Optimizing Pulping and Oxygen Bleaching to Improve Yield

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Introduction

Oxygen delignification has become one of the important technologies to decrease the kappa number of the to the bleach plant

- *Potential for improving yield by optimizing*
  - *Pulping*
  - *Oxygen bleaching*

Objective

- *Influence Of Kraft Pulping Conditions on*
  - *Pulping*
  - *Oxygen delignification*

- *Effect on Oxygen Delignification*
  - *Effect of Temperature, NaOH*
  - *To be analyzed by response variables*
    - *Kappa*
    - *Yield*
    - *Viscosity*

Joint Project

- *NC State University*
  - *Analyze The Influence of Process Parameters on Selectivity*
- *IPST*
  - *Chemistry of Extended Oxygen Delignified pulps, impact on physical properties of pulp.*

Single Stage Oxygen Delignification

- *Softwood 30 Kappa pulps prepared*
- *Varying pulping conditions*
  - *Low AA 17%AA*
  - *Medium AA 19%AA*
  - *High AA 21%AA*
- *Temperature kept constant at 170°C*
- *Single stage oxygen delignification studied using experimental design*

Single Stage Oxygen Experimental Plan

- % NaOH
  - 1 - 5%
- Temperature
  - 70-110^{o}C
- Carryover: 10%
- O_2 pressure: 40 psig
- Medium Consistency -10 %
- Conditions evaluated using statistically designed experimental plan - 11 experiments

Pulping Conditions 30 Kappa

	%AA	H-Factor	Kappa	Yield %	Viscosity cp
Low	**17**	**2200**	**30.0**	**46.0**	**33.9**
Medium	**19**	**1800**	**30.2**	**44.4**	**22.2**
High	**21**	**1250**	**30.1**	**43.0**	**20**

Oxygen Delignification

30 Kappa Pulps 17%AA

Low AA Pulping, 30 K					
NaOH%	Temp	Kappa	Yield	Viscosity	Total Yield
3	70-75	19.9	97.8	23.6	45.0
1.6	76.5-78	20.0	97.0	26.2	44.6
4.4	76.5-78	17.4	95.0	22.6	43.7
1	90-92	20.0	96.0	21.8	44.2
3	90-92	15.6	94.7	18.0	43.6
5	90-92	13.9	93.5	15.1	43.0
1.6	104-105	15.6	94.0	15.9	43.2
4.4	104-105	12.0	94.2	13.3	43.3
3	108-112	12.3	95.0	15.2	43.7
3	88-92	15.5	96.2	20.4	44.3
3	90-92	15.7	95.5	18.6	43.9

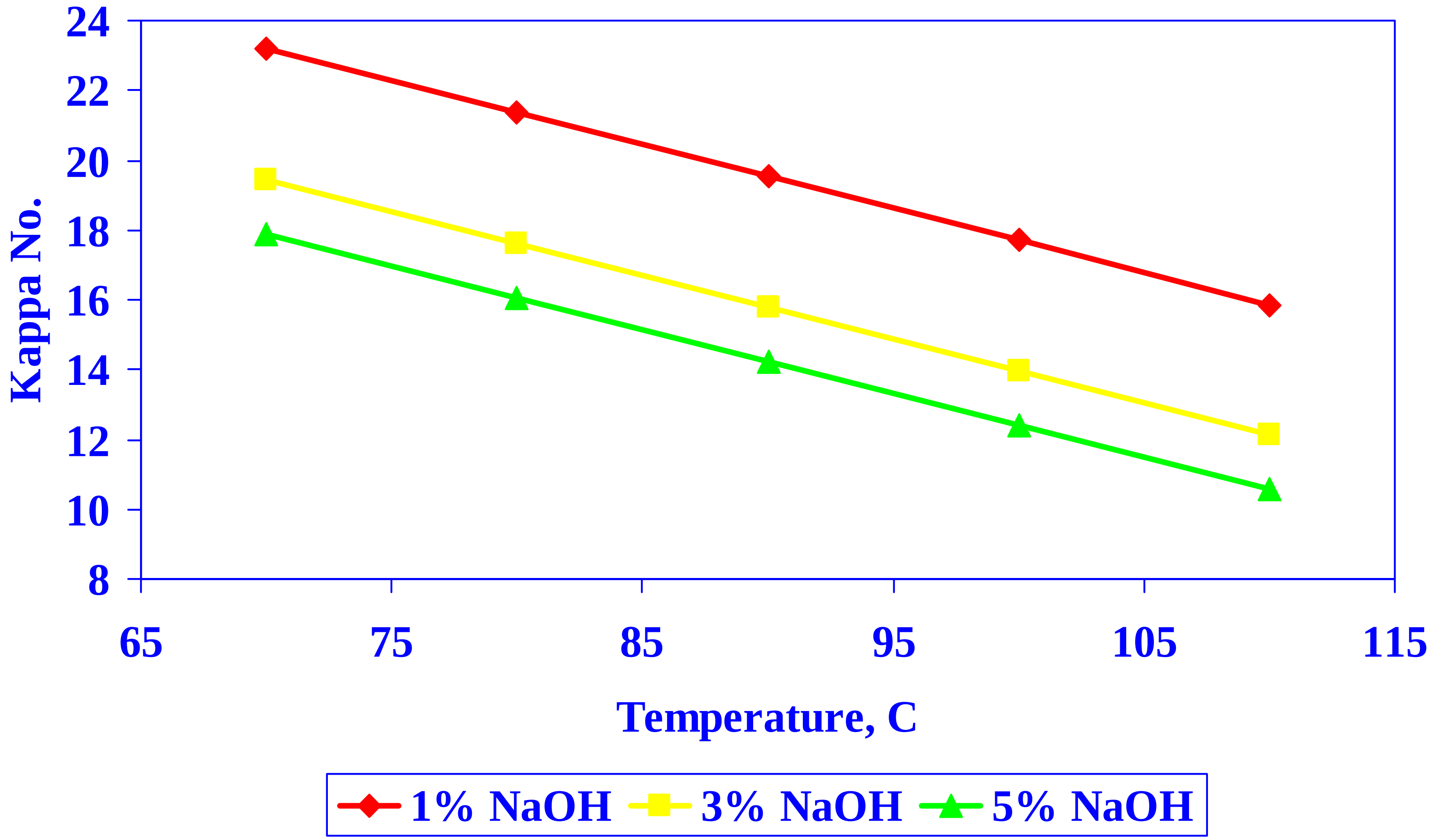
Models for Low AA

30 Kappa Pulps 17%AA

- *LOW AA PULP:*
  - *KAPPA= 15.77 –2.636*((NaOH –3)/2)– 3.652*((Temp-90)/20) + 1.1115*((NaOH-3)/2)^2*
  - *YIELD= 44.06 –0.4444 *((NaOH –3)/2)– 0.646 *((Temp-90)/20) –0.5525*((NaOH-3)/2)^2*
  - *VISCOSITY= 19.154 –2.788 *((NaOH –3)/2)– 5.686 *((Temp-90)/20)*

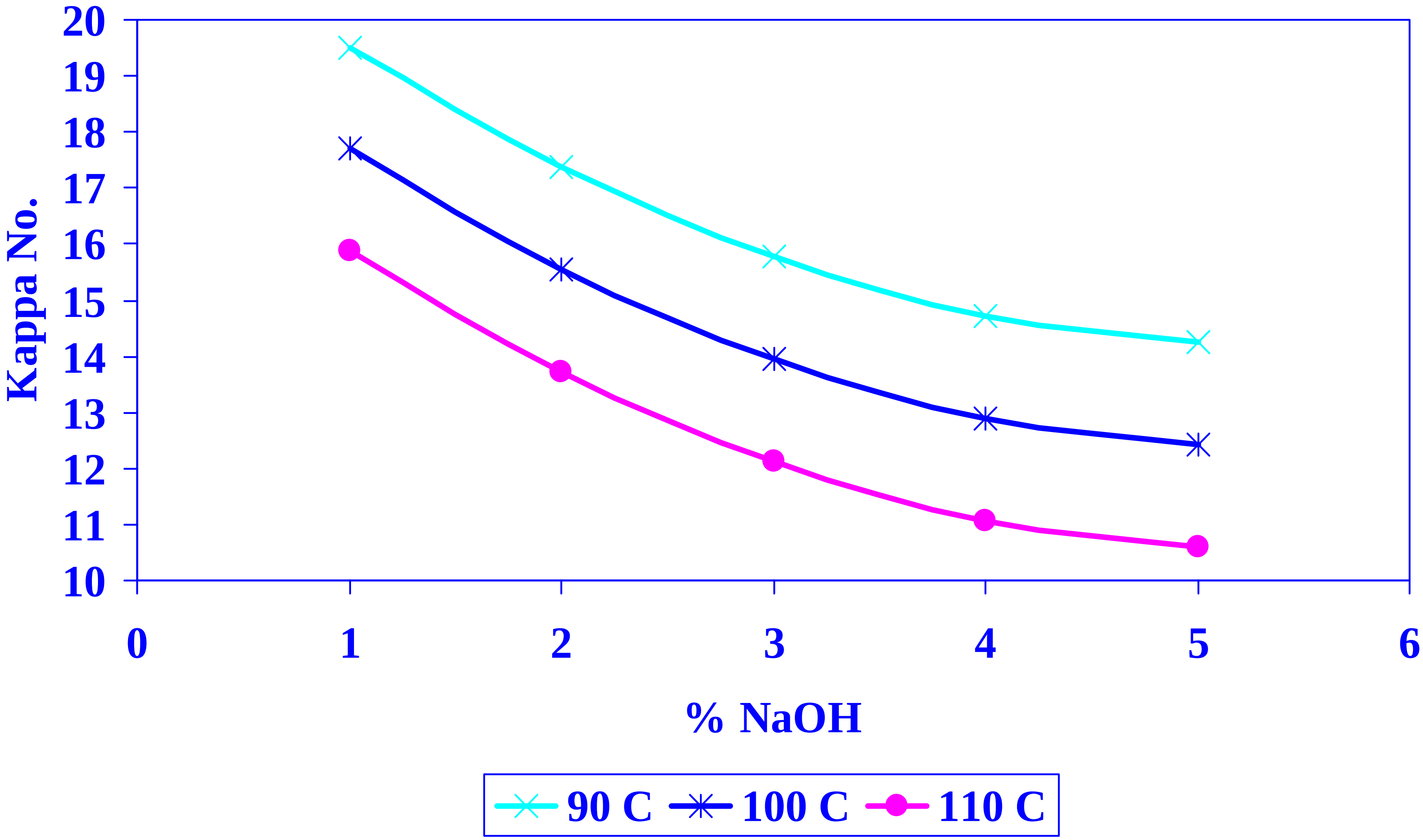
Effect of Temperature

30 Kappa Pulps 17%AA



Effect of %NaOH

30 Kappa Pulps 17%AA



Oxygen Delignification

30 Kappa Pulps 19%AA

% NaOH	Temp	Yield	Kappa	Viscosity	Total Yield
3	70.5	98.3	22.3	20.3	45.7
1.6	77.5	99.4	21.0	18.6	46.2
4.4	77.5	98.5	17.3	17.0	45.8
1	93.2	99.2	20.2	19.2	46.1
3	93.2	98.2	15.4	16.9	45.7
5	93.2	98.5	15.9	16.0	45.8
1.6	103.4	98.2	17.7	17.3	45.7
4.4	103.5	95.0	12.4	12.7	44.2
3	109.5	96.0	12.2	13.4	44.6
3	90.5	98.5	16.5	17.2	45.8
3	91	98.7	16.8	17.2	45.9

