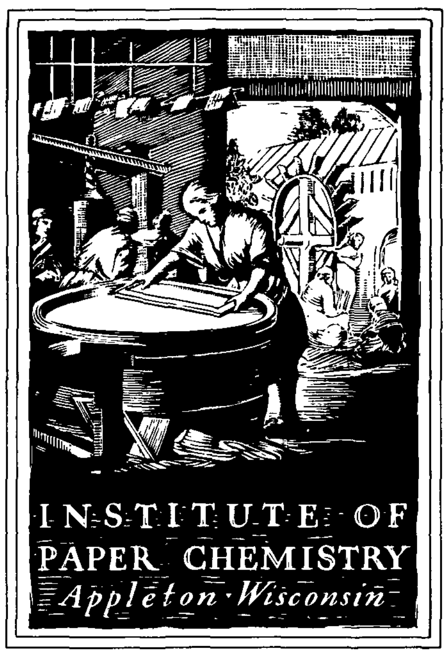
PROJECT ADVISORY COMMITTEE

Subcommittee on Engineering



IPC STAFF STATUS REPORTS

This information represents a review of on-going research for use by the Project Advisory Subcommittees. The information is not intended to be a definitive progress report on any of the projects and should not be cited or referenced in any paper or correspondence external to your company.

Your advice and suggestions on any of the projects will be most welcome.

FOR MEMBER COMPANIES ONLY

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Your advice and suggestions on any of the projects will be most welcome.

THE INSTITUTE OF PAPER CHEMISTRY
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October 3, 1988

TO: Members of the Engineering Project Advisory Committee

Enclosed is advance reading material for the October 20-21 meeting of the Engineering Project Advisory Committee. Included are status reports for active projects, an agenda, and a current committee membership list.

Rooms have been reserved in the Continuing Education Center, and meals will be provided as stated on the agenda. If you haven't already indicated your attendance, please do so at your earliest convenience by returning your registration form or calling Jennifer Schuh at 414/738-3320. Also enclosed is the Security Card with the number to gain entrance into the Continuing Education Center.

For all Project Advisory Committee meetings, the Institute invites its member companies to send one or more representatives to attend the review sessions (first day) of any or all of the meetings. These invitations were mailed in September. PAC members from member companies are also welcome to attend the other meetings, and may stay in the CEC and attend meetings and meals of their choice, at no cost. If you wish to attend any of the other meetings, but haven't registered, please call Jennifer Schuh to do so. A meeting schedule is enclosed for your information.

We look forward to meeting with you on October 20-21.

Sincerely,

Clyde

Clyde H. Sprague, Director
Engineering Division

CHS/lms
Enclosures

THE INSTITUTE OF PAPER CHEMISTRY

Project Advisory Committee Fall Meetings
Member Dues - Funded Research Reviews

October 18, 19, 20, 25, and 26

1988

Continuing Education Center
Appleton, Wisconsin
(414) 734-9251

Committee	Review Schedule	Research Area*
Pulping Processes	Tuesday, October 18 8:30 AM - 5:30 PM Dinner at 6:00 PM	Kraft Chemical Recovery Furnace Processes Chemical Pulp Alkali Pulping Oxygen Bleaching Chlorinated Organics Analytical Techniques Analysis of Chlorinated Organics Microstructure of Wood Fibers High Lignin Pulps Photochemistry
Paper Properties	Wednesday, October 19 8:30 AM - 5:30 PM Dinner at 6:00 PM	Board Properties and Performance Process, Properties, Product Relationships Internal Strength Enhancement Strength Improvement and Failure Mechanisms On-line Measurement of Paper Mechanical Properties Fundamentals of Paper Surface Wettability
Engineering	Thursday, October 20 10:00 AM - 5:30 PM Dinner at 6:00 PM	Corrosion Recovery Boiler Fireside Corrosion Kraft Liquor Corrosivity Suction Roll Failures Corrosion-Resistant Coatings Papermaking Displacement Pressing Wet Pressing Impulse Drying

*Not in order of agenda

Committee	Review Schedule	Research Area*
Systems Analysis	Tuesday, October 25 1:00 PM - 5:30 PM Dinner at 6:00 PM	MAPPS Simulator Development Continuing System Development Performance Attribute Modeling Optimization with MAPPS MAPPS Applications and Field Experience
Forest Genetics	Wednesday, October 26 1:00 PM - 5:00 PM Dinner at 6:00 PM	Softwood Somatic Embryogenesis Initiation Development/Maturation Conversion Biochemistry of Embryo Development Hardwood Cloning

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AGENDA

ENGINEERING PROJECT ADVISORY COMMITTEE MEETING

October 20-21, 1988

Continuing Education Center (CEC)
The Institute of Paper Chemistry
Appleton, Wisconsin

Thursday, October 20, 1988

10:00am	-- INTRODUCTION	Sprague/Rounsley
10:15	-- CORROSION AND MATERIALS ENGINEERING GROUP	
	- Recovery Boiler Fireside Corrosion	Crowe/Ahlers
	- Fundamentals of Kraft Liquor Corrosivity	Crowe/Ahlers
12:00	LUNCH	
1:00pm	- Fundamentals of Corrosion Control in Paper Mills	Crowe/Ahlers
	- Evaluation of Structural Coatings for Pulp and Paper Mills	Crowe
2:00	-- PAPERMAKING PROCESSES GROUP	
	- Fundamentals of Drying	Orloff
2:45	-- BREAK	
3:00	- Fundamentals of Wet Pressing	Lindsay Aidun
4:00	- Fiber and Paper Performance Attributes in Process Simulation (MAPPS)	Jones
5:30	-- COCKTAILS	
6:00	-- DINNER - CEC DINING ROOM	

Friday, October 21, 1988

7:15am	--	BREAKFAST - CEC DINING ROOM	

COMMITTEE ACTIVITIES

8:00am	--	Project Reviews	Committee and Staff
9:30		BREAK	
9:45	--	Continued Discussion	
10:30	--	Report Preparation	Committee
11:00	--	Adjourn	
	--	LUNCH - CEC DINING ROOM	

NOTE: The spring Engineering PAC meeting is scheduled for March 23-24, 1989.

ENGINEERING

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9/88
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S T A T U S   R E P O R T S

To The

Engineering Project Advisory Committee

October 20-21, 1988
The Institute of Paper Chemistry
Continuing Education Center
Appleton, Wisconsin

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3628

RECOVERY BOILER FIRESIDE CORROSION

October 20, 1988

PROJECT SUMMARY FORM

DATE: September 9, 1988

PROJECT NO.: 3628 - Recovery Boiler Fireside Corrosion

PROJECT LEADER: David C. Crowe

IPC GOAL:

Improve safety and increase the operating life of equipment by proper selection of materials of construction and by identifying suitable process conditions.

OBJECTIVE:

To understand the causes of corrosion in the kraft recovery boiler, as a basis for devising methods of reducing corrosion damage.

CURRENT FISCAL BUDGET: $ 75,000

SUMMARY OF RESULTS SINCE LAST REPORT: (March 1988 - Sept. 1988)

A probe access port has been installed in the secondary windbox of a B & W boiler to hold a probe for the study of air port corrosion. Using this access, temperatures under the deposits located on the back side of air port tubes have been measured and found to be high enough to support corrosion.

Progress has been limited by staff changes.

INTRODUCTION:

Fireside corrosion of recovery boiler components in the lower furnace is a chronic problem. The primary concern is the possibility of a smelt explosion if the water should leak from the tubes or smelt spouts, with possible injury to personnel and loss of production. Higher operating costs include periodic inspection and repairs, plus downtime. Moreover, the cost of insurance has been increasing due to the large number of recovery boiler accidents. The last status report identified the air ports as an area of focus for this project.

Air port corrosion involves the wastage of stainless steel from composite air ports to expose the underlying carbon steel. This serious problem has been attributed to NaOH condensation, but NaOH is unstable in the boiler and often has not been detected in corrosion deposits. An alternative mechanism for this corrosion has been proposed involving pyrosulfates and chloride. By obtaining a better understanding of the corrosion mechanism, remedial measures may be devised, and conditions which increase corrosion may be avoided. Additional information is needed on the environments in the vicinity of the air ports to better define the problem.

As described in the last status report, a corrosion probe has been proposed for use in air ports. Originally, it was to be inserted through the primary windbox of a boiler so that the tip of the probe is located at the upper crotch of an air port, where corrosion has been observed. The probe was to be oriented at approximately a 45 degree angle pointing downward. Current plans are for the probe to be comprised of a stainless steel outer tube enclosing an aluminum or kanthal inner tube. The inner tube will contain molten sulfur (mp 113 C, bp 445 C) heated by a cartridge heater immersed in it. Cooling will be provided by a cooling coil located outside the windbox. The cartridge heater will be controlled by a temperature controller using a thermocouple located between the aluminum inner tube and the outer stainless steel tube. Molten sulfur will be used to maintain the temperature of the probe because it will not pose an explosion hazard if it leaks into the boiler, and it is molten throughout the range of temperatures of interest. Uniform temperature inside the probe should be attained by thermal convection of the sulfur. At the tip of the probe will be a small cup which will fill with smelt or be filled prior to the test. This cup will also serve as the corrosion coupon. The cup would maintain the corrosion deposit on the corroded surface after withdrawal from the furnace.

PROGRESS:

A probe access port has been installed in the secondary windbox of a B & W boiler to accommodate a probe for the study of air port corrosion. This access is illustrated in Fig. 1, and is the pipe protruding from the weld patch above and to the right of the rodding port. The pipe (1 3/4 in. OD) is pointed downward in the windbox and ends about 3 cm from the back face of the tube which forms the right side of the air port. This area has experienced wastage of the stainless steel cladding over a fairly large area. Access to a primary air port could not be obtained because of concerns that the probe would decrease air flow by obstructing one of the air ports. The tip of the probe will not be located in the port itself due to concerns that rodding might damage it. The access pipe is plugged when it is not in use to prevent it from filling with deposits. Using this access, temperatures in deposits located on the back side of air port tubes were measured. This is the first step in an effort to better define conditions in the corroding area.

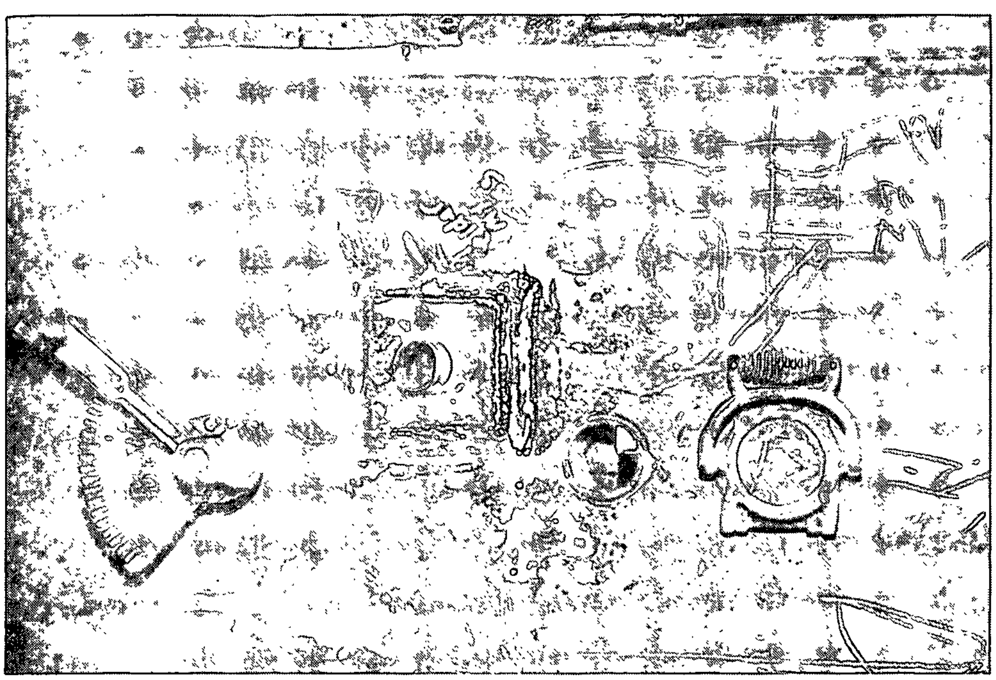

Figure 1. Probe access port for study of air port corrosion.

Temperatures were measured with a 36 inch long Inconel-sheathed Chromel-Alumel thermocouple which was inserted into the access port. The thermocouple is illustrated in Fig. 2, above the glove. The damper was closed in that windbox and the damper of the adjacent windbox was open. Only one of the pair is open at a time. The rodding port was stuck open. There was a considerable flow of air out of the slightly open rodding port, and through the access port when the thermocouple was withdrawn from it. There were not many deposits in the secondary windbox. Figure 3 is a view into a rodding port showing some deposits on the side of the air port tube located mostly near the floor of the windbox. The thermocouple was pushed down firmly into the deposits so that it touched the tube surface. Temperatures in the deposits were measured to be 200 to 270 C. The hottest area was at the bottom of the air port on the backside of the air port tube, near the floor of the windbox. This temperature rose to the highest value (270 C) following rodding of the ports. The temperatures were stable for about two hours after that. After two hours, the damper to the secondary windbox was opened and the adjacent one was closed. At this time the rodding port in the windbox was unjammed and closed. (These should close automatically). Air flow out of the windbox increased. The temperatures in the deposits then fell substantially to the range of 210 C but later increased to the range of 225 C. During this time, some of the deposits must have been blown back into the boiler because they appeared to decrease in quantity. Rodding was performed about every 2 hours; the operator noted that the air ports had been especially dirty when he had arrived that morning to start his shift.

During the test period at the mill, the temperatures varied considerably, reaching values that were surprisingly high. Temperatures were higher in the windbox while the damper was shut. At that time, gases from the boiler could have been blown into the windbox and reacted with the draft air leaking in through the open rodding port. There were more deposits in the windbox when the damper was closed; this may further contribute to a problem.

When the port was plugged and the windbox closed, temperatures were in a range where corrosion is possible. Corrosion attributed to sodium hydroxide has been found in areas of recovery boilers with temperatures of 280 to 315 C. Mixtures of KCl and NaCl may be corrosive at 260 C. Corrosive mixtures of potassium and sodium pyrosulfate may have eutectic temperatures down to 280 C.

