High-consistency bleaching: a must for high brightness targets?

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Bleaching simulations are based on models that predict how the final brightness, H_2O_2, and total alkali residuals relate to the bleaching conditions.

The introduction of high-yield pulps in the market of fine paper grades is a major incentive for new developments in bleaching technology. It is justifiable to add large quantities of peroxide if the purpose is to achieve high quality in optical properties and strength. Nevertheless, to balance quality factors with cost, the consumption of the bleach chemicals must be kept to a minimum.

When bleaching high-yield pulps with hydrogen peroxide, the main factors are high H_2O_2 concentration, pH, and temperature. Economical bleaching requires the search for an optimum balance between the last two factors (*1*). Removing metal ions by washing the pulp in the presence of a chelant also contributes to a lower cost (*2*), as does adequate H_2O_2 stabilization.

The pulp bleachability (that is, the response of a specific pulp to the bleaching agent) is another key factor (*3, 4*). However, the actual concentration of H_2O_2 is critical and will increase with the targeted brightness. As more bleaching agent is applied for high brightness targets, more residual is available at the end of the bleaching reaction. Recovering as much bleach chemical as possible is thus an efficient way to decrease the bleaching cost.

The principle of high H_2O_2 concentration is at the core of the more recent bleaching technology currently proposed by equipment makers. This technology entails:

- High bleaching consistency
- Recirculation of chemical residuals
- Two-towers bleaching systems.

Higher brightness targets are reached at conditions of high consistency (*5-7*). However, little information is available about quantitative determinations of consistency effects.

Here, we will examine how the actual H_2O_2 concentration depends on the interactions of several factors:

- The pulp's bleachability and the brightness target
- Bleaching consistency
- The bleaching system and the recycling of the bleach liquor.

To support this study, computer simulations were performed based on the results of actual bleaching experiments.

Bleaching conditions

Chemicals

All chemicals are expressed as 100% except sodium silicate (38°Bé) and DTPA (40% active material).

Bleaching experiments

Air-dried pulp samples were diluted to 3% consistency with distilled water and 0.4% DTPA on dry pulp. The samples were hot defiberized at 80°C, and the pulp was thickened to 40% consistency.

The bleaching liquor was mixed with the pulp using the dilution-extraction method (*6*). Mixing was performed at 10% consistency before thickening up to the bleaching consistency (15-40%). The collected liquor was titrated, and the actual peroxide and total alkali addition levels were calculated. All bleaching trials were performed in plastic bags in hot water baths. After bleaching, the pulp was diluted to 10% consistency before thickening and acidification at pH 5.5.

High-consistency hand-mixing is compared with medium-consistency mixing in **Table I**. A higher H_2O_2 consumption and a lower brightness was observed when mixing at high consistency: hand-mixing should not be performed at consistencies higher than 20-25%. Since this work was focused on high bleaching consistencies, we used the dilution-extraction technique. The fixed parameters and the ranges of the variable parameters are given in **Table II**.

Computer simulations

Bleaching models

We studied four different wood species and/or pulping conditions. Their characteristics are given in **Table III**.

For each pulp, 36-40 bleaching experiments were statistically designed. Mathematical relationships between the variables and the responses were obtained by fitting the experimental results to polynomial equations

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I. Consistency and mixing effects in bleaching for pine TMP

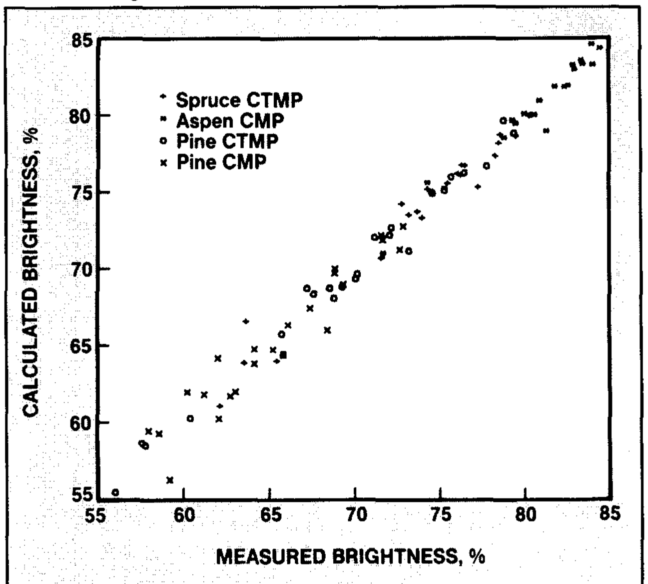
Mixing consistency	*25%*	*12%**	*40%*	*12%**
Bleaching consistency, %	25%	25%	40%	40%
Residuals, kg/ton				
Hydrogen peroxide	12.7	12.0	6.2	9.6
Total alkali	2.6	3.5	2.7	4.7
Brightness, % ISO	73.5	74.2	72.2	76.4

