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TREATING RECYCLED PAPERS WITH NaOH FOR STRENGTH IMPROVEMENT

by

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A Thesis
Submitted to
The Department of Paper Science and Engineering
in partial fulfillment of the
requirements for the
Degree of Bachelor's Science in Engineering

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ABSTRACT

Loss of strength is one of the worst aspects of recycled papers. Even though several factors are responsible for this phenomenon, loss of fiber swelling and inter fiber bonding are believed to be the main contributors. Therefore, prevention of loss in swelling and inter fiber bonding of recycled pup should result in the minimum strength loss of recycled papers.

Chemicals with hydroxyl group such as NaOH are known to provide superior swelling power to pulp, and their swelling power might be utilized to minimize the strength loss of recycled paper.

In this study, batches of bleached kraft paper were repulped at varying NaOH charge levels and recycled, and effects of NaOH addition on freeness, tensile strength, and tear resistance of recycled paper in successive recycling were observed. The NaOH charge levels used in this experiment were 0%, 5%, 10%, and 20% by weight.

Large fluctuation in freeness of stocks with NaOH was observed, and freeness values of these stocks did not correlate to strength of papers.

The 5% NaOH paper showed higher tensile strength than regular recycled paper (paper with no NaOH) at the first recycling, but the regular recycled paper outperformed other papers in tensile strength at every recycling level.

Recycled papers with NaOH demonstrated reduction in tear strength in successive recycling while tear strength of regular recycled paper increased. The 5% NaOH paper showed the least deviation of tear index from that of the virgin paper.

Deterioration of inter fiber bonding and fiber structures were detected at all the NaOH charge levels except 0%, and the degree of deterioration was greater at higher NaOH levels.

The amount of NaOH relative to the amount of pulp present during repulping appeared to be too much in this experiment, and the positive effects of NaOH on recycled paper as anticipated were not obtained at these NaOH charge levels. However, since the 5% NaOH recycled paper showed positive results in tensile strength and tear strength, lower NaOH charge level might provide better results in strength of recycled papers.

TABLE OF CONTENTS

Table of Contents Continued

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In the recent years, the amount of paper products recycled has been increasing due to the limited availability of landfills and an effort to conserve natural resources. Unfortunately, recycled paper products demonstrate relatively weak strength compared to that of virgin papers. Reduction in fiber length, fiber strength, fiber swelling and water holding ability, and inter fiber boding ability caused during recycling operations are all responsible for this phenomenon. However, loss of fiber swelling and inter fiber bonding abilities are believed to be the main contributors. Therefore, if one could prevent loss in fiber swelling and inter fiber bonding, the loss of strength of recycled papers could be kept to a minimum.

Chemicals like NaOH are known to provide superior swelling to pulp. By utilizing this greater swelling power of NaOH during stock preparation, one might be able to improve the strength of recycled papers. If it does actually work, we might be able to improve the quality of the final product. We would then be able to increase the amount of recycled fibers in certain paper making operations, or be able to reuse papers more times than currently possible.

In this experiment, batches of bleached kraft paper were repulped at varying NaOH charge levels and recycled. The characteristics of the resulting stocks and recycled papers were compared to determine the effects of NaOH concentrations during recycling on fibers and papers.

REVIEW OF LITEATURE

For preliminary literature review, the references of the interest were those regarding properties of fibers which are important to strength of recycled papers, behavior of recycled papers with successive recycling, effects of NaOH on fibers, and effects of NaOH on strength of recycled papers.

Properties of Fibers Important to Strength of Recycled Papers

The properties of fibers which are important to the strength of recycled papers are fiber strength, fiber length, fiber swelling, and fiber bonding potential (1). Even though the surface properties of fibers maybe also important factors, it has not yet been proven (1).

Behavior of Recycled Fibers and Papers

Freeness

Freeness of recycled fibers is reported to increase slightly if they are unrefined, but refined recycled fibers show a considerable decrease in freeness (1).

Strength Properties

It is reported that nearly all strength properties decrease with recycling. However, tear resistance of recycled paper increases, and zero span tensile strength stays nearly constant (1). It suggests that fiber strength is not greatly affected by recycling, and deterioration of fiber strength is not a significant cause of loss of recycled paper strength (1).

Conformability of Recycled Fibers

Recycled fibers are less conformable than virgin fibers due to irreversible hornification and increase in cellulose crystalinity which prohibit water penetration into fibers, and these fibers provide less relative bonded area. Also, recycled fibers treated to the same degree of swelling as virgin fibers produce papers with equivalent strength (1).

Effects of NaOH on Fibers

Swelling

Liquid with hydroxyl (such as NaOH solution) or hydroxyl group with high dielectric constant produce a high rate of swelling of fibers (2).

Greater swelling of fibers would provide more relative fiber bonding area, and should improve strength of papers.

Exothermic Characteristics of Water Absorption by Fibers

Water absorption by fibers is an exothermic reaction (heat is released by reactants), and increasing temperature at constant relative humidity decreases the amount of water absorbed by fibers. It is reported that fibers refined at high temperature produce weak papers (3).

Because mixing of NaOH and water is also exothermic and should increase the temperature of the solution, heat released by mixing of NaOH and water might retard water absorption by fibers and result in low paper strength.

PROBLEM STATEMENT AND OBJECTIVE

Problem Statement

Recycled papers made out of chemical pulp demonstrate lower strength than the virgin paper. Loss of fiber swelling and inter fiber bonding potential are mainly responsible for this phenomenon (1). However, hydroxyl group such as NaOH increases the rate of swelling of fibers and provides greater fiber swelling (2). Therefore, by utilizing the superior swelling power of NaOH solution, we might be able to improve the strength of recycled papers.

Objectives of the Study

The objectives of this study are:

1. To determine the degree of improvement in the strength of recycled papers at varying NaOH charge levels in successive recycling.
2. To determine freeness change with successive recycling at varying NaOH charge levels.