Models for Medium AA

30 Kappa Pulps 19%AA

- MEDIUM AA PULP:
  - KAPPA= 15.484 –2.577*((NaOH –3)/2)– 4.0 *((Temp –90)/20) + 1.3317*((NaOH-3)/2)^2
  - YIELD= 43.25 –0.41162 *((NaOH –3)/2)– 0.65 *((Temp-90)/20) –0.561 *((NaOH –3)/2)*((Temp-90)/20) – 0.723*((TEMP-90)/20)^2
  - VISCOSITY= 16.89 –1.904 *((NaOH –3)/2)– 2.732 *((Temp-90)/20)

Oxygen Delignification

30 Kappa Pulps 21%AA

High AA Pulping, 30 K					
NaOH%	Temp	Kappa	Yield	Viscosity	Total yield
3	70-73	19.0	98.8	18.2	42.5
1.6	76-77	20.0	99.0	19.3	42.6
4.4	76-77	16.7	98.0	16.4	42.1
1	90-91	18.4	99.0	18.9	42.6
3	90-91	16.8	98.5	17.5	42.4
5	89-92	13.4	97.9	12.3	42.1
1.6	102-104	15.3	98.0	15.4	42.1
4.4	102-104	11.0	97.5	8.9	41.9
3	107-109	11.3	97.2	9.7	41.8
3	92-94	15.0	98.0	13.8	42.1
3	90-91	16.6	98.7	17.3	42.4

Models for High AA

30 Kappa Pulps 21%AA

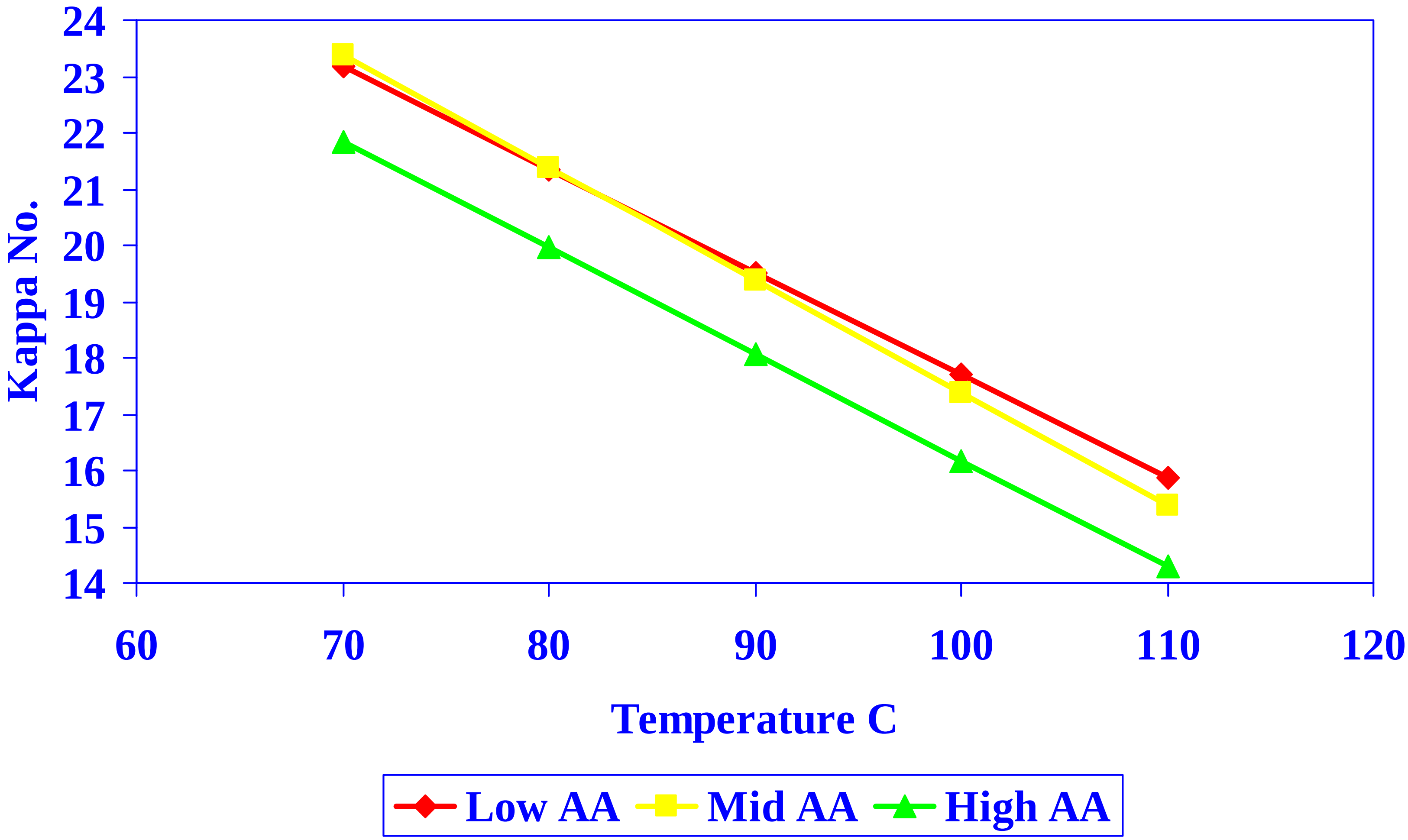
- *HIGH AA PULP:*
  - *KAPPA= 15.323 –2.606*((NaOH –3)/2)– 3.78*((Temp-90)/20) + 0.137*((NaOH-3)/2)^2*
  - *YIELD= 41.3059 –2.0 *((NaOH –3)/2)– 0.3005 *((Temp-90)/20) –0.1909*((Temp-90)/20)^2*
  - *VISCOSITY= 15.245 –3.328 *((NaOH –3)/2)– 4.162*((Temp-90)/20)*

Influence Of Pulping Conditions

- *Kappa Reduction*
- *Yield Selectivity*
- *Viscosity Selectivity*

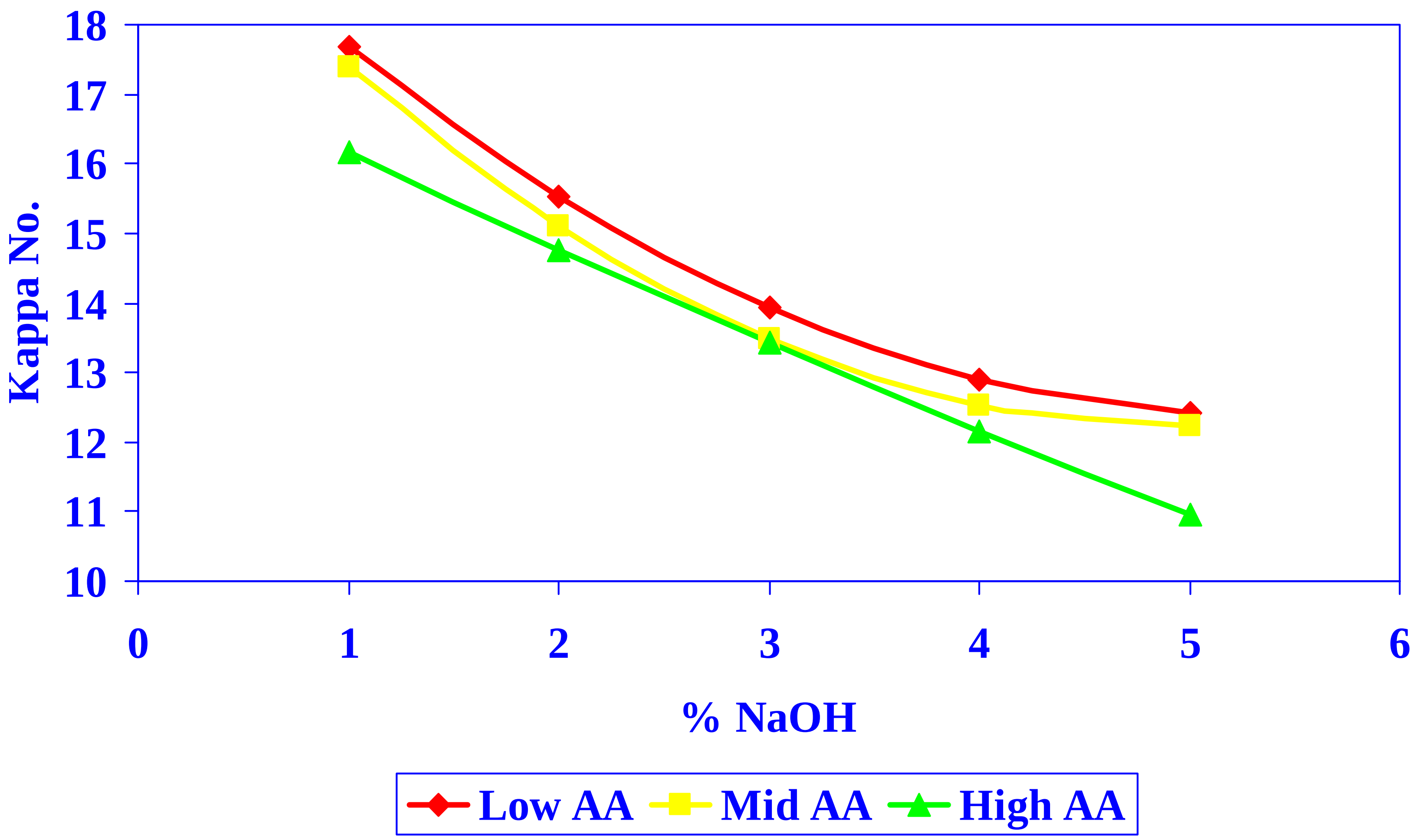
Kappa vs Temp (1% NaOH)