*With dilution-extraction mixing. Bleaching conditions: 60°C, 120 min, 4% H_2O_2, 3.5% NaOH, 4% silicate.

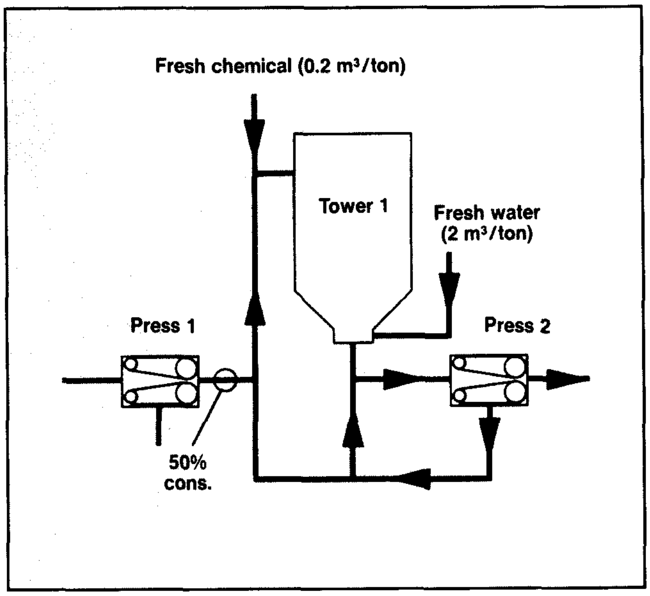
II. Bleaching experiments, parameters and variables

Pretreatment	0.4% DTPA D40
Retention time	120 min
Temperature	60°C
Silicate (38°Bé)	3% on o.d. pulp
Range, % on o.d. pulp	
Hydrogen peroxide	1.0-5.0
Total alkali	0.5-3.5
Consistency	15-40%

1. Correlation curve showing the relationship between measured and calculated brightness



2. Single-stage peroxide bleach system



of the second order. Third-order terms were included to describe some of the interactions between variables.

The bleaching simulations are based on a set of bleaching models that predict how the final brightness, H_2O_2, and total alkali residuals relate to the bleaching conditions. Statistical tests dealt only with the significant parameters. **Figure 1** shows how the model predictions fit real measurements of the pulp brightnesses.

Response surface analysis

Response surfaces were analyzed for a minimum application of H_2O_2. Each brightness is targeted at the optimum addition of total alkali.

Recirculation efficiency

The fraction of chemical residuals (H_2O_2 and total alkali) which can be re-used in the bleaching system is calculated on the basis of a carefully designed water balance. Single-stage and two-stage bleach systems are illustrated in **Figs. 2 and 3** with the chosen consistencies, liquor feeds, and water flows.

To recycle effectively and wash efficiently, the water balance strategy must be effective in preventing too much dilution of the recirculated chemicals (*7*). Make-up water is needed in the tower dilution loop to improve chemical recovery and washing efficiency (*8*). The volumes of fresh bleach liquor and dilution water are set at 0.2 m^3/ton of dry pulp and 2.0 m^3/ton of dry pulp in the simulated single-tower bleaching (0.2 m^3/ton and 4.0 m^3/ton in the two-tower system).

Moreover, the difference in consistency between the bleach tower and the previous press should be kept as large as possible. This difference allows us to add a large amount of residual liquor. For computer simulation purposes, the pulp is delivered by the presses at a consistency of 50%—a very high consistency for the purpose of keeping a high recirculation ratio even at a high bleaching consistency (*9*).

Figure 4 shows the effect of consistency on the recirculation of the chemical residuals in the single-tower and the two-tower bleaching systems. Flows and consistencies are as indicated in Figs. 2 and 3.