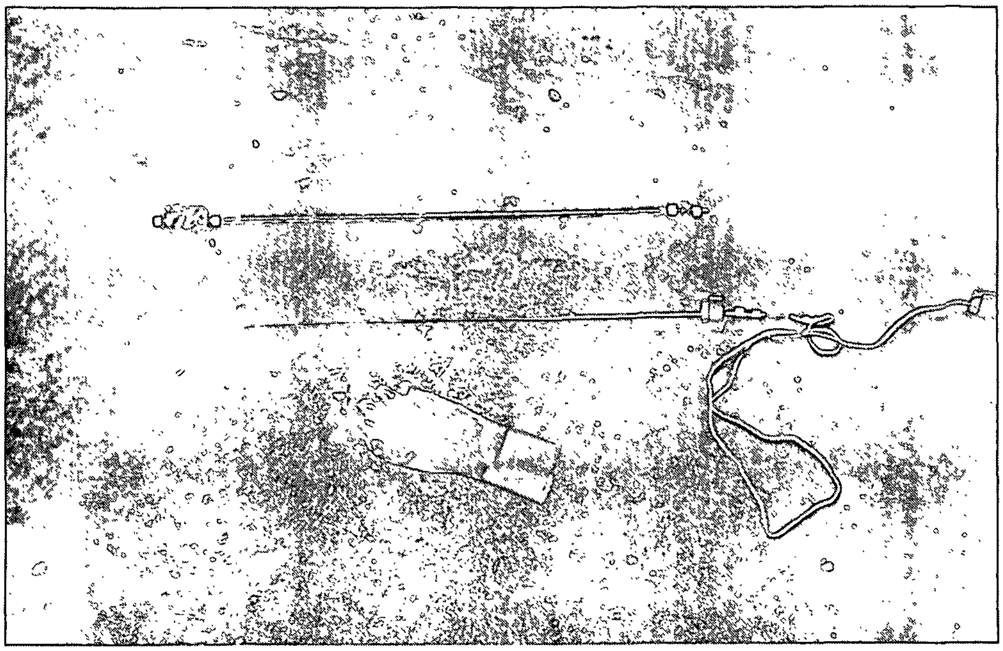

Figure 2. The thermocouple probe used for measuring temperatures in the corrosion deposits.

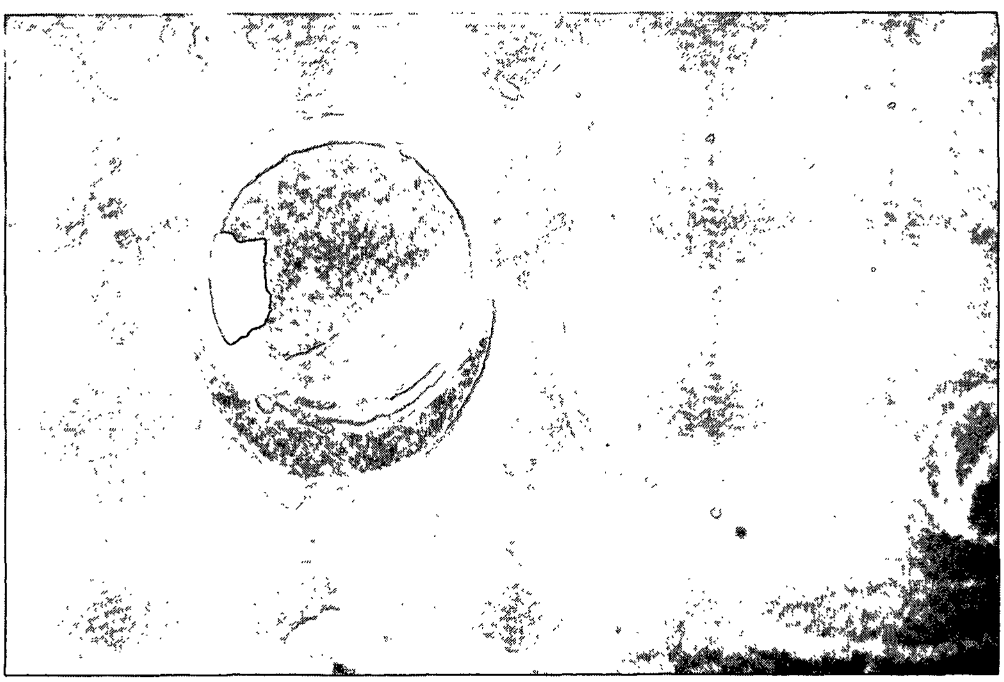

Figure 3. A view into the rodding port showing deposits on the air port tube.

Degree of pluggage of air ports can vary throughout the day, resulting in variations of air flow and deposit accumulation. The air pressure from the secondary air ports appeared to vary during the test period at our mill test site. With the damper shut, flow was lower when the ports were more plugged. Under these conditions, furnace gas may be more likely to be drawn into the windbox. In a recent publication (R.I.Anthony, Pulp and Paper, p.49 July 1988) air port cleaning systems were shown to improve recovery boiler stability. Port plugging and manual rodding caused large fluctuations in the primary air pressure, with swings to higher pressure when the ports were plugged. As noted in the article, distribution of air around the perimeter of the furnace is probably affected by port plugging and manual rodding. The degree of plugging will vary around the boiler. The fact that the primaries are smaller than the secondaries will mean that they will plug more easily, shifting air flow to the secondaries. Temperatures at the primaries may also be higher. Both increased plugging and higher temperatures may contribute to higher corrosion rates.

According to Anthony, automatic rodding resulted in significant decreases in SO_2 and TRS emissions at one boiler. During periods of pluggage, bed temperatures are decreased, as reflected in slow declines in steam production as the ports plug up. At these lower temperatures, more H_2S and gaseous sulfur would be produced. This would mix with the excess O_2 and oxidize to form SO_2. A mechanism for air port corrosion involving pyrosulfate formation has been proposed in the last status report. It requires SO_2 or SO_3. The SO_3 may form from SO_2 which is produced in higher quantities when the air ports are plugged and when deposits have accumulated. The SO_2 could gain access to windboxes where the dampers are closed (as was the situation in the windbox where the access port is installed).

Anthony found that each time the ports were rodded, the O_2 level in the flue gas increased. A similar increase would be expected in the air port areas, giving a more oxidizing atmosphere. Oxidizing and reducing environments could move up and down according to the extent of pluggage, leading to cycling of corrosion processes.

The temperatures of deposits on the back sides of air port tubes were higher when the windbox damper was closed and deposits had accumulated. The quantity of deposits was also larger at this time. At these higher temperatures, corrosion is more likely. Removal of deposits and even flow of air will decrease temperatures and the chance of corrosion. Thus, frequent rodding, even air flow, and stable operation may contribute to lower corrosion rates.

ACTIVITIES PLANNED:

1. Detailed design of the corrosion probe will be done. The probe will need to be heated internally because the windbox ambient temperature will be lower than the desired test temperatures. The molten sulfur probe continues to look attractive for this application.
2. Construct the corrosion probe and bench test it.
3. Confirm the observations of temperatures in the windbox area at other times and places.
4. Obtain samples of smelt and ash withdrawn from the vicinity of air ports and perform chemical analyses to obtain a better knowledge of local conditions in the boiler.
5. Begin laboratory studies with powdered simulated smelt samples using tube furnaces. These will focus on identifying conditions which will result in corrosion rates of stainless steel which exceed those of carbon steel. These tests were outlined fully in the last status report.

SIGNIFICANCE TO THE INDUSTRY:

An improved knowledge of corrosion mechanisms in recovery boilers will aid in the design of remedial measures which will extend the operating life and improve safety.

Preliminary observations suggest that conditions for corrosion could be present when the air ports are plugged and the windbox damper is closed.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3556

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

October 20, 1988

PROJECT SUMMARY

DATE: August 19, 1988

PROJECT NO.: 3556 - Fundamentals of Kraft Liquor Corrosivity

PROJECT LEADER: David Crowe

IPC GOAL:

Increase the useful life of equipment by proper selection of materials of construction and by identifying suitable process conditions.

OBJECTIVE:

To understand the causes of corrosion and corrosion-assisted cracking of carbon steels exposed to kraft liquor as a basis for developing methods for reducing corrosion damage in kraft process streams.

CURRENT FISCAL BUDGET: $ 75,000

SUMMARY OF RESULTS SINCE LAST REPORT: (March 1988 - Sept. 1988)

Additional preliminary results have been obtained concerning the effects of velocity on corrosion in kraft white liquor. Both the rotating cylinder electrode and the flow loop have been used. There was considerable scatter in corrosion rates measured throughout the range of velocity tested even when the corrosion potential was controlled.

INTRODUCTION:

Corrosion rates in kraft white liquor increase as the velocity of the liquor is increased. Measurements made in mills have shown this effect is especially pronounced in piping. Typical white liquor design velocities are 1 to 5 ft/s in troughs, 6 to 7 ft/s in underflow lines from the clarifier and 8 to 10 ft/s in pumped 6 to 8 inch lines. Stainless steel would be used in many of these locations. At the high flow rates, the Reynolds number is of the order of 10^6 and the shear stress is 12-14 N/m^2. At low flow rates, the Reynolds number is 10^4 to 10^5 and the shear stress is 0.1 N/m^2. An improved understanding of the relationship between the corrosion rate and the velocity will assist equipment designers in sizing equipment or choosing materials to minimize the costs due to corrosion.

Testing of the effects of velocity using pipe loops is cumbersome and slow, and involves large quantities of liquor. The rotating cylinder electrode (RCE) is an alternative which allows systematic and relatively rapid investigation of the effects of velocity. Smaller quantities of liquor may be used compared to flow loops, providing better control of liquor conditions.

The objective of this work is the development of the RCE technique for the study of velocity effects in kraft liquor. This will then be used to develop data to provide to pipe designers so they can relate flow parameters such as velocity in pipes to corrosion rate via shear or Reynolds number (Re). The corrosion rate will be related to shear stress, Re and mass transfer for the RCE and compared with relations between corrosion rate, Re, shear and mass transfer in the flow loop to determine if they are similar. If they are, the RCE may be used to study velocity effects by modelling the flow in pipes or other geometries in white liquor.

PROGRESS:

The rotating cylinder electrode has been described and illustrated in previous reports. A schematic diagram of the flow loop is shown in Fig. 1. A bypass loop was added during the last period to attain lower flow rates in the test section of the loop. Approximately 30 L of liquor are used in the flow loop. Other details of construction were described previously. All potentials are quoted with respect to the silver/ silver sulfide reference electrode.

Previous results have shown that there is significant scatter in the corrosion rates measured at the same velocity and temperature with the rotating cylinder electrode. Effects of temperature or length of test were difficult to establish due to this scatter, which was apparently the result of differences in corrosion potential.

The different corrosion potentials reflected the fact that some electrodes passivated before others. Some of these results are shown in Fig.2. There was no clear effect of temperature or exposure time.

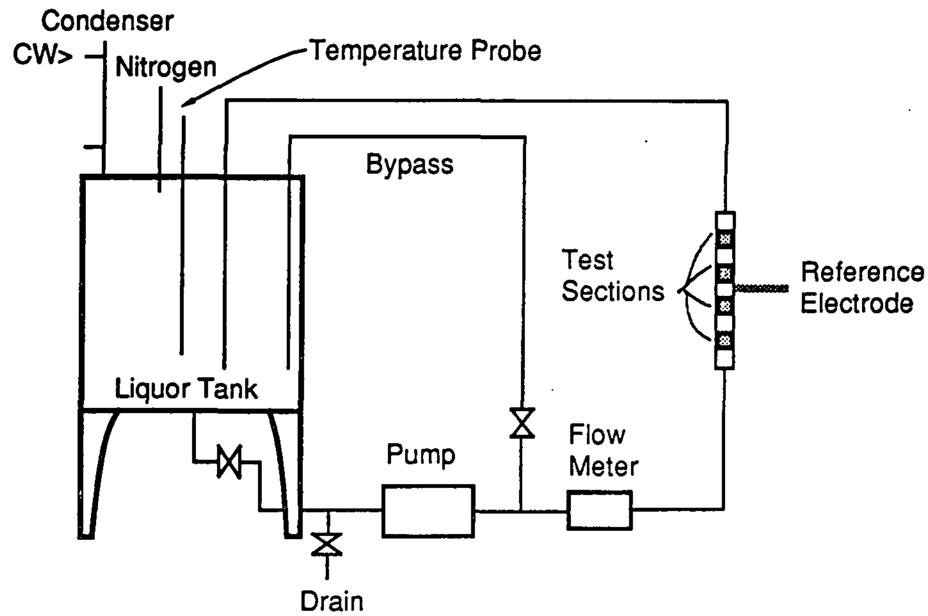

Figure 1. The pipe flow loop.

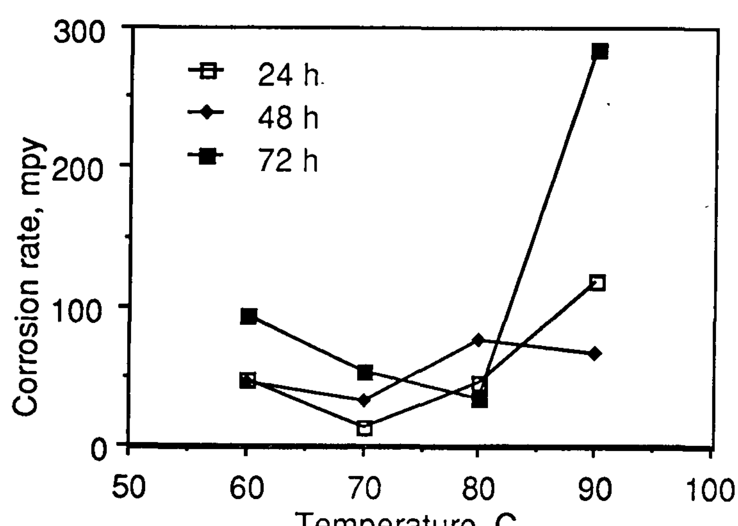

Figure 2. Corrosion rates (weight loss) at 1000 rpm for a range of exposure time and temperature at the free corrosion potential.

If potential is uncontrolled, its changes will confound the variation in corrosion rate due to velocity changes as it did the data above concerning temperature. Corrosion rate was measured at various potentials via weight loss tests to determine how the potential influences the corrosion rate in flowing liquor and to establish the potential at which to conduct further tests. The results are illustrated in Fig. 3. They show the strong effects of flow and potential on corrosion rates. The corrosion rate of 1786 mpy is the highest ever measured in this laboratory in white liquor. These results account for the great variability in tests with uncontrolled potential. Very high rates would be measured even if only a short time were spent between -50 and -100 mV. This range corresponds to the active/passive peak of the polarization curve, where dissolution currents are greatest.

