# Performance of enzymatically deinked recovered paper on paper machine runnability*

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ABSTRACT

*The process of enzymatic deinking has been proven to be an effective method for removing noncontact inks from recovered paper. A secondary effect of enzyme treatment is enhanced pulp drainage. This study investigated the effects of enzymatic deinking on paper machine runnability, specifically drainage and wet-web strength enhancement. Three deinking trials were conducted on industrial-scale equipment. Two trials used the enzymatic deinking method developed at the Forest Products Laboratory, and one trial was a surfactant control. Pulp produced in each of the three trials was used in a pilot paper machine run. During each run, overall runnability, drainage, pressing response, and wet-web strenght were evaluated. In general, the enzyme-treated pulp ran better than the control pulp. Mainly, it was the enhanced drainage and wet-web strenght that contributed to the improvement in runnability.*

***Application:***

*Practical implications due to enhanced drainage and wet-web strength for the papermaker include (a) better sheet formation if a lower headbox consistency is used and (b) greater production rates or reduced drying energy us if headbox consistencies are maintained.*

ENZYMATIC DEINKING HAS BEEN proven on a laboratory and industrial scale to be an effective and economical method of deinking wastepaper *(1 4)*, especially on papers containing laser ink *(1, 5)*. Drainage enhancement is known to be a secondary benefit of enzymatic deinking. Researchers have also reported successful laboratory- and industrial-scale studies of enzyme treatment of pulp for the sole purpose of drainage enhancement *(6- 12)*.

When treating pulp with enzymes, specifically cellulases, the cellulose is hydrolyzed into various sugars, including glucose. This degradation of cellulose is expected to result in a loss in fiber strength and sheet strength. However,Jackson *et al. (11)* described the hydrolysis effect as a fiber surface cleaning with the degradation of fines, which results in a significant increase in freeness with less than a l0% loss in strength. In previous studies, researchers reported that enzymatic deinking enhances drainage while losing little or no sheet strength *(5);* other studies reported sheet strength enhancement *(2, 13)*. The majority of experiments, where pulp was treated with enzymes for the sole purpose of drainage enhancement, resulted in strength loss *(7, 9, 10, 12)*. The difference may be from the fact that typically five to ten times greater cellulase dosages and longer exposure times were used when treating for drainage enhancement purposes rather than for deinking purposes. However, in cases where refining was before or after enzyme treatment, either sheet strength was enhanced *(7)* or no strength was lost *(6, 8, 14)*.

Fiber strength, bonding potential, and drainage rate of the pulp slurry influence paper machine runnability. Currently, there is no literature on the effects of enzymatic deinking on paper machine runnability. This paper reports on the drainage and wet-web strength results of pilot paper machine runs using pulp that was enzymatically deinked on an industrial scale in a cooperative effort between Voith Sulzer, the Forest Products Laboratory, and the National Council for Air and Stream Improvement (NCASI) *(15)*.

## PROCEDURE

### Enzymatic deinking runs

Three deinking trials were conducted at the Voith Sulzer pilot plant in Appleton,WI. Approximately 3300 kg of sorted high-value office paper consisting of at least 90% laser-printed white paper was used in each of the trials. The recovered paper had a very low colored-paper content and was approximately 12% ash.

The first of the three deinking trials was the control. Heat-killed enzyme was used with surfactant as deinking aids in a high-consistency pulper. The enzyme was a commercial cellulase. In the other two trials, active enzyme and surfactant were used as deinking aids. However, the latter of the two active enzyme trials was the most successful in deinking efficiency All three deinking trials consisted of the sequence of high-consistency pulping, screening, flotation, cleaning screening, washing, and pressing to form wet lap. Deinking conditions for the deinking trials are discussed in detail by Heise *et al. (15)*. TAPPI standard handsheets were made from the wet-lap pulp and tested for tensile, tear, and burst strength. The average fiber length of each wet lap was determined by a Kajaani FS-100 fiber length analyzer. Canadian standard freeness