30 Kappa 100 C

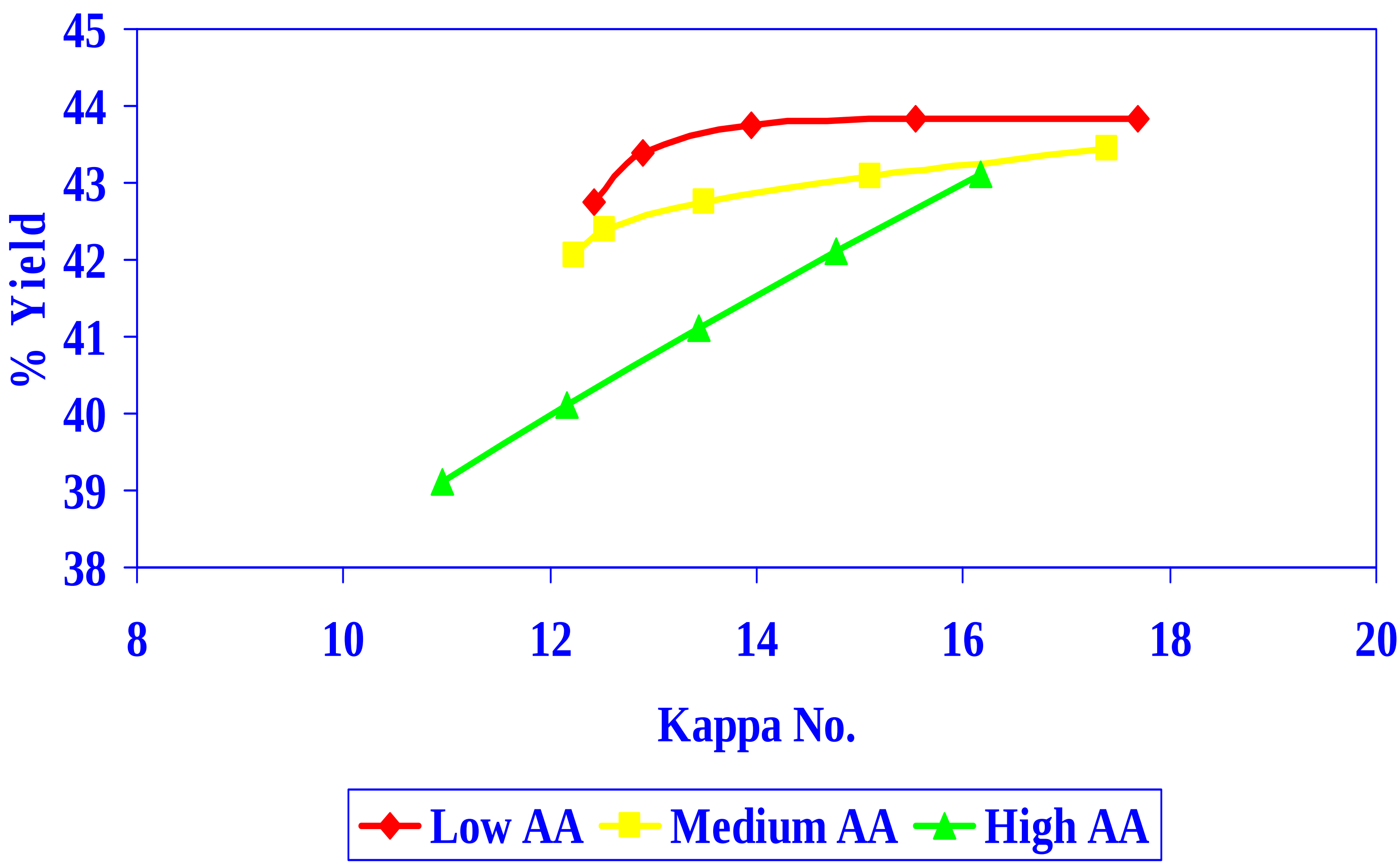


Delignification in Oxygen Stage

30 Kappa 100 C

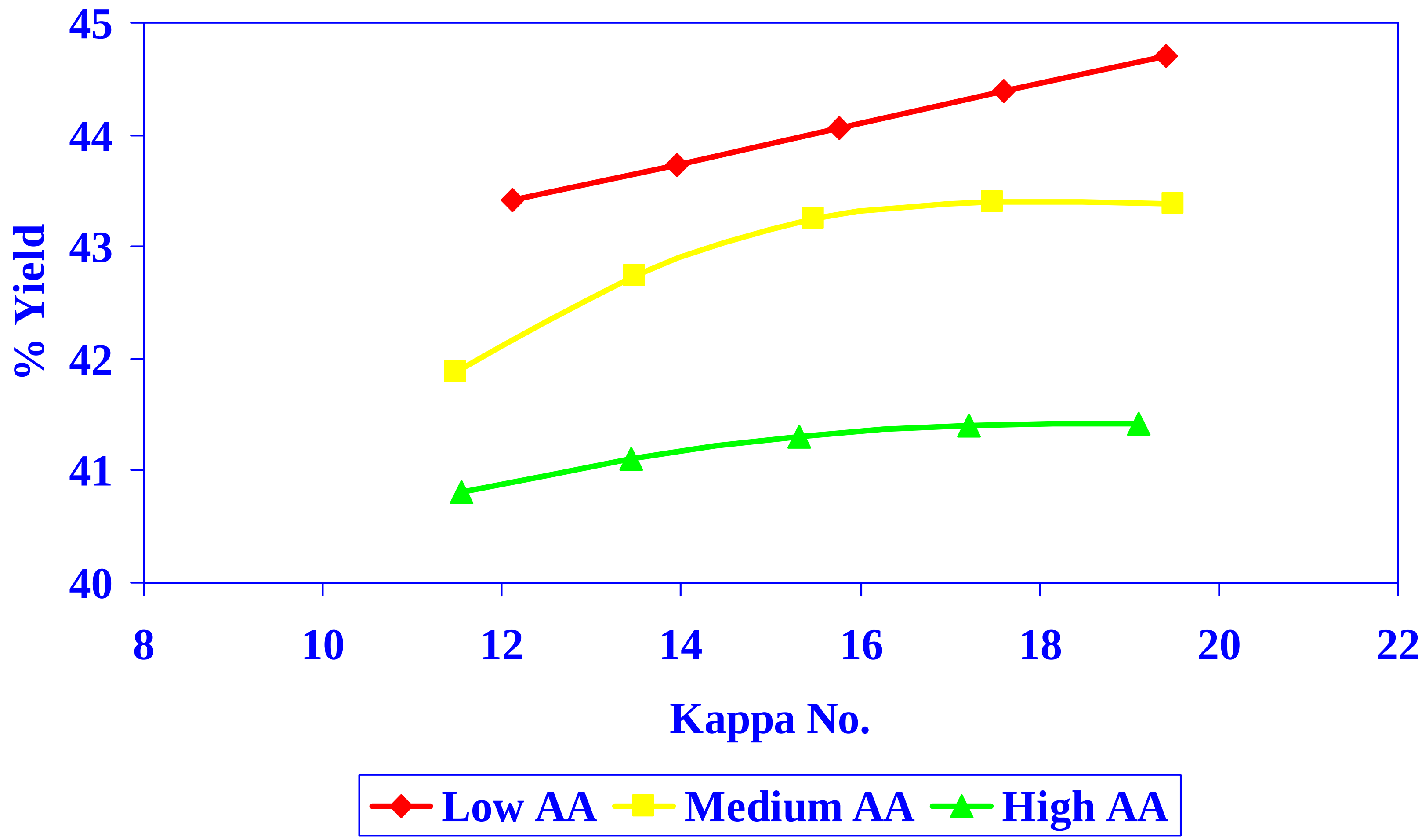


Yield vs Kappa Number
30 Kappa 100 C

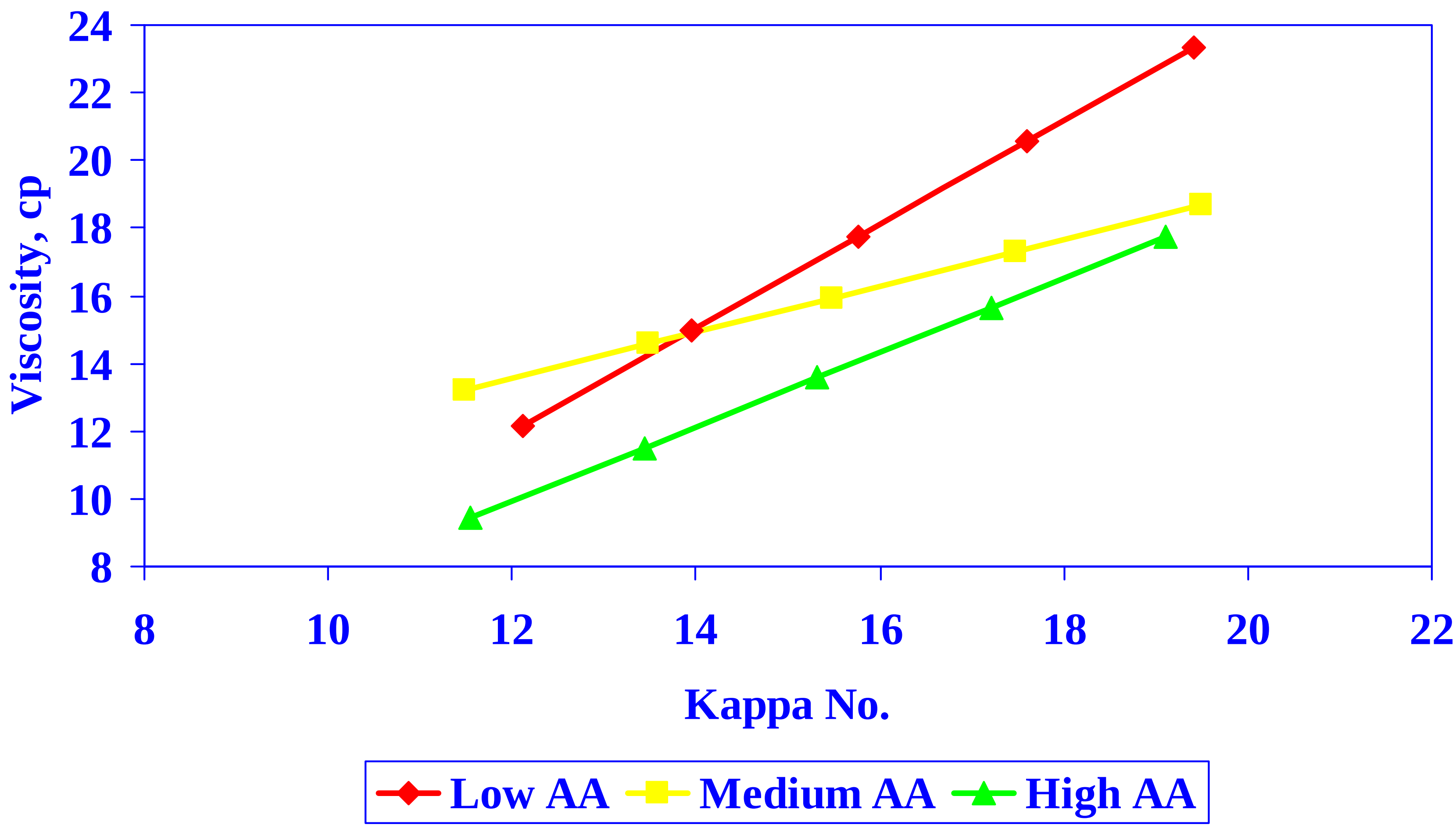


Yield vs Kappa

30 Kappa 3% NaOH



Viscosity vs Kappa No.
30 Kappa 3% NaOH



Hardwood Pulping Data

AA%	H Factor	Kappa No	Yield. %
14	1000	19.1	53.2
16	650	19.4	47.3
18	500	19.9	47.2

Hardwood Oxygen Models

LOW AA (14%)

KAPPA =14.8-1.53*NAOH-2.84*TEMP+0.4*NAOH2

VISCOSITY =40.3-4.68*NAOH-4.69*TEMP

YIELD= 43.8 -0.35354*NAOH - 0.51515*TEMP

MEDIUM AA (16%)

KAPPA=14.41-1.38*NAOH-2.54*TEMP+.97*NAOH2

YIELD = 40.54-.01*NAOH-.06*TEMP+.124*TEMP2+.27*NAOH2

VISCOSITY= 1.39129+0.62753*NAOH+2.32143*NAOH*TEMP-2.77632*TEMP2

Hardwood Oxygen Models

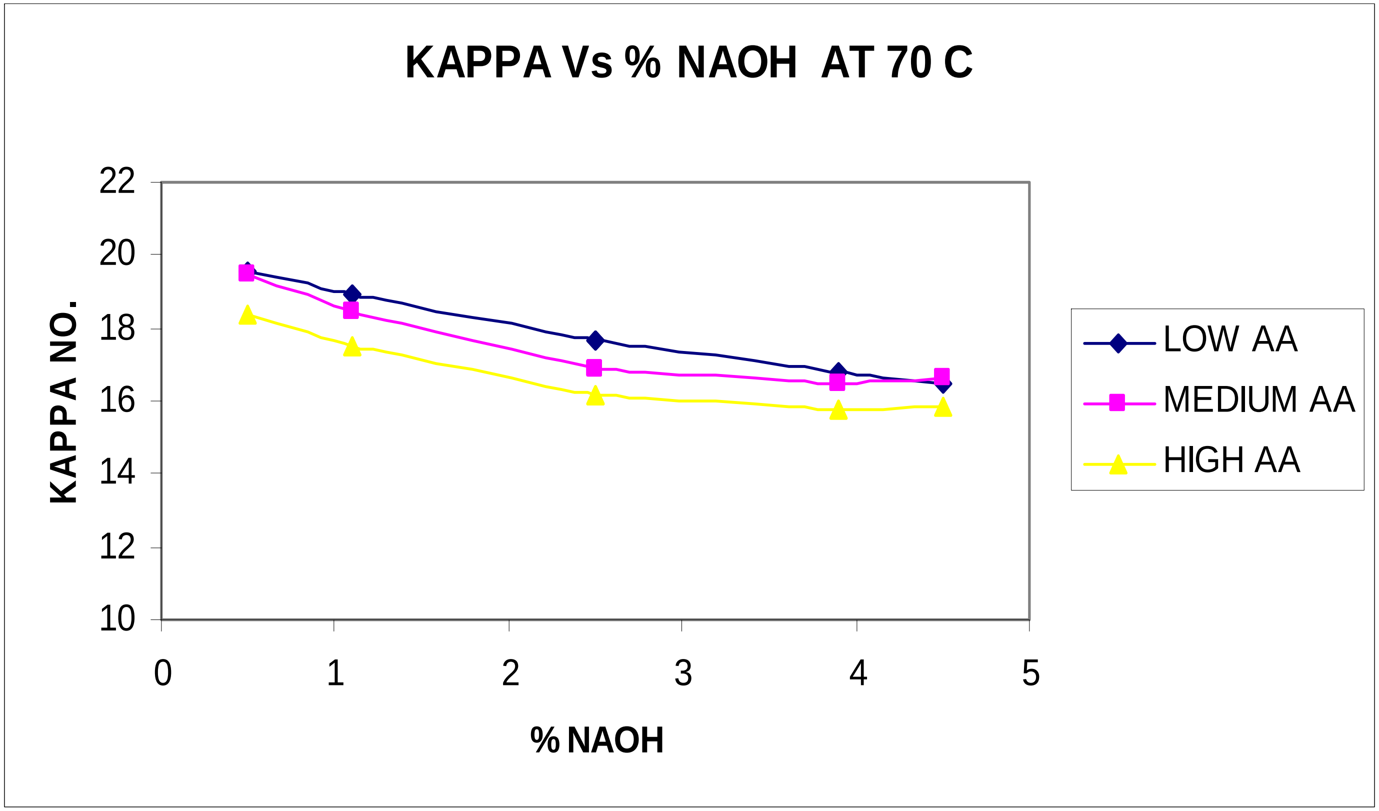
HIGH AA (18%)

YIELD =98.81956-0.28535*NAOH-0.19444*TEMP+0.42546*NAOH2

KAPPA =14.2-2.0*NAOH-1.98*TEMP

