Topical Report on XL-2 Project at IP, Jay, Maine
Results of Laboratory O_2 Delignification Experiments

By

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MANAGEMENT SUMMARY

The objective of the study reported here was to determine the effects of consistency, temperature, caustic addition rate and reaction time on the level of delignification for softwood brownstock pulp produced at Jay.

Performance of Current System

Analysis of mill process data suggests that the current oxygen delignification system at Jay achieves approximately a 25 to 27% reduction in kappa number. The pulp leaving the oxygen system typically has an intrinsic viscosity of about 1100 cc/gram and corresponds to a TAPPI viscosity of about 39 centipoises, which is quite high. Samples taken of the pulp going to the oxygen reactor indicate that the alkali concentration going to the reactor is about 3 grams per liter and approximately 100 Kg per metric ton of COD and 200 Kg per metric ton of Color are carried over from the brown stock washers. Based upon the experimental results it was concluded that approximately half of the alkali in the pulp going to the pressurized oxygen reactor currently comes from the alkali in the carryover from the brownstock washers. The laboratory results further suggest that approximately 65% of the delignification that is taking place in the oxygen delignification process in the mill takes place in the 15 minute pressurized reactor and the piping prior to the reactor; while about 35 % of the drop in kappa number takes place in the atmospheric tower.

Important Process Variables Controlling Delignification

Important process variables controlling the level of oxygen delignification, in their order of importance, are the reaction temperature, alkali concentration and oxygen pressure. Of the variables investigated experimentally, raising the temperature in the reactor is the most important variable driving the reaction. High pressure is desirable because it reduces the volume of gas that must be mixed into the pulp by the high shear mixer. The alkali concentration going to the reactor is determined by the carry over of alkali, the pulp consistency and the alkali being added to the reactor.

Experimental Results

The mill results could be matched quite closely in the laboratory reactor. Based upon the experimental results it was concluded that it should be possible to increase the percent delignification to 35 to 40% or even higher from the current level of approximately 25% to 27% delignification. To achieve high levels of delignification the temperature in the oxygen reactor must be raised from the current operating value of about 175 ^{o}F. The desired temperature in the high pressure reactor and the atmospheric tower should be at least 190 ^{o}F, and preferable 200 to 205 ^{o}F.

Mixing Effects. The laboratory results reported here were performed using an infinite supply of oxygen so that the delignification reactions were not limited by the amount of oxygen that was available for reaction with the lignin in the pulp. Operating with the large excess of oxygen did not appreciably improve the delignification results over what the current system is achieving. Thus, it was concluded that the current level of mixing in the mill operation is, most likely, not limiting the extent of delignification being observed in the mill.

Addition of Mixing Equipment. To achieve the desired 35 to 40% delignification in the oxygen system would require the addition of a new steam line, injection nozzles and steam mixer to ensure that the steam is well mixed into the pulp and the desired temperature is achieved. Addition of a second mixer, although desirable and recommended, was felt to be of secondary importance compared to adding equipment necessary to raise the temperature of the pulp going to the oxygen reactor and atmospheric tower. Addition of a second oxygen mixer prior to the high pressure reactor would permit the oxygen and caustic addition rates to be split and would thus permit more effective control of the system. In addition, at 40% delignification or higher, the effect of mixing will become more important. In our experiments we were comparing the results at 25% delignification. Thus, addition of a second mixer is recommended -- provided sufficient funds are available.

Anticipated Reductions in Color and COD in Mill Effluent. It is estimated that improving the oxygen delignification system on the softwood side to 40% would result in a reduction of COD going to the river of about 1.9 Kg COD per metric ton of pulp; and about 5 kg per metric ton of pulp for Color. The exact reduction to be gained for COD and Color will depend upon the starting kappa number, the level of delignification, the pulp washing efficiency, the reduction factor, and the efficiencies for removal of COD and Color in the wastewater treatment system.

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INTRODUCTION

An XL-2 Project is being conducted at the International Paper (IP) paper mill in Jay, Maine. Under the terms of the XL agreement, the IP mill is exempt from Best Management Practice (BMP) in the water pollution portion of the Cluster rules. In exchange for this exemption, IP has agreed to take a number of projects designed to improve the quality of the mill effluent for COD and Color beyond the levels likely to be attained through implementation of the BMP requirements. IP operates a mini-oxygen delignification system in the softwood pulp mill, designated Mill A. Improvements in the mini-oxygen delignification system have been suggested as one way in which the cluster rule funds might be expended.

Objective and Scope of Study

The objective of the work reported here was to determine strategies for raising the level of delignification in the mini-oxygen system in the “A” softwood pulp mill at Jay, Maine. In pursuit of this objective, laboratory studies were performed to determine the effects of consistency, temperature, caustic addition rate, and time of reaction on the level of delignification for softwood brownstock pulp produced at the IP mill located in Jay, Maine. The delignification experiments were performed to separate the effects of the 15 minute pressurized reactor from the 60 minute atmospheric tower. An ancillary objective was to determine the effects of mixing on the level of reaction that could be achieved in the oxygen reactor.

O_2 Delignification System at IP-Jay.

Figure 1 illustrates the softwood “mini” O_2 delignification system at the Androscoggin mill. In this system, caustic is added to brownstock kraft pulp in a standpipe following the brownstock washer. Steam entry prior to the reactor has been discontinued. Rather, hot wash water is being added in the brownstock washer to raise the temperature of the pulp. From the standpipe, the pulp is pumped with a medium consistency pump through a high shear mixer and through a pressurized reactor. The residence time in the piping before the reactor is about 3 minutes while the residence time in the high pressure reactor is approximately 15 minutes. The pulp is then brought to atmospheric pressure in a blow tube and pumped through an atmospheric tower where the residence time is approximately 60 minutes. The pulp is then washed in post-oxygen washers and finally sent to a decker where the pulp is further washed and sent to storage. Decker filtrate is used to wash the pulp in the post oxygen washer and works its way back to the digester via the brownstock washers.