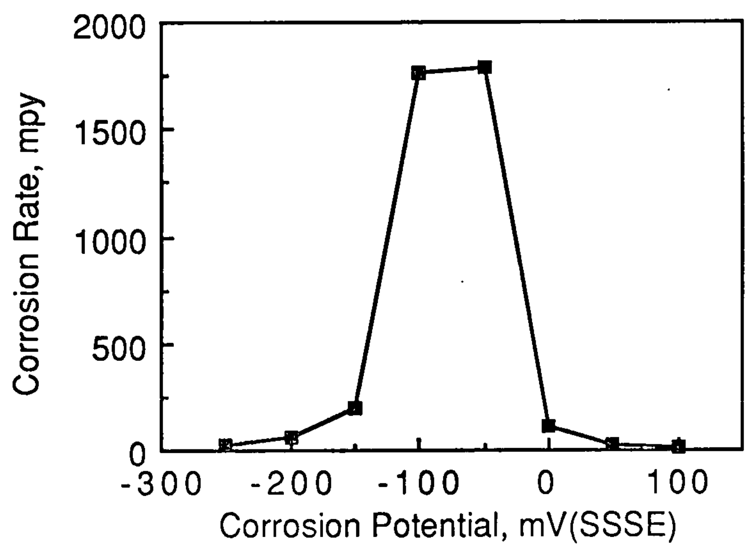

Figure 3. Corrosion rates were extremely high at active/passive potentials, 90 C, 1000 rpm.

To minimize scatter and improve repeatability, some testing to determine effects of velocity was done at controlled potential. A potential of -150 mV was selected for the tests. This is in the range of previously observed free corrosion potentials. Tests were performed to measure corrosion rate as a function of rotation rate, and are summarized in Table 1 and Fig. 4. Multiple tests were done at the same conditions to determine the repeatability at 90 C with a controlled potential. The measured corrosion rates showed considerable scatter, especially at the high rotation rates. This was surprising because it had been expected that, by controlling the potentials, corrosion rates would be more reproducible. The variation seen in Fig. 2 may have been not entirely due to shifts in the corrosion potential. The reasons for the variation even when the potential is controlled, are unknown at this time.

Table 1

Dependence of Corrosion Rate on Rotation Rate

rpm	C.R.,mpy	v, m/s	Re	τ, N/m^2
0	33, 76, 39	0	0	0
10	158, 129, 83	$4.8x10^{-3}$	83	$5.3x10^{-4}$
100	64, 63, 61	$4.8x10^{-2}$	832	$2.7x10^{-2}$
500	143, 121, 137	0.24	4160	0.41
1000	217, 169, 118, 223, 145	0.48	8322	1.34
2500	313, 59	1.20	20805	6.37
3000	-	1.44	24966	8.68

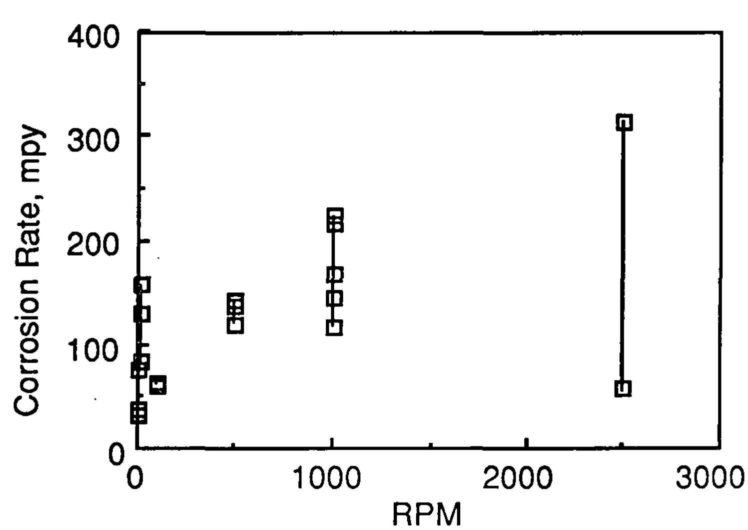

Figure 4. Dependence of corrosion rate on rotation rates at -150 mV, 90 C.

There are some possibilities which may explain the scatter in corrosion rates, and these will be investigated. A corroded layer may spall off more easily or frequently from some test electrodes. The iron sulfide film is inherently poorly formed, and may be more so on certain samples. Efforts will be made to obtain an adherent layer by potentiostatting the sample for some period of time before beginning to rotate the electrode. There is some variability in the currents to polarize the carbon steel at -150 mV, with peaks found at varying potentials depending on the rotation rate; this may cause some variation in corrosion rates. Perhaps a different control potential will have to be selected.

Preliminary tests were done in the flow loop. Pumping rate was adjusted to 2.08 gal/m to give Re = 24966, the same as expected on the RCE at 3000 rpm. Unfortunately, the RCE could not be used at this high speed due to severe vibration. Results are summarized in Table 2.

Repeatability was poor for the flow loop results in agreement with the results for the RCE. The same test coupons were used in all runs, so compositional differences should have been minimal. Composition of the liquor was confirmed following the tests. Improvements in surface finish are planned in the hope that this will improve the reproducibility.

In run 1, there were difficulties controlling the potential, so that the control potential was not established until halfway through the run. There were no problems with subsequent runs. The similarity of corrosion rates for the electrodes at controlled potential and free corrosion potential reflects the fact that the free corrosion potential was in the same range as the control potential during the test. This was similarly true in run 4. In run 2, the electrodes which were freely corroding started to passivate, as reflected by the corrosion potential of +15. Time spent at potentials at the active/passive potential could account for the higher corrosion rates relative to the control potential electrodes. The high corrosion rates in run 3 are unexplained.

Table 2

Flow Loop Results

	Corrosion rate, mpy			
Electrode	5	6	7	8
Potential	-150 mV	-150 mV	Ecorr	Ecorr
Run 1	158	138	162	155
			E = -240/-102 mV	
Run 2	95	94	271	214
			E = -234/+15 mV	
Run 3	346	285	254	304
			E = -145/-85 mV	
Run 4	83	79	95	82
			E = -104/-125 mV	

Under freely corroding conditions, passivation should occur after some period of time, as was observed in stagnant liquor tests (16), and the electrode will pass through the active/ passive potential range, where dissolution currents are high. The amount of fluctuation in this range and the time spent in the active/passive range both determine the corrosion rates. This effect is expected in flowing liquor, and is quite pronounced, as corrosion rates are extremely high in the active/passive range, as seen in Fig. 3. Increased dissolution rates in the active/passive range at higher velocities are due to improved mass transfer of corrosive species to and from the surface. Thus, corrosion rates will be higher in the flowing liquor, and so will be the size of the variation or scatter. On the other hand, even in the tests with controlled potential, corrosion rates showed surprising variability. Perhaps differences in surface conditions or alloy composition change the form of the polarization curve.

The rotating cylinder electrode technique is based on well established hydrodynamic theory and has been demonstrated to be useful for study of flow effects on corrosion. Its relevance in kraft white liquor should be confirmed by performing parallel tests with the flow loop at similar conditions. Then the method may be used with confidence to systematically investigate velocity effects.

PLANS FOR THE NEXT PERIOD:

1. Continue testing using the RCE and pipe flow loops to obtain information on effects of potential, velocity (Re, τ) and surface finish on corrosion rates.
2. Validate the RCE method for testing velocity effects.
3. Perform preliminary tests with stainless steels.
4. Convert data to a form useful to pipe designers.
5. Verify the validity of the polarization resistance technique under flow conditions so that it may be used for corrosion rate measurement or for on-line monitoring.
6. Justify the completion of design and demonstration of the corrosion monitoring system through investigation of commercially available units.

SIGNIFICANCE TO THE INDUSTRY:

In tests of the effect of velocity on corrosion in white liquor, very high corrosion rates have been measured, confirming the importance of flow on corrosion rates. The RCE technique shows promise for the study of these flow effects on corrosion. Development of the RCE technique will simplify testing to relate corrosion rates to hydrodynamic parameters used by pipe and equipment designers.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3309

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

October 20, 1988

PROJECT SUMMARY FORM

DATE: August 19, 1988

PROJECT NO.: 3309 - Fundamentals of Corrosion Control in Paper Mills

PROJECT LEADER: David Crowe

IPC GOAL:

Increase the useful life of equipment by proper selection of construction materials and by identifying suitable process conditions.

OBJECTIVE:

To improve the life of paper machine suction rolls through corrosion and corrosion fatigue studies to establish mechanisms that limit lifetime and to identify failure preventive measures.

CURRENT FISCAL BUDGET: $ 150,000

SUMMARY OF RESULTS SINCE LAST REPORT: (Feb. 1988 - Sept. 1988)

No results have been obtained in the last period due to staff changes and reassignments.

FUTURE PLANS:

1. Continue near threshold fatigue testing of current test materials using an environment which simulates the composition of the electrolyte in a pit or crevice. Attempt to relate this data to cost per revolution of the suction roll. If possible, obtain Alloy 86 for testing.

2. Continue the rotating bending fatigue testing and alternating bending testing of Alloys 63 and 75 in a simulated pit environment saturated with ferric

chloride and chromic chlorides with the pH adjusted to 1 with HCl. So far, the fully reversed loading S-N tests have been of little value in differentiating between suction roll alloys. If this work in a simulated pit environment does not provide results which distinguish between alloys, then this line of inquiry should be discontinued.

3. Extend the investigation of crack path through the suction roll microstructures in an effort to identify those metallurgical phases which are responsible for rapid cracking and those which may be responsible for crack retardation in the materials tested in near threshold fatigue studies.

4. Investigate the microstructure of weld deposits on repaired suction rolls when filler metal has been added, especially for A75, A86 and VKA378. These results could be compared with the results of Task 3 to indicate how this welding might affect fatigue life.

5. Investigate the effect of superimposed mean stresses on the crack initiation resistance of suction roll alloys in simulated white waters, to simulate residual stress effects.

6. Investigate the effect of surface finish on fatigue crack growth initiation behavior in suction roll alloys exposed to simulated white water environments.

7. Investigate corrosion current transients of suction roll materials with different simulated white waters utilizing tests to obtain a quantitative evaluation of the dissolution rates occurring at the crack tip.

8. Summarize the results to date in a report.

SIGNIFICANCE TO THE INDUSTRY:

The near threshold crack growth behavior has been shown to agree with service performance provided that residual stress effects are considered. This will aid in prediction of performance of new alloys with better success than in the past.

It has been confirmed that cosmetic welding, without post weld stress relief, will accelerate corrosion and stress corrosion in suction roll alloys. Cosmetic welding should be minimized.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3607

EVALUATION OF STRUCTURAL COATINGS FOR PULP AND PAPER MILLS

October 20, 1988

PROJECT SUMMARY FORM

DATE: August 18, 1988

PROJECT NO.: 3607 - Evaluation of Structural Coatings for Pulp and Paper Mills

PROJECT LEADER: David Crowe

IPC GOAL:

Increase the useful life of equipment by proper selection of materials of construction and by identifying suitable process conditions.

OBJECTIVE:

To rank commercially available paint systems based on their ability to protect structural steel in the aggressive environments found in the pulp and paper mill, especially if applied under less than optimum conditions.

CURRENT FISCAL BUDGET: None. Funded by Project 3309.

SUMMARY OF RESULTS SINCE LAST REPORT: (Sept. 1987 - Sept. 1988)

The painted panels have been inspected after six months exposure in the mills.

INTRODUCTION:

Failure of structural coatings is a costly problem for pulp and paper mills. A common sight is the degradation of coatings on beams, machine supports, and other structures which rely on coatings for protection from corrosion. This degradation is caused by the combined action of high humidity, aggressive gases and salt deposits. There is a lack of information regarding the durability of the coatings based on pulp and paper mill exposure. Comparisons of the performance of various coatings under identical conditions are often unavailable. The objective of this project has been to evaluate and rank coatings based on their durability in pulp and paper mills.

The quality of surface preparation prior to application is critical for many coatings. Most mills experience difficulties in obtaining full compliance with surface recommendations made by vendors. The sensitivity of the coatings to inadequate surface preparation may be a significant factor in coating selection, and so the effects of surface preparation are being explored in this project.

Standardized carbon steel (KTA-Tator) test panels were exposed for approximately three months at five mills. Test areas included the recovery boiler area, paper machine wet end, bleach plant, and other potentially corrosive areas. After the pre-rust exposure period, these panels simulate a rusted mill structure with impurities such as chloride incorporated into the rusted surface.

The pre-rusted panels were then forwarded to KTA-Tator Co. for surface preparation and coating under the direction of IPC personnel. Conditions of application and dry film thickness were documented. On the return of the panels to the Institute, the coatings were intentionally damaged in a reproducible fashion by scribing a "T" that penetrated the coating to the metal substrate. This was done in an effort to determine the effects of surface damage. The coated panels were then reinstalled in the mills.

Ten coating systems have been selected for the test program and are compatible with the range of surface preparation techniques used. A range of surface preparation techniques from better to worse than those recommended by the coating vendor are being tested. The coatings systems and surface preparations are listed by number in Appendix 1.

PROGRESS:

The coated panels were inspected after 6 months exposure. The specific area in which the test panels were located, performance rank of each coating system, and description of types of damage for the coating are listed in Appendix 2. Summaries of the performance rank for each coating system are listed in Tables 1 to 4. Remember that within each coating system, a variety of surface finishes was used; these were summarized in the last status report.

Table 1

Frequency of various performance ranks for each coating system in all mill locations.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure		6				15				7
Poor	1	8		2	1	3				5
Fair	9	7	1	7	4		1		12	5
Good	20		5	5	6	1		5	8	2
Excellent	53	3	9	21	19	12	13	9	62	11
No Observ.	4	5	5	1	1	2			5	1

Table 2

Frequency of various performance ranks for each coating system in bleach plants.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure										
Poor										
Fair										
Good								5		
Excellent	14			4	4	4	13	9	13	2
No Observ.										

Table 3

Frequency of various performance ranks for each coating system in recovery areas.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure						10				4
Poor	1			2	1	3				4
Fair	6			3	4		1		10	4
Good	13			1	2				3	
Excellent	32			15	13	8			41	8
No Observ.										

Table 4

Frequency of various performance ranks for each coating system in paper machine areas.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure		6				5				2
Poor		8								1
Fair	2	7	1	3					1	2
Good	7		5	4	4	1			5	1
Excellent	7	3	9	2	2				6	1
No Observ.	4	5	5	1		2			5	1

Visual examination of the test racks revealed that several of the coating systems underwent extensive damage while others remained unchanged. The general condition was ranked, types of damage were noted, and the panels were photographed.