Assumptions

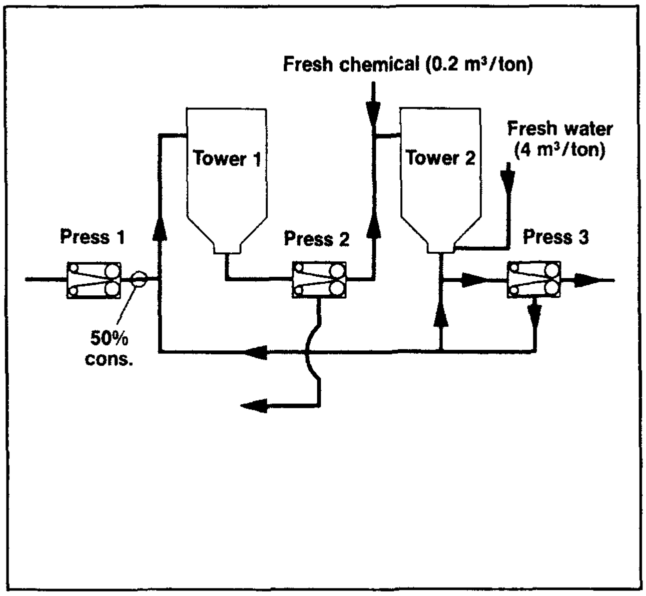
The main postulate relates to the liquor quality and H_2O_2 stability. The recirculated bleach liquor is assumed to be equivalent to the fresh liquor (*9-11*).

The total retention time in the bleach system is 120 min.

III. Characteristics of the raw pulps

	Loblolly pine CTMP	Loblolly pine CMP	White spruce CTMP	Aspen CMP
Sulfur, %	0.11	0.59	0.16	0.07
Freeness, mL CSF	140	384	190	196
Brightness, % ISO	57	52	60	69
Opacity, %	94	86	89	87
Breaking length, km	2.4	2.3	3.8	3.2
Burst strength, mN•m²/g	0.96	0.78	1.87	1.01
Tear strength, kPa•m²/g	8.2	9.3	9.6	5.1

3. Two-stage peroxide bleach system



For simulation purpose, both towers are at the same consistency in the two-stage system: bleaching is simulated at the consistency of the second tower. This assumption would lead to an overestimation of the brightness gain, because bleaching performance would be lower at a lower consistency. In fact, the consistency must be kept lower in the first tower to increase the volume of re-used bleach liquor (**Fig.** 5). Nevertheless, for a given brightness target, this underestimation of the actual H_2O_2 addition amount should be limited because of the lesser amount of H_2O_2 applied in the first tower.

Definition

The percent recirculation is the amount of residual chemicals that are recycled to the unbleached pulp, divided by the volume of residual chemicals at the tower output.

Consistency effects and pulp's bleachability

H_2O_2 addition amount

At high consistency, a higher proportion of the bleaching liquor is kept in the fiber and is available for bleaching. Moreover, a larger concentration gradient is obtained between the liquid and the fiber.

Although possible variations in mixing efficiency influence the relative performance at various consistencies (Table I), these effects were not covered in this study. Nevertheless, other factors are known to influence the effect of consistency in peroxide bleaching—the brightness target and the pulp's bleachability.

The variability of consistency effects on the H_2O_2 application is illustrated in **Fig. 6** for three different pulps at medium consistency (15%) and high consistency (35%). The higher the brightness target, the higher the impact of consistency on the minimum H_2O_2 addition amount.

The pulp's bleachability is another key-factor. The upper curves indicate little or no interest for bleaching the aspen CMP at high consistency, even to high brightnesses of up to 84% ISO. However, savings are observed for spruce CTMP and pine CMP.

H_2O_2 consumption

As shown for spruce CTMP (**Fig.** 7) and pine CMP (**Fig.** 8), the actual H_2O_2 consumption is not significantly influenced by the consistency.

The mixing system (dilution-extraction) applied in our bleach experiments could have some impact on the bleaching performance and the actual peroxide consumption. Although the data generated in this manner do not conflict with data previously generated in our laboratory with hand-mixing (**Table IV**), the influence of the mixing efficiency influences consistency effects. This problem will be studied in the near future.