VISCOSITY=31.39129+0.62753*NAOH+2.32143*NAOH*TEMP-2.77632*TEMP2

Harwood Delignification



Harwood Delignification

Summary

- *The higher alkali charge in pulping resulted in lower yield at the same kappa number*
  - *17%AA 46% yield*
  - *21%AA 43% yield*
- *The pulps produced with the low AA were slightly more difficult to delignify as compared to the high AA pulps*
- *The yield and viscosity selectivity was higher for the low %AA in pulping*
  - *improvements of up to 2% in yield*
  - *improvements of up to 4cp in viscosity*

Summary

- Similar results were observed with hardwood
  - Low %AA pulps were slightly more difficult to delignify
  - The yield form the low AA pulps were significantly higher especially at 14%AA

Validation of Results- Softwood

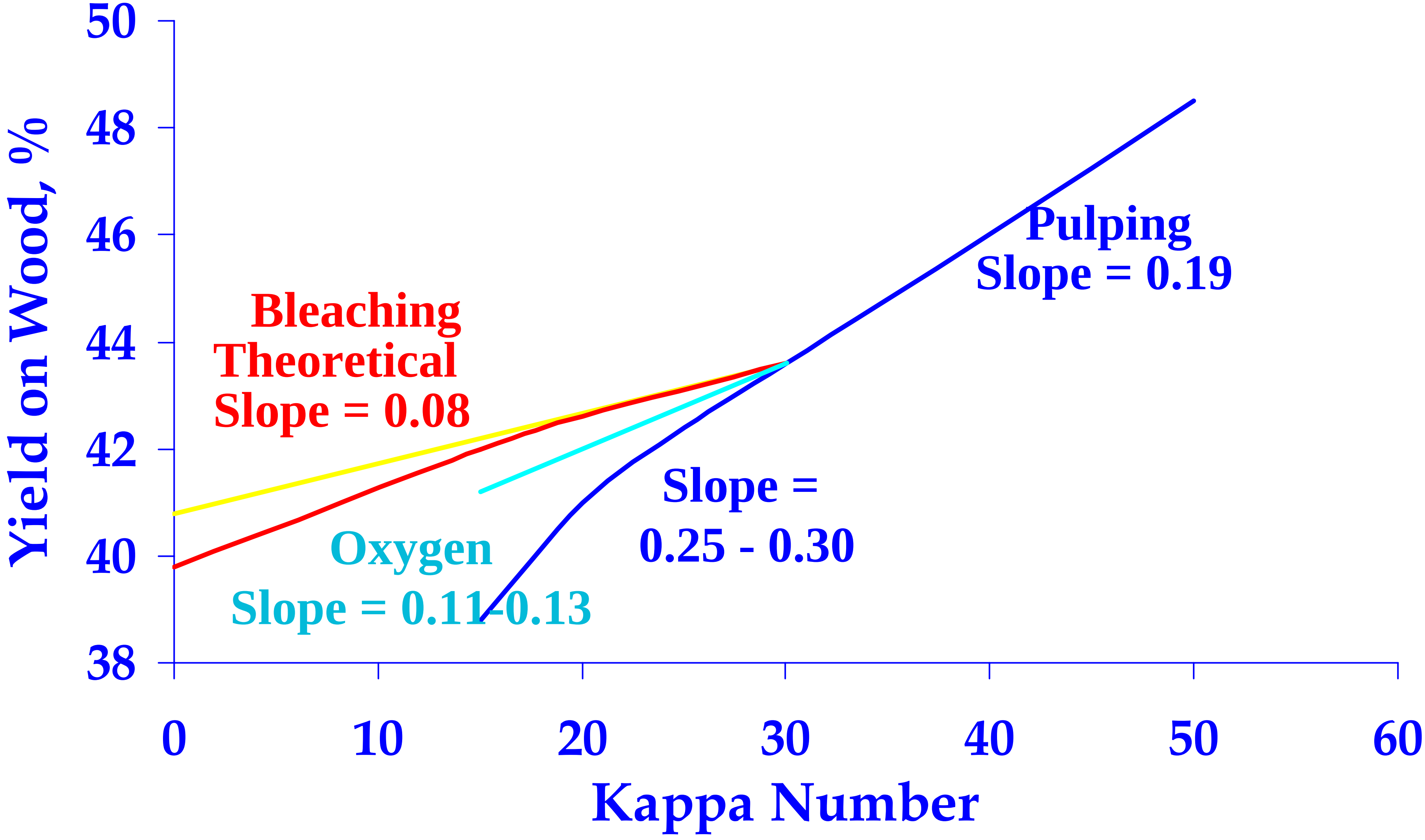
	17% AA	21% AA
Pulping		
%AA	17	21
H Factor	2200	1250
Kappa	30	30
Yield, %	46.5	43.5
Viscosity, cp	33.7	27