Photographic examples of the various forms of damage experienced by the coatings, as described in the Appendix, are shown in Figures 1-5. Figure 1 shows cracking, blistering and delamination experienced by panels coated with a zinc rich epoxy primer and chlorinated rubber topcoat (system 2). These panels were exposed near the wet end of paper machines. System 3, a three coat zinc primer/ epoxy combination, provided good to excellent performance in the paper machine area. The panels coated with System 3 which gave only 'good' performance had a commercial blast surface preparation. The panel in only fair condition was coated over a new surface; the reason for degradation is unknown.

The one step conversion coating, system 6, proved to be inadequate in nearly all of the various areas of the mill, with widespread rusting, pitting and blistering occurring on the panel surfaces as seen in Fig. 2. Further trials with the conversion coating should include an epoxy topcoat. Panels coated with one coat of gloss epoxy, system 10, suffered various types of coating failure during exposure in different mill areas. Examples of permeation, pin-holing, blistering, and edge damage which occurred on these panels are shown in Fig. 3 and 5.

Panels coated with a first coat epoxy mastic and second coat epoxy phenolic, system 4, experienced undercutting damage in one recovery area as shown in Fig. 4. System 4 was good to excellent in most locations. The fair and poor panels were in the paper machine, recovery and recausticizing areas, which were especially harsh in those mills.

System 5, alkyd primer with 2 coats of epoxy, seems to have been most challenged in the recovery area. It rusted in 3 of the mills. System 7 gave very good performance with only one panel ranking 'fair' in an outside structure (grouped with recovery boiler in the tables). System 8, the vinyl ester was tested in the bleach plant area only, and disappointingly, some panels degraded to 'good' condition. System 9 should be similar to system 3, the only difference being between inorganic and organic zinc primers. Behavior was similar in the paper machine area where both systems were evaluated. System 9 did not fare well in the recovery area.

Summary

The environmental conditions experienced by the coatings in the 6 areas within the mills were often significantly different. For example, in the recovery area some racks were outside, while at other mills the racks were indoors. Thus there was a wide variation in type of exposure within any type of area. The conversion coating, the chlorinated rubber and the single coat of epoxy were generally inadequate.

FUTURE PLANS:

Inspect the panels in spring 1989. At that time, panels with the chlorinated rubber (system 2), the conversion coating (system 6) and the single coat of epoxy (system 10) will be removed. These panels may be replaced with others with different coating systems.

ACKNOWLEDGMENT

This project was managed for the past year by Mark Revall who developed the data base for the project and contributed substantially to this report.

SIGNIFICANCE TO THE INDUSTRY:

This project will provide mills with an independent assessment of the long-term reliability of various structural coating systems for pulp and paper mill applications.

Clorinated rubber over inorganic zinc primer is inadequate for paper machine areas and most other areas of the pulp and paper mill. Conversion coatings cannot be expected to provide satisfactory performance, although topcoating them with epoxy may provide improved performance. This project may provide justification for the added cost of proper surface preparation prior to coating.

APPENDIX - Coating Systems & Surface Finish Prior to Coating

Coating Systems

Specified thickness requirements (in mils) are indicated in parentheses.

System 1: 1st coat: Plasite 7103 epoxy amide primer (4.0-5.0), 2nd coat: Plasite 7122 epoxy phenolic topcoat (6.0-7.0).

System 2: 1st coat: Porter Zinclock 351 inorganic zinc rich epoxy primer (2.5), 2nd coat: Porter CR1131 chlorinated rubber (3.0).

System 3: 1st coat: Porter Zinclock 308 organic zinc rich primer (2.5), 2nd coat: Porter 4361 high build epoxy (5.0), 3rd coat: Porter 4310 gloss epoxy (2.0).

System 4: 1st coat: Plasite C720 epoxy mastic (7.0), 2nd coat: Plasite 7122 epoxy phenolic topcoat (6.0-7.0).

System 5: 1st coat: Porter U-Prime alkyd primer (2.0), 2nd coat: Porter 4361 high build epoxy (5.0), 3rd coat: Porter 4310 gloss epoxy (2.0).

System 6: Neutrarust 661 conversion coating (1.0-2.0).

System 7: 1st coat: Porter Zinclock 351 inorganic zinc rich epoxy (2.5), 2nd coat: Porter 4361 high build epoxy (5.0), 3rd coat: Porter 1710 vinyl (1.5).

System 8: Plasite 4100 vinyl ester, 2 coats (35.0-45.0).

System 9: 1st coat: Porter Zinclock 351 (2.5), 2nd coat: Porter 4361 high build epoxy (5.0), 3rd coat: Porter 4310 gloss epoxy (2.0).

System 10: Porter 4310 gloss epoxy (2.0).

Surface Preparation

1. Water Wash
2. Wash + Power Tool Cleaning According to SSPC-SP3
3. Commercial Blast according to SSPC-SP6
4. White Metal Blast according to SSPC-SP5
5. New, not prerusted.

APPENDIX 2 - List of Paint Panel Results

Key

Location = Mill ID Code

Area

1 - Recovery
2 - Paper Machine
3 - Bleach Plant
4 - Chemical Preparation
5 - Exterior Structure
6 - Evaporators, Recausticizing

Coating Type/ Product = Coating System

Finish = Surface Preparation Method

Relative Rank of Performance

0 - No Observation

1 - Excellent

2 - Good

3 - Fair

4 - Poor

5 - Failure

Perf. = Damage Descriptions

0 - No change

1 - Cracking

2 - Pinpoint rusting

3 - Undercutting

4 - Blistering

5 - Peeling

6 - Flaking or scaling

7 - Rust in scribe area

8 - Rust in discontinuous areas and edges

9 - Pitting

10 - Permeated

PLATE	RACK	LOCATION	AREA	COATING	PRODUCT	FINISH	REL RANK	PERF.
82210	455	5	1	4	4	2	1	0
82569	147	4	1	6	6	1	1	0
82564	499	3	1	9	9	4	1	0
82260	455	5	1	6	6	1	1	0
82563	499	3	1	9	9	4	1	0
82211	455	5	1	9	5	4	1	0
82561	499	3	1	1	1	4	1	0
82233	455	5	1	4	4	2	1	0
82555	499	3	1	9	9	3	1	0
82217	455	5	1	1	1	4	1	0
82712	499	3	1	9	9	5	1	0
82262	455	5	1	6	6	1	1	0
82586	147	4	1	1	1	4	1	0
82218	455	5	1	5	5	2	1	0
82574	147	4	1	4	4	2	1	0
82229	455	5	1	10	10	1	1	0
82573	147	4	1	4	4	2	1	0
82219	455	5	1	1	1	3	1	0
82572	147	4	1	10	10	1	1	0
82227	455	5	1	1	1	4	1	0
82591	147	4	1	4	4	2	1	0
82220	455	5	1	9	9	3	1	0
82590	147	4	1	10	10	1	1	0
82766	455	5	1	1	1	5	1	0
82589	147	4	1	6	6	1	1	0
82221	455	5	1	5	5	2	1	0
82588	147	4	1	9	9	4	1	0
82235	455	5	1	5	5	2	1	0
82765	455	5	1	1	1	5	1	0
82576	147	4	1	5	5	2	1	0
82236	455	5	1	10	10	1	1	0
82585	147	4	1	1	1	4	1	0
82209	455	5	1	9	9	3	1	0
82723	147	4	1	9	9	5	1	0
82767	455	5	1	9	9	5	1	0
82570	147	4	1	6	6	1	1	0
82567	147	4	1	9	9	4	1	0
82377	124	2	1	10	10	1	1	0
82721	147	4	1	1	1	5	1	0
82790	124	2	1	9	9	5	1	0
82791	124	1	1	9	9	5	1	0
82380	124	2	1	4	4	2	1	0
82562	499	3	1	1	1	4	1	0
82379	124	2	1	4	4	2	1	0
82550	499	3	1	4	4	2	1	0
82382	124	2	1	5	5	2	1	0
82579	147	4	1	9	9	3	1	0
82792	124	2	1	1	1	5	1	0
82580	147	4	1	9	9	3	1	0
82788	124	2	1	1	1	5	1	0
82722	147	4	1	9	9	5	1	0
82384	124	2	1	1	1	3	1	0
82578	147	4	1	1	1	3	1	0
82396	124	2	1	9	9	3	1	0
82231	455	5	1	9	9	4	1	0
82385	124	2	1	9	9	3	1	0
82234	455	5	1	1	1	3	1	0
82378	124	2	1	10	10	1	1	0
82768	455	5	1	9	9	5	1	0
82386	124	2	1	9	9	3	1	0
82552	499	3	1	5	5	2	1	0
82376	124	2	1	6	6	1	1	0
82575	147	4	1	5	5	2	1	0

82391	124	2	1	1	1	4	1	0
82592	147	4	1	5	5	2	1	0
82793	124	2	1	9	9	5	1	0
82571	147	4	1	10	10	1	1	0
82294	124	2	1	9	9	4	1	0
82539	455	5	1	10	10	1	1	0
82375	124	2	1	6	6	1	1	0
82556	499	3	1	9	9	3	1	0
82293	124	2	1	9	9	4	1	0
82720	147	4	1	1	1	5	1	0
82789	124	2	1	1	1	5	1	0
82226	455	5	1	6	5	1	1	0
82228	455	5	1	4	4	2	1	0
82577	147	4	1	1	1	3	1	0
82292	124	2	1	1	1	4	1	0
82383	124	2	1	1	1	3	2	8
82904	398	1	1	1	1	5	2	8
82693	398	1	1	9	9	5	2	8
82292	398	1	1	1	1	4	2	8
82395	124	2	1	1	1	3	2	8
82283	398	1	1	1	1	3	2	8
82554	499	3	1	1	1	3	2	8
82295	398	1	1	1	1	3	2	8
82709	499	3	1	1	1	5	2	78
82294	398	1	1	9	9	4	2	8
82279	398	1	1	4	4	3	2	8
82294	398	1	1	1	1	3	2	8
82281	398	1	1	5	5	2	2	6
82713	499	3	1	1	1	5	2	78
82291	398	1	1	1	1	4	3	8
82692	398	1	1	1	1	5	3	8
82694	398	1	1	9	9	5	3	8
82903	398	1	1	9	9	5	3	8
82381	124	2	1	5	5	2	3	68
82298	398	1	1	9	9	3	3	8
82551	499	3	1	5	5	2	3	78
82292	398	1	1	5	5	2	3	8
82293	398	1	1	9	9	4	3	8
82716	499	3	1	9	9	5	3	8
82296	398	1	1	9	9	3	3	8
82695	398	1	1	1	1	5	3	8
82296	398	1	1	9	9	3	3	8
82290	398	1	1	4	4	2	3	8
82562	499	3	1	5	5	2	4	76
82549	499	3	1	4	4	2	4	8
82275	398	1	1	6	5	1	4	7810
82553	499	3	1	1	1	3	4	8
82276	398	1	1	5	6	1	4	7810
82567	499	3	1	4	4	2	4	8
82566	499	3	1	10	10	1	4	27810
82545	499	3	1	6	6	1	5	478910
82547	499	3	1	10	10	1	5	23489
82449	499	3	1	10	10	1	5	3578
82278	398	1	1	10	10	1	5	278
82277	398	1	1	10	10	1	5	279
82548	499	3	1	6	6	1	5	3578
82565	499	3	1	6	6	1	5	48910
82714	600	4	2	2	2	5	0	0
82667	600	4	2	2	2	2	0	0
82677	600	4	2	9	9	4	0	0
82732	600	4	2	1	1	5	0	0
82715	600	4	2	3	3	5	0	0
82668	600	4	2	4	4	2	0	0
82729	600	4	2	1	1	5	0	0

82670	600	4	2	1	1	3	0	0
82669	600	4	2	5	5	2	0	0
82733	600	4	2	2	2	5	0	0
82735	600	4	2	9	9	5	0	0
82675	600	4	2	2	2	4	0	0
82672	600	4	2	3	3	3	0	0
82673	600	4	2	9	9	3	0	0
82683	600	4	2	9	9	4	0	0
82682	600	4	2	3	3	4	0	0
82676	600	4	2	3	3	4	0	0
82734	600	4	2	3	3	5	0	0
82731	600	4	2	9	9	5	0	0
82688	600	4	2	6	6	1	0	0
82674	600	4	2	1	1	4	0	0
82666	600	4	2	10	10	1	0	0
82671	600	4	2	2	2	3	0	0
82665	600	4	2	6	6	1	0	0
82350	273	2	2	9	9	3	1	0
82347	273	2	2	1	1	3	1	0
82624	256	3	2	3	3	3	1	0
82338	273	2	2	1	1	4	1	0
82800	273	2	2	1	1	5	1	0
82689	276	1	2	3	3	5	1	0
82755	222	5	2	3	3	5	1	0
82334	273	2	2	1	1	3	1	0
82756	222	5	2	9	9	5	1	0
82331	273	2	2	4	4	2	1	0
82299	222	5	2	9	9	4	1	0
82619	256	3	2	10	10	1	1	0
82435	276	1	2	9	9	4	1	0
82807	273	2	2	9	9	5	1	0
82728	256	3	2	1	1	5	1	0
82806	273	2	2	3	3	5	1	0
82623	256	3	2	2	2	3	1	0
82340	273	2	2	3	3	4	1	0
82622	256	3	2	1	1	3	1	0
82434	276	1	2	3	3	4	1	0
82711	256	3	2	3	3	5	1	0
82348	273	2	2	2	2	3	1	0
82628	256	3	2	3	3	4	1	0
82337	273	2	2	9	9	3	1	0
82621	256	3	2	5	5	2	1	0
82351	273	2	2	1	1	4	1	0
82730	256	3	2	9	9	5	1	0
82346	273	2	2	5	5	2	1	0
82349	273	2	2	3	3	3	1	0
82901	273	2	2	2	2	5	1	0
82636	256	3	2	4	4	2	1	0
82640	256	3	2	3	3	3	2	78
82427	276	1	2	5	5	2	2	8
82250	222	5	2	1	1	4	2	8
82626	256	3	2	1	1	4	2	78
82239	222	5	2	3	3	4	2	8
82629	256	3	2	9	9	4	2	79
82211	222	5	2	4	4	2	2	7
82691	276	1	2	1	1	5	2	8
82808	222	5	2	5	5	2	2	8
82431	276	1	2	9	9	3	2	8
82332	273	2	2	5	5	2	2	6
82358	276	1	2	3	3	3	2	8
82907	222	5	2	4	4	2	2	7
82432	276	1	2	1	1	4	2	8
82336	273	2	2	3	3	3	2	8
82625	256	3	2	9	9	3	2	78

