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The Reprocessing of Aged Newsprint

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THE REPROCESSING OF
AGED NEWSPRINT

by

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ABSTRACT

The objective of this thesis was to determine the most efficient strength of bleach to whiten aged, unprinted news keeping strength loss to a minimum. The paper was aged in natural sunlight on a clothesline at four levels of exposure: No aging, 3 days, 12 days and 24 days. Bleaching sequence used was a two-stage hydrogen peroxide/sodium hydrosulfite. One percent, 2%, and 3% peroxide levels were used. The hydrosulfite was kept at constant 1%. All percentages were based on oven dry fiber.

Results showed an increase in yellowing of the paper with greater sun exposure; one percent peroxide effected a brightness recovery of three to seven days aging. A small amount of natural sunlight radiation does appear to increase paper strength whether pulp is bleached or unbleached. The 12 day aging sample peaked most frequently for all physical testing values.

INTRODUCTION

The objective of the following summary of available literature is to discuss the results of groundwood aging and the most efficient bleaching sequence after recycling. Stressed will be the effects and the mechanisms of aging on paper produced from mechanical pulp with a high lignin content. Very little research has been done in this specific area. This study will analyze related paper aging data and will attempt to define the effects of aging on the original paper sample and on the sample after recycling. A second aspect of this thesis was a determination of the most efficient amount of bleach for whitening aged unprinted news without excessive strength loss. A common hydrogen peroxide-sodium hydrosulfite bleaching sequence was used.

THEORETICAL DISCUSSION

In the natural state the basic factors involved in the environmental deterioration of paper are heat, light, moisture, and gases, either alone or in combination. Surveys have been made on paper permanence with no clear picture emerging on exactly how the above conditions affect it. In the past studies have been restricted to a few grades of paper and mainly to bleached chemical pulps. In addition the distinction between pulp and paper has not always been kept clear. Very little research has been directed at high lignin mechanical pulps with negligible bleaching. Thus the literature reported may not hold completely true for this experimental subject.

Chemical Considerations

Many studies have concluded that a loss of paper permanence follows a decrease in paper pH. This acid hydrolysis is known to affect aging specifically. The reaction takes place in the hemicelluloses which hydrolyze at a much greater rate than cellulose. This process is catalyzed by the organic acids produced by the cleavage of acetal and methoxyl groups from the hemicelluloses (1). The net effect of hydrolysis is a decrease in the chain length of the cellulose polymer by random breaking of the chains, the extent of which depends on acidity (2). A major contributor in the hydrolysis of cellulose is the acidity present in papers as a result of the processes and materials used in its manufacturing. The degradation products of both cellulose and hemicellulose, which hydrolyzes more readily, may increase the acidity of the sheet causing further degradation (3). It is known that this reaction occurs at normal temperatures (2). The

hydrolysis of hemicellulose could manifast itself both in a loss of fiber strength and of bond strength, two major factors determining the mechanical properties of paper (1). Acidic groups may also be introduced from other sources, such as the bleaching process. Carboxyl groups, aldehydic or ketone groups definitely affect color formation (1). In bleached and unbleached pulps sulfonic anc carboxylic acids from the lignin may be present together with native aldonic and uronic acids. Also phenolic groups may be found in unbleached pulps (1). Chlorine, either in the lignin or extractives, is released as hydrogen chloride under accelerated aging conditions, causing color reversion and possible loss in mechanical properties (1).

Oxidation reactions are also thought to contribute to paper deterioration, but understanding of them is not complete. Higgins et al. (4) showed that mild oxidation decreases tensile strength, but that higher degrees of oxidation produce permanent increases in tensile strength and brittleness while reducing extensibility and folding endurance. The relative contributions of oxygen-independent and oxygen-dependent reactions on the total rate of deterioration is based on temperature. Graminski (5) noted that just as the rates of deterioration of different papers do not decrease in the same proportion when temperature is lowered, the rates of different chemical processes within a single paper also may not decrease in the same proportion. It is possible, therefore, that deterioration of paper at 100 C. (accelerated aging) may result from reactions that are of little importance at room temperature (natural aging). Which reaction predominates depends very strongly on, not only temperature, but also type of paper, humidity of the surrounding atmosphere, and the physical property being monitored (6). Arney and Jacobs (7) concluded with over 95% confidence the

relative importance of atmospheric oxidation and oxygen-independent processes leading both to loss of strength and yellowing are indeed temperature dependent. Tests conducted at 100 C indicate that only 37% of total strength loss occurred because of acid hydrolysis, but at 20 C. oxygen-independent deterioration is predicted to play the predominant role. Arney and Jacobs (6) also concluded that yellowing was caused primarily, but not totally, by atmosphric oxidation. Tensile strength loss was caused mainly by atmospheric oxidation also. They also concluded that newsprint was affected by oxygen-independent reactions more than oxygen-dependent processes. A common feature of both newsprint and rag paper was that deterioration rate varied linearly with oxygen concentration (positive slope) but that the rate did not go to zero in the absence of oxygen.

Crosslinking reactions are known to lead to brittleness in paper. This reaction may be an important factor in paper permanence. Back (8) believed that crosslinks were hemiacetals and that this change was catalyzed by acidity. Crosslinking is generally associated with dry heat treatment; but if this reaction can occur at moist conditions and ambient temperatures, it could be a major part of natural aging. There is some evidence that crosslinking may occur at moist conditions. Back and his co-workers noted that since crosslinking produces stiffness in untreated boards, it could be an important factor in the deterioration of heat aged papers. Increased stiffness lowers folding endurance and the increased bonding would lower Elmendorf tear resistance (9). Luner (1) has written that if a crosslinking reaction occurs in the aging of paper, the rate and extent of this reaction would be proportional to the original bonded area. A paper with initially more areas of bond would develop crosslinks more rapidly upon aging. If these bonds are detrimental to folding endurance, then the initially more highly bonded

paper will show a relatively greater loss in fold than does a more weakly bonded paper. Crosslinking also leads to increased wet strength, with the loss of fold proportional to the reciprocal of wet strength (1).

Other Considerations

Light also causes a deterioration in the mechanical and optical properties of paper. Bleaching effects are sometimes observed from the photochemical action of light on paper (10). The degradation proceeds much faster when cellulose is exposed to light in the near or far ultraviolet region. It was observed that a shorter UV wavelengths the presence of water retards cellulose degradation and oxygen does not react with paper. The reverse is true at longer UV wavelengths. These results were explained by the high energy of photons in the UV region which are strong enough to break chemical bonds. Commerical papers which were UV tested (11), showed an initial increase in reflectance to a maximum, followed by a decrease in relfectance which proceeded at a rate that increased with relative humidity. Spirova and Flyate (12) observed that changes caused by ultraviolet radiation are similar to those caused by thermal aging. Launer (10) speculated that light deterioration may really be due to heat, since (1) the products of photolysis and low heat pyrolysis of paper are similar. Luner (1) writes, "It has recently been observed that the wet strength of papers which have been exposed to ultraviolet light is greatly increased in a fashion similar to that of the thermal treatment of paper. These results have led to a greater emphasis on a free radical mechanism during the photolysis and thermal treatment of cellulose...radical scavengers stabilize the degradation of cellulose, resulting in a retention of the mechanical properties of paper."

More rapid aging is also induced by cycling of the paper's moisture content. Machine made paper is under stress from the greater shrinkage and orientation of fibers in the machine direction and the differential stresses induced during drying. The paper will undergo fluctuations in stress when temperature and/or humidity is varied. These stresses could accelerate the loss in the mechanical properties of the fiber and the paper when many cycles of temperature and humidity have occurred (1).

Research has shown that temperature and humidity vary the reactions causing cellulose aging. Thermal degradation of paper was studied by Major (13) who concluded that in an oxygen vs nitrogen atmosphere, the greater deterioration in the paper was promoted by an oxygen atmosphere. Oxygen acted as a non-specific oxidant. Barrow (14) reported that in thermal aging, a 20 C. difference in aging temperature changed the deterioration rate by a factor of 7.5. Luner (1) reported that slight thermal aging or no aging caused paper tested to fail by bond breakage, while highly aged samples broke by fiber failure especially in folding endurance.

Moisture greatly accelerates paper aging, but the rate of this increase depends very much on the type of pulp tested (15). The presence of moisture leads to hydrolysis of glucosidic linkages in cellulose and hemicellulose, and probably also accelerates the reactions of impurities (trace metal and extractives) with cellulose (9).