Validation of Results

	17% AA	21% AA
Oxygen Stage		
%NaOH	3.3	3
Temp, C	92	92
Kappa	16	16.5
Oxygen yield, %	97	96.8
Total yield,% (Pulp+O2)	45.1	42.1
Viscosity, cp	24.5	21

High-Kappa Pulping
and
Extended Oxygen Delignification
to Increase Yield

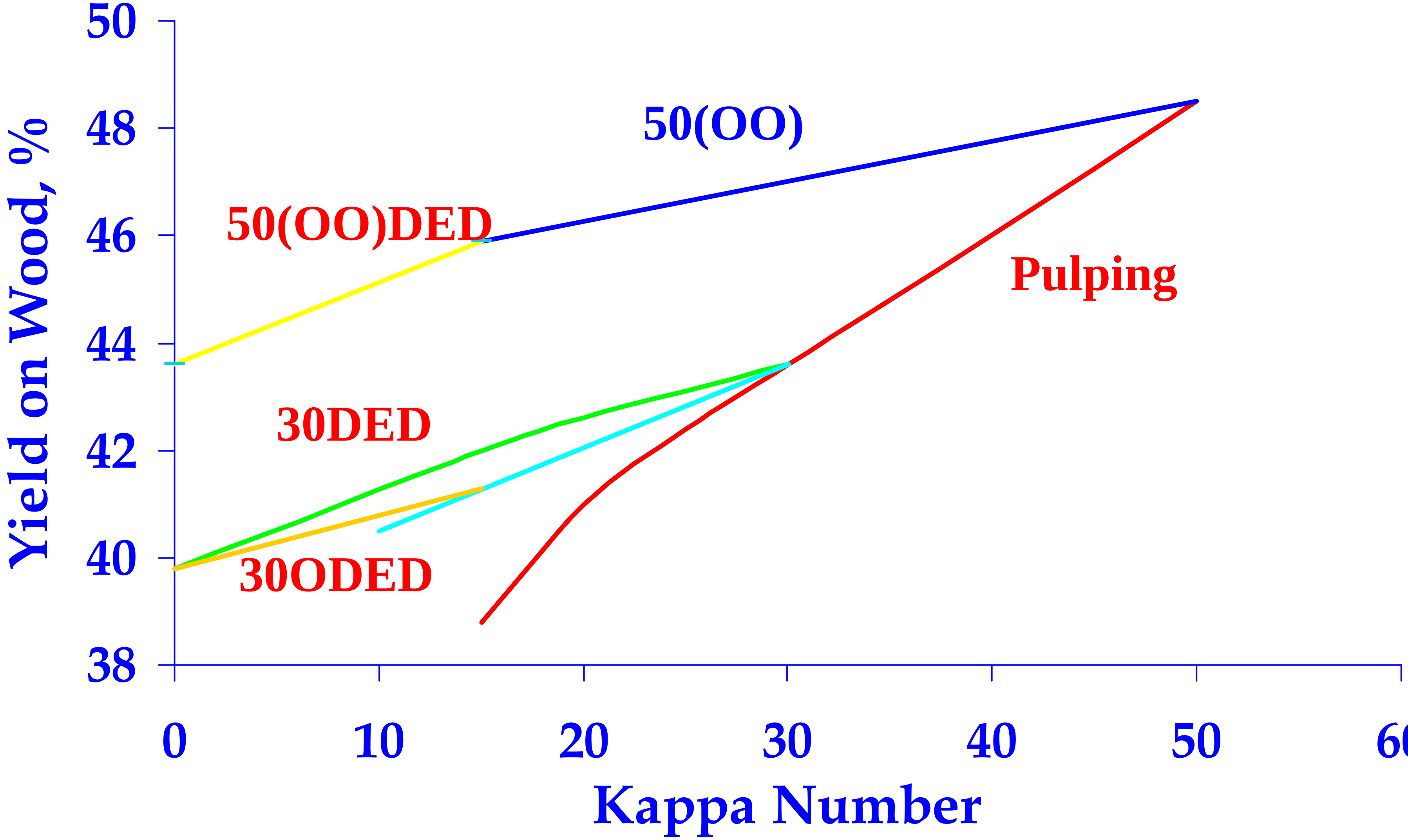
Yield Kappa Relationships



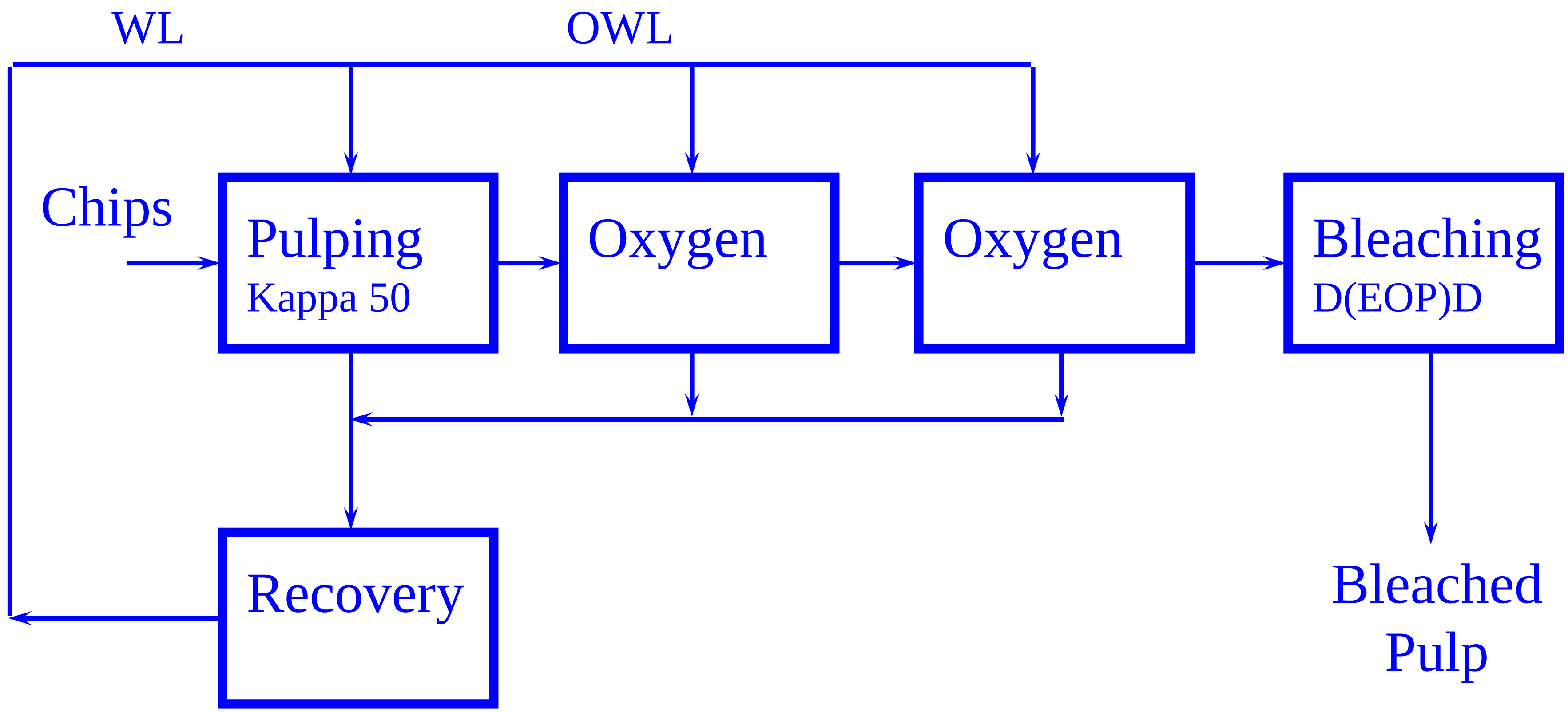
Extended Oxygen Delignification

- *Selectivity of oxygen delignification is higher than than that for pulping*
- *Why not stop pulping at a higher kappa number and use extended oxygen delignification to decrease the kappa number ?*
  - *Kleppe, Gratzl, Air Products*

Yield Kappa Relationships



Proposed System



Yield Results

	Pulping	Post Oxygen	Bleaching
30ECF	43.3		39.8
30(O)ECF	43.3	41.9	39.9
40(OO)ECF	46.3	43.7	41.8
50(OO)ECF	49.3	45.9	43.6