EXPERIMENTAL APPROACH

Experimental Plan

Originally, recycled papers were to be repulped in water and then to be refined in NaOH solution, because refining is the most widely used and the most effective method to develop paper strength. However, this plan was abandoned due to the fact that refining of recycled fibers considerably reduces freeness of the stock and would make handsheet making operation with Noble and Wood machine almost impossible. Therefore, it was decided to repulp recovered papers in NaOH solutions. It is documented that repulping of recycled papers increases freeness and should cause no difficulty in making handsheets (1). Also, because every recovered paper must be repulped before paper making operation in actual paper mills, it should not add any extra process to a production line.

The pulp to be used in this experiment was 100% softwood (Northern pine) bleached kraft. It is documented that papers made of bleached chemical pulp are most affected by recycling, and are expected to show the effects of recycling more clearly than other types of pulp (1). Also, bleached kraft pulp (dried) was readily available for the experiment.

Four groups of handsheets were repulped at certain NaOH charge levels and recycled three times. These NaOH charge levels were 0%, 5%, 10%, and 20%. Every time they are recycled, freeness, tensile index, tear index, and temperature change of the stock were measured. The original virgin stock from which all handsheets were made was to be refined to freeness of about 350 mL CSF to obtain the optimum strength of handsheets. However, handsheet making operation at that low freeness value appeared to be difficult because of very slow drainage. Also, refining stock to low freeness could result in deterioration of fiber structures. For these reasons, freeness of the original virgin stock was increased to about 550 mL CSF.

Since NaOH is toxic and could cause sever chemical burns on skin, protective measures such as rubber gloves, safety goggles, and rain jacket were used to prevent contact of NaOH and skin. Also, dust masks were used to prevent inhalation of NaOH particles into lungs.

Experimental Procedure

Phase I Experiment

Several trials were conducted to determine NaOH charge levels for the phase II experiment and to determine the feasibility of this project in the fall of 1995.

During the first trial, 300 g of dried 100% softwood bleached kraft was refined with 23.0 L of water in Valley Beater to prepare a stock (consistency 1.46%). As the freeness reached 330 mL CSF, beating was stopped. From this stock, handsheets with basis weight of 60g /m^2 +/- 5% was made, and their tensile index, tear index, burst index, and folding endurance were determined. After strength tests, the handsheets were separated in two groups. One group was repulped in a British Disintegrator with no NaOH, and the other group was repulped in the same disintegrator with 0.5% NaOH. Both the groups consisted of 30g (oven dried weight) of handsheets, and repulping was carried out at consistency of 1.5% (2.0 L water). The speed of the rotor was 3200 rpm and the slushing time was maintained at 10 minutes.

After freeness and pH of the stocks were measured, handsheets were separately made from each stock. The same strength tests as the virgin paper were conducted on the recycled handsheets, and the strength of each group was compared with that of the other group and the virgin paper. This trial proved that handsheet making with NaOH stocks is troublesome because handling of stocks with NaOH requires extreme caution due to their toxic nature.

From the results of the first trial, it was decided to lower the pH of recycled stock with NaOH solution to vicinity of seven for the ease of handling. Therefore, the recycled stock with NaOH was rinsed with water in the second trial to wash away residual NaOH from the stock. However, it appeared that it was impossible to reduce pH value to below 12 after an hour of rinsing, and a significant fine loss was observed at the same time. Therefore, rinsing stock to lower pH was decided as impractical, and this concept and the second trial were abandoned all together.

For the third trial, it was decided to increase the NaOH charge level from 0.5% to 5.0%. As in the first trial, 360g of dried 100% softwood bleached kraft pulp was beaten in Valley Beater at a consistency of 1.46% to freeness 340 mL CSF. After pH was measured, virgin handsheets were made from the stock for strength tests.

After strength tests, the handsheets were separated into two groups. One group was repulped in the British Disintegrator with no NaOH, and the other group was repulped in the same integrator with 5% NaOH concentration. The both groups consisted of 30g (oven-dried weight) handsheets and were repulped for 10 minutes at 3200 rpm with 2.0 L solution as in the first trial.

After pH and freeness were measured, recycled handsheets were separately made from each stock, and their strength properties were compared.

The first and third trials showed that handsheet making operation at freeness 300 mL CSF or below with NaOH is extremely difficult due to a very low drainage rate of water from fiber mat in Noble and Wood handsheet making machine.

In the fourth trial, freeness of the virgin stock was increased to 620 mL CSF for the ease of handsheet making. The same procedure as the third trial with the same parameters was repeated in the fourth trial at higher freeness value. The fourth trial demonstrated an ease of handsheet making operation with Noble and Wood handsheet making machine at higher freeness with NaOH.

These trials indicated that NaOH concentrations affect characteristics of recycled papers and stocks, and also suggested that the phase II experiment should be carried out at relatively high freeness for ease of handsheet making.

Phase II Experiment

Based on the results obtained from the phase I experiment, parameters were set for the phase II experiment. In the phase II experiment, four groups of handsheets were recycled three times separately. Each group was assigned to a certain NaOH charge level. These NaOH concentrations were 0%, 5%, 10%, and 20% by weight (weight of NaOH / weight of solution). Each group consisted of 40g of handsheets, and all the groups originated from the same stock of 100% softwood (Northern pine) bleached kraft pulp beaten in Valley Beater to freeness 540 mL CSF.

The same British Disintegrator used in the phase I experiment was used for the phase II experiment. The run time was 10 minutes per each repulping, and speed of the rotor was 3200 rpm.

Every time handsheets were repulped, pH, freeness of the stock, and temperature change of the stock was measured before the next handsheet making operation. The basis weight of handsheets was set to be 60g/cm^2 +/- 5%. Tensile index and tear index were measured on these handsheets every time they were made. After the strength tests, these handsheets were sent to the next cycle of repulping and handsheet making (total three cycles).

After the third recycling, opacity and zero span tensile strength of each group were measured to evaluate the relative bond area and fiber strength.

During the experiment, NaOH concentration was the only controlled variable, and all the other parameters were held constant as much as possible throughout the experiment to evaluate the effects of NaOH concentrations on characteristics of stocks and recycled papers.

The phase II experiment was conducted in the fall of 1996, and was completed in November 1996.

From the data obtained in the phase I and phase II experiments, graphs and tables were constructed for evaluations and analysis. All the tests were conducted according to TAPPI standard methods.