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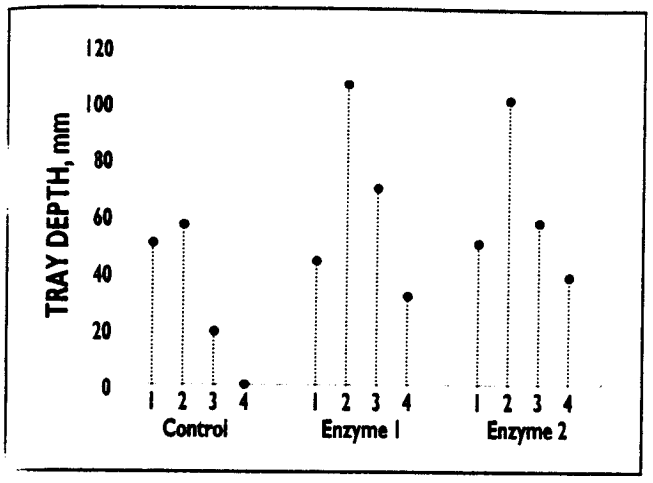
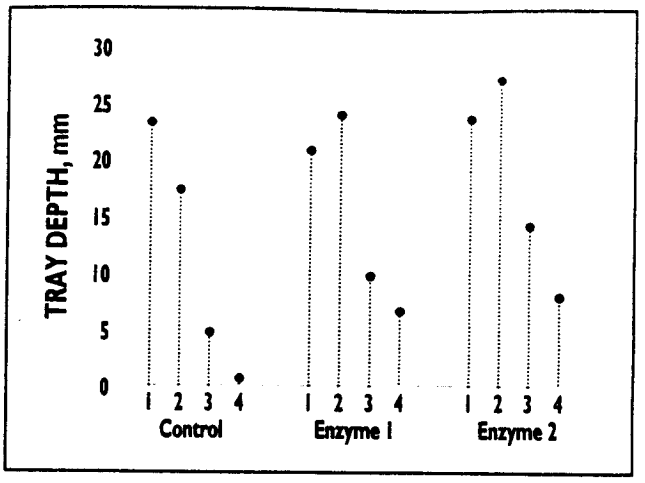



*1. Drainage profile comparison as measured by tray depths (trays 1–4)*




*2. Drainage profile comparison as measured by tray flow rates (trays 1–4)*

(CSF) was measured according to TAPPI T 227.

### Pilot paper machine runs

The pilot paper machine runs took place at the Forest Products Laboratory in Madison, WI. For each paper machine run, the wet-lap pulp was pulped to approximately 3% consistency in the machine chest. The pulp was diluted at the stuff box and delivered unrefined to the headbox. A 105-g/m$^2$ sheet was formed on the pilot paper machine with a decide of 38 cm at a speed of 9.1 m/min. The paper was dried on cylinder dryers in three sections at 85°C, 100°C, and 85°C, respectively. The paper was lightly calendered using only the weight of the rolls as pressure.

A sample of pulp was taken from the machine chest to measure CSF according to TAPPI T 227. When the paper machine had stabilized, tray depth, drainage, and cnsistency were measured for each of the four white water collection trays.

Samples of the wet web were taken off the couch, first, second, and third presses and immediately put into plastic resealable bags for wet-web tensile, stretch, and solids testing.

Machine-direction wet-web tensile and stretch testing was performed on an Instron tensile tester immediately after sampling. Sample strips (25.4 mm wide) were cut while remaining between the two sides of the plastic bag. The plastic was removed only when the strips were inserted into the Instron tensile tester. The couch samples were too weak to be measured; therefore, a two-ply couch sample was tested, and the tensile value was ap proximate by dividing by two.

| Deinking trial | Kajaani fiber lenght,mm | Tensile index, kN-m/g | Burst index, kPa-m$^2$/g | Tear index, mN-m$^2$/g |
|---|---|---|---|---|
| Control | 1.88 | 0.0410 | 2.20 | 4.28 |
| Enzyme 1 | 2.01 | 0.0431 | 2.42 | 4.39 |
| Enzyme 2 | 1.87 | 0.0412 | 2.34 | 4.25 |