Process conditions and system performance data are summarized in Table 1 for the time period of March 14 through February 14, 2002. The production through the system varied between 325 to 783 BD US tons per day with an average value of about 571 tons per day with high coefficient of variation (19%). Other data that appear to have a high coefficient of variation besides the production rate are the stock consistency in the MC pump (14%) and the percent delignification (21%). The percent delignification averages about 27%.

Analysis of Samples Going to Oxygen Reactor

As part of the current XL project, six samples were obtained for the stock going to the oxygen delignification process. These samples were collected over the period May 21 through May 23, 2002. Two (2) samples per day were taken during this three day period, one sample in the morning and one sample in the afternoon. The samples were taken from the standpipe after the caustic was added (about 1.5% NaOH) based upon pulp. The samples that had been collected were analyzed for consistency, intrinsic viscosity, inlet kappa number, pH, caustic level (grams equivalent NaOH per liter), COD and Color. Standard TAPPI methods were used in determining the analytical data. Figure 2 shows the intrinsic viscosity of the pulp plotted versus the kappa number. These data represent pulp coming from the digester and indicate a high variability on the kappa number.

The measured values for the caustic level (C, grams NaOH/l) were converted to percent on pulp (P_{NaOH}), and the COD and Color carryover were converted to Kg/tonne of pulp.

$$P(\%\ on\ Pulp) = \left(C_{NaOH}, \frac{g\ NaOH}{liter} \right) * \left(\frac{1\ liter}{1\ Kg\ liquid} \right) \left(\frac{1Kg\ NaOH}{1000\ g\ NaOH} \right) * \left(\frac{1}{C/100} - 1, \frac{1\ Kg\ Liquid}{Kg\ Pulp} \right) * 100 \quad (1)$$

$$COD(Kg/tonne) = \left(C_{COD}, \frac{mg}{liter} \right) * \left(\frac{1}{C/100} - 1 \right) * \frac{1}{1000} \quad (2)$$

$$Color(Kg/tonne) = \left(C_{Color}, \frac{mg}{liter} \right) * \left(\frac{1}{C/100} - 1 \right) * \frac{1}{1000} \quad (3)$$

This calculation assumes that all of the alkali titrated using HCl is in the form of NaOH. This assumption neglects any alkali present in the form of sodium carbonate. The results are summarized in Table 2. The mean value for the caustic addition rate is approximately 3.1% based upon pulp. Jeff Pike, pulp mill superintendent of the pulp mill indicated that the fresh caustic addition rate is about 1.5% based upon pulp. Thus, approximately half of the caustic in the pulp going to the oxygen reactor comes from carryover from the brownstock washers. Jeff Pike has indicated that the caustic going to the oxygen reactor has been measured and gives about 3 grams per liter NaOH which coincides with the values measured here.

Similarly, the COD and Color carryover going to the oxygen reactor was estimated to be about 100 Kg/tonne on the COD and approximately 204 Kg/tonne for the Color with a coefficient of variation of approximately 15% for both of these values. Carryover of COD to the oxygen delignification system reflects the efficiency of the brown stock washers. High carryover of black liquor solids would be expected to decrease the percent delignification in the oxygen system. A plot of Color versus COD is shown in Figure 3 and indicates that there is a strong linear relationship between Color and COD.

Possible Improvements to the Oxygen Delignification System at Jay

One project being considered by the Technical Team on the IP XL-2 project is the upgrade of the mini-oxygen delignification system. Possible project work includes installation of a second mixer in the system, raising the temperature in the oxygen delignification reactor, addition of both an oxygen level transmitter and an oxygen consistency transmitter, and improvements to the chute feeding the system. Since upgrading of the oxygen delignification system involves considerable expenditure of funds, the Technical Team recommended that laboratory experiments be performed in support of any decision to upgrade the system in the softwood pulp mill. Improving the oxygen system is attractive because the dissolved solids from the system are recycled to the recovery boiler. Thus, these solids, although very dilute, are used as a heat source rather than going to the bleach plant where they are discharged as COD.

RESULTS OF OXYGEN DELIGNIFICATION EXPERIMENTS

Laboratory experiments were performed in support of the XL-2 program in the University of Maine Pulp and Paper Process Development Center. Pulp samples were obtained from the Jay, Maine mill for use in these experiments. Details of the experimental design and procedures used in the conduct of the experiments are given in Appendix A. Results of the experiments are summarized in Appendix B together with relevant graphs. A detailed discussion of the experimental results is given in Appendix B.

Discussion of Results

The experimental results strongly suggest that raising the temperature will achieve the largest reduction in kappa number going to the bleach plant; see Figures 4 and 5 reproduced from Appendix B. The data shown in Figure 4 clearly show that temperature is a more important variable than caustic addition. Although pressure was not investigated, several experimental studies have shown that pressure is of less importance than either temperature or caustic addition in driving the lignin removal reactions to completion; see for example Agarwal and co-workers (1997, 1999).

Also, the data shown in Figure 4 show that the laboratory experiments essentially duplicate the performance of the mill system. These results suggest that the delignification reaction in the mill system is most likely not being limited by the transfer of oxygen to the pulp, but rather by the chemistry of the delignification reactions themselves. This conclusion is drawn because essentially the same level of delignification was obtained when the caustic and temperature levels were fixed at the mill values and the laboratory experiments were conducted with a great excess of oxygen. Based on these results, it is concluded that the mixing in the mill is most likely not limiting the results seen in the mill.