Variables

The NaOH charge level was the only controlled variable in this experiment. Drying temperature and temperature of water were the main uncontrolled variables.

Constants

The constants in this experiment were:

1. Pulp used for all the handsheets (100% SW bleached kraft)
2. Pulping parameters
    - Pulper (the same machine was used for all repulping operations)
    - RPM of the repulper (3200 rpm)
    - Repulping duration (10 minutes for every repulping)
    - Consistency of the stocks (Phase I: 1.5%, Phase II: 2.0%)
3. Handsheet making parameters
    - Noble and Wood machine (the same machine was used for all handsheet making operations)
    - Pressing

        Number of pressing on each handsheet (1 pass per sheet)

        Pressure of the nip (Load: 10 lbs)

RESULTS AND DISCUSSIONS

Freeness

Freeness of stock with no NaOH steadily increased with number of recycles. After the first repulping, a stock with no NaOH originating from a virgin stock with freeness of 330 mL CSF had a freeness value of 410 mL CSF. After the first, second, and third repulping, a stock with no NaOH originating from a virgin stock of freeness 540 mL CSF had freeness values of 550, 600, and 600 mL CSF respectively.

On the other hand, stocks repulped with NaOH demonstrated fluctuating freeness values. After the first repulping, the stock with 0.5% NaOH originating from a virgin stock with freeness 330 mL CSF had freeness value of 260 mL CSF.

After the first, second, and third repulping, the stock with 5% NaOH originating from virgin stock with freeness 540 mL CSF had freeness values of 445, 500, and 540 mL CSF respectively.

After the first, second, and third repulping, the stock with 10% NaOH originated from a virgin stock with freeness 540 mL CSF had freeness values of 600, 470, and 380 mL CSF respectively.

After the first, second, and third repulping, the stock with 20% NaOH originated from a virgin stock with freeness 540 mL CSF had freeness of 630, 600, and 640 mL CSF respectively.

Table 1: Freeness Change of Stocks during Recycling

Phase I Experiment

Trial 1

Original Stock, 0% NaOH	330 mL CSF
First Recycling, 0% NaOH	410 mL CSF
First Recycling, 0.5% NaOH	260 mL CSF

Trial 3

Original Stock, 0% NaOH	340 mL CSF
First Recycling, 0% NaOH	335 mL CSF
First Recycling, 5.0% NaOH	263 mL CSF

Trial 4

Original Stock, 0% NaOH	620 mL CSF
First Recycling, 0% NaOH	600 mL CSF
First Recycling, 5.0% NaOH	575 mL CSF

Phase II Experiment: Original Stock, 0% NaOH 540 mL CSF

NaOH Level	1st Recycle	2nd Recycle	3rd Recycle
0%	550	600	600
5%	445	500	540
10%	600	470	380
20%	630	600	640