Finally, while higher consistencies reduce the amount of fresh H_2O_2 applied, this benefit can be balanced by:

- The lower volume of re-used bleach liquor (Fig. 5)
- The lower H_2O_2 residual, as illustrated for spruce CTMP (Fig. 7) and pine CMP (Fig. 8).

Some calculations are necessary to evaluate how the relative performances of different tower bleaching systems depend on the pulp's bleachability and brightness target.

Consistency effects in tower bleaching systems

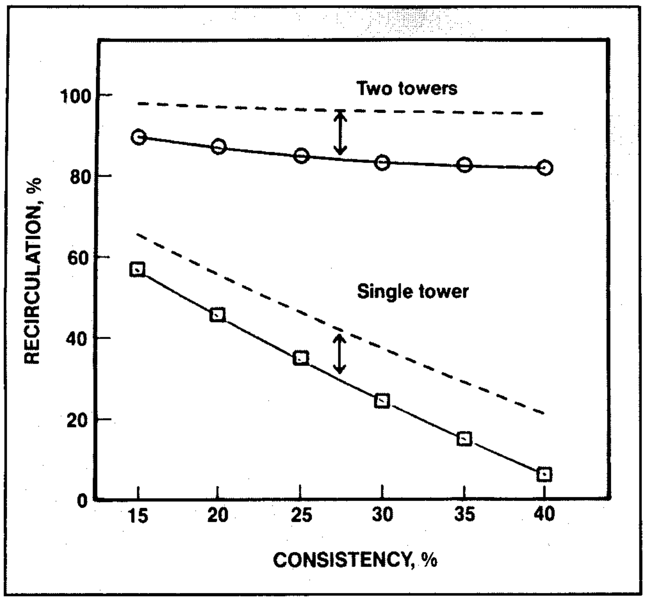
Single-tower vs. two-tower bleaching systems: consistency effects

In a single-tower, high-consistency bleach system, there is little room for introducing the residual liquor. Although displacement washing may improve the efficiency of recirculation (*13*), calculations did show a limited increase of the recycled bleach liquor volume (Fig. 4, dotted lines). For the sake of clarity, we have not included here the additional benefit of displacement washing, but savings would be significant only for high displacement ratios. [A displacement ratio of 40% is a maximum for pulps of high freeness (*13*).]

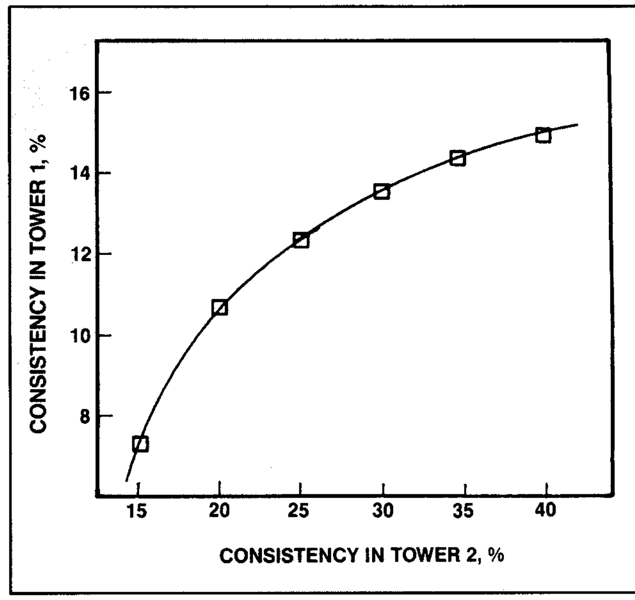
A well-designed, two-stage system (medium consistency then high consistency) can re-use much more residual (Fig. 4). However, at high consistency, less residual is available because the actual H_2O_2 consumption is not significantly modified (Fig. 8).

