better sulfonated and carboxylated than the pulps produced by vapor-phase cooking. This improves interfiber bonding but reduces tear resistance somewhat, as seen in **Fig. 10**. At high levels of freeness, the vapor-phase CMPs are comparable with the kraft pulp in tear index. However, there is no evidence that the sudden decompression that takes place during explosive discharge improves handsheet tear strength. The vapor-phase pulps refined in a blender showed similar results, as seen in **Fig. 11**.

Figure 12 shows that exploded pulp refined in a blender had lower tear index than exploded pulp from a refiner, indicating once more that blender-refined pulps are not comparable with refined pulps. Microscopic observations of pulps showed that a PFI mill tends to cut fibers, reducing the average fiber length. Therefore, at low levels of freeness, the tear index of PFI pulps was inferior to those of the refiner and blender pulps.

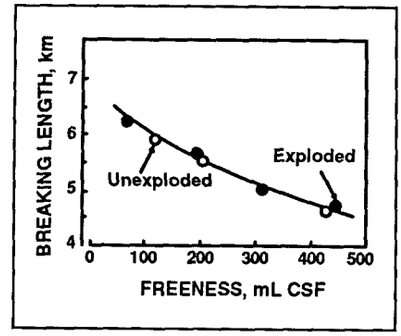
Stretch

Figure 13 demonstrates that the stretch (dry handsheets) of unexploded pulp was comparable with, if not higher than, that of exploded pulp. The highly sulfonated conventional CMP showed better stretch than the pulps produced by vapor-phase cooking and was comparable with that of kraft pulp. The results for vapor-phase pulps refined in a blender, presented in **Fig. 14**, show no differ-

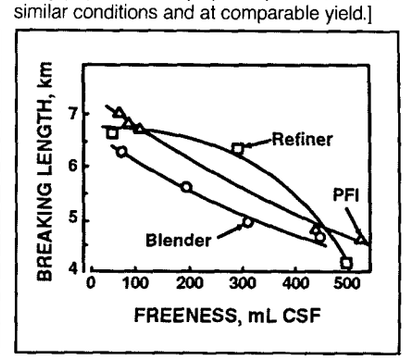
4. Breaking length of refiner pulps as a function of freeness



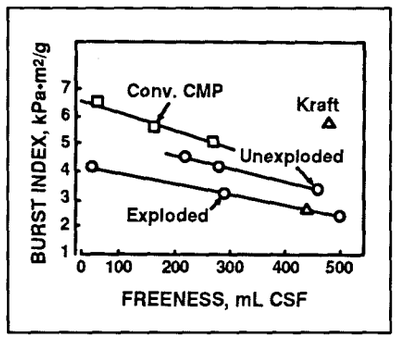
5. Breaking length of blender pulps as a function of freeness



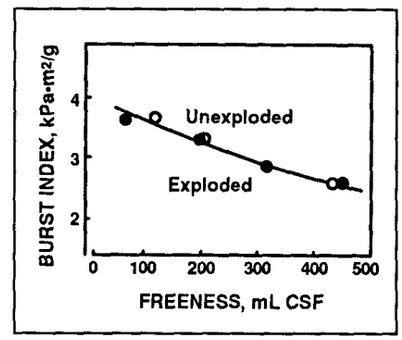
6. Breaking length as a function of freeness for exploded pulps refined in a blender, a refiner, and a PFI mill. [Data for the PFI-refined pulp in Figs. 6, 9, and 12 were taken from a previous study (*11*), where the pulp was produced under similar conditions and at comparable yield.]



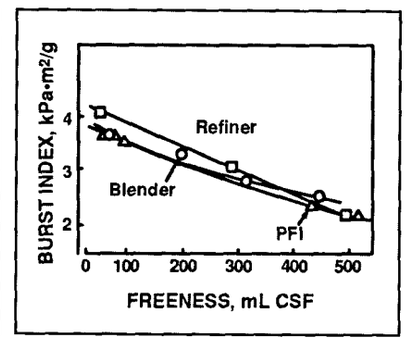
7. Burst index of refiner pulps as a function of freeness



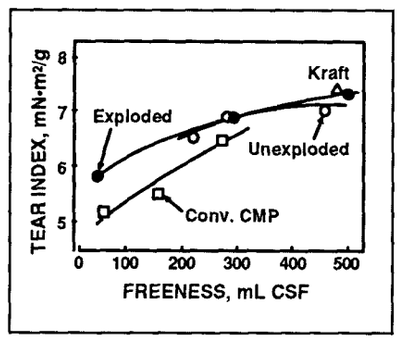
8. Burst index of blender pulps as a function of freeness



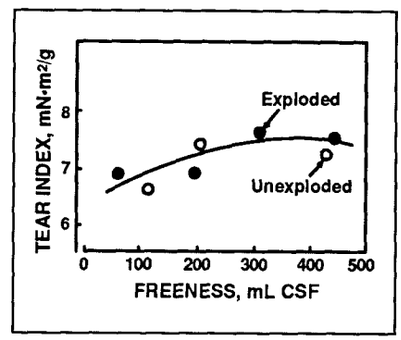
9. Burst index as a function of freeness for exploded pulps refined in a blender, a refiner, and a PFI mill