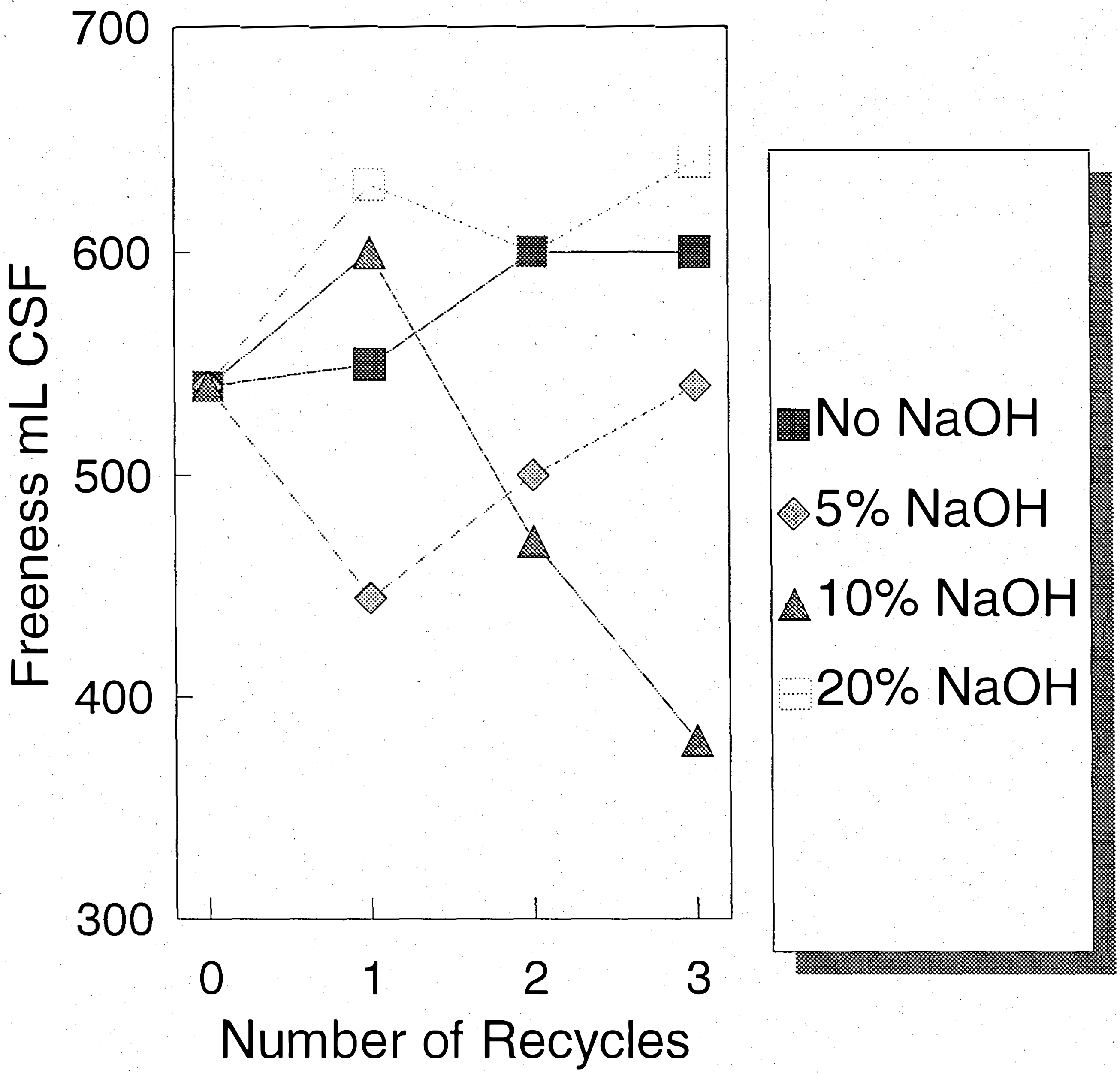

Figure 1. Effect of NaOH Addition on Freeness
after Successive Recycling

Increase in freeness of 0% NaOH stock with number of recycle suggests the loss of water holding power and an increase in fiber stiffness. During recycling process, some irreversible structural changes such as formation of water resistant crystalinity and water resistant intra fiber bonds occur in fibers which permit less water penetration into fibers. It also results in increased stiffness of fibers which make for a less permeable, less water holding mat which results in a higher water drainage rate from mat and increase in freeness.

The lower freeness values of the stocks with NaOH might have resulted from more water penetration into fibers or increased viscosity of the stocks. Hydroxides are supposed to penetrate into water resistant fiber structures to provide more water holding capacity to fibers, and to soften and swell fibers to create larger surface areas for more inter fiber bonding. Softer fibers with more surface area have lower freeness due to their large water holding capacity, and make paper with higher tensile strength. However, addition of NaOH into pulp appeared to increase viscosity of the stock in this experiment. Viscous liquid drains more slowly from fiber mat, and could result in lower freeness. In this experiment, a low freeness value of stocks with high NaOH concentration did not correlate with high tensile strength of paper.

pH

The pH values of the stocks with 0%, 0.5%, 5%, 10%, and 20% NaOH concentrations were 7.6, 12.9, 13.1, 13.2, and 13.4 respectively.

Table 2: pH of Stocks

0% NaOH	7.6
0.5% NaOH	12.9
5% NaOH	13.1
10% NaOH	13.2
20% NaOH	13.4

Tensile Index

Tensile strength of all the recycled test samples decreased with number of recycling.

After the first, second, and third recycling, 0% NaOH handsheets had tensile index of 0.882, 0.817, and 0.853 Nm/g, and percent change was -27.4, -32.6, and -29.8% respectively.

After the first, second, and third recycling, 5% NaOH handsheets had tensile index of 0.97, 0.753, and 0.661 Nm/g, and percent change was -20.1, -38.0, and -45.6% respectively.

After the first, second, and third recycling, 10% NaOH handsheets had tensile index of 0.725, 0.431, and 0.314 Nm/g, and percent change was -40.3, -64.5, and -74.2% respectively.

After the first, second, and third recycling, 20% NaOH handsheets had tensile index of 0.637, 0.343, and 0.41 Nm/g, and percent change was -47.6, -71.8, and -66.1% respectively.

At the first recycling, 5% NaOH paper showed higher tensile index than that of 0% NaOH paper, but 0% NaOH paper showed the highest tensile index among the four at the second and third recycling. The non-NaOH paper also showed the mildest tensile strength decrease while high NaOH concentration papers showed steep tensile strength decrease.

Table 3: Tensile Index Nm/g

Phase I Experiment

First Trial

	Tensile Index	% Change
Original Paper	1.45	0
1st Recycle, 0% NaOH	0.97	-33.8
1st Recycle, 0.5% NaOH	0.92	-37.2

Third Trial

	Tensile Index	% Change
Original Paper	1.57	0
1st Recycle, 0% NaOH	0.79	-50
1st Recycle, 5% NaOH	0.89	-43

Phase II Experiment: Original Paper 1.22 Nm/g

NaOH Level	1st Recycle	2nd Recycle	3rd Recycle
0%	0.88	0.82	0.85
5%	0.97	0.75	0.66
10%	0.73	0.43	0.31
20%	0.64	0.34	0.41

% Change

NaOH Level	1st Recycle	2nd Recycle	3rd Recycle
0%	-27.4	-32.8	-29.8
5%	-20.2	-38.0	-45.6
10%	-40.3	-64.5	-74.2
20%	-47.6	-71.8	-66.1