Table 1.
Process Data for Softwood Delignification System
(February 11 through March 14, 2002[a])

Item	Prod. Rate (BDT/day)	Stock Cons. In MC1 Pump (%)	Mid-Tower Temp of O2 Reactor	Stock Temp to O_2 Washer (F)	Stock pH From O_2 Washer	P# Stock from BS Washer	P# of Stock from Decker	Kappa # of Stock from BS Washer to O_2 System	Kappa # of Stock from Decker	% Delig
Average	570.6	9.6	176.3	164.6	11.7	19.3	13.8	27.9	20.3	26.9
Sdt. Dev.	107.9	1.3	4.4	6.4	0.2	1.1	1.1	1.8	1.4	5.6
COV	18.9	13.9	2.5	3.9	1.3	5.8	8.0	6.5	6.7	20.7

(a) The data base consisted of 352 data points over the time period.+

Table 2.
Samples of Pulp Going to IP Mini O_2 Reactor Taken from Standpipe

Sample Collection Time	Consistency of sample, %	Intrinsic Viscosity cm^3/g	Kappa Number	End pH	Inlet NaOH, g/L	COD, mg/L	color, mg color/l	% NaOH on Pulp	COD Carryover (kg/tonne)	Color Carryover (kg/tonne)
5-21 9:00AM	9.10	1136	23.77	12.3	3.53	11059	22934	3.53	110.5	229.1
5-21 3:20PM	8.70	1085	23.37	12.3	3.37	10146	20161	3.54	106.5	211.6
5-22 8:00AM	7.40	1147	25.28	12.1	2.48	6960	14819	3.10	87.1	185.4
5-22 3:20PM	8.18	1045	23.45	12.2	2.80	8867	18851	3.14	99.5	211.6
5-23 8:00AM	11.69	1181	33.42	12.3	3.60	15984	30040	2.72	120.7	226.9
5-23 4:00PM	9.85	1072	20.9	12.2	3.08	8216	17440	2.82	75.2	159.6
Mean	**9.15**	**1111**	**25.03**	**12.2**	**3.14**	**10205**	**20708**	**3.1**	**99.9**	**204.0**
Std. Dev	*1.49*	*51.8*	*4.34*	*0.08*	*0.44*	*3175.0*	*5313.2*	*0.3*	*16.5*	*26.8*
COV (%)	*16.3*	*4.7*	*17.4*	*0.7*	*14.0*	*31.1*	*25.7*	*10.9*	*16.5*	*13.1*

Since steam must be added to the system, the experimental results further suggest that the first priority would be the installation of an efficient steam mixer to raise the temperature of the pulp to 190 or perhaps 200 °F going to the high-pressure reactor. Consequently, adding the steam mixer with associated piping to achieve the elevated temperature is seen as the highest priority for expenditure of XL-2 funds in the oxygen system.

There are however, other advantages to adding a second chemical mixer ahead of the primary reactor. A second mixer would permit split addition for both the caustic and the oxygen. It would also allow mixing in the three discrete sections of the oxygen delignification process; that is in the tortuous piping between the standpipe and the first reactor by using the first mixer, in the high pressure 15 minute reactor by using the second mixer, and lastly in the 60 minute atmospheric pressure tower by passing the pulp through the medium consistency pump. The split addition would lead to higher selectivity, that is, higher pulp viscosity at the same delignification.

Figure 5 is selectively curve plotted as intrinsic viscosity versus kappa number for the experiments. As the level of delignification is increased, the viscosity of the pulp begins to decrease (see Figure 5). This is especially true at high caustic concentrations. In Figure 5, as the level of delignification approaches 40% the intrinsic viscosity drops to about 900 cc/gram. With split addition of the caustic, the viscosity is expected to be higher. An intrinsic viscosity of 900 cc/gram corresponds to a TAPPI viscosity of about 25 centipoises, which is still high. If pulp viscosity becomes an issue, a simple solution would be to add $MgSO_4$ as a carbohydrate protector.

Estimated COD and Color Reduction in the Mill Effluent

The COD and color going to the river would be reduced by improving the oxygen delignification system, because with increased lignin removal more organic solids could potentially be washed from the pulp and sent to the recovery boiler. Thus, there would be less lignin that would have to be removed in the bleach plant and thus fewer solids would be discharged from the bleach plant to the waste treatment plant.

To make estimates for the Color and COD reduction resulting from improvements in oxidation, data are required for the effluent reduction factor (f_{COD} and f_{Color}), which is defined by McCubbin (2001) as the change in the COD (f_{COD}) and or color (f_{Color}) going to the waste treatment system per unit drop in kappa number. Using published data of Vice, Sieber and Bicknell (1995) for softwood, McCubbin (2001), suggested that the normalized COD discharge associated with lowering the kappa number going to the bleach plant is about 2.40 Kg COD per ADMT per unit drop in Kappa number. Additional data are presented by Liebergott and co-workers (1991) for the reduction in bleach plant Color and COD of a western hemlock kraft pulp brought about by the introduction of various oxidative pre-bleaching steps (Eo, Eop and O). The Liebergott data are summarized in Table 3 and suggest that the effluent reduction coefficient resulting from the introduction of an oxidative bleaching stage is about 2.75 Kg COD per metric ton per unit kappa drop and approximately 3.8 kg Color per metric ton per unit kappa number drop.