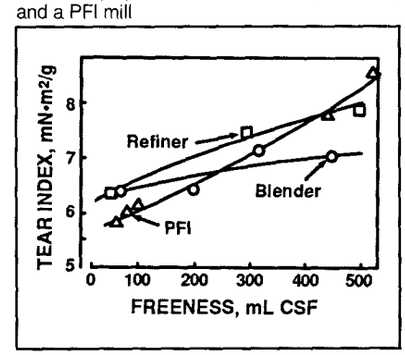
10. Tear index of refiner pulps as a function of freeness



11. Tear index of blender pulps as a function of freeness



12. Tear index as a function of freeness for exploded pulps refined in a blender, a refiner, and a PFI mill



ence in the performance of exploded and unexploded pulps.

Optical properties

Brightness

The initial brightness of exploded and unexploded pulps was about 60% ISO, indicating that explosive release had no influence on pulp brightness. The high brightness was due to the freshness of the chips used.

One-stage bleaching with 3% peroxide at 15% consistency improved the brightness of both exploded and unexploded pulps to about 79%, indicating that explosive discharge had no influence on the pulp's bleaching response.

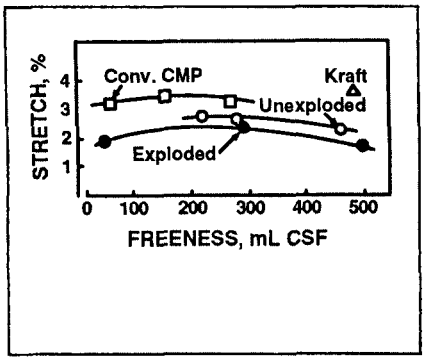
Opacity

At a freeness of about 500 mL CSF, both exploded and unexploded pulps had similar opacity of about 85%, indicating that explosive discharge had no effect on opacity.

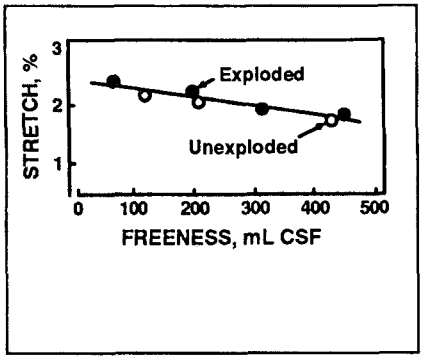
Specific scattering

Results for pulps obtained from a refiner showed that the exploded pulp

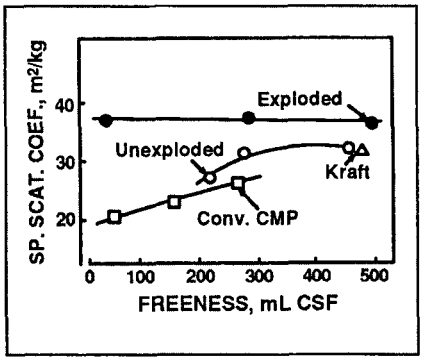
13. Stretch (dry handsheets) of refiner pulps as a function of freeness



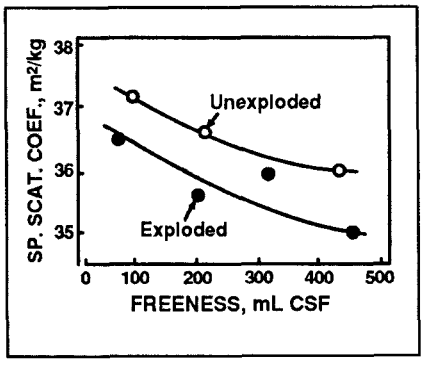
14. Stretch (dry handsheets) of blender pulps as a function of freeness



15. Specific scattering coefficient of refiner pulps as a function of freeness



16. Specific scattering coefficient of blender pulps as a function of freeness



had higher specific scattering coefficient than the unexploded pulp, as seen in **Fig. 15**. The conventional CMP and kraft pulp, because of their high sheet density, had relatively low specific scattering. On the other hand, the results for the blender pulps in **Fig. 16** indicated that the unexploded CMP is higher in scattering than the exploded CMP. This shows that reliance on blender results can lead to erroneous conclusions.

Conclusion

The results of this study support the following conclusions.

1. There is no evidence that explosive discharge after a vapor-phase cook reduces specific refining energy requirements.
2. Explosive discharge of the pulp does not diminish the wet fiber strength.
3. There is no indication that strength properties of dry handsheets are improved by the sudden decompression of the pulp.
4. Explosive discharge of steamed chips has no effect on pulp bleachability.
5. Steam-cooked chemimechanical pulps (CMP), exploded or unexploded, have lower interfiber bonding strength than kraft pulp or CMP produced by a conventional liquid-phase cook.
6. Results for pulps refined in a laboratory blender are not always comparable with those obtained for pulps beaten in a refiner.
7. It is questionable whether the explosive discharge following steam cooking serves any purposes other than to empty the reactor.
8. The explosion-pulping process is interesting mainly because of its short cooking time.
9. There is no evidence that explosion pulp can match kraft pulp in mechanical strength properties.□

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