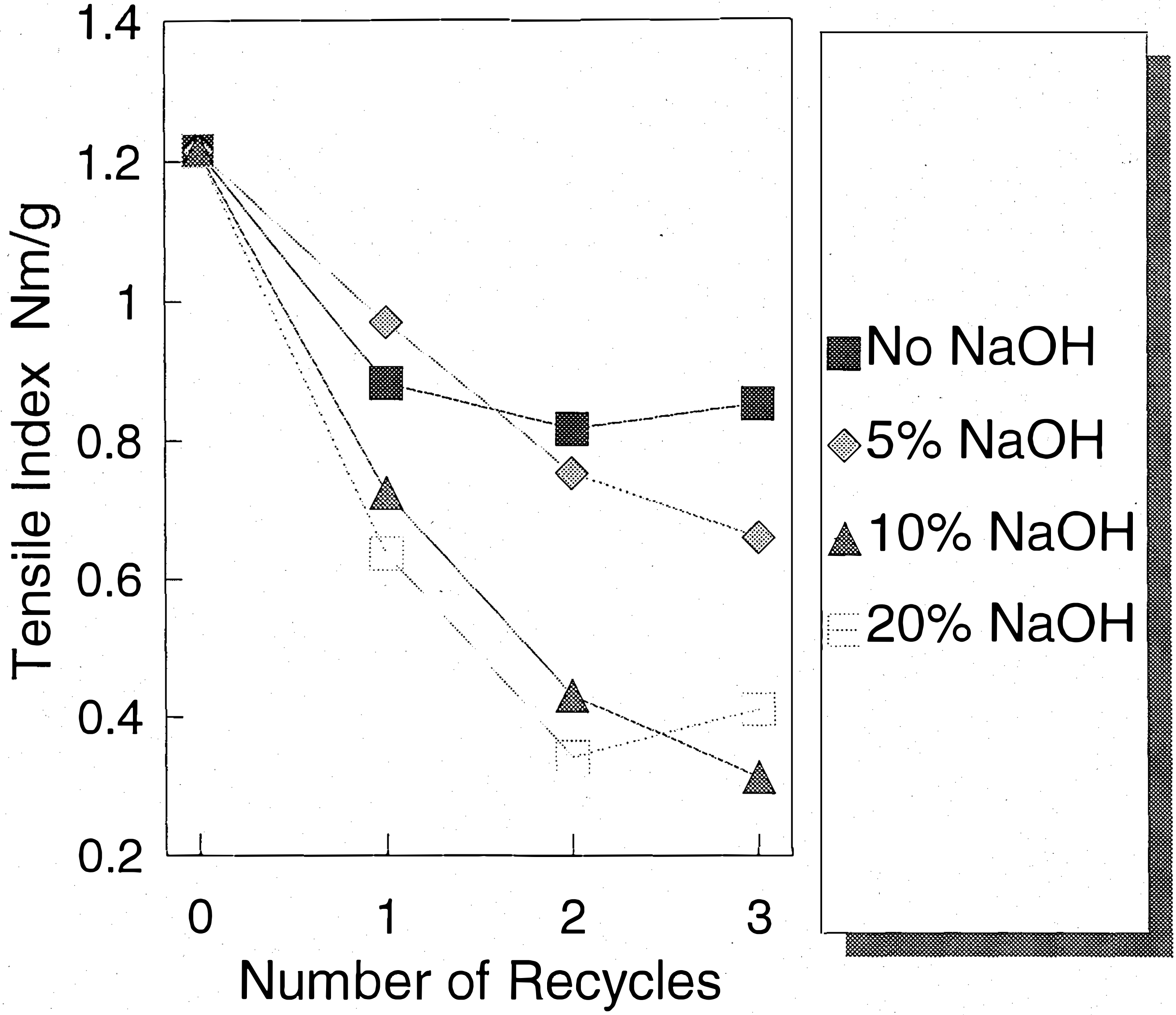

Figure 2. Effect of NaOH Addition on Tensile Index after Successive Recycling

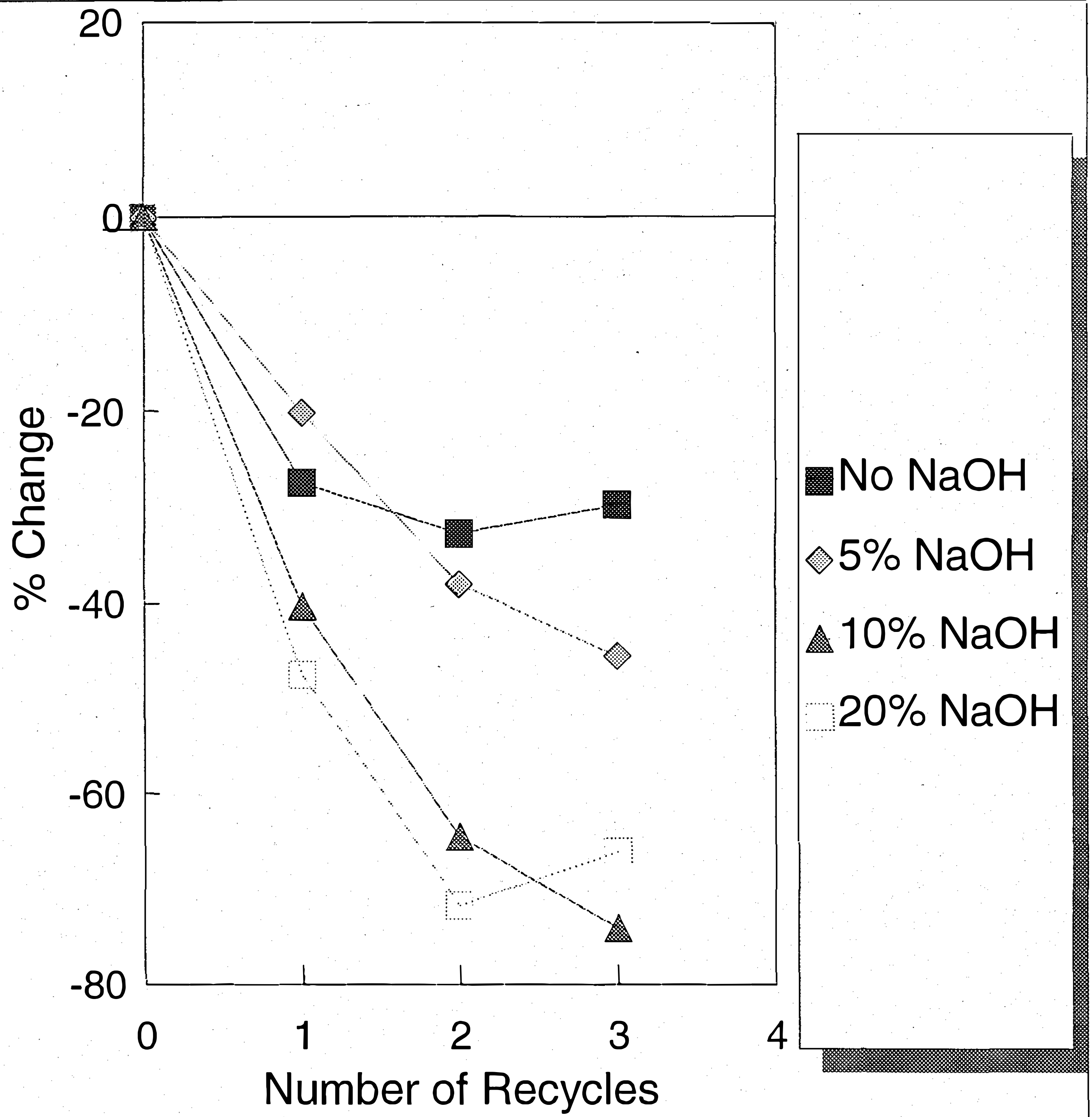

Figure 3. Effect of NaOH Addition on Tensile Index after Successive Recycling (% Change)

The cause of the progressive tensile strength loss of all the test samples with successive recycling could be a decrease in fiber fiber bonding, deterioration in fiber structure, and loss of fiber strength.