EXPERIMENTAL PROCEDURE

Test studies were performed using new, unprinted offset groundwood news obtained from the Kalamazoo Gazette, Kalamazoo, Michigan. This paper was cut into sheets approximately 15" X 25" and aged out-of-doors in natural sunlight at four levels of exposure. Table I shows the aging plan adhered to:

TABLE I AGING PLAN

Sample	Aging Procedure
N	Control Sample - Kept From All Light
A	Aged 3 Days
B	Aged 12 Days
C	Aged 24 Days

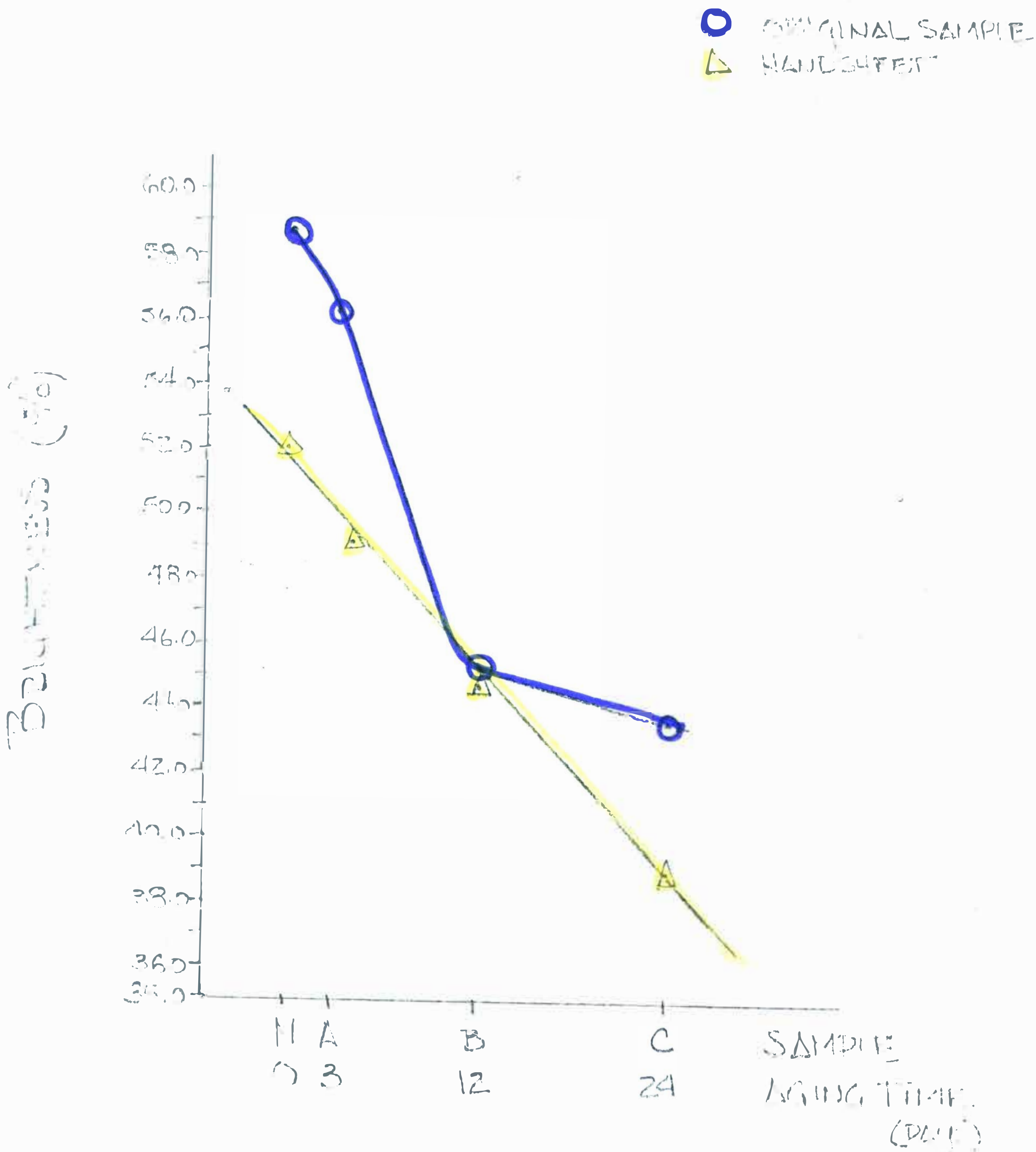
Paper conditioning took place in Winter Haven, Florida. The test samples were aged by hanging on a circular umbrella clothesline. Sheets did not overlap and were hung draped over the clothesline in the middle of the sheet. Each "day" was approximately nine hours; meteorological data is in Appendix D. Between aging sessions the samples were stored in black plastic bags in an outdoor shed.

After aging was completed all samples were tested machine direction and cross machine direction for strength and optical properties by tensile, tear, fold, mullen, opacity, and brightness. These tests were also accomplished on handsheets of each aged sample. Noble and Wood handsheets were made after slushing each sample in tap water in a Waring Blendor two minutes.

After this three point testing each sample was bleached in a two stage sequence of hydrogen peroxide/sodium hydrosulfite. Three levels of peroxide were tested: 1%, 2%, 3% based on oven dry fiber. A constant 1% hydrosulfite based on oven dry fiber was used in the second stages. One bleaching repetition was completed on the 2% peroxide sequence; no repetitions were attempted for the 1% peroxide and 3% peroxide sequences due to time constraints. Detailed bleaching procedures are included in Appendix A.