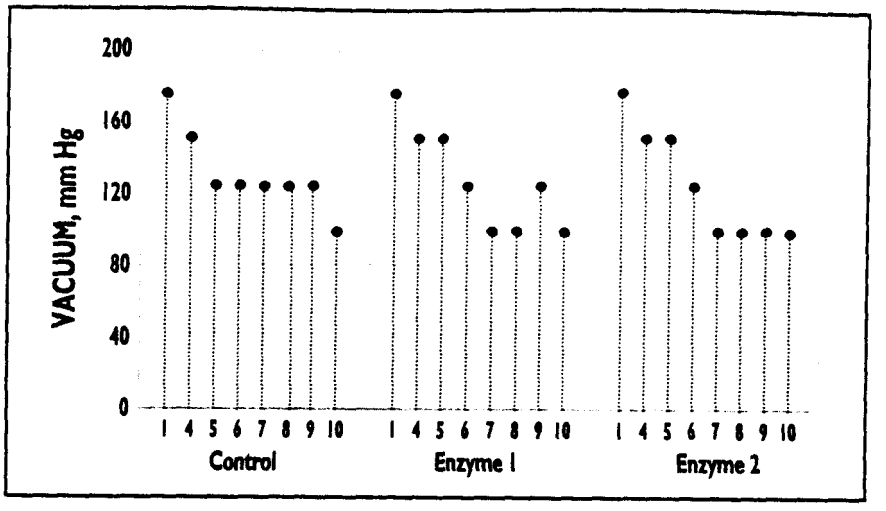
*I. Wet-lap pulp strength properties*

| Paper machine run | Machine chest consistency, % | Machine chest freeness, mL | Headbox consist-ency, % | Headbox flow rate, L/min | Total drainage rate, L/min | Total drainage, % |
|---|---|---|---|---|---|---|
| Control | 3.2 | 440 | 0.73 | 90 | 46 | 51 |
| Enzyme 1 | 3.4 | 535 | 0.42 | 128 | 61 | 48 |
| Enzyme 2 | 3.0 | 515 | 0.38 | 149 | 107 | 72 |

*II. Consistency, freeness, and drainage*

## RESULTS

AS noted in Heise *et al. (15)* and in **Table I** of this report, the wet-lap pulps produced in the three deinking trials had similar fiber length, tensile index, tear index, and burst index. The pulp strength was not affected by the enzyme treatment, most likely because the enzyme addition rates were very low (0.04% volume commercial enzyme preparation per weight of oven-dried paper) and the reaction time was relatively short (30 min) *(15).* This differed from the results seen when treating pulp for freeness enhancement, where addition rates are greater (0.1-0.6%) and reaction times are longer (0.5-4 hours) *(6-9, 12, 14).* Also, the cellulase that was used for deinking did not have as high a filter paper activity as cellulases that have been used for drainage enhancement *(5, 12, 15).* A cellulase with high filter paper activity will degrade the cellulose structure as a whole more quickly than one with a low filter paper activity. Both enzyme trials in the study reported here resulted in freeness levels approximately 60 mL greater than the control.




*3. Vacuum profile comparison (low-vacuum boxes 1, 4–10)*

| Paper machine run | SOLIDS,% Couch | 1st press | 2nd press | 3rd press |
|---|---|---|---|---|
| Control | 26.7 | 38.8 | 48.7 | 49.5 |
| Enzyme 1 | 26.9 | 37.5 | 49.1 | 49.9 |
| Enzyme 2 | 26.8 | 37.5 | 49.4 | 49.3 |

*III. Percentage of solids of wet-web samples*

| Paper machine run | STRENGTH·m/g* Couch | 1st press | 2nd press | 3rd press |
|---|---|---|---|---|
| Control | 0.93 | 1.78 | 1.91 | 2.10 |
| Enzyme 1 | 1.05 | 1.90 | 2.17 | 2.49 |
| Enzyme 2 | 1.07 | 1.96 | 2.25 | 2.45 |

*Values are normalized to the solids level of the control run.