82696	275	1	2	9	9	5	2	8
82214	222	5	2	3	3	3	2	8
82245	222	5	2	1	1	3	2	8
82637	256	3	2	5	5	2	2	78
82248	222	5	2	4	4	2	2	8
82429	276	1	2	1	1	3	2	8
82620	256	3	2	4	4	2	2	78
82638	256	3	2	1	1	3	2	78
82242	222	5	2	9	9	3	2	8
82617	256	3	2	6	6	1	2	78
82634	256	3	2	10	10	1	2	78
82249	222	5	2	10	10	1	3	78
82352	273	2	2	2	2	4	3	68
82426	276	1	2	4	4	2	3	8
82635	256	3	2	2	2	2	3	78
82753	222	5	2	1	1	5	3	78
82520	222	5	2	4	4	2	3	7
82446	276	1	2	4	4	2	3	8
82619	256	3	2	2	2	2	3	78
82802	276	1	2	3	3	5	3	8
82305	222	5	2	10	10	1	3	7
82710	256	3	2	2	2	5	3	78
82639	256	3	2	2	2	3	3	78
82690	276	1	2	9	9	5	3	8
82309	222	5	2	1	1	3	3	8
82243	222	5	2	2	2	3	3	7
82527	256	3	2	2	2	4	3	78
82341	273	2	2	9	9	4	3	8
82335	273	2	2	2	2	3	4	68
82433	276	1	2	2	2	4	4	2610
82330	273	2	2	10	10	1	4	7910
82306	222	5	2	2	2	2	4	1678
82308	276	1	2	2	2	5	4	27910
82339	273	2	2	2	2	4	4	68
82310	222	5	2	2	2	3	4	1678
82805	276	1	2	2	2	5	4	27810
82754	222	5	2	2	2	5	4	1679
82246	222	5	2	2	2	4	5	1678
82445	276	1	2	2	2	2	5	123678
82247	222	5	2	2	2	2	5	1678
82424	276	1	2	10	10	1	5	27910
82251	222	5	2	6	6	1	5	7810
82443	276	1	2	6	6	1	5	910
82304	222	5	2	6	6	1	5	7910
82444	276	1	2	10	10	1	5	2910
82333	273	2	2	2	2	2	5	579
82429	276	1	2	2	2	3	5	24810
82425	276	1	2	2	2	2	5	123479
82423	276	1	2	6	6	1	5	910
82329	273	2	2	6	6	1	5	579910
82701	234	4	3	1	1	5	1	0
82501	234	4	3	9	9	3	1	0
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82651	234	4	3	9	9	4	1	0
82253	325	5	3	9	9	4	1	0
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82757	325	5	3	1	1	5	1	0
82502	234	4	3	7	7	3	1	0
82254	325	5	3	8	8	3	1	0
82557	234	4	3	1	1	4	1	0
82760	325	5	3	7	7	5	1	0
82761	325	5	3	1	1	5	1	0
82764	325	5	3	7	7	5	1	0
82752	325	5	3	6	6	5	1	0

82216	325	5	3	8	8	4	1	0
82543	234	4	3	4	4	2	1	0
82257	325	5	3	6	6	1	1	0
82598	234	4	3	1	1	5	1	0
82259	325	5	3	7	7	4	1	0
82645	234	4	3	1	1	3	1	0
82763	325	5	3	9	9	5	1	0
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82648	234	4	3	7	7	3	1	0
82647	234	4	3	9	9	3	1	0
82224	325	5	3	1	1	4	1	0
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82255	325	5	3	5	5	2	1	0
82649	234	4	3	1	1	4	1	0
82264	325	5	3	1	1	3	1	0
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82225	325	5	3	7	7	4	1	0
82758	325	5	3	8	8	5	1	0
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82641	234	4	3	6	5	1	1	0
82256	325	5	3	4	4	2	1	0
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82650	234	4	3	8	8	4	2	8
82496	234	4	3	10	10	1	5	7810
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82316	123	5	4	6	6	3	1	0
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82750	123	5	4	8	8	5	1	0
82271	123	5	4	9	9	3	1	0
82319	123	5	4	1	1	4	1	0
82320	123	5	4	8	8	4	1	0
82317	123	5	4	9	9	3	1	0
82318	123	5	4	7	7	3	1	0
82321	123	5	4	9	9	4	1	0
82278	123	5	4	10	10	1	1	0
82312	123	5	4	10	10	1	1	0
82543	178	1	5	4	4	2	1	0
82522	178	1	5	5	5	2	1	0
82535	178	1	5	9	9	4	1	0
82521	178	1	5	4	4	2	1	8
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82538	178	1	5	4	4	2	1	0
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82519	178	1	5	4	4	2	1	0
82707	178	1	5	9	9	5	2	8
82523	178	1	5	5	5	2	2	8
82597	178	1	5	1	1	5	2	8
82533	178	1	5	1	1	4	2	8
82525	178	1	5	1	1	3	3	8
82705	178	1	5	1	1	5	3	8
82526	178	1	5	9	9	3	3	8
82524	178	1	5	1	1	3	3	8
82541	178	1	5	10	10	1	3	8
82537	178	1	5	7	7	3	3	8
82540	178	1	5	10	10	1	3	8
82532	178	1	5	1	1	4	3	9
82536	178	1	5	6	6	1	4	24910
82544	178	1	5	6	6	1	5	24910
82542	178	1	5	6	6	1	5	24910
82417	567	2	6	9	9	4	1	0
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82601	468	3	6	1	1	3	1	0
82600	468	3	6	5	5	2	1	0
82612	468	3	6	9	9	4	1	0
82602	468	3	6	1	1	3	1	0
82603	468	3	6	9	9	3	1	0
82410	567	2	6	9	9	3	1	0
82799	567	2	6	9	9	5	1	0
82794	567	2	6	1	1	5	1	0
82795	567	2	6	1	1	5	1	0
82610	468	3	6	1	1	4	1	0
82796	567	2	6	9	9	5	1	0
82725	468	3	6	1	1	5	1	0
82419	567	2	6	1	1	3	1	0
82727	468	3	6	9	9	5	1	0
82409	567	2	6	1	1	3	1	0
82407	567	2	6	1	1	3	1	0
82797	567	2	6	9	9	5	1	0
82416	567	2	6	1	1	4	1	0
82403	567	2	6	4	4	2	1	0
82611	468	3	6	9	9	4	1	0
82404	567	2	6	4	4	2	1	0
82724	468	3	6	1	1	5	1	0
82418	567	2	6	9	9	4	1	0
82599	468	3	6	5	5	2	1	0
82405	567	2	6	5	5	2	1	0
82798	567	2	6	1	1	5	1	0
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82604	468	3	6	9	9	3	1	0
82609	468	3	6	1	1	4	2	8
82406	567	2	6	5	5	2	3	78
82597	468	3	6	4	4	2	3	8
82420	567	2	6	9	9	3	3	78
82615	468	3	6	4	4	2	3	8
82401	567	2	6	10	10	1	3	78
82402	567	2	6	10	10	1	3	78
82409	567	2	6	9	9	3	3	78
82598	468	3	6	4	4	2	3	8
82595	468	3	6	10	10	1	4	278
82614	468	3	6	10	10	1	4	278
82596	468	3	6	10	10	1	4	278
82613	468	3	6	6	6	1	5	78910
82593	468	3	6	6	6	1	5	78910
82594	468	3	6	6	6	1	5	78910
82400	567	2	6	6	6	1	5	7810
82399	567	2	6	6	6	1	5	7810

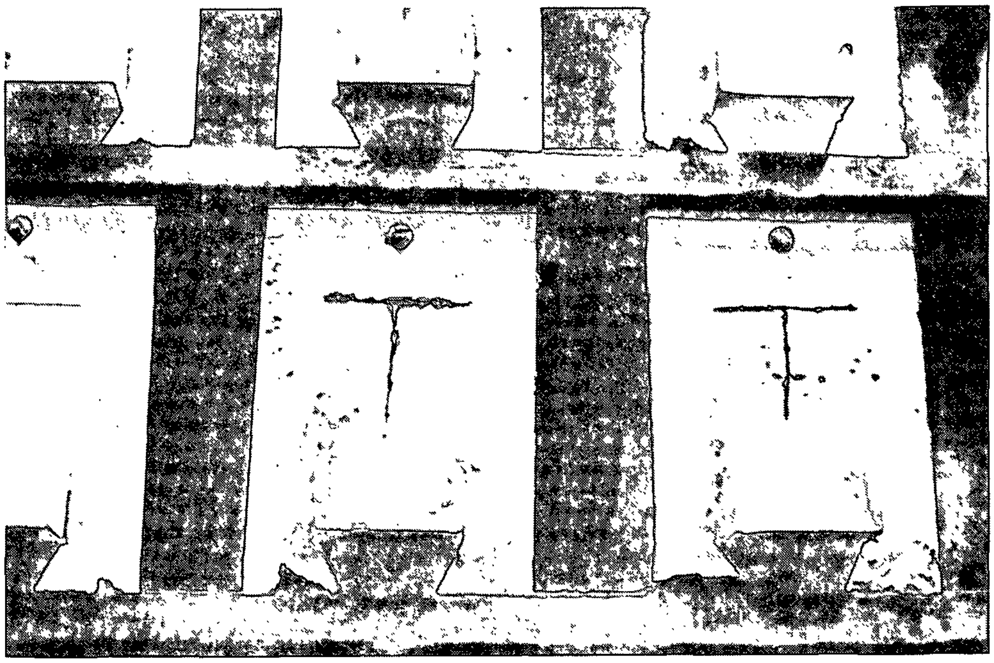

Figure 1. Porter ZincLock 351 (inorganic zinc rich epoxy), 2nd coat Porter CR1131 (chlorinated rubber) coated panels, 6 month exposure wet end paper machine. Failure by delamination, blistering, and cracking.

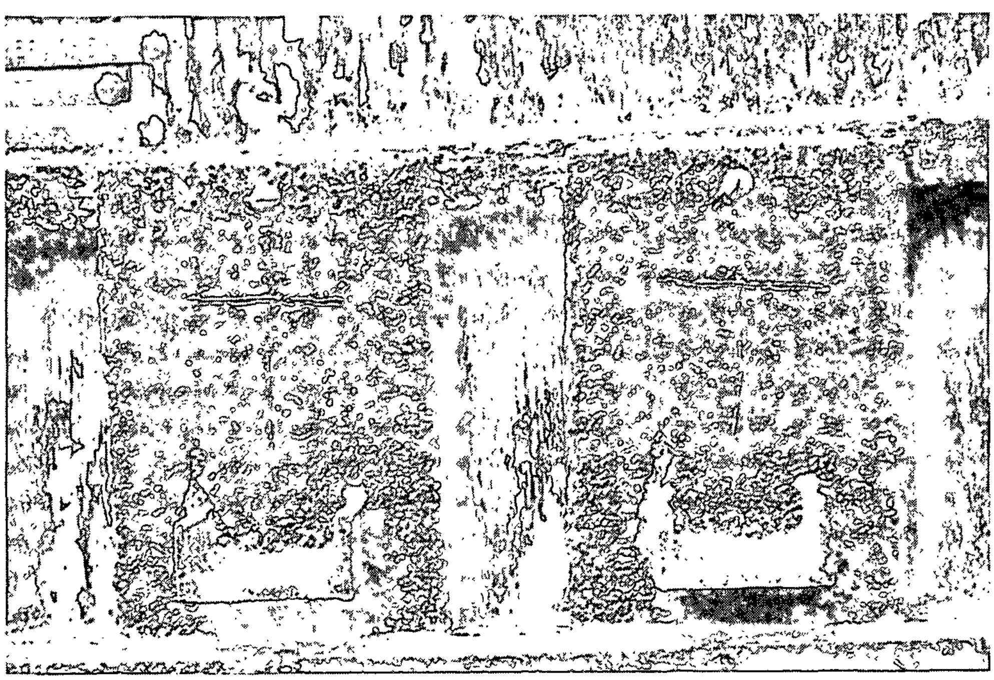

Figure 2. Neutrarust 661 (conversion coating) coated panels 6 month exposure outside near lime mud tank. Failure by severe blistering and pitting.

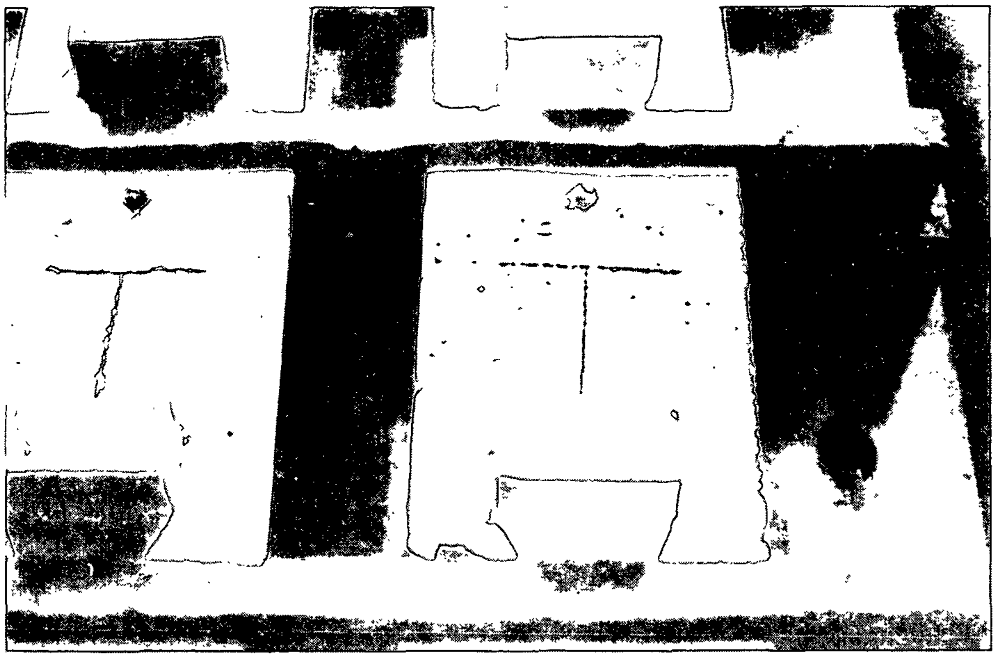

Figure 3. Porter 4310 (gloss epoxy) coated panel, 6 month exposure wet end paper machine. Failure by permeation, blistering, and edge attack.