RESULTS

The results of testing the original aged newspapers, the handsheets made from the original papers, and the handsheets produced from the bleached pulp have been organized into the following graphs. In each case the paper test is shown versus aging time. Tests include brightness, opacity, fold, tensile, elongation, mullen, and tear. Tables of the graphed data are in Appendix E.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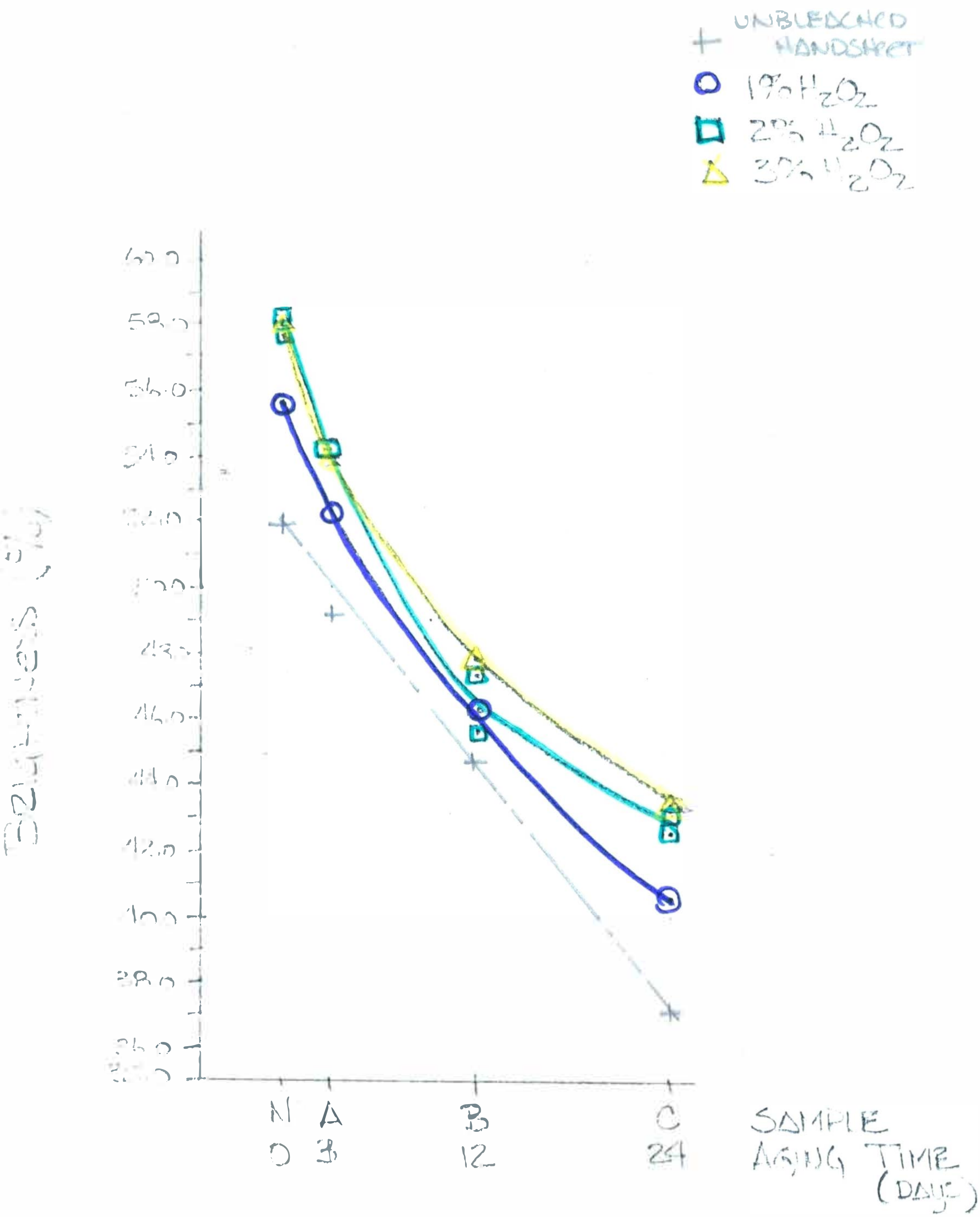
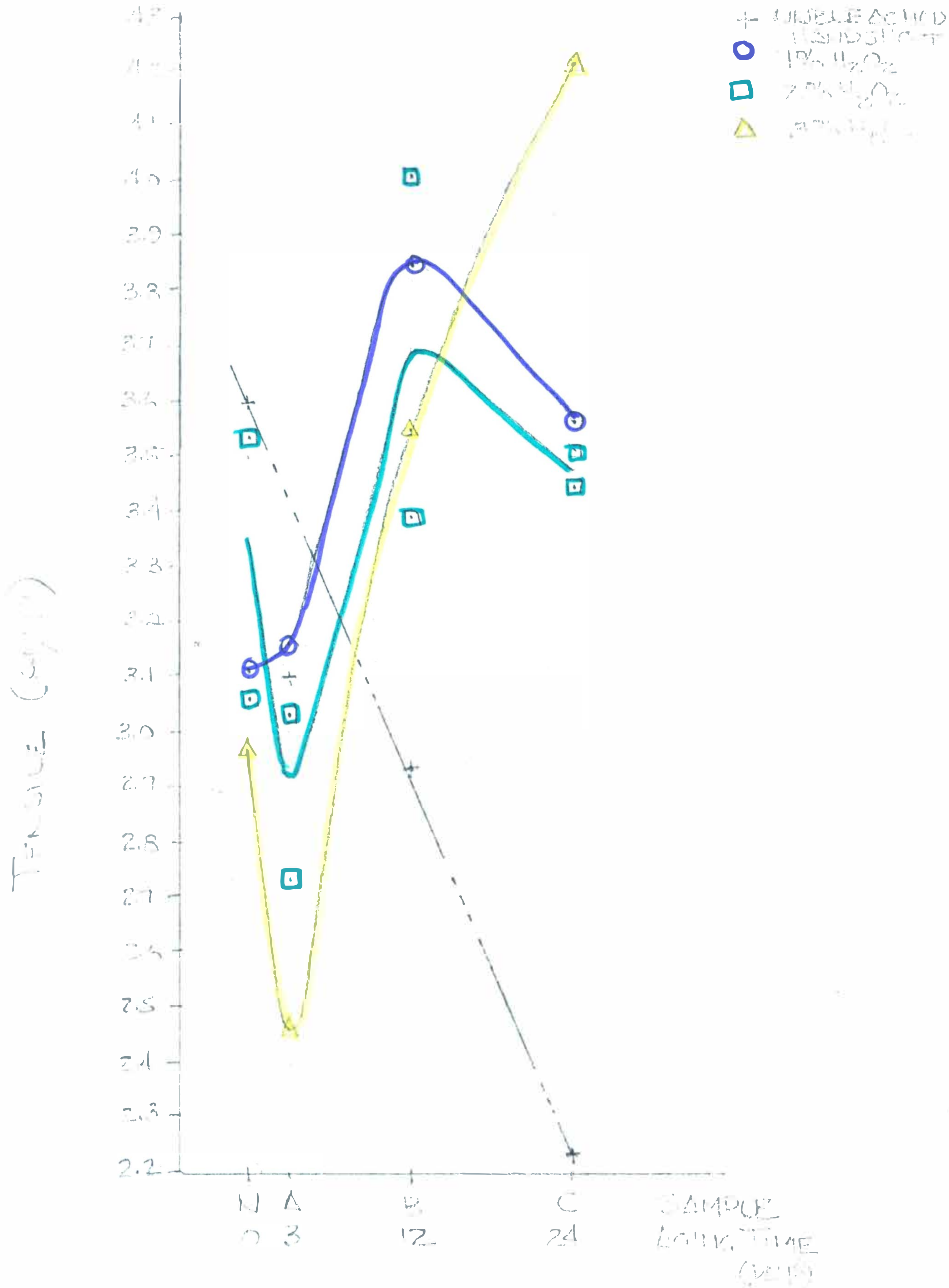
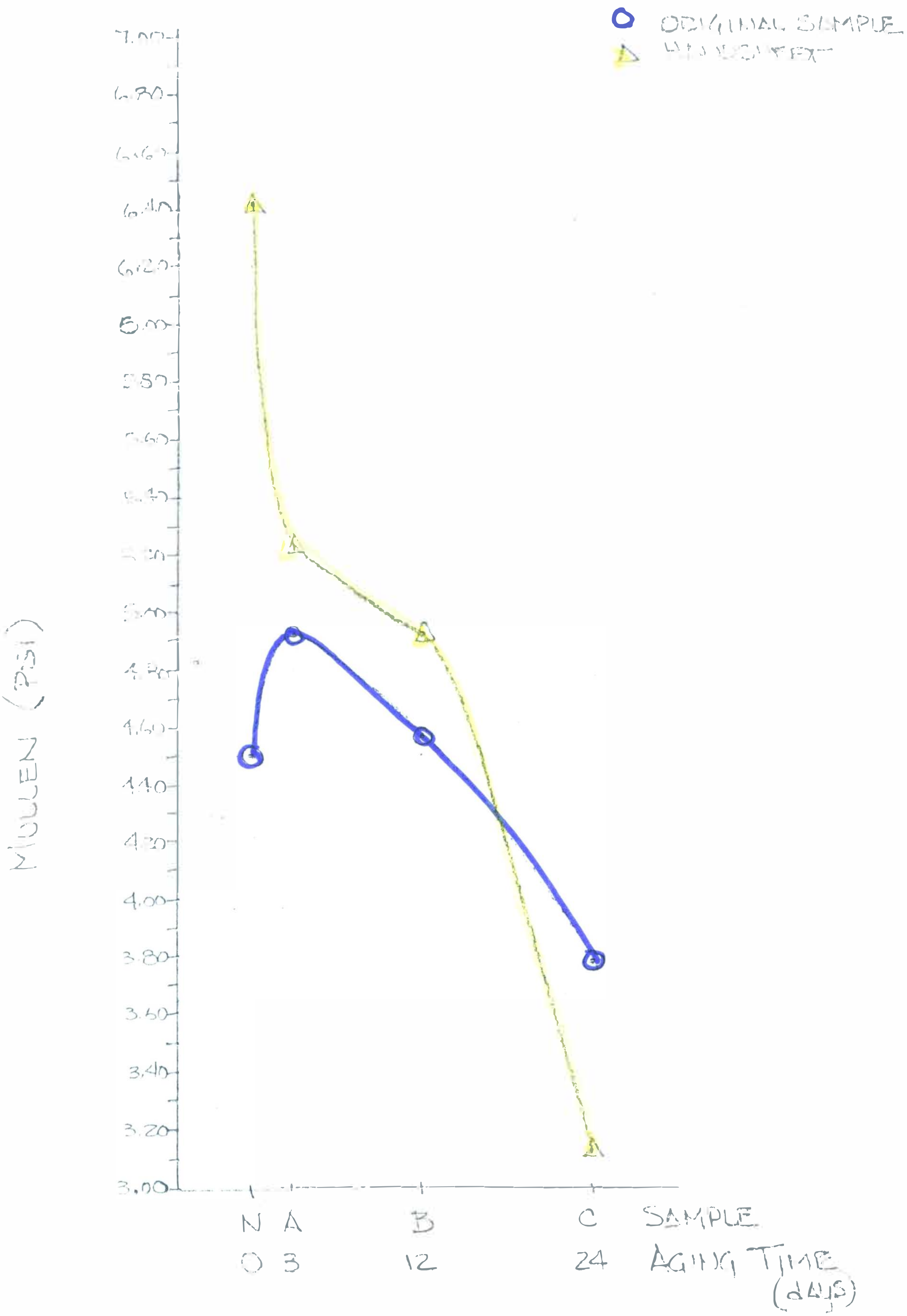
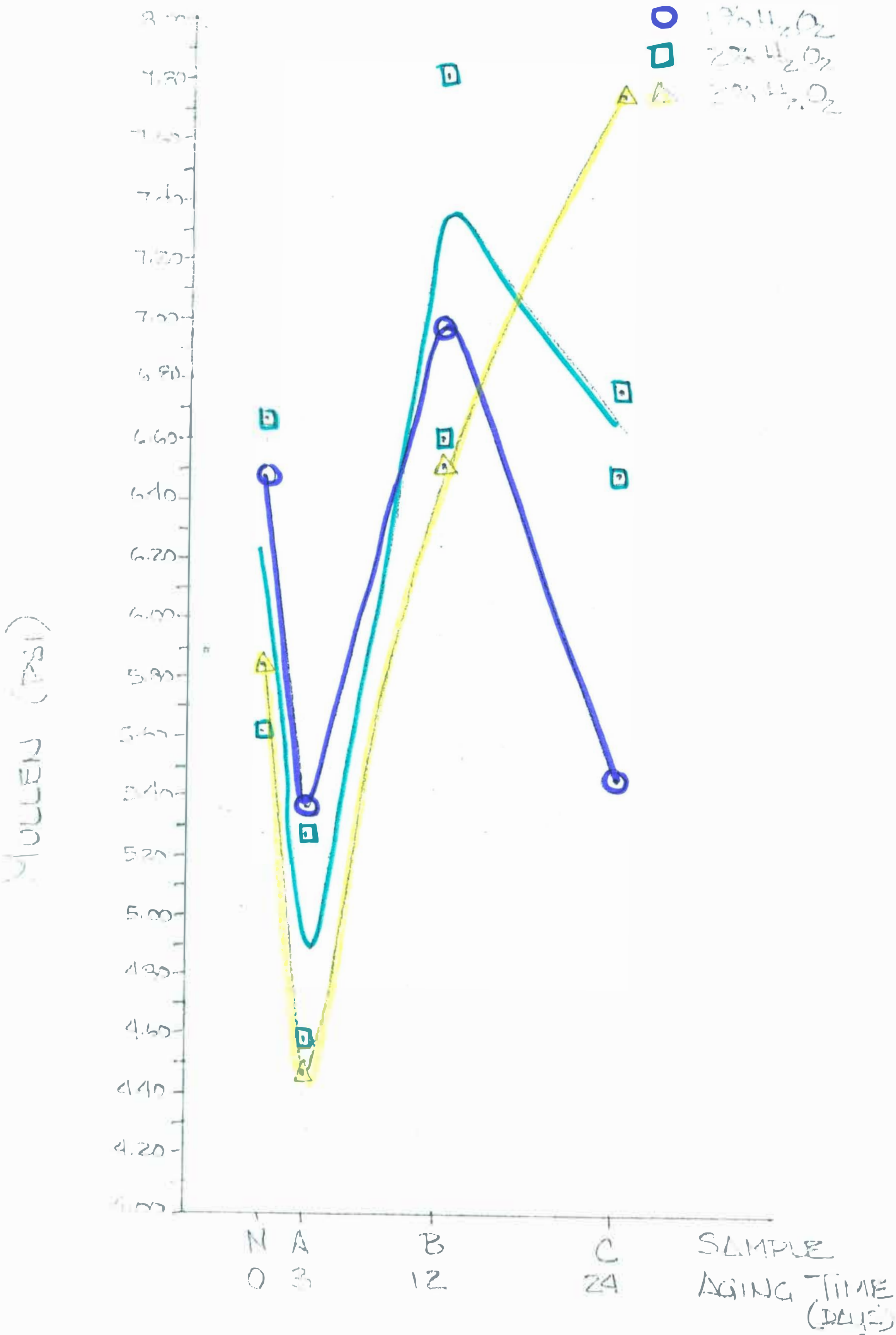
56.0
46.0
42.0
N A B C
0 3 12 24
SAMPLE