*IV. Wet-web tensile index results*

| Paper machine run | STRETCH,%* Couch | 1st press | 2nd press | 3rd press |
|---|---|---|---|---|
| Control | 7.23 | 5.30 | 4.09 | 3.90 |
| Enzyme 1 | 6.99 | 5.11 | 3.95 | 3.73 |
| Enzyme 2 | 8.84 | 5.18 | 3.63 | 3.75 |

*Values are normalized to the solids level of the control run.

*V. Wet-web stretch results*

**KEYWORDS**

*Deinking, drainage, enzymatic activity, fibers, mechanical properties, paper machines, paper making equipment, properties, protiens, reclaimed fibers, runnability, wet webs.*

The freeness values of the deinked wet-lap pulps were 508, 571, and 561 mL for the control, enzyme 1, and enzyme 2 deinking trials, respectively. However, during pulping, the mechanical action of the agitation lowered the freeness Values to 440, 525, and 515 mL for the control, enzyme 1, and enzyme 2 deinking trials, respectively.

A summary of the machine chest and headbox consistencies, freenesses, and drainage rates for each of the paper machine runs is given in **Table II.** Paper machine drainage was measured in two ways: tray depth and flow rate from each tray. **Figure 1** shows the drainage profile for each machine run as meansured by the depth of white water in each of the four collection trays; **Fig. 2** shows the drainage profiles as measured by flow rate for each of the trays. With either method, both of the enzyme-deinked pulps had considerably greater drainage rates compared with the control, as expected from the increase in freeness (Table II) However, the headbox flow rates were also significantly greater during the paper machine runs using enzyme-deinked pulp. To normalize the drainage rates, the total drainage rate was divided by the headbox flow rate to arrive at a total drainage value expressed as a percentage (Table II). When comparing the percentage of total drainage for each run, it was clear that the second run, using enzyme-deinked pulp, had a significantly greater drainage rate than the control and the enzyme 1 trial.

The drainage profile, as depicted by the vacuum profile of the low-vacuum boxes in Fig. 3, shows that, overall, both paper machine runs using enzyme-deinked pulp required less vacuum than the control. The couch vacuum readings were 229, 229, and 203 mm Hg for the control, enzyme 1, and enzyme 2 trials, respectively. The lower couch vacuum with the enzyme 2 trial (the more effective enzyme deinking run) is another indication that the enzyme-treated pulp drains better. A previous study on treatin once-dried fiber with enzymes to enhance paper machine runnability also showed enhanced drainage and lower vacuum reqirements for enzyme-treated pulp *(12).*

Because them was a difference in solids level in the press section between the three paper machine runs, the wet-web tensile index and stretch values were normalized to the solids content found at the individual presses of the control run. The wet-web solids level for each press section sample point is listed in **Table III.**

**Table IV** summarizes the wet-web tensile index results for all three paper machine runs. Results of the enzyme-deinked pulp runs show that the enzyme treatment enhances the

wet-web tensile strength, especially in the third press section, but does not enhance the dry strength (Table I).

Unlike the wet-web tensile index, wet-web stretch is adversely affected by enzyme treatment, as seen in **Table V.** The couch stretch for the second enzyme run was an exception. The reason for this deviation is not known.

## DISCUSSION

Ibis study confirms that enzymatic treatment of recycled pulp enhances drainage and wet-web strength and decreases vacuum requirements without a loss in dry strength. It has been reported that cellulases break down the cellulose that has a high affinity to water but do not contribute to the overall hydrogen bonding potential of the fibers *(7)*. This would explain the increase in drainage without a change in sheet strength. The increase in wet-web strength with enzyme treatment may be a sign of increased fiber swelling and associated water *(15)*. These effects will improve paper machine runnability without sacrificing product quality It is possible that refining will enhance wet-web stretch and dry strength *(12)*.

## CONCLUDING REMARKS

Compared with conventional deinked pulp, we conclude from this study that enzymatically deinked pulp will lead to better paper machine runnability without a loss in product quality. Strength and runnability may be enhanced even more after refining the enzymatically deinked pulp. However, additional studies are needed to fully understand the effects of refining on the runnability of enzymatically deinked pulp. **TJ**

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