Economics

	Boiler Load MMlb/day	Cost/ODTP $
30ECF	4.87	197
30(O)ECF	5.04	185
40(OO)ECF	4.67	184
50(OO)ECF	4.19	184

Pulping/Oxygen Delignification 50 Kappa

- *High kappa pulping followed by two stage oxygen delignification*
  - *single stage oxygen bleaching*
  - *two stage oxygen bleaching*

Single Stage Oxygen Delignification

- *Softwood 50 Kappa pulps prepared*
- *Varying pulping conditions*
  - *Low AA 15%AA*
  - *Medium AA 17%AA*
  - *High AA 19%AA*
- *Temperature kept constant at 170^{o}C*
- *Single stage oxygen delignification studied using experimental design*

Pulping Conditions 50 Kappa

	%AA	H-Factor	Kappa	Yield, %	Viscosity cp
Low	15	1650	50	51.0	
Medium	17	1400	50	48.5	34.1
High	19	1060	48	46.4	31.0

Oxygen Delignification

50 Kappa 15%AA

NaOH%	Temp	Kappa	Yield	Viscosity	Total Yield
3	70-75	35.5	98	27.5	50.0
1.6	76-77.5	40.3	98.5	29.1	50.2
4.4	76-77.5	34.9	96.8	22.8	49.4
1	90-94	41.0	99	28.0	50.5
3	90-94	30.0	95.7	25.2	48.8
5	90-94	26.0	93.2	18.8	47.5
1.6	100-104	34.0	94.5	22.8	48.2
4.4	104-106	20.0	94	18.0	47.9
3	110-111	24.0	94	17.0	47.9
3	90-94	30.0	95.64	21.1	48.8
3	90-94	30.0	95.5	21.5	48.7

Models for Low AA
50 Kappa 15%AA

- *LOW AA PULP:*
  - *KAPPA= 30.1123 –7.06581*((NaOH-3)/2) – 6.77534*((Temp-90)/20) + 3.70607*((NaOH-3)/2)*^{2}
  - *YIELD= 48.90639 –0.91451*((NaOH-3)/2)– 1.1175*((Temp-90)/2)*
  - *VISCOSITY= 21.84217 –4.673034*((NaOH-3)2) – 4.67303*((Temp-90)/20) + 1.73915*((NaOH-3)/2)*^{2}

Oxygen Delignification

50 Kappa 17%AA

Medium AA Pulping, 50 Kappa					
% NaOH	Temp	Yield	Kappa	Viscosity	Total yield
3	72	98.0	33.5	27.4	47.5
1.6	77	99.8	32.7	27.9	48.4
4.4	77	98.9	30.0	24.2	48.0
1	91	99.0	38.5	31.4	48.0
3	90	98.0	28.0	23.9	47.5
5	91	95.7	24.7	21.3	46.4
1.6	104	98.0	30.2	26.2	47.5
4.4	104	94.0	22.5	19.9	45.6
3	108	95.0	22.7	20.3	46.1
3	90	98.3	28.7	23.8	47.7
3	90	98.1	29.0	23.7	47.6

Models for Medium AA
50 Kappa 17%AA

- *MEDIUM AA PULP:*
  - *KAPPA= 28.00095 –5.31616*((NaOH-3)/2) – 3.997644*((Temp-90)/2) + 3.14666*((NaOH-3)/2)^2*
  - *YIELD= 47.298 – 0.80028*((NaOH-3)/2) – 0.84848*((Temp-90)/20) – 0.65933*((Temp-90)/2)*((NaOH-3)/2)*
  - *VISCOSITY= 23.6353 –4.28737*((NaOH-3)/2)– 2.55193*((Temp-90)/20) + 2.55147*((NaOH-3)/2)^2*

Oxygen Delignification

50 Kappa 19%AA

High AA Pulping, 50 Kappa						
NaOH%		Temp	Kappa	Yield	Viscosity	Total Yield
3		70-73	32.3	99.8	19.1	46.3
1.6		76-79	33.1	100.0	21.2	46.4
4.4		76-78	28.3	97.5	17.8	45.2
1		88-89	36.2	99.0	24.6	45.9
3		88-89	27.2	97.7	17.6	45.3
5		90-94	21.8	95.5	15.6	44.3
1.6		100-104	28.4	97.1	22.6	45.1
4.4		102-105	19.7	94.5	12.2	43.8
3		106-109	21.7	96.4	15.1	44.7
3		90-94	25.0	96.7	17.5	44.9
3		88-90	27.0	97.8	17.8	45.4

Models for High AA

50 Kappa 19%AA

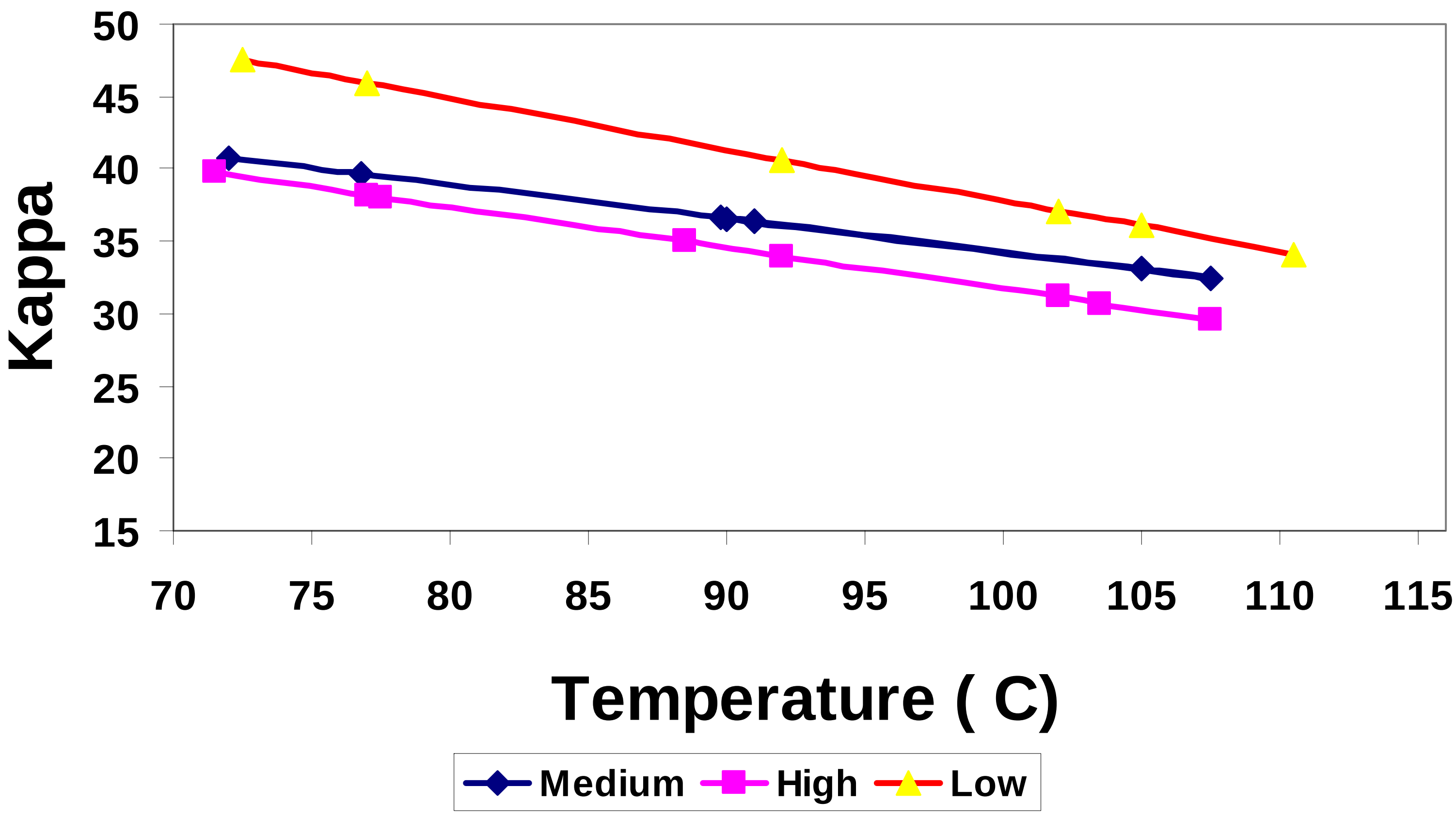
- *HIGH AA PULP:*
  - *KAPPA= 26.46762 –5.71586*((NaOH-3)/2) – 4.97502*((Temp-90)/20) –2.39037*((NaOH-3)/2)^2*
  - *YIELD= 45.21542 –0.77563*((NaOH-3)/2) – 0.85754*((Temp-90)/20*
  - *VISCOSITY= 17.33038 – 4.61892*((NaOH-3)/2) – 1.73502*((Temp-90)/20) –2.65152*((NaOH-3)/2)^2*