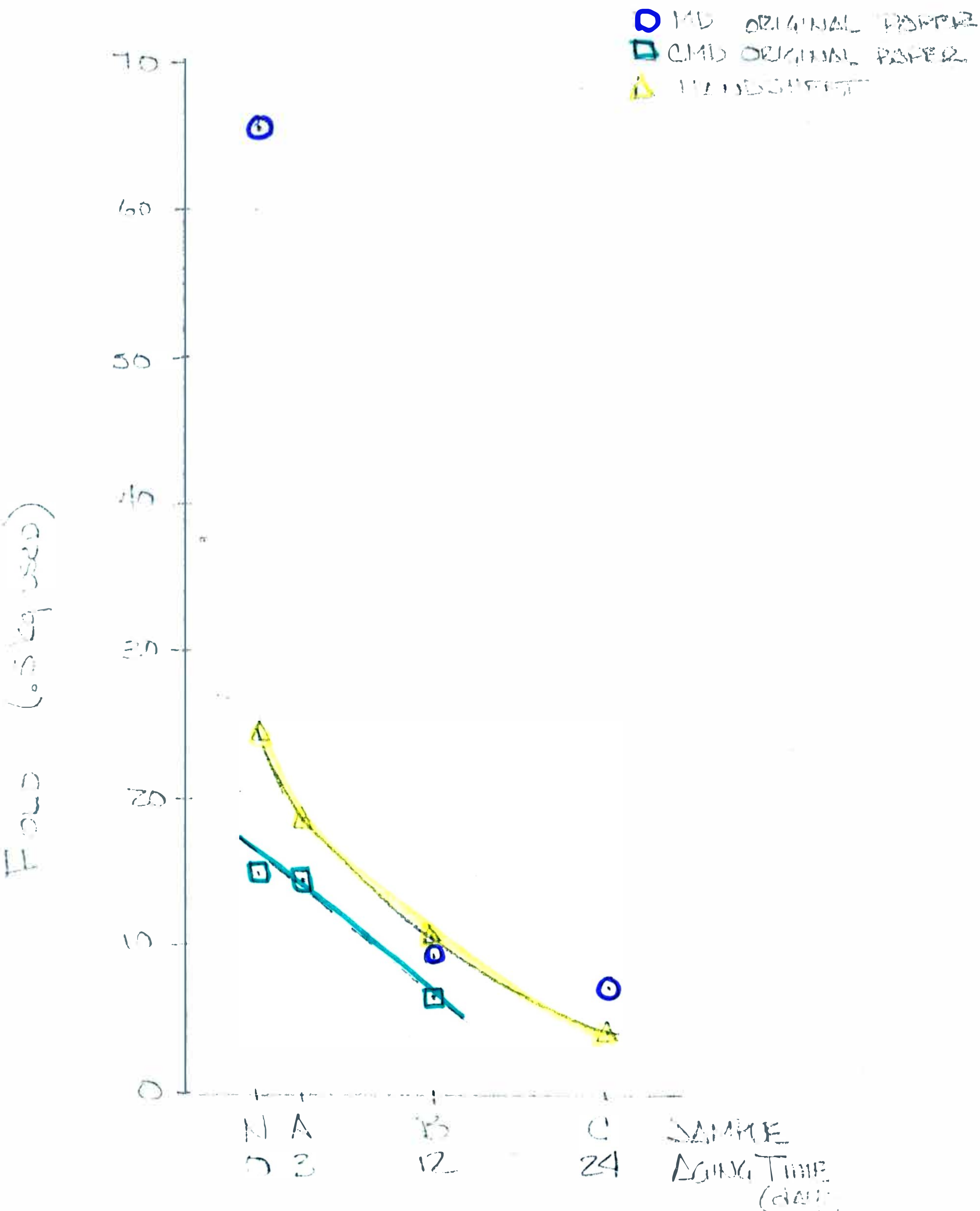


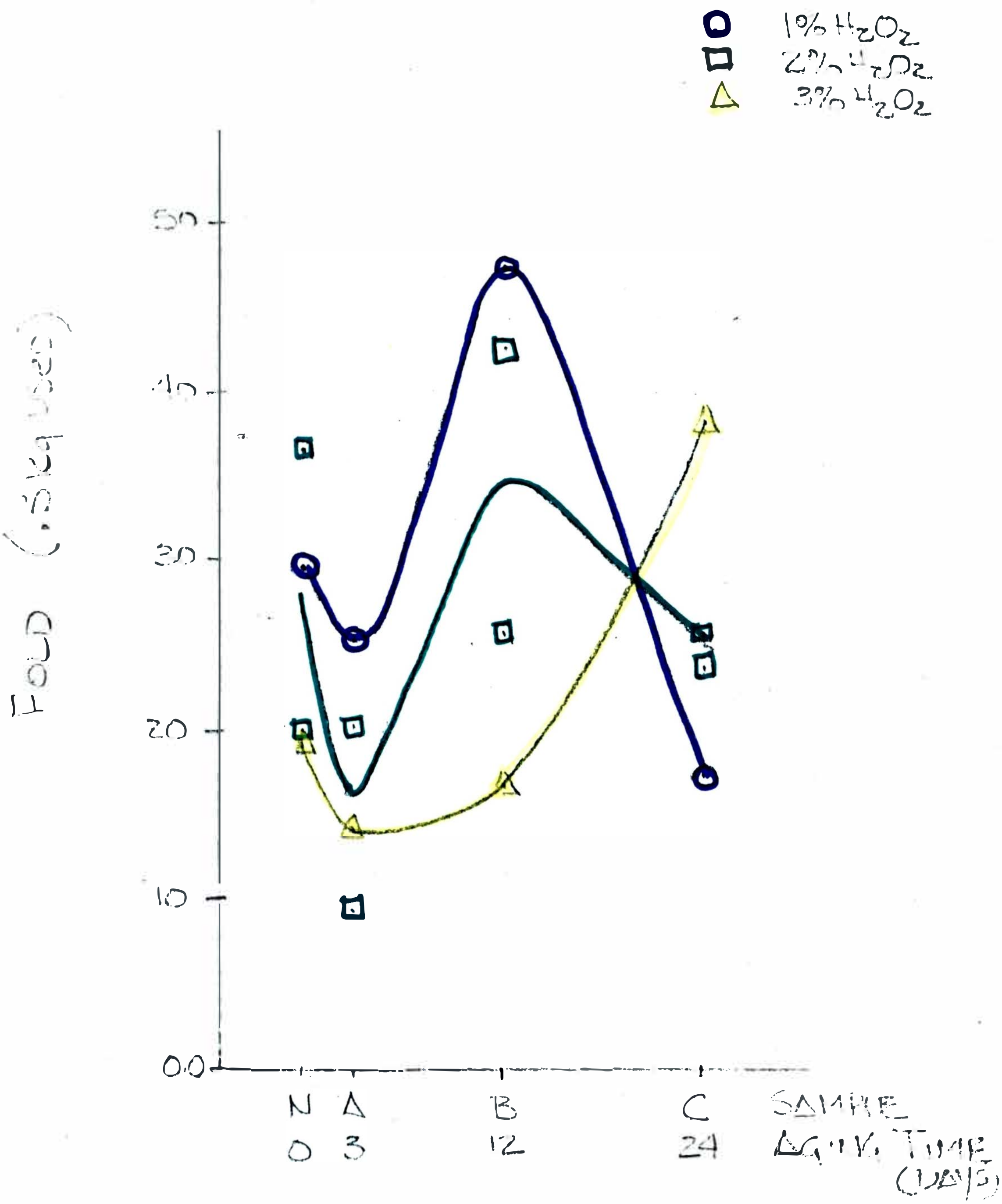
+ UNBLEACHED HANDSHEET
1% H_2O_2
2% H_2O_2
3% H_2O_2
N A B C
0 3 12 24
SAMPLE
AGING TIME
(DAYS)