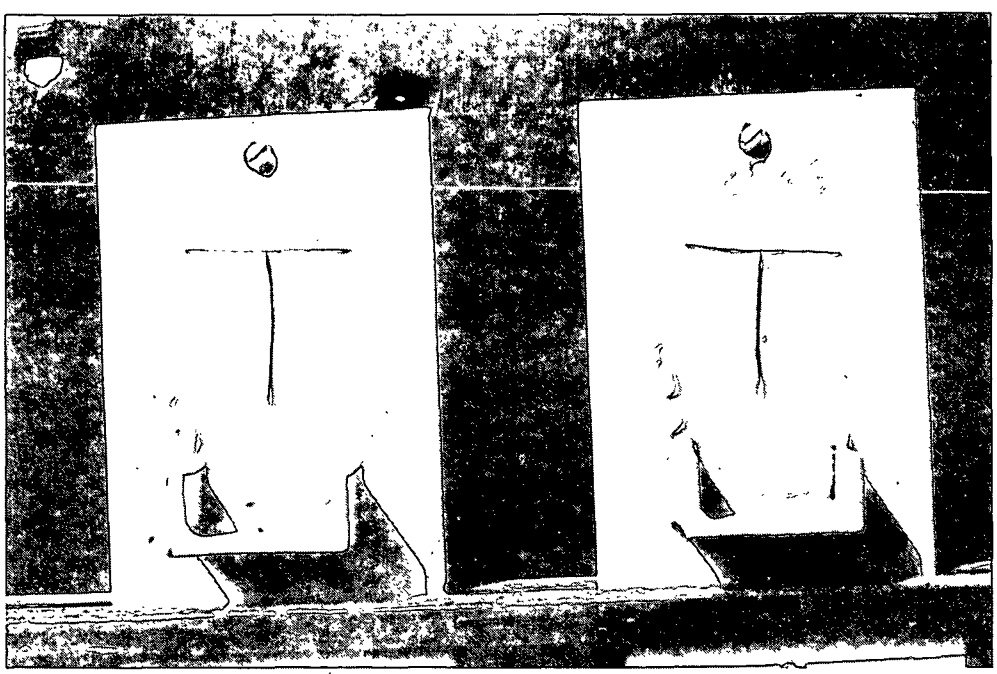

Figure 4. Plasite C720 (epoxy mastic), 2nd coat Plasite 7122 (epoxy phenolic) coated panels, 6 month exposure outside recovery boiler superstructure, failure by undercutting.

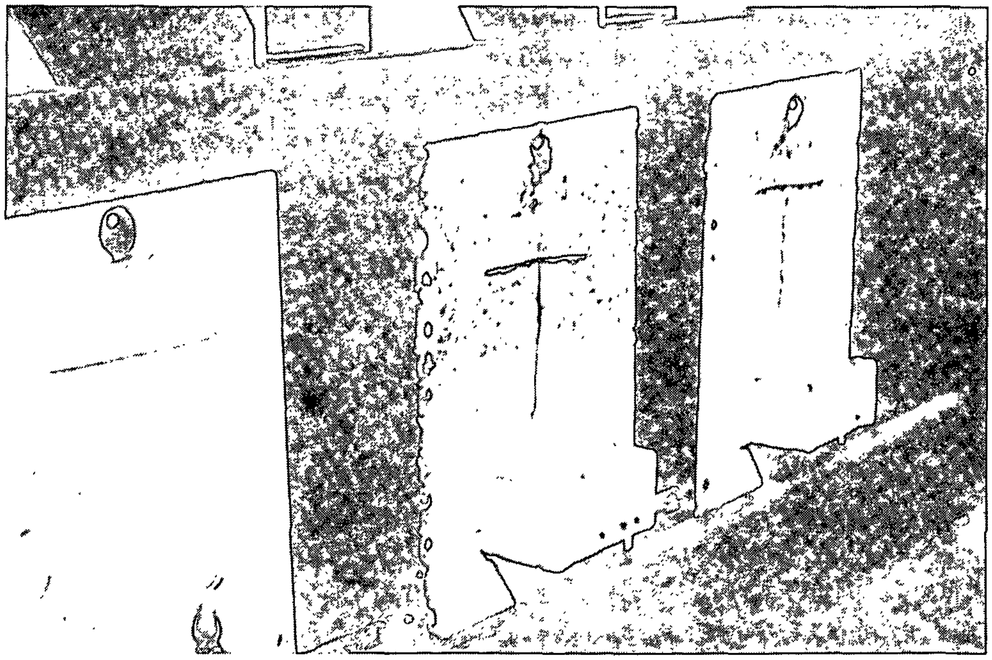

Figure 5. Porter 4310 (gloss epoxy) coated panels, 6 month exposure outside recovery boiler super structure, failure by blistering, undercutting, and edge attack.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3470

FUNDAMENTALS OF DRYING

March 29, 1988

PROJECT SUMMARY FORM

DATE: October 20, 1988

PROJECT NO.: 3470 - Fundamentals of Drying

PROJECT LEADER: David Orloff

IPC GOAL:

Reduction of the "necessary minimum" complexity in number and/or sophistication of process steps.

OBJECTIVE:

To develop an understanding and a database sufficient for the commercialization of advanced water removal systems, based on high-intensity drying principles. This new technology will reduce capital costs, increase machine productivity, reduce the amount of energy used, and improve paper properties.

CURRENT FISCAL BUDGET:

$150,000 from Institute funds, plus $350,000 through a Department of Energy grant (as Project 3595). This grant is for a total amount of $1.5 million over four years; this being the fourth of five budget periods for the project.

SUMMARY OF RESULTS FOR THIS REPORTING PERIOD: (March - September 1988)

Over the past several months there have been several changes in staffing of the impulse drying project team. As a consequence, available manpower has been limited and much of the project team is new including the project leader, a senior scientist, and two new technicians. Two design positions which have actively supported this project and a third technician position should also be refilled soon. Because the team is new and still limited in size, it has been necessary to devote considerable time to developing background, techniques and plans. This is now paying off in a return to a high level of productivity.

Two-nip Roll Impulse Dryer

In the last report, we described the design and the initial stages of fabrication of a second nip for the roll impulse dryer. Over this reporting period, assembly and checkout of this new system have been nearly completed. This was accomplished, in part, by contracting mechanical and electronic engineering services during the erection period.

One major purpose of the two-nip system is to permit two-sided impulse drying for side-to-side balancing of properties on grades where it is required; newsprint and writing papers are good examples. Accordingly, the second nip has a heated lower roll to complement the heated upper roll in the first nip. Induction heating of this roll permits rapid warm up. By physical adjustment of the spacing between heater segments and the roll, it is possible to control the CD surface temperature profile. This will be used later to examine the moisture leveling potential of the process. Other design features of the second nip are much like those of the first nip and have been documented before.

In this rebuilding process, we have also put venting grooves in the lower (cold) roll on the first nip to accommodate the large amounts of water expressed when heavy, very wet sheets are dried. The cold roll on the second nip is not vented since much less water is expressed in the second stage of drying. Plans for adding a web preheating steam shower (donated by Devron-Hercules) to the first nip are nearly complete.

Start-up of the second nip has been quite straightforward and no significant design or manufacturing flaws have been encountered. Considerable effort has been put into checkout and calibration of the instrumentation system, and leveling CD loading and temperature profiles. Some work remains to be completed, but this system can now be used for experimental purposes. Although they are unlikely candidates for two-sided drying, we have used 127 and 205 gsm linerboard sheets for checkout purposes because they were available from other activities.

In a related activity, we have put some effort into improving property control of sheets made on the Institute webformer. This is an important activity since we have typically used the webformer as the source of rolls of wet paper for impulse drying. Good formation and proper MD/CD strength ratios on heavy basis weights have been particularly challenging. This may require use of an outside source of wet paper for some weights and furnishes.

Process Development

In the past, our work has been devoted mostly to developing performance data and a fundamental understanding of impulse drying. This work has been reported to the Engineering PAC by the research staff and by students. It has also been documented in a number of Institute and DOE reports and papers published in various journals and proceedings. Results from this work have shown that impulse drying has the ability to produce high water removal rates and good properties. Energy efficiency is also an advantage.

The concept of impulse drying used in all these studies was that of a wet press, perhaps a wide nip press, operating single-felted with a homogeneous metal press roll heated to produce surface temperatures in the 400-700°F range. With such systems, practical nip residence times are limited to values up to a maximum of about 100 ms, so most of the work has been concentrated in this range. It is now apparent that impulse drying with systems of this type can lead to delamination of the sheet, especially for heavy or more refined grades.

Some of the early student and exploratory work reported delamination or blisters on the sheet, but most of the work with relatively lightweight, free grades was free of delamination. As we have moved to heavier grades and different furnishes, the significance of the problem of delamination has become very apparent. As a consequence, the work on this project has been refocused to examine the issues of delamination in three separate ways. These are outlined below, along with the progress toward each.

Performance and Delamination Database

It is now well recognized that delamination is a significant problem, one that must be examined and solved. From limited work on this issue, we know that the occurrence of delamination is a strong function of such variables as furnish characteristics, basis weight and operating conditions. Some lightweight grades are relatively immune and, thus, are good candidates for early implementation of impulse drying with systems along the lines of the one described above. Other grades are much more susceptible and may require a different approach for implementation. We do not, however, have the database required to define the range of acceptable operating conditions. Hence, as a first step, it is necessary to examine several grades, weights, furnishes and operating conditions to determine these boundaries. Such data will be useful in selecting targets for early application of the process. The degree of success of any alternative systems will also be apparent from corresponding changes in these boundaries. As this work is carried out, we will also gather performance data to extend the existing database on this subject.

Development of this database is relatively straightforward, but there are two important questions; which drying system to use and what to take as a measurement of delamination. Generally, the platen press has been a fairly good predictor of performance on the roll impulse dryer. It is also much more productive and efficient as an experimental system. For these reasons, we will use the platen press for these studies, and conduct only limited verification tests on the roll press. When delamination occurs, it may be virtually complete and visually obvious. It may also be present as small blisters, visible either directly or when the sheet is flexed and viewed in reflective light. In other cases, there may be no visible evidence, but property tests will reveal a strength deficiency caused by internal damage. For an accurate definition of a safe operating boundary, we need a quantitative measure of the degree of delamination. The STFI short span compressive strength test is a good indicator and may be adequate, but it examines only a very small test area, requiring many tests to get a representative value. For this reason, other more efficient tests are being examined for this purpose. Testing in this program will begin as soon as these issues are resolved.

Fundamentals of Delamination

A second major part of our examination of the delamination question is the development of a more complete fundamental understanding of the mechanisms of impulse drying and delamination. For sometime, our concept of the process has been that of a time sequence of overlapping and intermingled events including thermally augmented wet pressing, vapor displacement of liquid and flash evaporation with attendant fiber dewatering and collapse. Vapor displacement is believed to be responsible for the rapid dewatering and excellent energy efficiency of the process. The rapid temperature rise through the sheet is believed to be the result of boiling heat transfer at the hot surface, and an internal evaporation-condensation-liquid reflux (heat pipe) type of heat transfer.

This concept has been developed by inference from a number of measurements in and on impulse dried sheets. These include compression-time and temperature-time histories through the z-direction of the sheet, measurements of liquid dewatering through the use of chemical tracers, heat flux-time histories for a variety of sheet and drying conditions, etc. The concept is consistent with all these measurements, but has not or cannot be proven with irrefutable tests.

A second concept has been proposed by Beloit (1). While this paper does not state it explicitly, the Beloit concept precludes vapor displacement and the heat pipe-type of heat transfer process. Hence, the energy transfer to and within the sheet would have to be by a conduction mechanism and the sheet would be filled with only liquid until the nip is opened, permitting evaporation by a flashing process. Based on energy balance considerations alone, the paper argues that dewatering in impulse drying is by only two mechanisms, wet pressing and flash evaporation. While the validity of this concept cannot be tested in absolute terms either, there are several very questionable assumptions about the physics of the processes taking place. These call into question the accuracy of the energy balance calculations on which the conclusion is based. Nevertheless, the conclusion may be conceptually correct so the concept must be carefully examined for validity and a contribution to our understanding of the process.

Both concepts lead to essentially the same mechanism of delamination. As the sheet is heated under restraint in the early parts of the process, it stores energy in the form of superheated water. As the nip opens, this water is permitted to flash, either by a reduction in vapor pressure (IPC) or a reduction in the wet pressing hydraulic pressure (Beloit). This flashing process releases energy at a very high rate, leading to overpressure and failure of the unrestrained and very weak sheet. In the IPC concept, there is a vapor-liquid interface within the sheet with some part of the liquid pool near the interface being superheated. Flashing would occur in this liquid pool, but near the interface. Since the sheet is still liquid-saturated at this point, it is very weak and susceptible to damage. In the Beloit concept, the hydraulic pressure in the sheet falls as the nip is opened. At some point in time and within the sheet, this pressure distribution curve intersects the saturation pressure curve corresponding to the sheet internal temperature distribution. Flash evaporation would then occur at this point. There is some question as to whether such an internal intersection is physically possible.

Our fundamental work is aimed at examining these concepts and their relationship to delamination. In particular, we are examining the migration of temperature isotherms through the sheet. To do this, several thin but identical sheets are prepared. We place a thermocouple between a single sheet and a felt, and impulse dry it to a high solids level to avoid delamination. The time when the temperature at this point first reaches 100°C is recorded (or any other temperature level). We then repeat the experiment with two such sheets, stacked one on top of the other. We also run a separate experiment with a single sheet with the basis weight of the two. This type of experiment is conducted for several layers to thin sheets. The point of this is to show that the time of arrival of the 100°C isotherm is the same for layered and solid sheets of the same basis weight. Following this, experiments with layered sheets with thermocouple between pairs of plies are conducted. Finally, sheets of different furnishes are dried under a variety of conditions. These data will show how furnish, basis weight and operating conditions control the migration of temperature isotherms through the sheet. Much of the early data from these experiments has been gathered and is being analyzed and may be available at the meeting.

A second set of similar experiments will help us examine another part of the delamination concept. Here, single sheets of the same weights and furnishes used in the first experiment will be dried under conditions that will produce delamination, preferably complete delamination. From the respective weights of the two pieces of the split sheet, we will be able to determine where, in the z-direction, delamination was initiated. From the experiment outlined above, we should be able to relate this to the location of the various temperature isotherms at the time of delamination. Collectively, these data should provide considerable insight into the fundamentals of the process and their relationship to delamination. The data from the first experiment will also tell us what variables are most important in terms of achieving impulse dryer performance. This will be very important in the consideration of alternative impulse drying systems, as discussed below. These concepts, the corresponding experiments and the results from them will be discussed more fully at the meeting.