Table 3.
Reduction in Bleach Plant Color and COD for Western Hemlock (D_{90} + C_{10}) E_O (D_N) D Sequence by Introduction of an Oxidative (E_O, E_{OP}, or O) Pre-bleaching Step[(a)]

Pretreatment	**Kappa to Bleach Plant** *(ml)*	**Bleach Plant COD** *(kg/MT)*	**Bleach Plant Color**	**DCOD / DKappa** *(kg/MT Kappa)*	**Dcolor / DKappa**
None	27.6	58	67		
E_O	21.1	40	40	2.8	4.2
E_{OP}	18.5	32	33	2.9	3.7
O	14.6	24	21	2.6	3.5
Average				2.75	3.8

(a) Data taken from Liebergott, N. et al., "Modifying the bleaching process to decrease AOX formation", Pulp & Paper Canada, 92(3): 84-89 (1991).

In making the estimate for the potential of improving the oxygen delignification, the following assumptions were made.

Kappa Number Drop. The reduction in kappa number brought about by an improvement in the oxygen system result. This results in the percent delignification being increased from 25% to 40% which translates into an approximately 3.9 unit decrease in the kappa number going to the bleach plant assuming that the starting kappa number is 26.

$$\Delta Kappa\ \ No. = (0.4 - 0.25) * 26 = 3.9\ Kappa\ Units$$

COD and Color Reduction Factors. The normalized COD discharge per unit kappa number drop is an average considering the data of McCubbin (2001) and Liebergott (1991), that is about 2.6 Kg COD/ADMT per day. For Color the data of Liebergott were used, which amounted to 3.8 Kg Color/ADMT.

Washing Efficiency. Washing in the post oxygen washer removes 90% of the additional Color and COD dissolved with the pulp eminating from the oxygen delignification reactor. This material is then recycled back to the evaporators and recovery boiler where it is eventually burned.

Efficiency in Waste Treatment System. The efficiency in the waste treatment plant for removal of COD is 66% for COD and 38% for Color. These values were obtained in the second mill-wide COD balance (Genco, and van Heiningen, 2001).

Using these estimates the expected reduction in COD (Δ_{COD}) and Color (Δ_{Color}) in the mill effluent are:

$$\Delta\ COD_{Mill\,Effluent} = \Delta Kappa\, x\ f_b\ x(1 - t_{COD})^*\ f_{SW}\ ^*w = \ Kg / tonne \qquad (4)$$

$$\Delta\ Color_{Mill\ Effluent} = \Delta Kappa\, x\ f_b\ x(1 - t_{Color})^*\ f_{SW}\ ^*w = Kg / tonne \qquad (5)$$

$$\begin{aligned}\Delta COD_{Mill\,Effluent} &= \ Reduction\ to\ effluent\ treatment = \\ &(0.15 * Kappa\ No.\ x 2.6) x(1 - 0.66)(x 0.6 SW) x 0.9 \qquad (6)\\ &= 1.86 Kg\ \ COD / ADMT\end{aligned}$$

$$\begin{aligned}\Delta Color_{Mill\,Effluent} &= Reduction\ in\,Mill\ Effluent = \\ &(0.15 * Kappa\ No.\ x 3.8) x (1 - 0.38) x 0.6 SW) x 0.9 = \qquad (7)\\ &= 5.0 Kg\ COD / ADMT\end{aligned}$$

The results show that the estimated reduction in COD that can reasonably be expected with an improvement in oxygen delignification is approximately 1.9 kg per metric ton of pulp. Similarly, the reduction in Color in the mill effluent is estimated to be approximately 5 Kg per metric ton of pulp. The reductions in Color in the mill effluent is greater than the reductions in COD because the Color in the spent liquor are so poorly degraded in the waste treatment plant; only about 38% compared to 66% for the COD.

Also, the removal factor for Color, 3.8 Kg Color per metric ton per unit drop in kappa number, is greater than that for COD, about 2.6 Kg COD per metric ton per unit drop in kappa number.

CONCLUSIONS

The following conclusions were drawn after review of the data for the oxygen delignification experiments performed to simulate the process at IP-Jay, analysis of mill samples taken of the washed pulp and the pulp after going to the oxygen reactor after addition of caustic and the mill process data.

Current Level of Delignification in the System. Analysis of mill process data suggests that currently, the oxygen delignification system operating on softwood at Jay, Maine achieves approximately a 25 to 27% reduction in kappa number. The pulp leaving the oxygen system typically has an intrinsic viscosity of approximately 1,100 cc/gram; about 39 centipoise TAPPI viscosity, which is quite high.

Carry Over of Caustic, COD, and Color Into the Oxygen Delignification System. Samples taken of the pulp going to the reactor indicate that there is a high level of carryover of alkali, COD and Color coming from the brownstock washers going to the oxygen reactor. The high pressure reactor in the oxygen system currently operates with about 2.5 to 3.5% total alkali based upon pulp. This corresponds to 2.5 to 3.5 grams alkali per liter when operating at about 9% consistency. Of this value, approximately 1.5% alkali is coming from addition of caustic to the pulp by the operators after brown stock washing, and about 1.0% to 2.0% comes from carryover of alkali into the reactor due to incomplete washing. The carryover of COD and color going to the reactor corresponds to about 100 Kg per metric tonne of COD and approximately 200 Kg per metric ton of Color.

Level of Delignification in the High-Pressure and Atmospheric Towers Currently Being Achieved. Based upon the laboratory results, it is concluded that the ratio of delignification that is occurring in the oxygen delignification system at Jay, Maine is split in the ratio of 2 to 1 split between the pressurized reactor and the atmospheric tower. Approximately 65% of the delignification is taking place in the in the 15 minute pressurized reactor, including the piping prior to the reactor, and about 35% of the delignification is being achieved in the atmospheric tower. Thus, assuming a Kappa number of 26 going to the oxygen system, the kappa number following the blow tank would be approximately 21 to 22 and that following the atmospheric tower would be approximately 18 to 19. These levels of delignification can be raised by process improvements and proper control of the process.