At the first recycling, 5% NaOH paper showed higher tensile index than 0% NaOH paper (7% higher), and it suggests that NaOH improved inter fiber bonding at 5% concentration. However, 0% NaOH paper outperformed the other NaOH papers at every recycling. Also, 10% and 20% NaOH papers showed much steeper tensile strength deterioration than 0% and 5% NaOH papers. High opacity of 10% and 20% papers suggests that low tensile strength of these papers is due to relatively small quantity of fiber fiber bonding. Cause of less inter fiber bonding of high NaOH concentration papers could be deposits of positively charged sodium on negatively charged fiber surface which could interfere with close fiber-fiber contact necessary for the development of inter fiber bonding.

High NaOH concentration papers also showed relatively low zero span tensile strength which suggests deterioration of fibers themselves. Usually fiber itself is stronger than inter fiber bonding, and fiber bonding strength is the determining factor for tensile strength of paper. However, if fiber strength becomes lower than inter fiber bonding strength, then fiber strength would become the determining factor for tensile strength of paper. Both fiber strength loss and inter fiber bonding loss were detected in this experiment: however, the relative importance of the two factors in tensile strength was not determined.

Tear Index

Tear resistance of 0% NaOH paper increased with number of recycling while tear resistance of NaOH papers decreased with number of recycling.

At the first, second, and third recycling, 0% NaOH paper showed tear index of 18.1, 19.2, and 18.4 mNm^2/g, and percent change was +36.1, +44.4, and +38.3% respectively.

For 5% NaOH paper, tear index was 12.9, 12.4, and 12.0 mNm^2/g, and percent change was -3.0, -6.8, and -9.8% at the first, second, and third recycling respectively.

For 10% NaOH paper, tear index was 12.5, 6.2, and 3.1 mNm^2/g, and percent change was -6.0, -53.4, and -76.7% at the first, second, and third recycling.

For 20% NaOH paper, tear index was 16.3, 11.5, and 6.8 mNm^2/g, and percent change was +22.6, -13.5, and -48.9% at the first, second, and third recycling respectively.

Papers with high NaOH concentrations showed steep tear resistance loss with number of recycling.

Table 4: Tear Index mNm^2/g

Phase II Experiment: Original Paper 13.3 mNm^2/g

NaOH Level	1st Recycle	2nd Recycle	3rd Recycle
0%	18.1	19.2	18.4
5%	12.9	12.4	12.0
10%	12.5	6.2	3.1
20%	16.3	11.5	6.8

% Change

NaOH Level	1st Recycle	2nd Recycle	3rd Recycle
0%	+36.1	+44.4	+38.3
5%	-3.0	-6.8	-9.8
10%	-6.0	-53.4	-76.7
20%	+22.6	-13.5	-48.9

Increase in tear resistance of 0% NaOH paper suggests an increase in fiber stiffness of recycled fibers after successive recycling. On the other hand, 5% NaOH paper showed the minimum change in tear resistance with number of recycle which suggests small change in softness and permeability of fibers. It indicates that NaOH is serving its purpose to keep fibers permeable at 5% concentration. The drastic reduction in tear resistance of 10 % and 20% papers is believed to be due to loss of inter fiber bonding and loss of fiber strength.