Influence Of Pulping Conditions

- *Kappa Reduction*
- *Yield Selectivity*
- *Viscosity Selectivity*

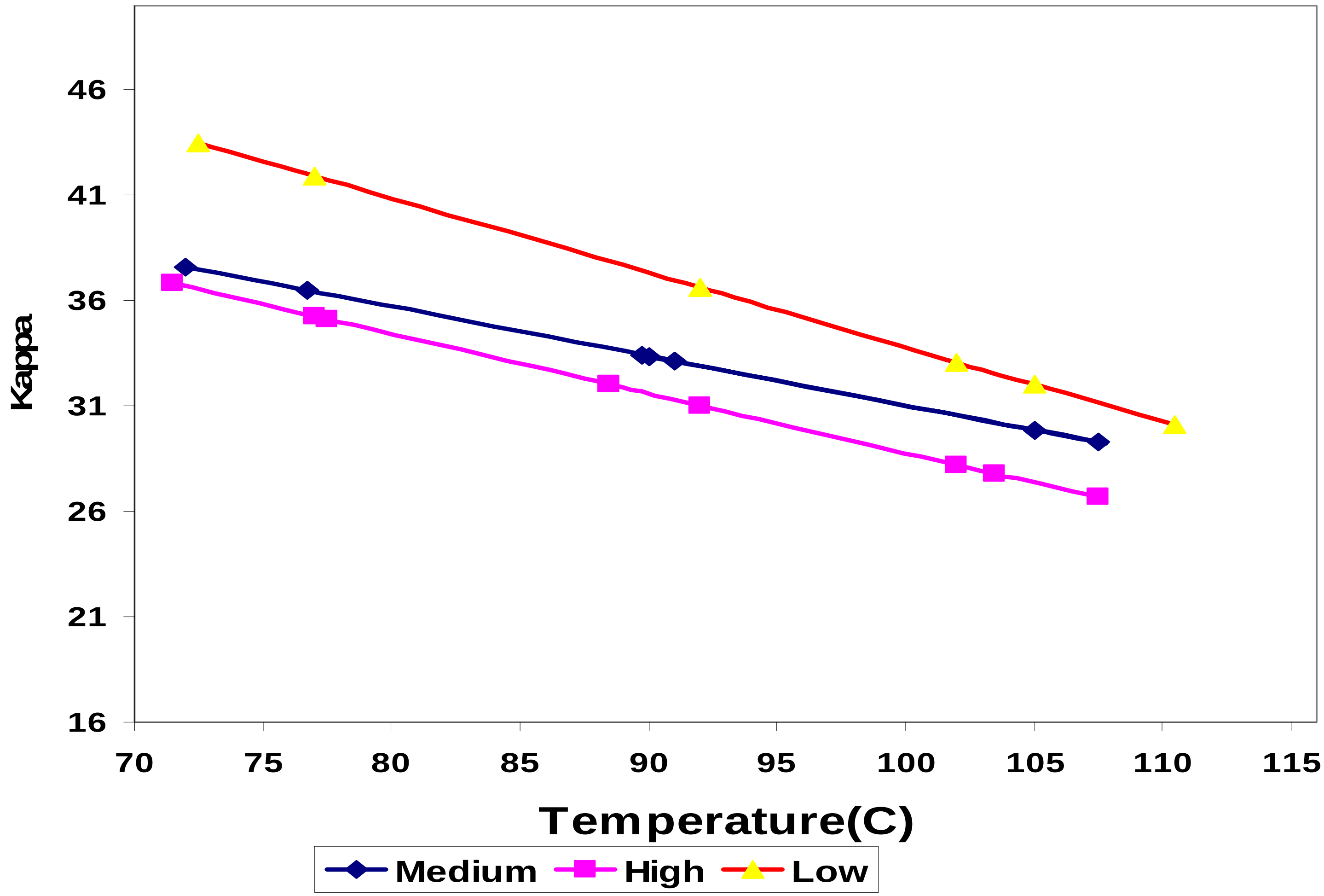
Kappa Reduction

1% NaOH

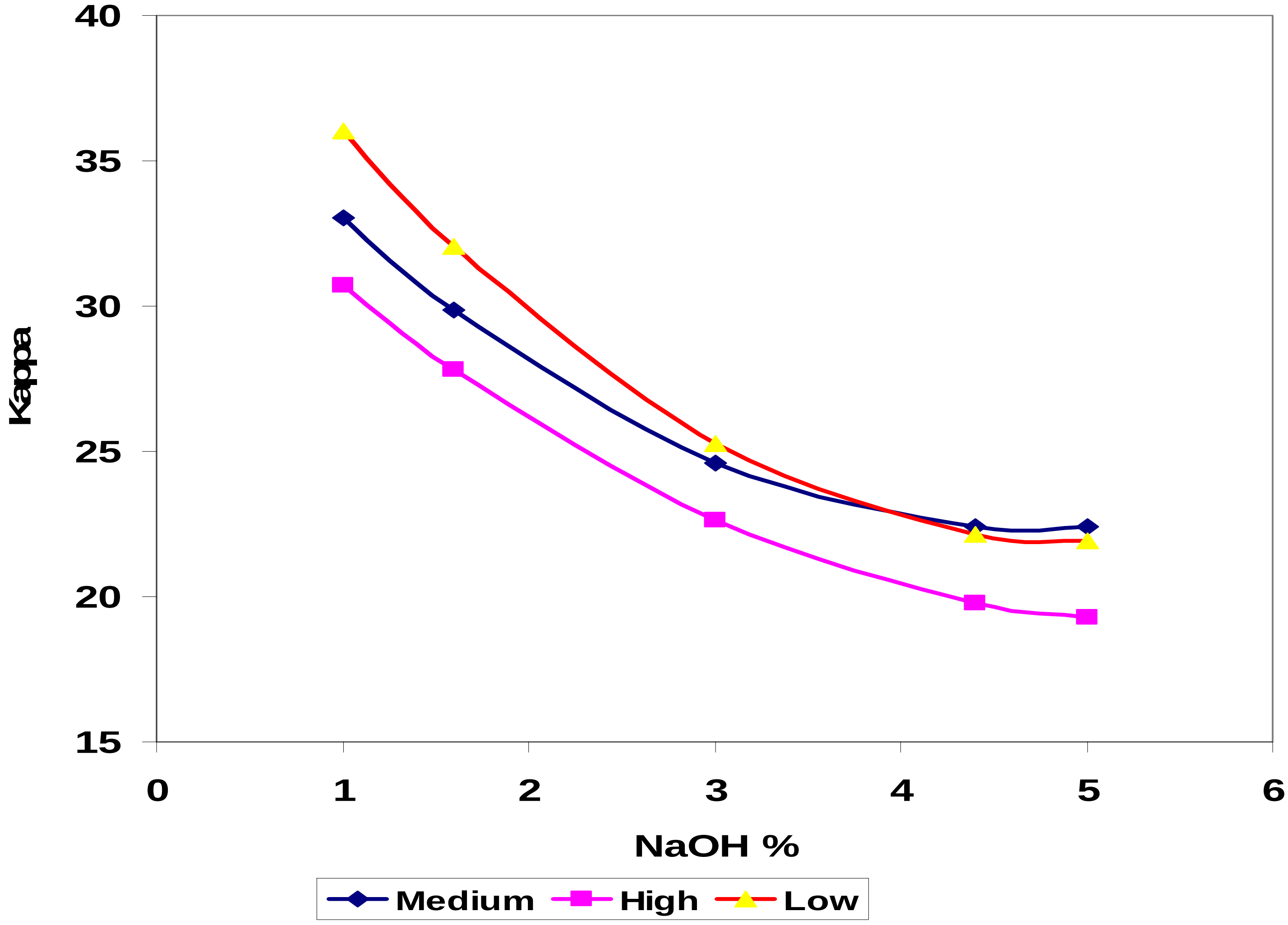


Kappa Reduction

3% NaOH

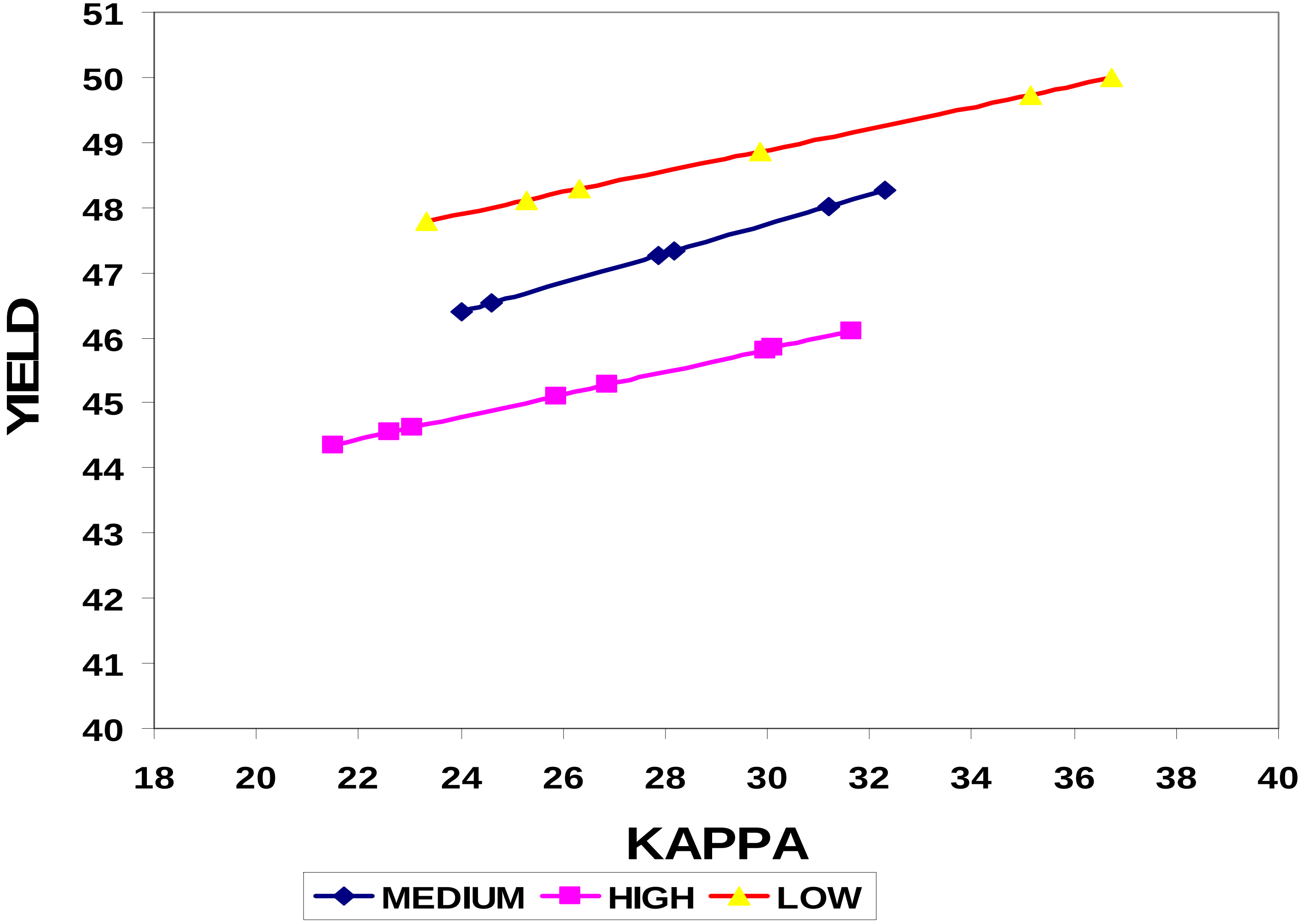


Kappa Reduction
100°C



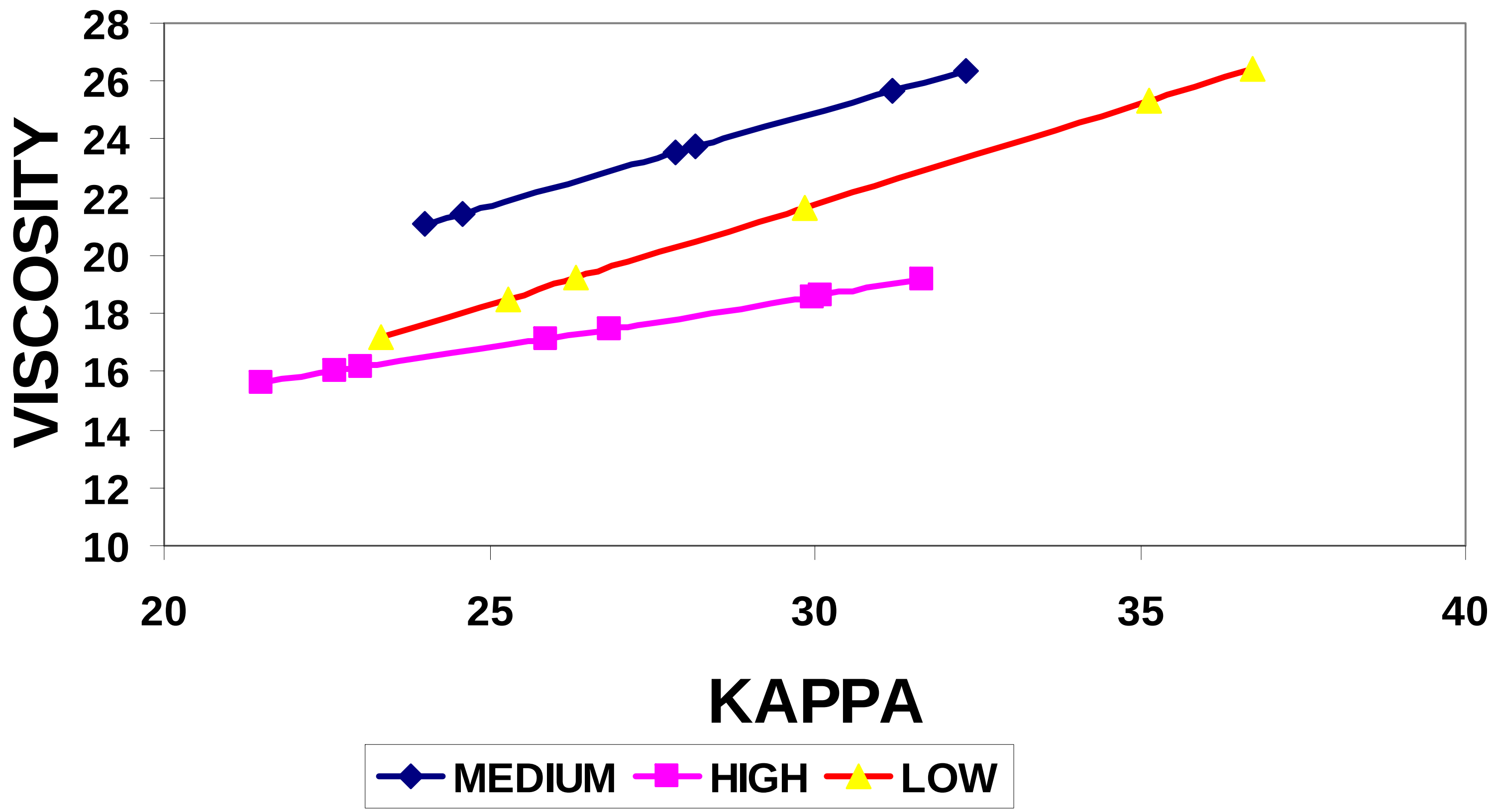
Yield Selectivity

3% NaOH

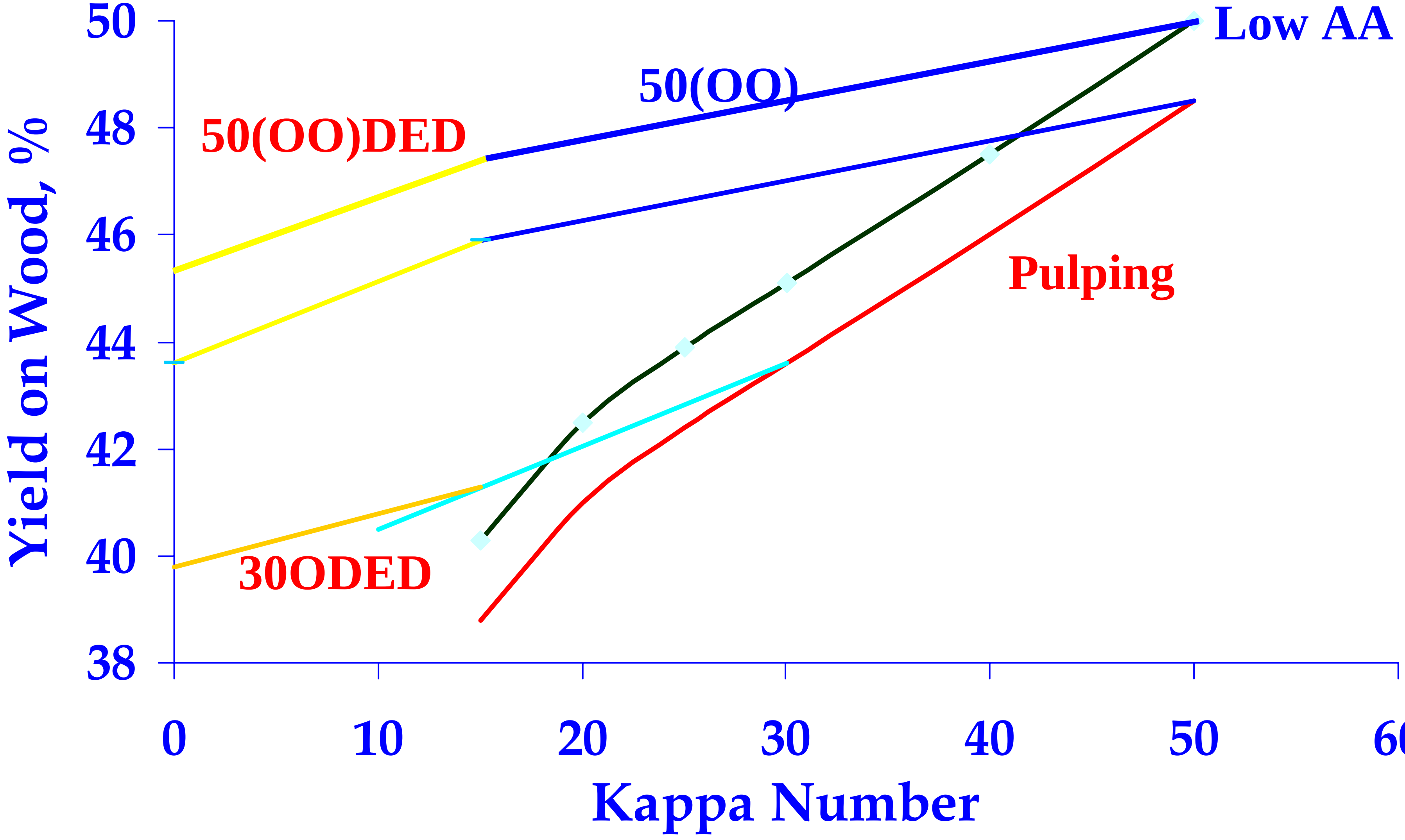


Viscosity Selectivity

3% NaOH



Yield Kappa Relationships



Validation of Results
50 Kappa

	17% AA	21% AA
Pulping		
%AA	15	19
H Factor	1650	1050
Kappa	49	48
Yield, %	49.5	47.5
Viscosity, cp	37 ??	40

Validation of Results
50 Kappa

	17% AA	21% AA
Oxygen Stage 1		
%NaOH	3	3
Temp, C	92	81
Kappa	30	30
Oxygen yield, %	97.5	97.9
Total yield,% (Pulp+O2)	48.3	46.5
Viscosity, cp	34.7	30.5

Validation of Results
50 Kappa

	17% AA	21% AA
Oxygen Stage 2		
%NaOH	3	3
Temp, C	110	110
Kappa	15.5	15
Oxygen yield, %	96.1	96.8
Total yield,% (Pulp+O2)	46.4	44.3
Viscosity, cp	22.3	21.8

Comparison to 30 Kappa Pulping

	17% AA	21% AA
Pulping Kappa	30	30
Pulping Yield, %	46.5	43.5
Oxygen Stage		
Kappa	16	16.5
Oxygen yield, %	97	96.8
Total yield,% (Pulp+O2)	45.1	42.1
Viscosity, cp	24.5	21

High Kappa Pulping of HW

- *Pulp HW to higher kappa number and use two stage oxygen delignification*
  - *Optimum kappa number*

Summary

- *At 50 kappa the oxygen stage performance similar to before*
  - *The higher alkali charge in pulping resulted in lower yield at the same kappa number*
  - *15%AA 51% yield*
  - *19%AA 46.4% yield*
  - *The pulps produced with the low AA were slightly more difficult to delignify as compared to the high AA pulps*
  - *The yield and viscosity selectivity was higher for the low %AA in pulping*
    - *improvements of up to 3% in yield*
    - *improvements of up to 6cp in viscosity*

Summary

- High kappa pulping in combination with extended oxygen delignification can be used to increase overall pulp yield
- The kappa number from pulping should be decided based on
  - pulp properties
  - economics
  - environmental
  - mill constraints (boiler, causticization)

Conclusions

- *The results show there is tremendous potential for improving the yield, pulp properties and oxygen bleaching performance by:*
  - *optimizing the pulping and oxygen bleaching together*