Results of Oxygen Delignification Experiments. Important process variables controlling the level of oxygen delignification in their order of importance are the reaction temperature, alkali concentration and oxygen pressure. Of the variables investigated experimentally, raising the temperature in the reactor is the most important variable driving the reaction. High pressure is desirable because it reduces the volume of gas that must be mixed into the pulp by the high shear mixer. The alkali concentration is determined by the carryover of alkali to the oxygen system, the consistency going to the reactor, and the alkali being added to the reactor.

In the experiments with well washed pulp, the desired twenty-seven percent (27%) delignification could not be achieved by adding only 1.5% NaOH when the reactor was operated at 175 ^{o}F**.** The low level of delignification (12 to 15%) resulted because the concentration of NaOH was too low (1 to 2 g/liter). Based upon these results it was concluded that the carryover of caustic into the reactor in the pulp from the brownstock washers contributes about half of the caustic required to cause the delignification reactions to proceed in the oxygen system.

Twenty seven percent (27%) delignification could be obtained when operating at 175 $^{\circ}$F with 3% caustic addition and 10% consistency (2.8 g NaOH per liter initial concentration). Thirty-eight percent (38%) delignification could be achieved by raising the temperature to 190 $^{\circ}$F in both the oxygen reactor and the atmospheric tower when operating at 10% consistency and 3.5% caustic addition (3.9 g/liter NaOH initial concentration). Forty percent (40%) delignification could be achieved when operating at 190 $^{\circ}$F with 3.5% caustic addition and 12 % consistency (4.8 g NaOH per liter initial concentration).

Level of Delignification Expected if the System Were Improved. Based upon the experimental results it is concluded that it should be possible to raise the percent delignification to 35 to 40% from the current level of approximately 25% delignification. To achieve high levels of delignification the temperature in the oxygen reactor must be raised from the current operating value of about 175 ^{o}F. The desired temperature in the high pressure reactor should be at least 190 ^{o}F, and preferable 200 to 205 ^{o}F.

Effect of Mixing. The effects of mixing could not be well discerned because operation with different levels of mixing was not possible in the apparatus used to perform the simulation experiments. However, using an infinite supply of oxygen in the laboratory did not appreciably improve the results over what the current system at Jay is achieving. This would lead us to conclude that, most probably, mixing in the mill is not limiting the kappa number reduction under the current conditions.

Addition of New Equipment. To achieve the desired 35 to 45% delignification in the oxygen system, it would require the addition of a new steam line, nozzles, and a steam mixer to ensure that the steam is well mixed into the pulp and the desired temperature is achieved. Addition of a second mixer prior to the high pressure reactor would permit the oxygen and caustic addition rates to be split and would thus permit more effective control of the system.

Reductions in Effluent from Improved O_2 Delignification. It was concluded that the reduction of COD going to the river can be reduced by about 1.9 Kg COD per metric ton of pulp and approximately 5 kg per metric ton of pulp for Color. The exact number will depend upon the washing efficiency, the starting kappa number, the reduction coefficient and the breakdown in the waste treatment system.

Possible Unforeseen Problems. If the temperature is raised in the oxygen reactor and the atmospheric tower, and the same level of caustic level is maintained, the mill may have to add $MgSO_4$ for viscosity protection. Post oxygen washing is very important if COD and color are to be reduced in the mill effluent from improvements in the oxygen system. Washing capacity was not investigated in this study.

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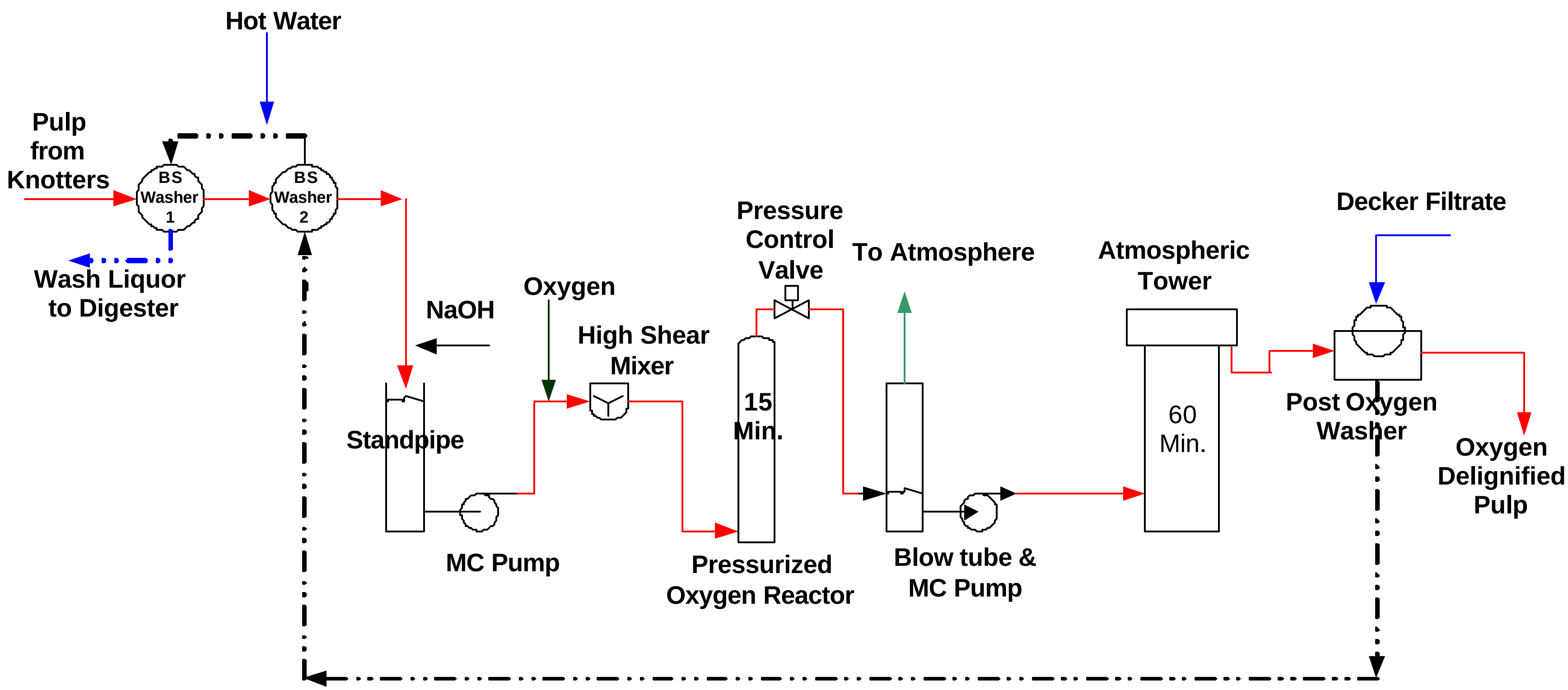