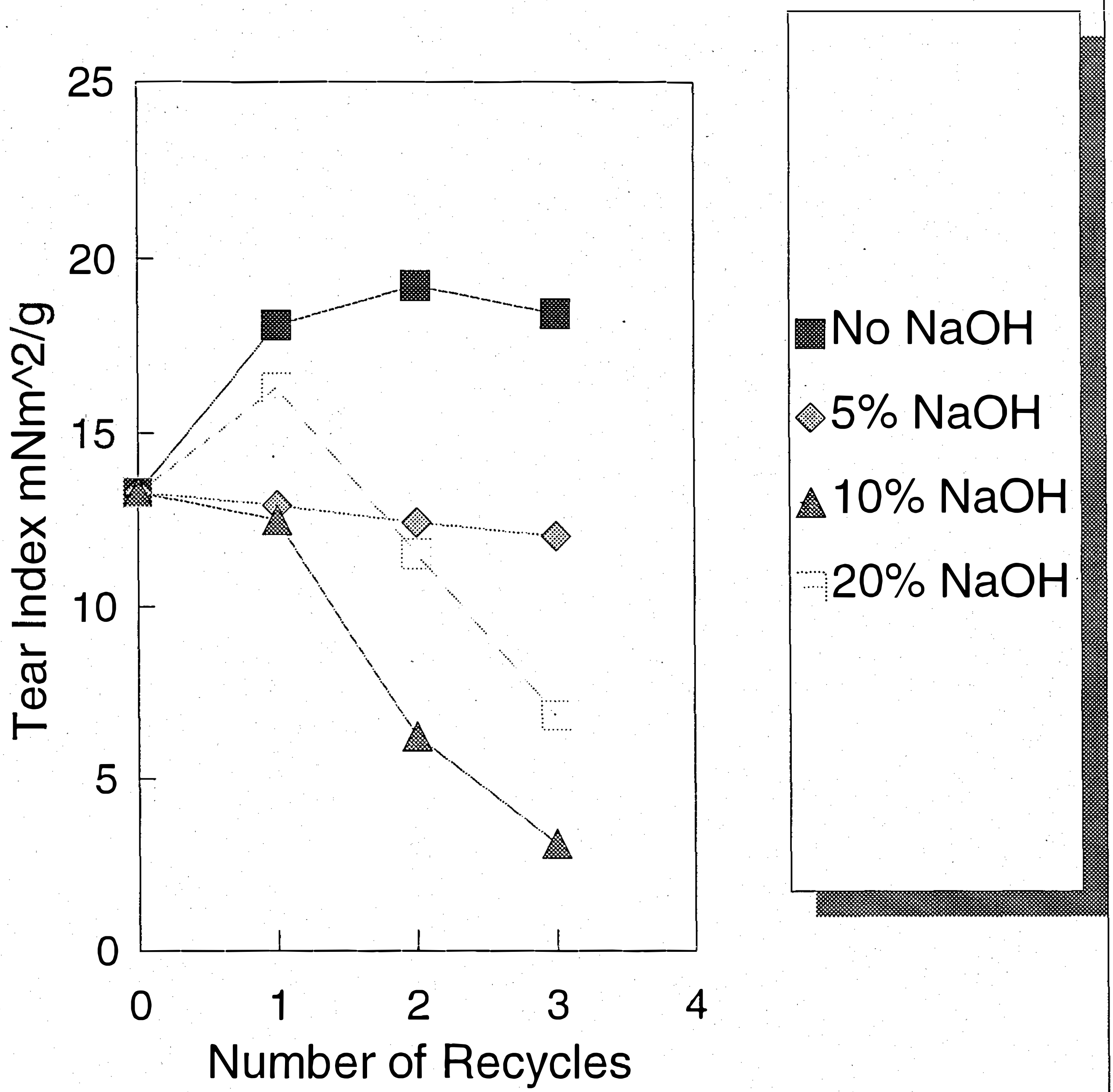

Figure 4. Effect of NaOH Addition on Tear Index after Successive Recycling

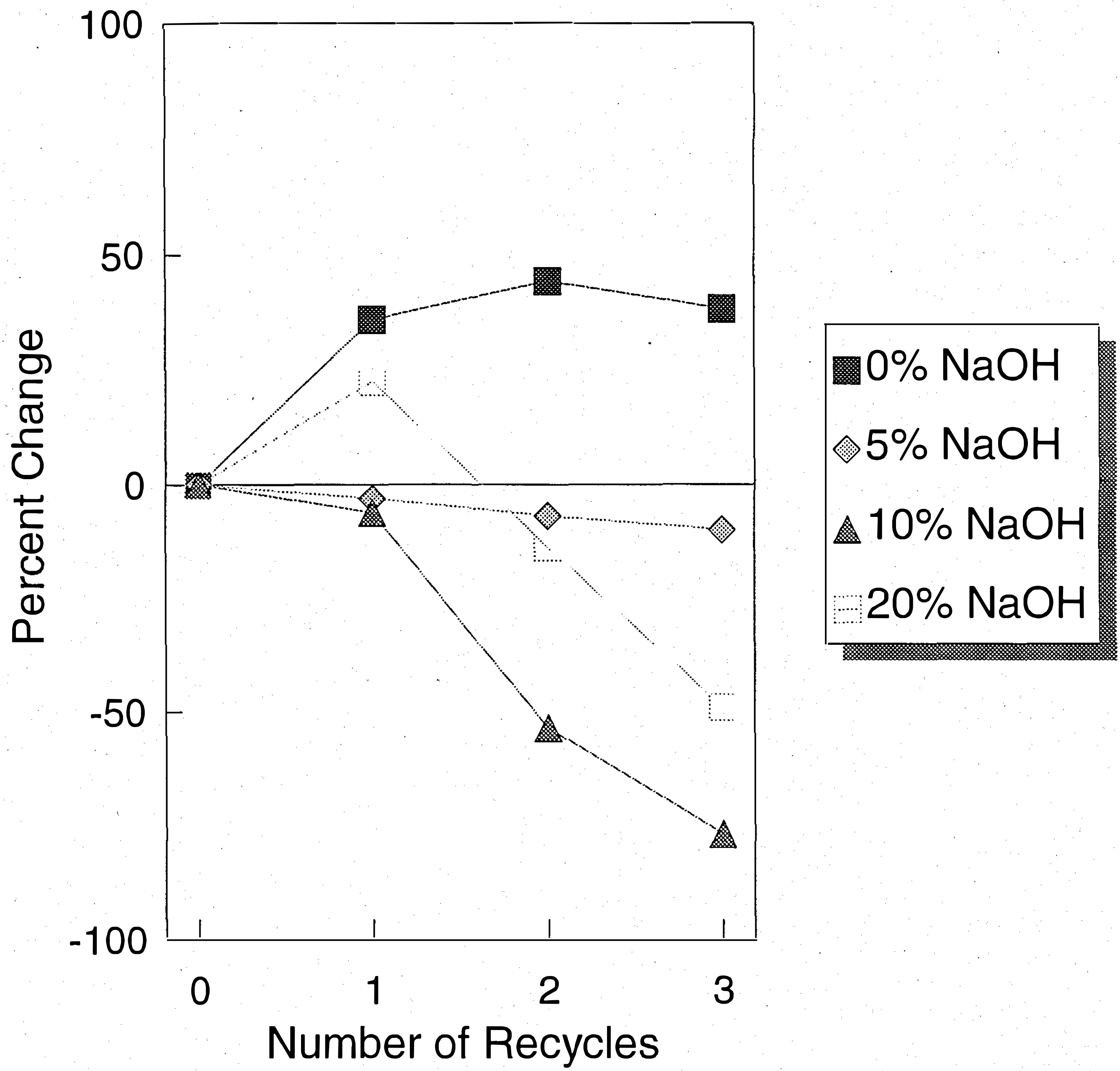

Figure 5. Effect of NaOH Addition on Tear Index after Successive Recycling (% Change)

Opacity

At the third recycling, TAPPI opacity of 0%, 5%, 10%, and 20 % papers were 79.3, 89.9, 91.2,. And 84.3% respectively.

This data show that opacity of these test samples was nearly directly proportional to NaOH concentration, and also tensile index is inversely proportional to opacity.

Table 5: TAPPI Opacity of Samples at the Third Recycling

0% NaOH	79.3%
5% NaOH	89.9%
10% NaOH	91.2%
20% NaOH	84.3%

High opacity of 10% and 20% NaOH papers suggest that there are a large surface area available for scattering light and small relative bonding area in these papers. This indicates that high NaOH content retards inter fiber bonding and provides weaker paper.

Folding Endurance

After the first recycle, folding endurance of 5% NaOH paper originating from a stock with freeness of 340 ml CSF was 269 (-80.7%). On the other hand, folding endurance of 0% NaOH paper originating from the same stock was 211 (-84.9%) after the first recycling.