Alternative Implementation Systems

All of the work on impulse drying thus far has been based on the implementation concept described above, i.e., a wide nip press operating single-felted with a heated, homogeneous metal roll. If the concept of delamination put forth above is correct, then we know that this implementation system supplies more heat energy to the sheet than can safely be used. The result is delamination. This leads, naturally, to the consideration of alternative implementation systems. It seems prudent to use our current understanding of the process to identify and examine such alternatives without waiting from improved fundamental understanding. In fact, the examination of such alternatives will undoubtedly improve our fundamental understanding, as well.

Our first approach to alternative systems is to examine two factors; heat addition to the sheet and control of energy release upon nip opening. To this end, we will investigate, in an exploratory experiment to begin shortly, several different heated surface configurations which cover a range of heat transfer parameters. The primary purpose of these experiments will be to identify which, if any, heat transfer system parameters are important in determining the existence or extent of delamination. Once the major parameters are identified, specific heat transfer systems can be designed to exploit them. Then, a more definitive set of experiments can be conducted to define potential design parameters and ranges, and the full extent of benefits to be gained from this approach.

For these experiments, a system for quickly interchanging heat transfer surfaces has been designed and constructed. Several types of surface are also available for test. To test these, a furnish-weight combination that experiences delamination in a typical dryer operating range will be selected. The influence of these various heat transfer systems on the location of the delamination boundary will be examined. In this way, we will be able to determine which heat transfer surface characteristics lead to reduced delamination without reduced dewatering or property development.

Summary

At the conclusion of the experiments in these three areas, we should have good information on the following:

1. The furnishes, weights and operating conditions where delamination is likely to occur. This will guide the selection of early application situations and operating conditions for the current impulse drying implementation schemes. It will also provide the database for assessing the value of these applications.

2. The fundamentals of the impulse drying process, including the mechanisms of delamination. This will provide good information for the guidance of experiments and alternative designs of implementation systems.

3. Direct information on the performance of alternative implementation systems, based primarily on examination of alternative heat transfer and energy release systems.

Collectively, the data from this work should indicate where it will be possible to operate with the implementation systems currently proposed and how these systems can be modified or replaced to broaden the application window. Impulse drying remains as a process with great potential for improving the quality and production of paper. The key is to find the best way of realizing the advantages offered by such processes.

REFERENCES

1. Macklem, E. A., and J. H. Pulkowski, Impulse Drying -- A Pressing/Flashing Drying Phenomena, 1988 TAPPI Engineering Conference Proceedings, Chicago, IL, September 20-22, 1988.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3480

Fundamentals of Wet Pressing

October 20, 1988

PROJECT SUMMARY FORM

DATE: Sept. 13, 1988

PROJECT NO.: 3480 – FUNDAMENTALS OF WET PRESSING

PROJECT LEADER: Jeffrey D. Lindsay

IPC GOAL:

Develop novel processes for efficient water removal with enhanced control over paper properties.

OBJECTIVE:

Develop a pilot-scale displacement device which demonstrates that high water removal rates can be achieved while maintaining control over paper properties such as bulk.

SUMMARY OF RECENT PROGRESS

Recent experimental work has provided new insight into the physics of displacement processes such as impulse drying. Flash x-ray radiography has been used to visualize vapor and liquid regions during impulse drying. The results appear to demonstrate that a vapor phase is generated within the paper sheet early in the impulse drying process. The x-ray image work provides important experimental data for the validation of MIPPS, a numerical model for impulse drying and general displacement processes in paper.

Heat flux measurements in a model porous system consisting of round glass fibers have strengthened the hypothesis that capillary resupply is important in the heat transfer mechanism of impulse drying. These measurement also provide data which will be used for the validation and refinement of MIPPS.

The first successful measurements of anisotropic permeability in paper have been obtained. New analytical tools were developed to facilitate future measurements of this important paper property. The results show lateral (in-plane) permeabilities on the order of 1-2 times the normal permeability. The results have ramifications for wet pressing and displacement dewatering processes.

DISCUSSION

I. Displacement Dewatering Processes

A. Introduction

There are many ways in which one fluid can displace another in a porous medium. Impulse drying is an form of displacement in which a gas phase is generated in paper by heat transfer. Because the gas phase is generated indirectly, impulse drying can be classified as indirect displacement dewatering. Gas can also be directly injected while the sheet is under a compressive load in order to displace water, and the possibilities of this approach (called direct displacement dewatering or simply displacement dewatering) is the focus of the current study.

Direct displacement is an undeveloped technology, although it is a cousin to through drying. Through drying, however, relies primarily on evaporation as opposed to true displacement , and it requires large volumes of air. More efficient displacement should be possible in which only a small amount of vapor is needed to expel liquid from a sheet. The simultaneous application of mechanical pressure is needed in order keep the sheet in a nearly saturated state as the vapor pressure pulse begins. A motivation in studying displacement dewatering is the expectation that dryness can be partially decoupled from density, giving the papermaker additional control over his product. Energy savings may also be possible.

B. Experimental Investigations of Direct Displacement Dewatering

An experimental displacement device (Figure 1) has been constructed and testing has begun. The displacement device consists of two heads installed in an MTS hydraulic press. The hydraulic ram drives the upper head, and can control the motion and applied mechanical pressure to simulate pressing conditions. The upper head consists of a hollow chamber above a drilled brass plate. The plate can apply mechanical pressure to paper, and at the same time allow gas pressure to be applied. High-pressure gas is released from a pressure vessel into the upper chamber by a rapid solenoid valve. The extended, tapered sides of the upper head fit over the lower head and form a seal with an O-ring that encircles the lower head. The lower head is also a hollow chamber with a drilled brass plate on top to allow gas to pass from the upper into the lower head, and from thence into the atmosphere through a hole in the lower frame of the MTS system. If desired, the volume of gas passing through the system can be measured with a flow meter or collection bag at the end of the exhaust line from the lower head.

For displacement dewatering of paper, a 3-inch handsheet disk is placed on a 3-inch felt. A fine, stiff disk of forming fabric is placed on top of the paper to help distribute the gas pressure more uniformly over the paper and to prevent embossing the paper with the pattern of the drilled upper plate. Tests have indicated that the gas pressure is being applied evenly to the paper. The

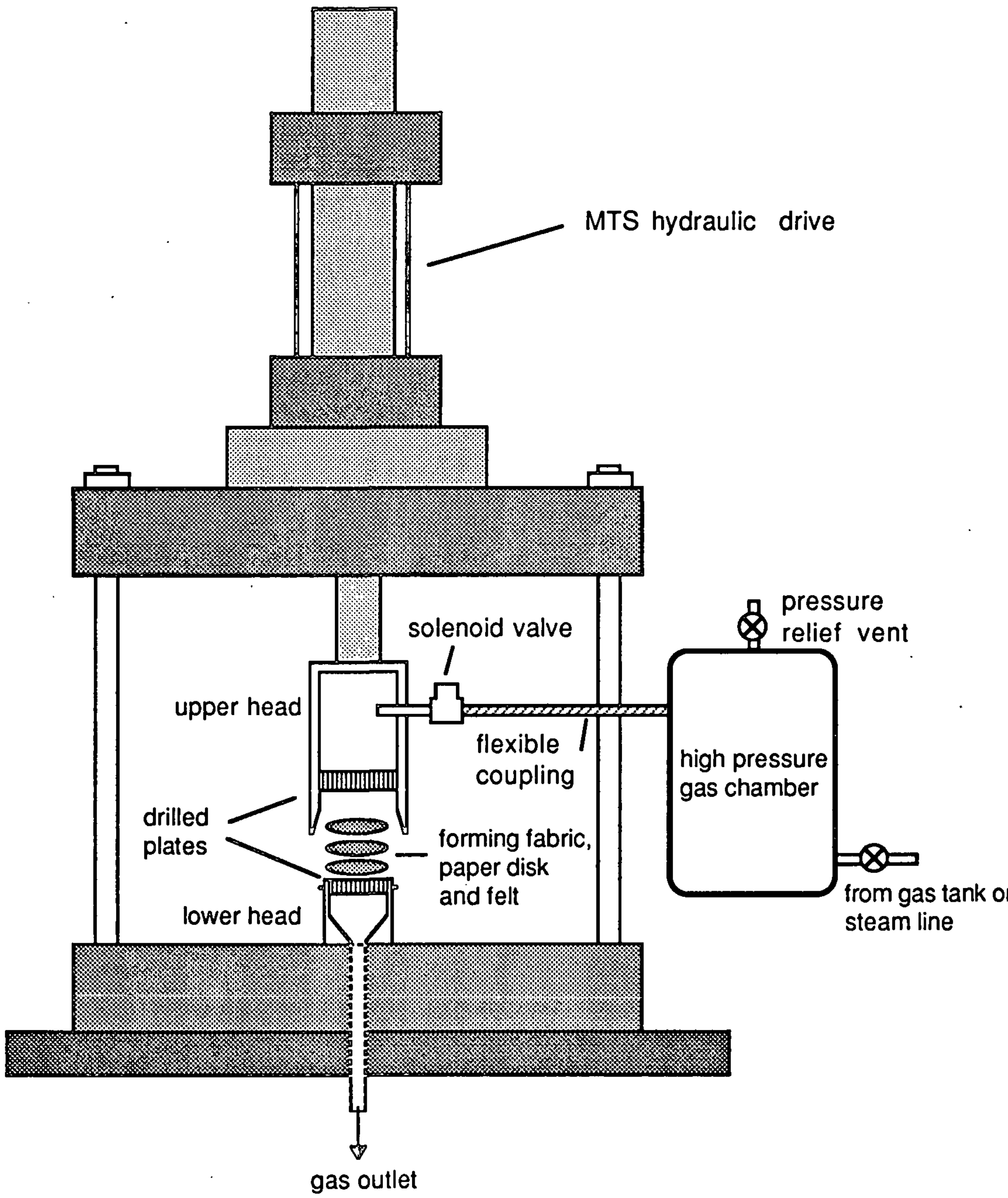

Figure 1. Experimental displacement dewatering device installed in the MTS hydraulic system.

fabric-paper-felt stack is placed on the lower drilled plate. An electronic switch then drives the upper head downward to apply a controlled pressure pulse typically lasting for 20-100 milliseconds. As the mechanical pressure pulse begins, a relay opens the solenoid valve for a specified time (usually 20-50 ms) and the pressurized gas then fills the upper chamber and begins to assist the dewatering of the paper. Gas pressures of 30-110 psi have been used.

Unfortunately, the solenoid valve (the fastest solenoid valve which has been located so far) has a lag time of about 20 ms before the valve is fully open. Once the valve is open, the chamber reaches full pressure in about 5 milliseconds. Plans have been made to adjust the trigger to fire 20 milliseconds before compression of the paper begins so the gas pressure will be applied during more of the pressing event.

The displacement device requires use of the MTS hydraulic system, and must compete with many other projects for time. To date, only room temperature air has been examined as the displacing phase. Tests have been conducted with several furnishes, including linerboard, high-yield linerboard, newsprint, and other light-weight kraft furnishes.

Results with room temperature air have been ambiguous. To achieve a given degree of dryness, displacement with air seems to offer only slight increases (0-15%) in bulk over wet pressing. Increased rates of dewatering are seen, but they are not as dramatic as those in impulse drying.

Typical data sets from recent runs are shown in Figures 2 and 3. Wet pressing and displacement dewatering tests were conducted with a variety of conditions, but the press conditions for wet pressing tests were the same as several of the displacement tests in both cases, except that no gas phase was applied. The data of Figure 2 suggest that some gains are possible, there are insufficient data at this time to draw solid conclusions.

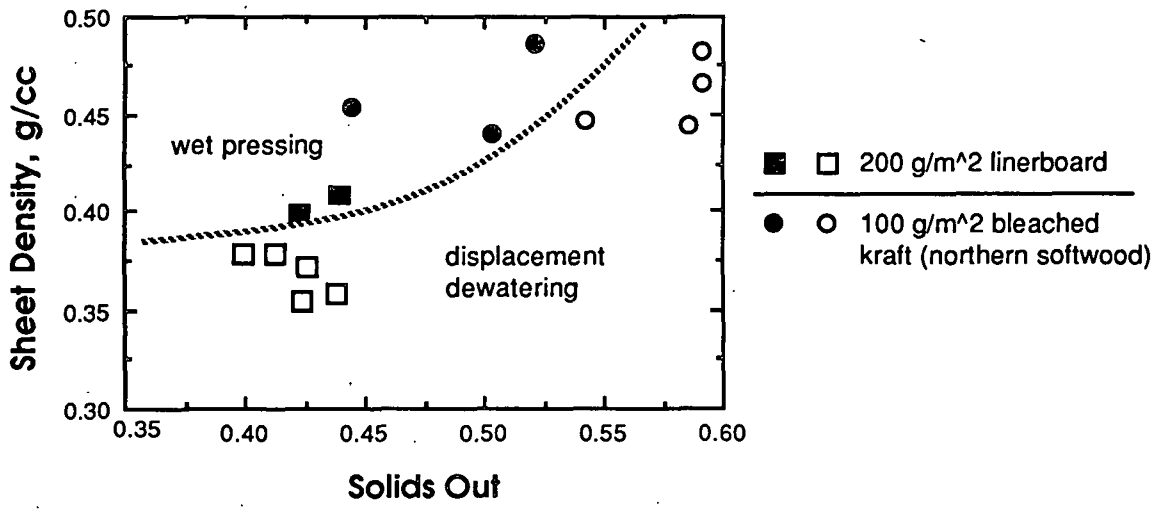

Figure 2. Density-dryness data from displacement dewatering and wet pressing for two furnishes. Nip residence times ranged from 60 to 120 ms, air pressures ranged from 60 to 100 psi, and peak mechanical loads ranged from 200 to 300 psi for the linerboard and from 500 to 650 psi for the bleached kraft handsheets.