Figure 1.
Mini-Oxygen Delignification System at IP Jay, Maine
Operating on Softwood Pulp

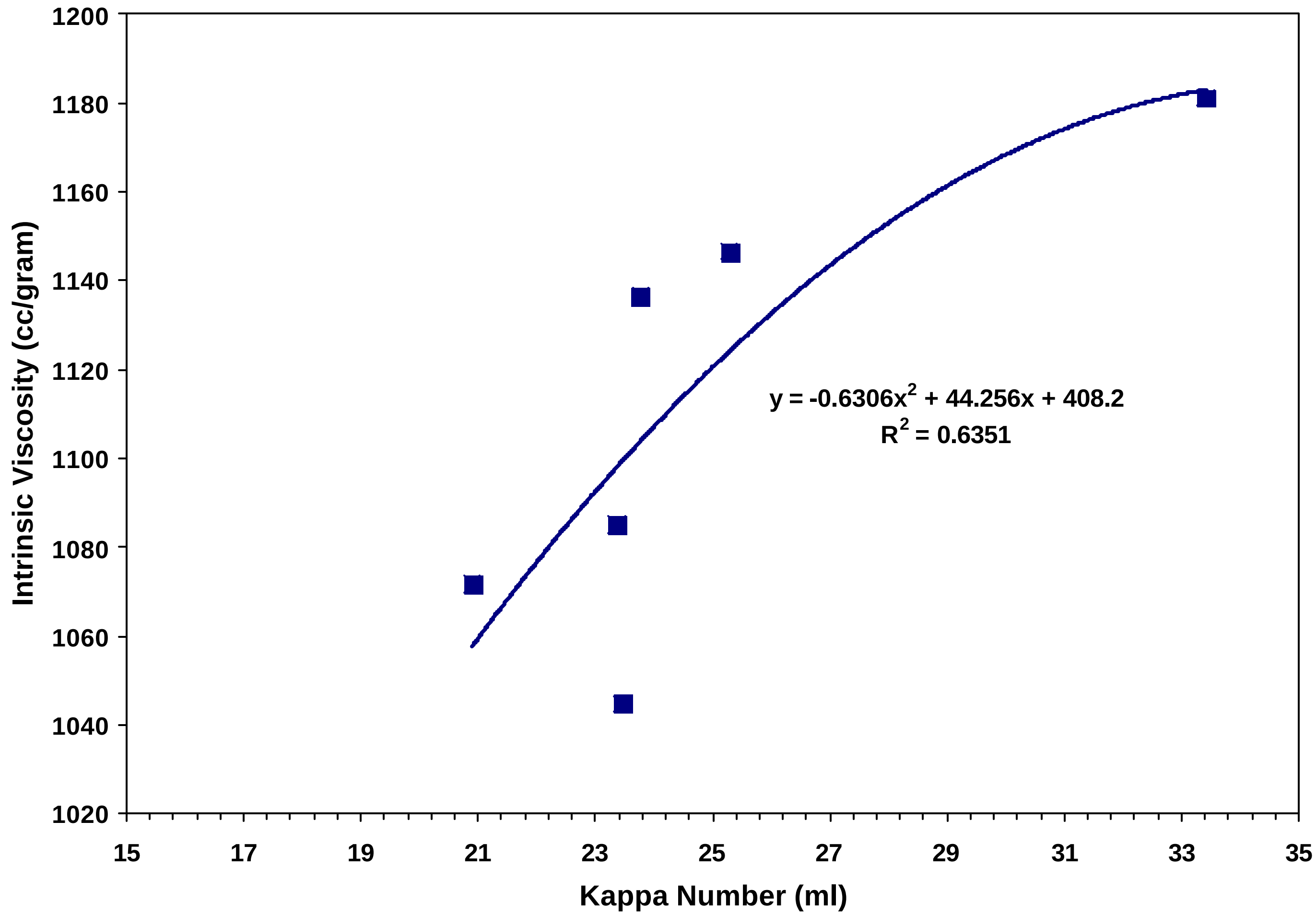
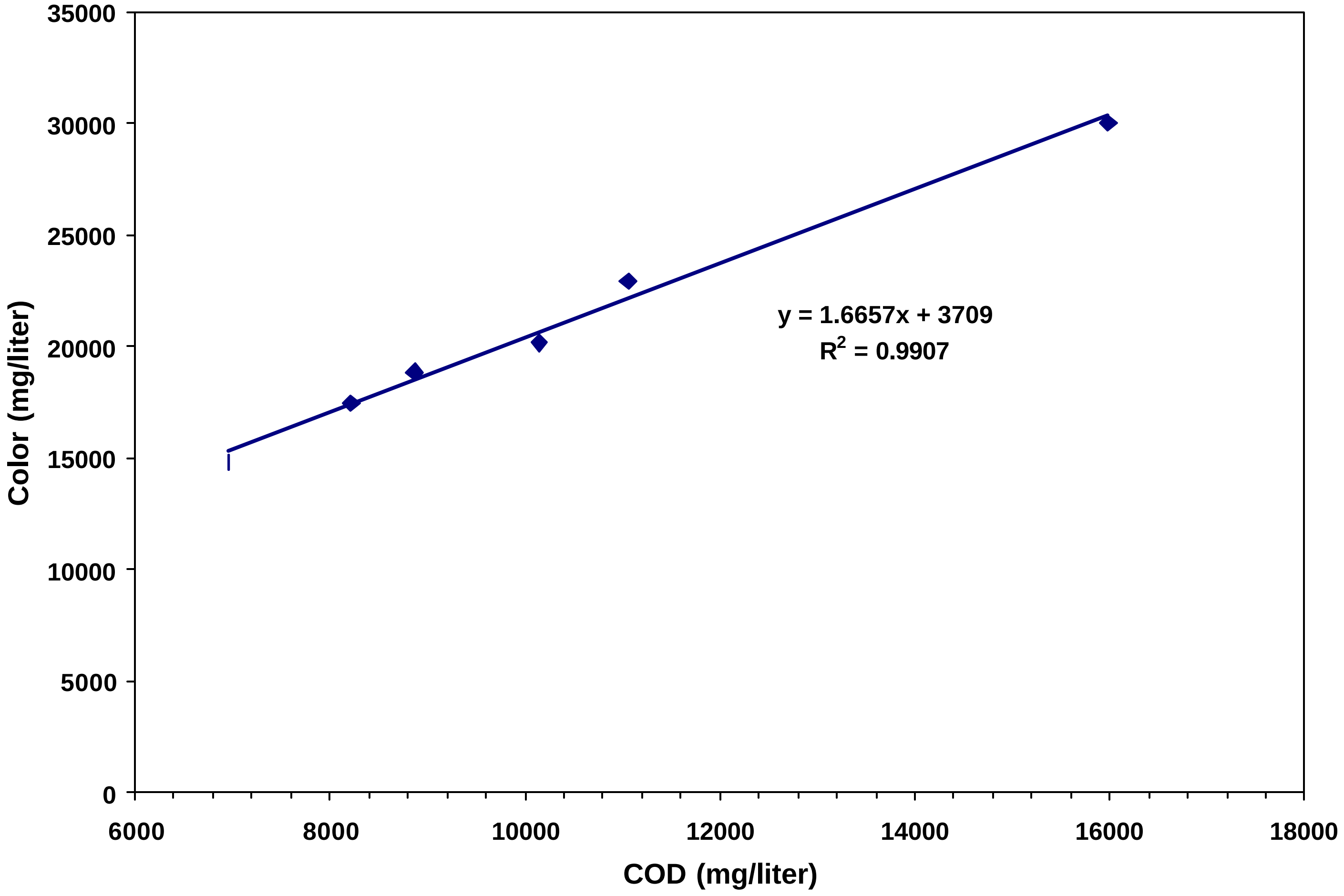