After the first recycling, folding endurance of 0.5% NaOH paper originating from a stock with freeness 330 mL CSF was 425 (-73.4%), while folding endurance of 0% NaOH paper originating from the same stock was 560 (-64.9%).

No clear correlation between NaOH concentrations and folding endurance was observed in this experiment.

Table 6: Folding Endurance

Phase I Experiment

First Trial

	No. of double folds	% Change
Original Paper, 0% NaOH	1596	
1st Recycle, 0% NaOH	560	-64.9
1st Recycle, 0.5% NaOH	425	-73.4

Third Trial

	No. of double folds	% Change
Original Paper, 0% NaOH	1395	
1st Recycle, 0% NaOH	211	-84.9
1st Recycle, 5% NaOH	119	-80.7

Burst Index

After the first recycling, burst index of 5% NaOH paper originated from a stock with freeness 340 mL CSF was 3.67 kPam^2/g (-43.5%). On the other hand, burst index of 0% NaOH paper was 3.68 kPam^2/g (-43.3%) after the first recycling.

After the first recycling, the burst index of 5% NaOH paper originating from a stock with freeness 620 mL CSF was 3.75 kPam^2/g (-32.1%), while that of 0% NaOH paper from the same stock was 2.72 kPam^2/g (-50.7%).

Also, after the first recycling, the burst index of 0.5% NaOH paper originating from a stock with freeness 330 mL CSF was 4.10 kPam^2/g (-32.6%), while that of 0% NaOH paper originating from the same stock was 3.87 kPam^2/g (-36.3%).

Both the 0.5% and 5% NaOH papers had about the same burst index as 0% papers after the first recycling at low freeness values (330 and 340 mL CSF). However, 5% NaOH paper outperformed 0% NaOH paper in burst index with a wide margin after the first recycling at freeness 620 mL CSF.

Table 7: Burst Index kPam^2/g

Phase I Experiment

First Trial

	Burst Index	% Change
Original Paper, 0% NaOH	6.08	
1st Recycle, 0% NaOH	3.87	-36.3
1st Recycle, 0.5% NaOH	4.10	-32.6

Table 7 Continued:

Third Trial

	Burst Index	% Change
Original Paper, 0% NaOH	6.49	
1st Recycle, 0% NaOH	3.68	-43.3
1st Recycle, 5% NaOH	3.67	-43.5

Fourth Trial

	Burst Index	% Change
Original Paper, 0% NaOH	5.52	
1st Recycle, 0% NaOH	2.72	-50.7
1st Recycle, 5% NaOH	3.75	-32.1

Zero Span Tensile Strength

After the third recycling, zero span tensile strength (load at rupture) of 0%, 5%, 10%, and 20% NaOH papers were 37.0, 27.2, 14.2, and 20.0 Psi respectively. Zero span tensile strength appeared to be inversely proportional to NaOH concentration.

Table 8: Zero Span Tensile Strength of Samples at the Third Recycling (Load at rupture)

0% NaOH	37.0 Psi
5% NaOH	27.2 Psi
10% NaOH	14.2 Psi
20% NaOH	20.0 Psi

This data indicates that high NaOH content weakens fiber structures. Intense alkalinity could have attacked cellulose structures in fibers which resulted in fiber strength loss. Since strength of fiber itself is one of the major factors determining strength of paper, the adverse effect of high NaOH content on fiber strength should result in lower strength of paper.

Temperature Change of Stocks during Repulping

The temperature change of 0%, 5%, 10%, and 20% NaOH stocks during repulping with respect to the temperature before repulping were +3, +12, +20, and +38°C respectively.

Table 9: Temperature Increase of Stocks during Repulping

0% NaOH	+3°C
5% NaOH	+12°C
10% NaOH	+20°C
20% NaOH	+38°C

Since both water absorption by fibers and mixing of NaOH and water are exothermic reactions, the high temperature increase of repulped stock with high NaOH content might have decreased the amount of water to be absorbed by fibers, and it might have killed the purpose of using NaOH for better water penetration into fibers for better swelling.

Since 5% NaOH paper showed some positive results (higher tensile strength than 0% NaOH paper at the first recycle, and the least deviation of tensile index from that of the virgin paper), using relatively low NaOH dosage (below 5%) might provide better result. The optimum NaOH concentration for strength improvement of recycled paper may lie between 0 and 5%.

At high NaOH concentration (above 5%), NaOH has adverse effects on recycled paper by reducing inter fiber bonding and fiber strength. Also deterioration of fiber structures by NaOH should shorten the life span of the paper products.

Also, NaOH powders and solutions could cause chemical burns on skin, and NaOH fume is quite unpleasant. Therefore, from the stand point of safety and practicality, NaOH level should be kept to the minimum.

CONCLUSIONS

NaOH concentrations used in this experiment did not provide the positive effects on recycled papers as anticipated. NaOH concentration above 5% tends to retard inter fiber bonding and destroys fiber structure which result in lower tensile and tear strength of recycled paper and shorter life span of the paper products. Heat released by mixing of NaOH and water could be significant enough to retard water absorption by fibers which is also exothermic.

Possible change in viscosity of stock with addition of NaOH might have affected freeness, and freeness of stock with NaOH did not correlate with the strength of papers in this experiment. However, low NaOH concentration seems to keep recycled fibers permeable, and 5% NaOH paper did have higher tensile strength than 0% NaOH paper at the first recycle. NaOH concentration below 5% might provide better results.

It appeared that NaOH concentrations used in this experiment were too high, and the optimum NaOH concentration for strength improvement of recycled paper should lie between 0 and 5%. Furthermore, NaOH charge levels should have been relative to the amount of pulp present as the practice in the paper industry and should not have been decided as the NaOH concentration by weight in a solution.

SUGGESTIONS FOR FURTHER STUDY

The NaOH charge level should be determined relative to the amount of pulp present in a stock instead of weight of NaOH in a solution.

Because the weight ratio of NaOH in 5% concentration solution (the NaOH concentration which showed higher tensile strength than no NaOH recycled paper) and fibers in the stock was 3.3 to 1, the weight of NaOH relative to the weight of fibers in the stock should be lower than 3 or even much lower than 1.

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