Consistency effects are illustrated in the following case study for the spruce CTMP. The actual (fresh) H_2O_2 addition amount is illustrated for a brightness target of

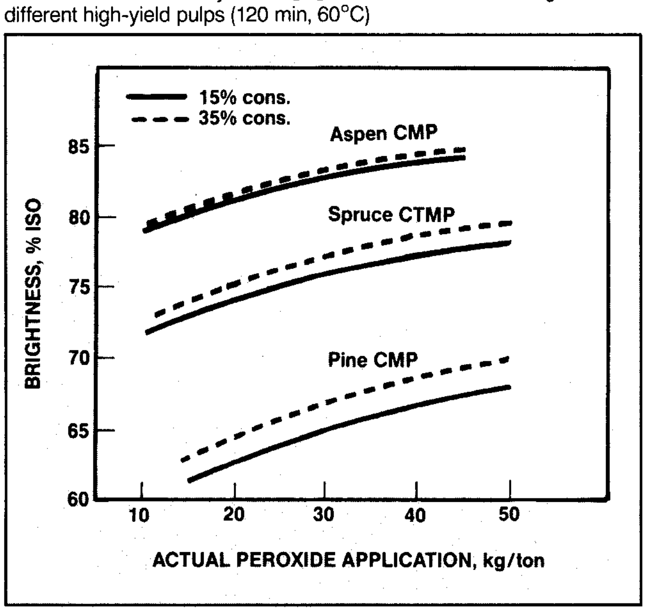
4. The efficiency of the recirculation (↕ maximum capability of displacement washing)



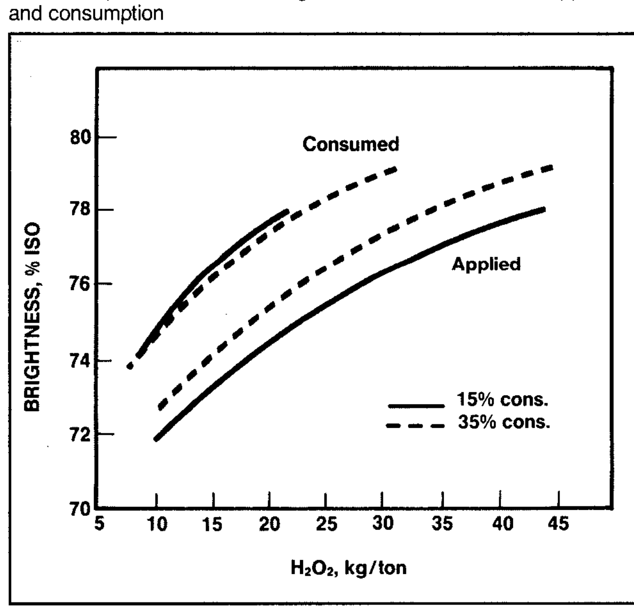
5. The relationship between the consistencies in the second and the first tower to maximize the amount of recycled liquor



6. Effect of consistency and H_2O_2 amount on the final brightness of different high-yield pulps (120 min, 60°C)



7. White spruce CTMP: final brightness vs. the actual H_2O_2 application and consumption



78% ISO in **Fig. 9**. Three different bleaching systems are represented:

- Curve A: a single tower without recycling
- Curve B: the single tower with recirculation of the spent bleach liquor
- Curve C: two towers with recirculation.

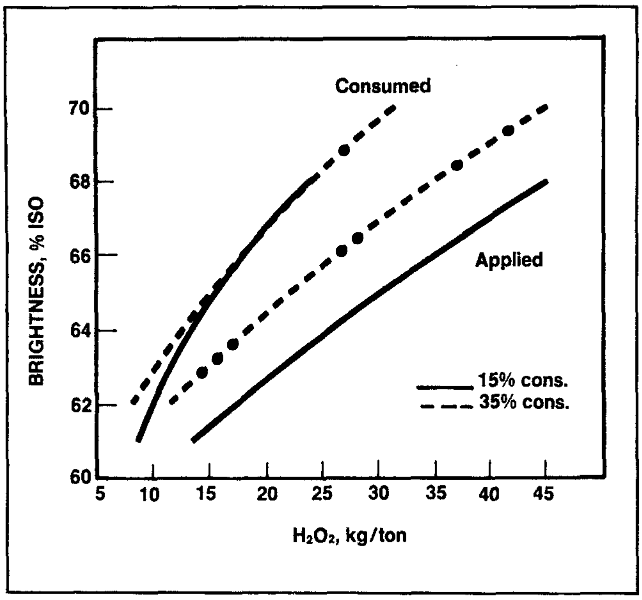
Significant differences between the simulated systems are observed if a higher brightness is targeted (78% ISO). Depending on the bleach system (one or two towers), recirculation can save 10–20 kg H_2O_2/ton on dry pulp at medium consistency.