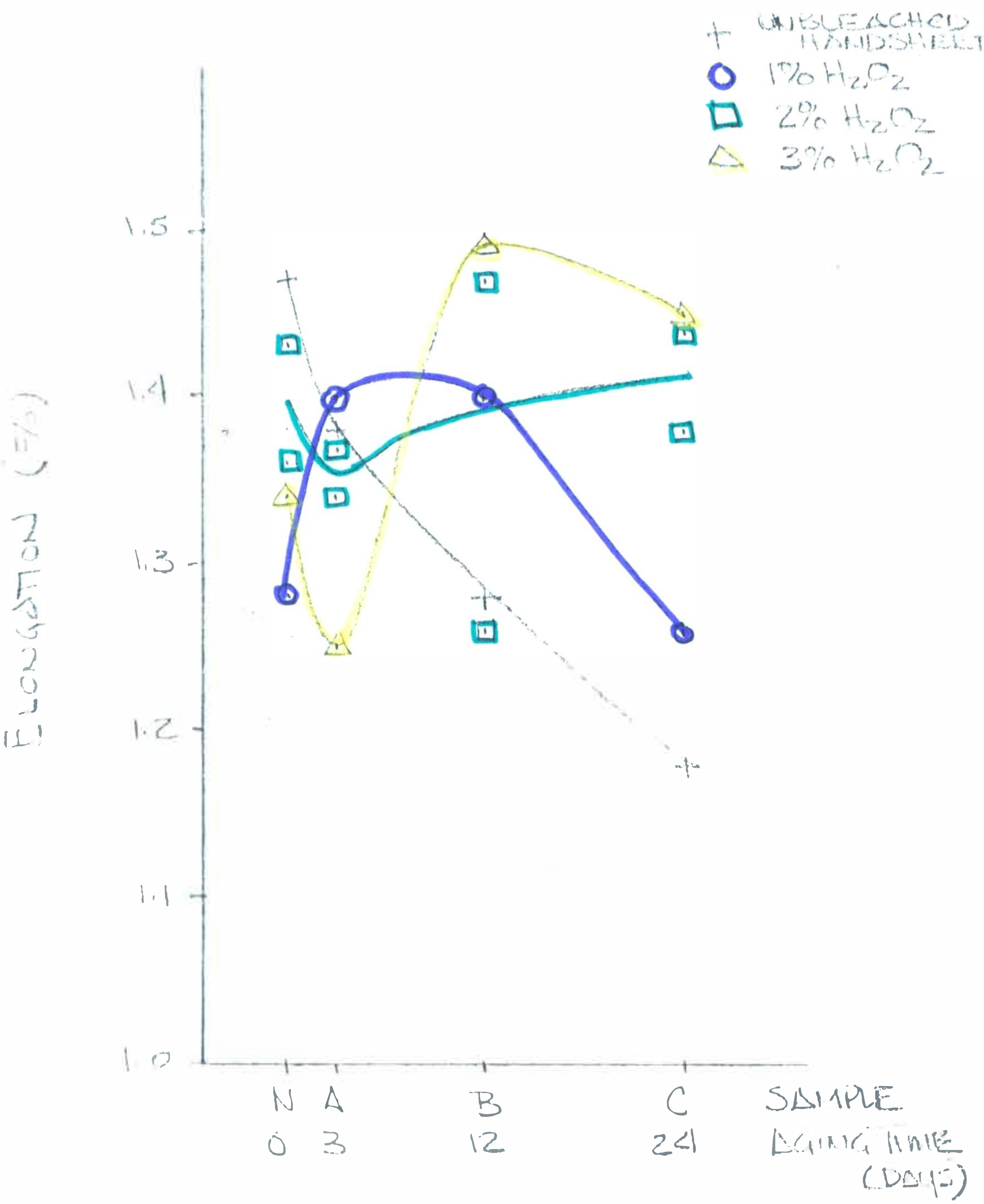

1% H_2O_2
2% H_2O_2
3.9
3.8
3.4
3.1
3.0
2.8
2.5
2.2
N
A
B
C
0
3
12
24
SAMPLE

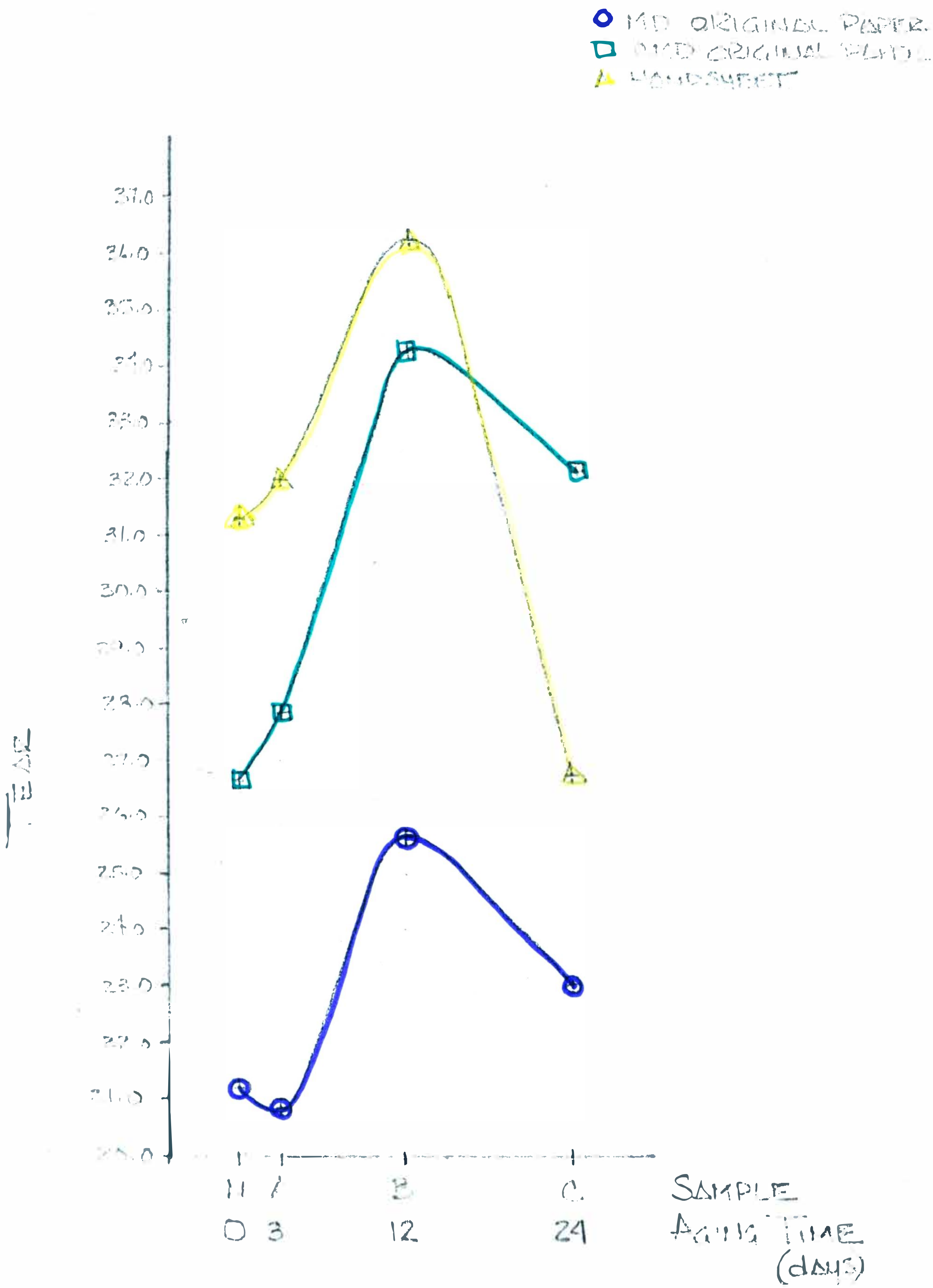

ORIGINAL SAMPLE
MULLEN (PSI)
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
N A B C SAMPLE
0 3 12 24 AGING TIME
(days)