Figure 2.
Kappa Number and Intrinsic Viscosity of Pulp Going to the Oxygen Reactor at IP Jay, Maine



35000
30000
25000
20000
15000
10000
5000
0
Color (mg/liter)
y = 1.6657x + 3709
R2 = 0.9907
6000
8000
10000
12000
14000
16000
18000
COD (mg/liter)

Figure 3.
Color and COD Going to Oxygen Reactor at IP, Jay Maine

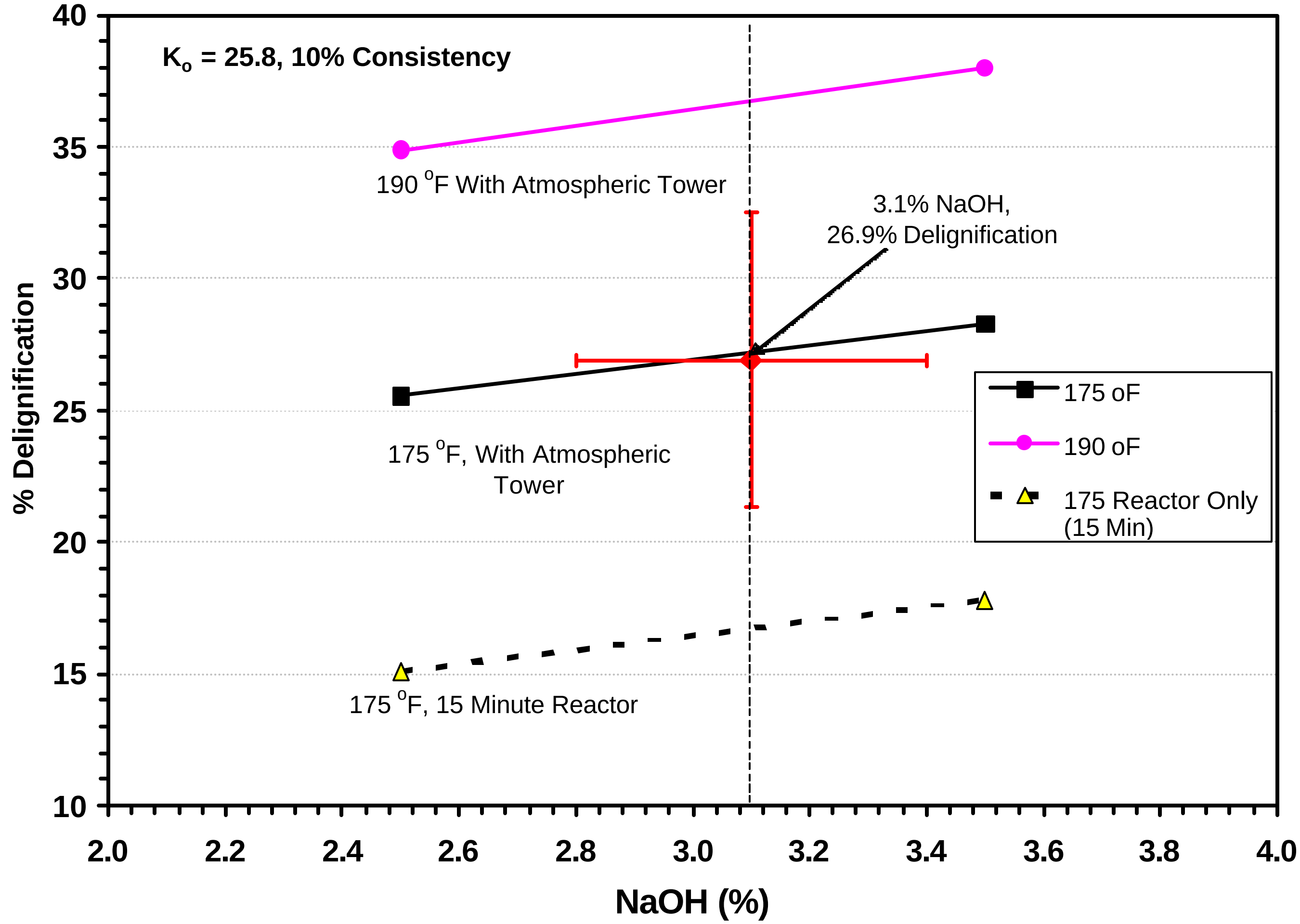


Figure 4.
Effect of Caustic (NaOH) Addition and Temperature on Delignification at 10% Consistency
(15 Minute Reactor plus Atmospheric Tower)

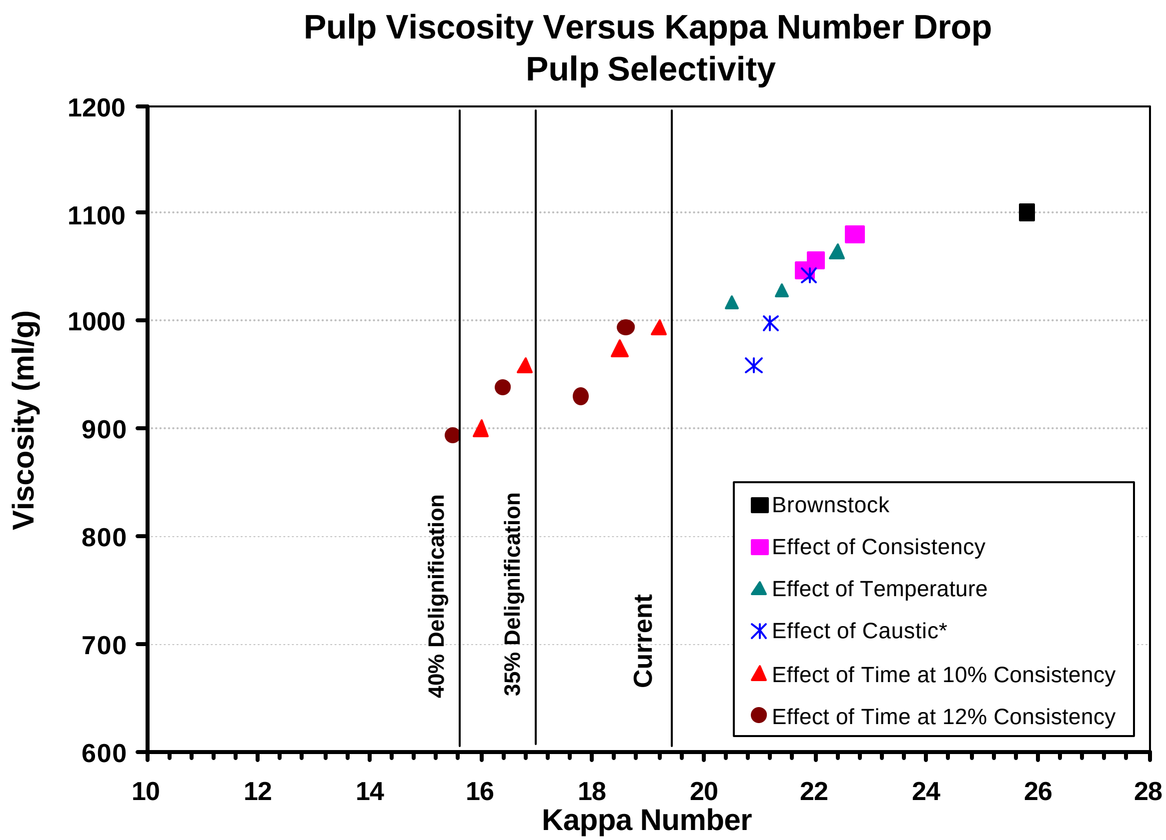


Figure 5.
Plot of Pulp Selectivity Defined as Pulp Viscosity Versus Kappa Number