Raising the consistency is less efficient if recirculation is performed in either a single-tower or two-tower bleach system. At high consistency, the lower volume of re-used bleach liquor and the lower H_2O_2 residual offset most of the advantage of the lower level of peroxide addition.

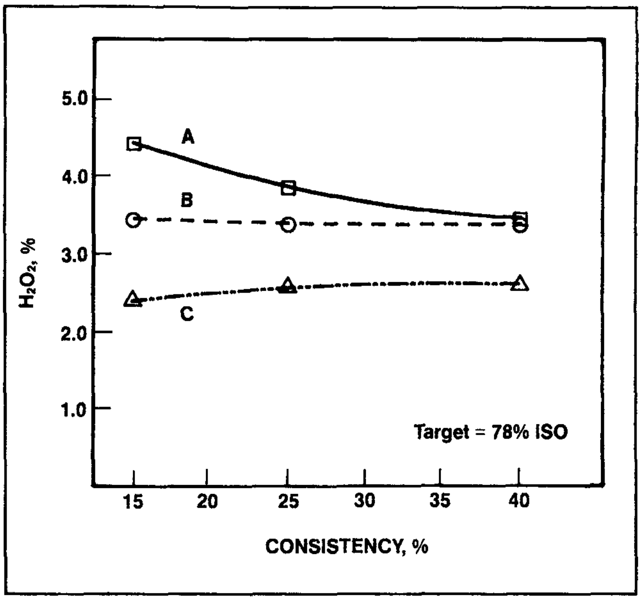
The influence of pulp's bleachability

The pulp's bleachability also influences the relative benefits of the various bleach systems. The case of pine pulps is shown in the histograms of **Figs. 10 and 11**. For each pulp, bleaching is performed at three different consistencies (15%, 25%, and 40%) at the optimum alkali level. The additions and consumptions of H_2O_2 are indicated, as well as the actual addition amounts in the single-stage and two-stage bleach systems.

8. Loblolly pine CTMP: final brightness vs. the actual H_2O_2 application and consumption



9. Consistency effects on the actual peroxide applied for spruce CTMP for (A) a single tower without recycling, (B) a single tower with recirculation, (C) two towers with recirculation



IV. Data generated previously comparing peroxide consumption after moderate and high-consistency lab bleaching

Pulp type	*Cons., %*	*Brightness, % ISO*		*Hydrogen peroxide, kg/ton of dry pulp*		
		Unbl.	*Target*	*Applied*	*Consumed*	*Residual*
Spruce stone groundwood	12	64.0	76.4	18	12	6
	20	...	76.5	13	12	1
Spruce stone groundwood	12	...	77.9	25	19	16
	20	...	77.9	20	17	3
Stone groundwood	12	56.0	68.5	15	13	2
	20	...	68.4	12.5	11	1.5
Fir and aspen TMP	15	48.0	75.0	40	30	10
	30	...	76.2	40	33	7
Pine CMP	15	53.2	72.0	40	20	20
	30	...	74.0	40	25	15
Spruce and fir stone groundwood	12	63.5	76.8	15	12	3
	30	...	77.0*	12	10	2

Variable bleaching conditions: hand mixing, optimum alkali level, retention time of 2-4 h, temperature of 55-65°C.

*Average values.

Whatever the pulping conditions, most of the advantage of high consistency is lost when the bleach liquor is recirculated efficiently (as it is with two-tower systems).

By comparing Figs. 10 and 11, we see that the benefit of higher consistencies is greater for "difficult-to-bleach" pulps (such as pine CMP) than for "easy-to-bleach" pulps. Moreover, the increase in peroxide addition yields more H_2O_2 residuals and makes recirculation even more profitable for the "difficult-to-bleach" pulps.