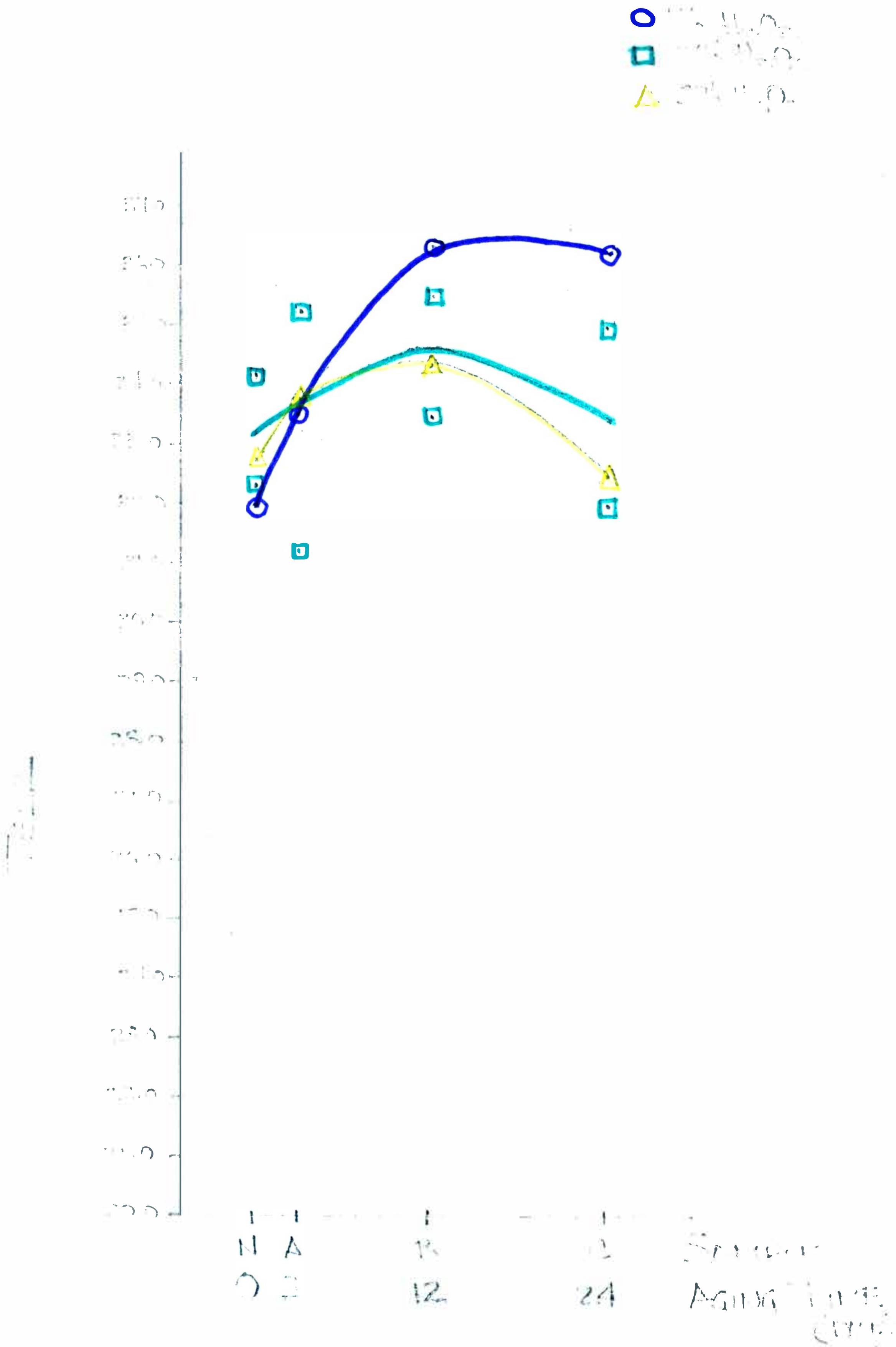

MULLEN (PSI)
7.20
7.00
6.60
6.40
6.20
6.00
5.20
5.00
4.60
4.40
4.20
N A B C
0 3 12 24
SAMPLE
AGING TIME
(DAYS)