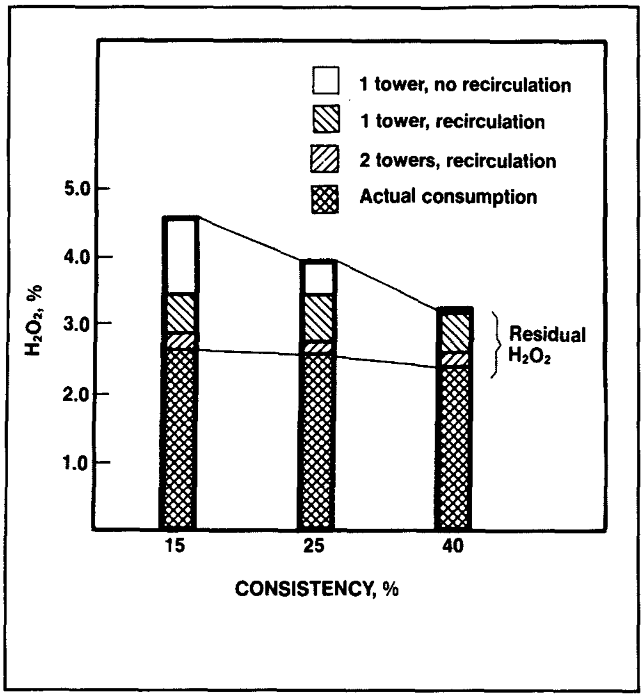
The influence of the brightness target

With a higher brightness target, more peroxide is used, as mentioned. The more peroxide used, the greater the residuals, regardless of bleaching consistency, and the greater should be the interest in an efficient recirculation system.

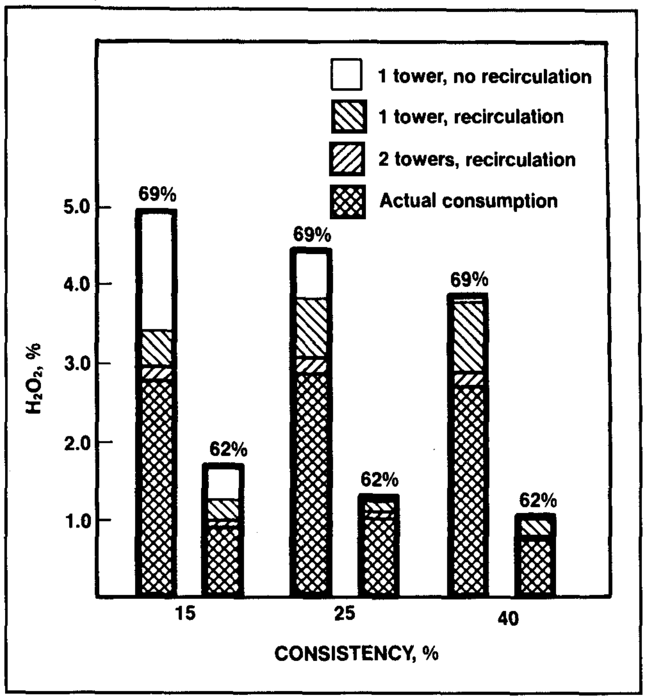
This point is illustrated in Fig. 11 for pine CMP. The peroxide demand rises rapidly with the targeted brightness, and so does the benefit of a more efficient bleaching system.

Remember that searching for economical bleaching methods requires the control of all the bleaching variables and their interactions. For example, raising the bleaching temperature of heavily sulfonated pulps above the classical 55-65°C can decrease the actual charge of bleaching chemicals, even if the residual H_2O_2 is recirculated (*4*, *9*).

10. Consistency effects on the actual peroxide applied for pine CTMP bleached to 75% ISO in different bleaching systems (120 min, 60°C)



11. Consistency effects on the actual peroxide applied for pine CMP bleached to 69% ISO and 62% ISO in different bleaching systems (120 min, 60°C)



Conclusion

High-consistency bleaching often results in significantly lower levels of H_2O_2 addition. Chemical savings vary with the pulp's bleachability and the brightness target, with more significant consistency effects observed for difficult-to-bleach pulps, such as highly sulfonated pulps (CMP). In a single tower, the benefit of high-consistency bleaching is offset by the lower proportion of residuals that can be re-used in the bleach system.

Whatever the consistency, two-stage bleaching systems can actually consume less chemicals than any single-stage system. The combination of medium and high consistency (MC-HC) results in a lower peroxide demand than with a single-stage high-consistency system. However, on the basis of our data, the advantage of the MC-HC system vs. the MC-MC system is still questionable.

Finally, the brightness target alone does not justify the choice of a bleaching system. The influence of other factors—such as pulp bleachability, washing efficiency, and the performance of the mixing at varying consistencies—should be studied on a case-by-case basis.□

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Received for review Aug. 10, 1989.

Accepted Sept. 18, 1989.

Presented at the TAPPI 1989 Pulping Conference.