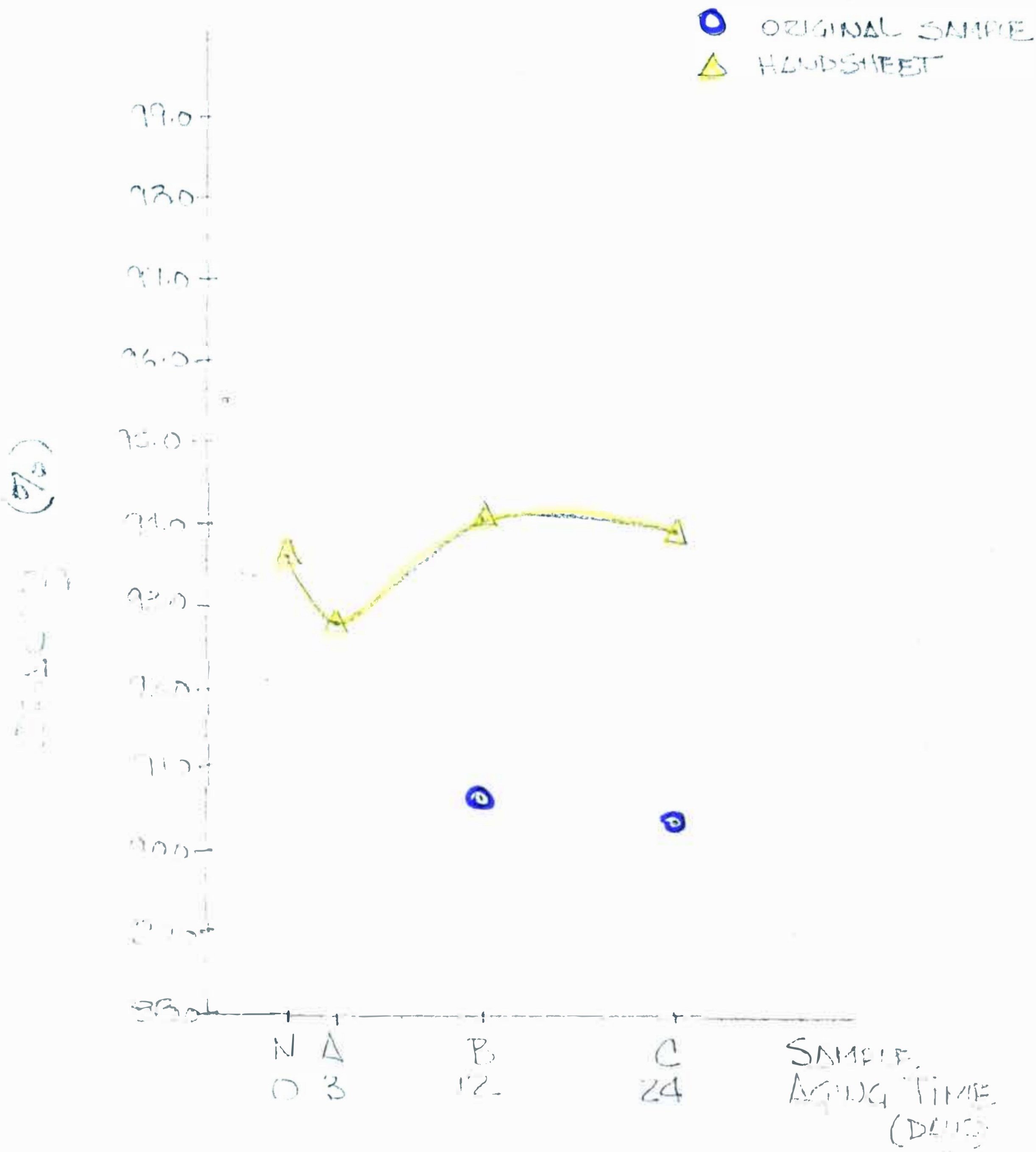

MD ORIGINAL PAPER
CMD ORIGINAL PAPER
70
60
50
40
30
20
10
0
FOLD
N
A
B
C
SAMPLE
0
3
12
24
AGING TIME

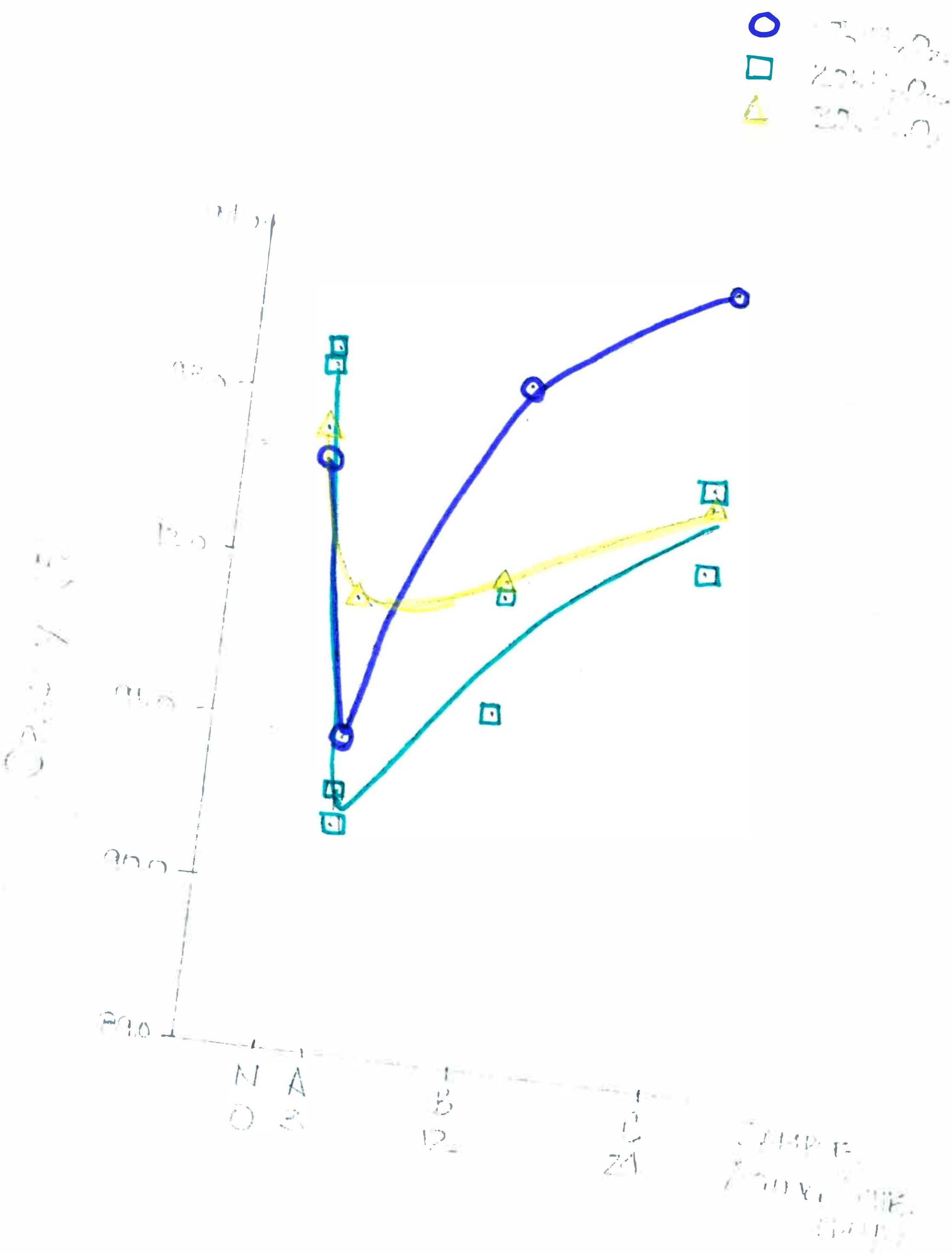

1% H_2O_2
2% H_2O_2
3% H_2O_2
FOLD (.5kg used)
50
40
30
20
10
0.0
N
A
B
C
SAMPLE
0
3
12
24
AGING TIME (DAYS)


UNBLEACHED HANDSHEET
1% H_2O_2
2% H_2O_2
3% H_2O_2
ELONGATION (%)
1.5
1.4
1.3
1.2
1.1
1.0
N A B C SAMPLE
0 3 12 24 AGING TIME (DAYS)


MD ORIGINAL PAPER
HANDSHEET
SAMPLE
AGING TIME
(days)
0
3
12
24


N A
0
12
24


ORIGINAL SAMPLE
HANDSHEET
99.0
N
0
A
3
B
12
C
24
SAMPLE
AGING TIME
(DAYS)


N A
0 3
B
12
24

DISCUSSION OF RESULTS

Brightness decreased as aging time increased for the unbleached papers, as expected, in a linear form. Brightness also decreased with aging time for the bleached papers and at the same rate as the unbleached papers; the bleached paper curves were parallel to (within experimental error) each other and the unbleached paper response. The bleached papers overall had a higher brightness than the unbleached. These graphs allow one to conclude that any one percent of whitening chemicals reversed the effects of 3-7 days of sunlight. Furthermore though 1% peroxide produced a potentially cost effective brightness response, the expense incurred at 3% peroxide returned much less than a proportional brightness increase so that 2% or 3% peroxide is probably not economical.

Tensile, mullen, fold and elongation all decreased with aging time for the unbleached samples. After bleaching a decrease in paper strength was seen from zero aging to three days followed by a large increase in strength at the 12 day aging point past the unbleached level. A subsequent slight decline in strength at the 24 day level held for the 1% and 2% peroxide addition; at 3% peroxide the paper aged 24 days kept increasing in strength past the 12 day level. Therefore, paper in the 12-24 day aging category can be strengthened spectacularly by addition of 3% peroxide. These results conflict with previous theory which held that paper strength lost to aging can never be recovered past the unbleached point by bleaching and that aged paper is stronger at higher bleach addition levels than at lower.

Tear values show an increase in unbleached paper strength from zero to 12 days aging followed by a decrease at 24 days, a remarkable response since aging has not previously been known to strengthen paper. After bleaching the tear resistance increased up to the 12 day aging level then fell. The one percent peroxide curve was overall higher than the unbleached curve showing an increase in physical strength with small additions of peroxide. The 2% and 3% curves were lower than the one percent curve but higher overall than the unbleached strength except at the 12 day aging level.

General physical testing showed a strength peak in almost all cases of the unbleached paper at the 12 day aging level. No definite explanation can be given for this occurrence although possible reasons could be an increase in fines from bleaching, aging, and the severe Waring Blendor action which could cause an increase in bonding.

Aging had no appreciable effect on unbleached opacity. The bleached papers showed a sharp decrease in opacity on three days of aging followed by an increase in opacity up to the 24 day aging level. At this point opacity attained or exceeded the zero days aging level. This slight overall increase in opacity with aging in the bleached paper may be due more to decreased brightness than light scattering.

CONCLUSIONS

Yellowing of the paper increased with sun exposure.

The peroxide/hydrosulfite bleaching sequence used did not effect a substantial increase in paper brightness although one percent peroxide did negate the effects of three to seven days of sunlight aging.

A small amount of natural sunlight radiation does appear to increase paper strength whether pulp is bleached or unbleached. The 12 day aging sample peaked most frequently for all physical testing values.

RECOMMENDATIONS

1) Bleach in a nitrogen gas atmosphere to minimize oxygen degradation of bleaching chemicals.

2) Use an alternate bleaching sequence.

3) A more fundamental study on the exact mechanisms of pulp bleaching and their relation to paper strength.

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APPENDIX A

BLEACHING PROCEDURE

1. 100 g oven dry fiber (O.D.F) was slushed with ∿2 l distilled water (150°-200° F) in a Waring blender for two minutes.

2. The slushed fiber was Buchner filtered using a plastic mesh screen. The filter pad was then weighed, plastic bagged and adjusted to 13.3% consistency with distilled water (130° F).

3. Two hundred fifty millilitres bleach liquor was added and kneaded through the pulp one minute bringing consistency to 10%.

   Bleach liquor was made by adding the following chemicals in this order to a screw top glass jar:

   240 ml distilled water (130° F)
   .5 g Epsom Salts (.5% based on O.D.F.)
   4 g 41.6 Bé sodium silicate (4% based on O.D.F.)
   hydrogen peroxide in 30% solution (1%, 2%, or 3% used based on O.D.F.)

   PH of bleach liquor was adjusted to 10.

4. Pulp was placed in a hot water bath (120° F) 1.5 hours.

5. After first stage bleaching was completed pulp was washed on a Buchner filter using ∿2 l distilled water (120° F, 4.5 pH).

6. The filter pad was then weighted and adjusted to 10% consistency with distilled water (120° F, 4.5 pH).

7. One gram sodium hydrosulfite was kneaded into the pulp for one minute.

8. Consistency of the pulp was readjusted to 4% with distilled water (120° F, 4.5 pH) and pulp was placed in constant temperature bath at 90° F for 45 minutes.

9. After stage two bleaching was completed, pulp was washed on a Buchner filter using ∿2 l tap water.

10. Ten Noble and Wood handsheets were made each weighing 1.90 g-2.10 g corresponding to the average basis weight of 49.15 g/m^2 of the original news.

APPENDIX B

CHEMICAL AND MATERIAL REQUIREMENTS

3600 g oven dry new, unprinted news

8 g Epsom Salts

107 ml hydrogen peroxide (30% solution)

64 g 41.5° Be sodium silicate

101 l distilled water

100 ml 5% NaOH solution for pH adjustment

100 mg 5% HCl solution for pH adjustment

APPENDIX C

EQUIPMENT REQUIREMENTS

4 l Waring Blender with locking cover

2 umbrella clotheslines, strung

100 spring type clothespins

20 kitchen plastic trash bags

4 black heavy duty trash bags

2 l Buchner Filter

Aspirator with rubber tubing

Tap water source with aspirator hookup

2 thermometers (-20° F-250° F)

6 l stainless steel beaker

4 l stainless steel beaker

pH meter

Eye dropper

~30 ml amber glass bottle with screw top

2 hot water baths (90° F, 120° F)

Balance, triple beam

Metler Balance (to 4 decimal places)

Metler Balance (to 500 g)

1 l graduated cylinder

250 ml graduated cylinder

10 ml graduated cylinder

Plastic wire mesh to fit Buchner Filter

2 Bunsen burners with rubber tubing

Gas hookup

Electrical outlet

2 boxes matches

Clock with second hand

Padlock and key

Elmendorf tear tester

Bausch & Lomb opacimeter

Brightness meter

Tensile tester with elongation graph

Mullen tester

M.I.T. folding resistence tester

APPENDIX D

METEOROLOGICAL CONDITIONS

SAMPLE	DAY	TEMPERATURE (°F)	HUMIDITY	WIND SPEED (MPH)	REMARKS
A	1	50°-73°	48%	4	Somewhat overcast, intermittent sunshine
	2	50°-81°	30%	4	Mostly sunny
	3	60°-82°	63%	4	Sunshine
B	1	60°-79°	58%	15	1/2 day sunshine 1/2 day overcast
	2	60°-80°	49%	15-18	Variable cloudiness
	3	42°-90°	44%	10-15	Sunny
	4	50°-64°	43%	13	Sunny
	5	38°-62°	44%	15	Sunny
	6	42°-72°	46%	5	Partly cloudy
	7	45°-72°	43%	10	Wind gusting to 25 mph
	8	50°-72°	47%	15-20	Wind gusting to 25 mph
	9	63°-83°	76%	7	Mostly cloudy
	10	70°-73°	66%	7	Rained 35 minutes; covered tops of clothes lines with plastic; left papers on lines overnight to dry

SAMPLE	DAY	TEMPERATURE (°F)	HUMIDITY	WIND SPEED (MPH)	REMARKS
B	11	60°-70°	61%	7-10	Mostly cloudy
	12	57°-70°	75%	9	Mostly cloudy
C	1	60°-79°	58%	15	Sunshine until noon; afternoon variable cloudiness
	2	60°-80°	49%	15-18	Sunny until noon afternoon variable cloudiness
	3	42°-70°	44%	10-15	Sunny
	4	50°-64°	43%	13	Sunny
	5	38°-62°	44%	15	Sunny
	6	41°-72°	46%	5	Partly cloudy
	7	44°-72°	43%	10	Wind gusting to 25 mph
	8	50°-73°	47%	15-20	Wind gusting to 25 mph
	9	66°-83°	56%	10-15	Wind gusting to 25 mph Cloudy until noon; sunny afternoon
	10	60°-76°	52%	23	Wind gusting to 26 mph variable cloudiness
	11	63°-83°	76%	7	Cloudy

SAMPLE	DAY	TEMPERATURE (°F)	HUMIDITY	WIND SPEED (MPH)	REMARKS
	12	68°-73°	66%	7	Variable cloudiness; rained 35 minutes; covered tops of clothes lines with plastic; left papers on lines overnight to dry
	13	63°-70°	61%	7-10	Overcast
	14	57°-77°	75%	9	Mostly cloudy
	15	54°-76°	71%	18	Variable cloudiness; left papers on clothes line overnight covered with plastic; to damp to remove
	16	62°-83°	76%	5	Partial cloudiness
	17	58°-71°	87%	7	Cloudy
	18	58°-83°	55%	10	Partial cloudiness before noon; sunny afternoon
	19	52°-70°	56%	10	Partial cloudiness before noon; sunny afternoon
	20	48°-77°	42%	16	Partial cloudiness
	21	68°-83°	76%	8	Heavy fog until mid-morning then sunny

SAMPLE	DAY	TEMPERATURE (°F)	HUMIDITY	WIND SPEED (MPH)	REMARKS
	22	57°-83°	90%	7	Heavy fog until mid-morning then sunny
	23	56°-78°	84%	3	Heavy fog until mid-morning then sunny
	24	78°	30%	7	Sunny

APPENDIX E

BRIGHTNESS VALUES

(percent)

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	52.0	58.8	53.6	58.2, 57.7	58.2
S	0.49	0.33	0.51	0.45, 0.49	0.71

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	49.1	56.2	52.4	54.2 54.2	54.1
S	0.34	1.09	0.65	0.64, 0.36	0.47

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	44.7	45.4	46.4	45.6, 47.4	47.7
S	0.31	2.69	0.38	1.35, 0.66	0.54

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	39.0	43.0	40.5	43.1, 42.5	43.4
S	0.69	5.67	0.44	0.33, 0.68	0.50

TENSILE VALUES

(kg/1 inch)

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	3.60	3.11	3.53, 3.06	2.97
S	0.48	0.45	0.28, 0.45	0.31

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	3.10	3.16	3.03, 2.73	2.46
S	0.39	0.32	0.21, 0.34	0.33

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	2.93	3.85	4.01, 3.39	3.55
S	0.44	0.41	0.57, 0.41	0.31

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	2.23	3.57	3.52, 3.45	4.22
S	0.39	0.93	0.20, 0.40	0.44

MULLEN VALUES

(psi)

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	6.41	4.50	6.48	6.67, 5.63	5.85
S	0.79	0.68	1.23	0.96, 1.27	0.61

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	5.24	4.92	5.36	5.28, 4.59	4.47
S	0.79	0.60	1.26	1.17, 0.73	1.49

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	4.92	4.56	6.98	7.83, 6.61	6.52
S	0.77	0.64	0.93	0.97, 0.94	0.87

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	3.12	3.77	5.47	6.50, 6.77	7.76
S	0.93	1.06	0.92	0.95, 0.54	0.89

FOLD VALUES

(0.5 kg Used)

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	24.5	65.5	15.75	29.5	36.5, 20.2	19.4
S	10.97	38.00	9.43	13.20	20.20, 8.88	8.15

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	18.7	N.A.	14.3	25.2	20.2, 9.4	14.1
S	11.8	N.A.	7.66	8.11	7.83, 2.80	5.74

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	10.8	9.4	6.9	47.3	42.5, 25.9	16.9
S	2.15	4.50	1.85	18.50	10.20, 9.60	7.00

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	4.40	7.1	N.A.	17.1	25.9, 23.9	38.2
S	1.65	3.18	N.A.	6.72	6.95, 5.90	11.10

ELONGATION VALUES

(percent)

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	1.47	1.28	1.43, 1.36	1.34
S	0.20	0.22	0.24, 0.15	0.21

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	1.38	1.40	1.34, 1.37	1.25
S	0.13	0.12	0.07, 0.06	0.17

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	1.28	1.40	1.47, 1.26	1.49
S	0.20	0.28	0.15, 0.21	0.09

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	1.18	1.26	1.44, 1.38	1.45
S	0.21	0.13	0.16, 0.23	0.20

TEAR VALUES

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	31.3	21.2	26.6	32.0	34.2, 32.3	32.8
S	2.20	0.63	0.47	4.20	2.25, 1.53	1.06

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	32.0	20.8	27.8	33.5	35.2, 31.2	33.8
S	1.41	0.86	0.28	2.12	3.89, 0.35	0.35

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	36.2	25.7	34.2	36.3	33.5, 35.5	34.3
S	4.60	2.75	3.77	1.04	1.41, 2.12	2.75

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	MD ORIGINAL PAPER	CMD ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	26.75	23.0	32.2	36.2	32.0, 35.0	32.5
S	3.18	2.68	2.49	3.18	3.54, 2.83	0.71

OPACITY VALUES

(percent)

SAMPLE N NO AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	93.6	N.A.	92.6	93.2, 93.3	92.8
S	0.46	N.A.	1.37	1.15, 1.04	0.78

SAMPLE A 3 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	92.8	N.A.	90.9	90.6, 90.4	91.8
S	0.55	N.A.	1.19	0.78, 0.95	1.23

SAMPLE B 12 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	94.1	90.7	93.2	91.9, 91.2	92.0
S	0.88	0.76	0.68	0.73, 1.19	0.46

SAMPLE C 24 DAYS AGING	UNBLEACHED HANDSHEET	ORIGINAL PAPER	1% H_2O_2	2% H_2O_2	3% H_2O_2
$\bar{x}$	94.0	90.4	93.9	92.2, 92.7	92.6
S	0.35	1.06	0.84	0.54, 0.57	0.76