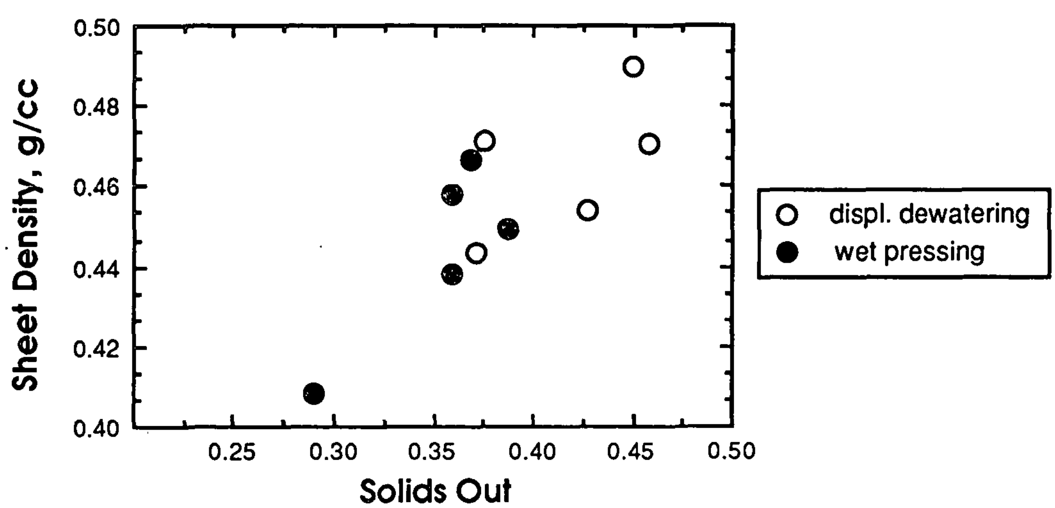

Figure 3. Density-dryness data from displacement dewatering and wet pressing for 125 g/m^2 linerboard. Operating parameters were approximately the same as those for the linerboard data in Figure 2.

Less encouraging are the data shown in Figure 3. These results from a second linerboard furnish show no clear gain in bulk, but improved dewatering is observed. The scatter in the data could easily obscure important effects, so much more data must be obtained.

To guide experimental efforts, an understanding of displacement physics is needed. One simple but key issue in displacement dewatering is the length of time the gas pressure must be applied. Consider the motion of a stable gas-liquid interface driven by constant gas pressure through a uniform porous medium, as shown in Figure 4.

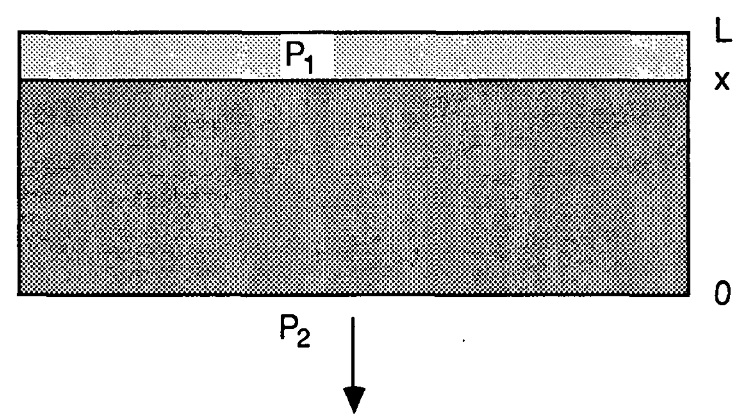

Figure 4. One-dimensional displacement in a porous medium.

Let L be the sheet thickness, μ the viscosity of the liquid, $\Delta P = P_1 - P_2$ the constant pressure drop across the sheet, and K the permeability of the sheet. Neglecting inertial effects and neglecting pressure drop in the gas phase, we can apply Darcy's law to determine the interface velocity:

$$V_i = \frac{dx_i}{dt} = \frac{K}{\varepsilon\mu}\frac{\Delta P}{x_i} \qquad (1)$$

where V_i is the interface velocity and x_i is the interface position. The time required for the interface to move across the porous medium beginning at the upper surface (x_i) is given by integration:

$$\int_0^L x\,dx = \int_0^{t'} \frac{K\Delta P}{\varepsilon\mu}\,dt \qquad (2)$$

resulting in

$$t' = \frac{\varepsilon\,\mu\,L^2}{2K\,\Delta P} \qquad (3)$$

where t' is the required time. For example, with room-temperature water (μ = 0.001 Pa-s) in a sheet 0.2 mm thick with a permeability of 1.0×10^{-15} m^2, a porosity of 0.7, and a pressure drop of 0.5 MPa (72.5 psi) will move the interface across the sheet in 28 ms. A thicker or less permeable sheet will require more time. In reality, the interface will not move smoothly but will break up into viscous fingers that reduce the rate and efficiency of the displacement process (Homsy, 1987). Experience with the displacement apparatus has suggested that gas pressure must be applied on the order of 50-100 ms to achieve significant dewatering.

Impulse drying has the advantage that heat transfer and condensation mechanisms stabilize the interface and reduce the water viscosity (Miller, 1973). Heat transfer in direct displacement dewatering should offer similar advantages. The next stage of testing will be with heated air and then steam.

C. Investigation of Impulse Drying Mechanisms (Indirect Displacement)

Heat Transfer Mechanisms. The heat transfer mechanism in impulse drying is of paramount importance. The possibility of capillary resupply of water to the hot surface has been suggested through numerical modeling work. The modeling has shown that the high rates of heat transfer observed experimentally are not possible unless boiling is maintained long after the bulk of the fluid has moved away from the hot surface. Capillary resupply of water to the hot surface, similar to a heat pipe mechanism, has been offered as an explanation (Lindsay and Sprague, 1988). However, with the complex structure of wood fibers, an alternative hypothesis might be that pockets of water are trapped in hollow fibers, and are only able to boil away long after the bulk liquid is gone. This could then give a sustained phase-change heat transfer rate. While the latter probably happens, it seems unlikely that it could account for the high, sustained heat transfer rates which are observed.

To see if capillary forces really can provide a sustained supply of liquid for boiling (or reboiling) near the hot surface in an impulse drying event, a model porous media was used. Disks of fiberglass insulation were cut and soaked in water, then blotted dry to give initial solids contents on the order of 25%. The disks were then impulse dried, and the heat flux in time was determined. During impulse drying, the sheets had minimum porosities of about 0.3-0.4, similar to the minimum porosities of paper during impulse drying. The fiberglass fiber diameters, as observed with an electron microscope, were similar to those of paper. The planar orientation of the fibers also resembled that of paper. In essence, then, the compressed fiberglass disks were models of paper. The main difference is that the glass fibers are smooth, cylindrical and solid, while paper fibers can be rough, elliptical, and hollow.

The observed heat flux characteristics of impulse drying with fiberglass were remarkably similar to that of paper, with sustained high heat transfer rates that lasted well over 100 ms. The heat transfer rates were about 2 to 3 times less than those of typical linerboard, however, which agrees well with theory. Differences in fiber shape should give paper a permeability that is several times lower than that of fiberglass at a given porosity (Brown, 1975). A lower permeability means lower capillary forces (capillary forces generally go as the square root of permeability) and thus a lower rate of liquid resupply to the surface. The fiberglass data also provide useful information for the validation of MIPPS, the numerical model for displacement processes.

A major experimental study of boiling heat transfer mechanisms in a model porous medium is about to begin as part of Gary Rudemiller's Ph.D. work. His apparatus has been constructed and tested, and his model porous medium has been characterized. Useful insights into impulse drying heat transfer mechanisms are expected from this study.

Flash X-ray Study of Interface Motion in Impulse Drying. The current work of a masters student, Joseph Zavaglia, is providing new experimental evidence about the mechanisms of impulse drying. Flash x-ray radiography is being used to visualize the motion of liquid in a rectangular section of linerboard during impulse drying. Drops of x-ray absorbing silver nitrate are placed on top of the linerboard strip. A heated platen is then dropped from a height onto the linerboard, resulting in a simulated impulse drying event. A flash x-ray picture taken during the event freezes the motion and shows the location of the silver nitrate solution in the sheet.

Several such radiographs are shown in Figure 5. Figure 5-a shows an x-ray image of linerboard on a felt during compression by a falling metal platen. Darker regions indicate higher density. The solid black regions are the metal platens. Figure 5-b is a similar image but now silver nitrate droplets have been added to the upper surface of the paper, creating zones of high x-ray absorption that appear as black as the solid metal platen. The motion of the silver nitrate is evidenced by the light gray regions underneath the droplets. Figure 5-c was

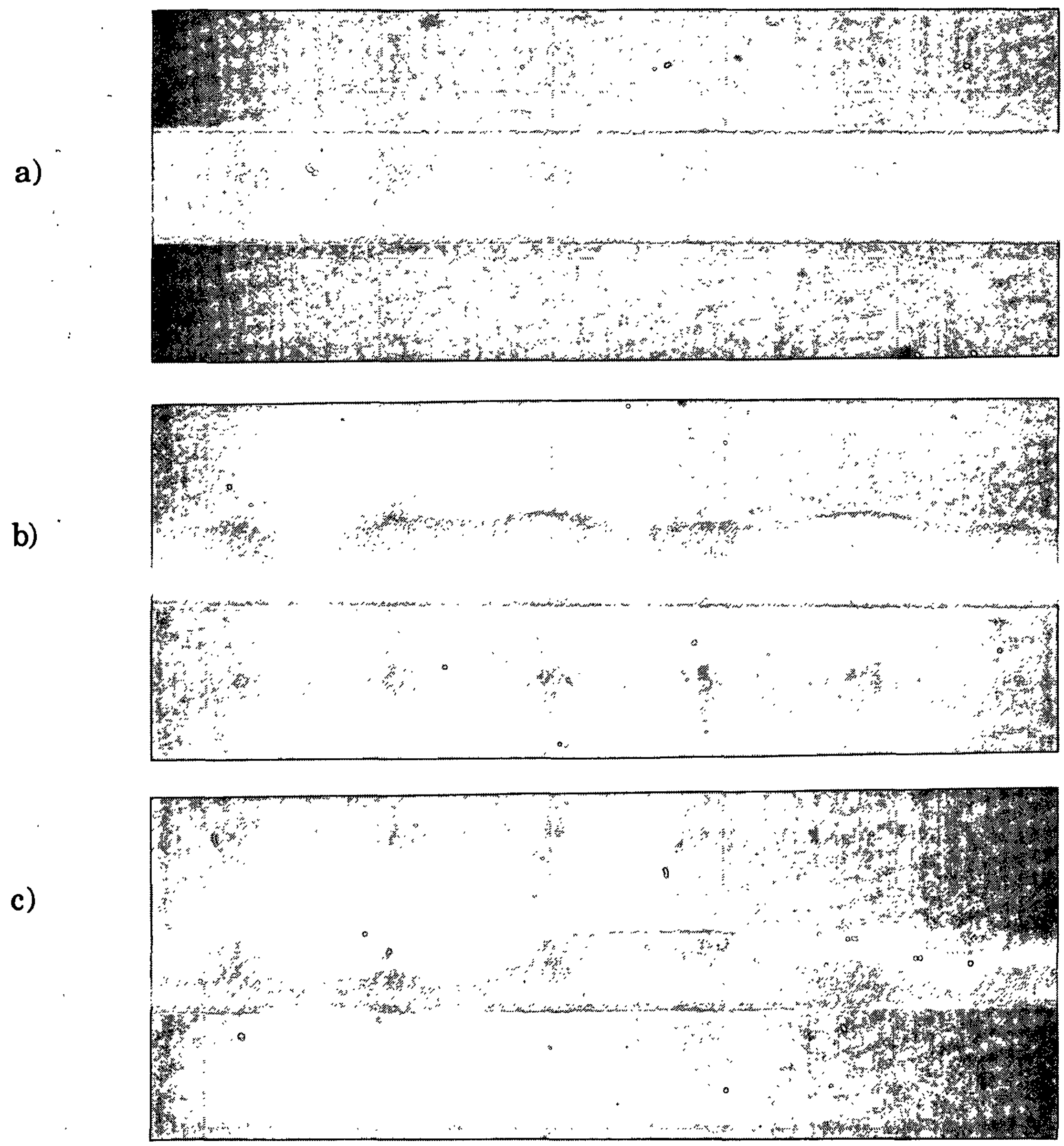

Figure 5. Flash x-ray radiographs of wet pressing and impulse drying events in linerboard on felt in a “rock-dropper” press simulator: a) no x-ray tracer used, impulse drying event; b) silver nitrate tracer on upper surface of paper, wet pressing event; c) silver nitrate initially on upper surface of paper, impulse drying event. Surface temperature = 245°C (470°F).

taken under the same conditions and at the same time after contact, but now the surface of the platen is 245°C, creating an impulse drying event. In contrast to the wet pressing event of Figure 5-b, bulk displacement of the silver nitrate is apparent. The silver nitrate has been displaced away from the upper surface of the paper and is entering the felt below. The squeezing effect of wet pressing alone could not create the x-ray absorption profile seen in Figure 5-c.

When these photos were taken, the timing of the x-ray was based on a delay time after the falling platen passed a trigger above the paper surface. The delay time was 14 ms for each image, but it is uncertain how long of a contact time that translates to. Our estimate is that there had been 6-7 ms of contact time when the x-ray was activated. An improved control system is now being implemented to provide precise information about contact times for each x-ray image. In any case, the x-rays were taken early in the impulse drying and wet press events (before the rebound of the upper platen began).

While this work has just begun, the images appear to be direct evidence that a steam-water interface is created during (not just after) the impulse drying process and that displacement (not just enhanced wet pressing) does occur during the impulse drying event. Further data using this method will be obtained and applied to the numerical modeling work that is underway.

Numerical Modeling. Work has continued in the development of MIPPS, a numerical model for studying the moving boundary problems of impulse drying and displacement dewatering. A new approach is being developed to allow MIPPS to properly handle the two-phase zone that may exist in displacement processes without having to make *ad hoc* specifications of capillary resupply rates. The new model will also properly treat paper as a compressible porous medium whose permeability changes during a pressing event. A number of serious difficulties have been encountered in this effort which require further time to solve.

The recent experimental data for heat fluxes and for interface motion provide useful tools for validating and refining MIPPS. The very existence of a steam-water interface, as seen in Figure 5-c, is important evidence which justifies some of the assumptions of MIPPS.

II. Anisotropic Permeability of Paper

A. Overview

Two-dimensional flows are known to be important in wet pressing and in other processes (Mukhopadhyay and Kingsbury, 1980). However, it appears that no measurements of in-plane permeability in paper have been published, although such measurements have been made in textiles, felts, and other materials. The in-plane permeability of paper is therefore usually assumed to be equal to the measured transverse permeability. Methods have now been developed to measure and analyze the anisotropic permeability of paper, including measurements of the two in-plane permeability components. A full report on the this study to date is given in a recent IPC Technical Paper (Lindsay, 1988).

Because of the complexity of flow in anisotropic materials, numerical modeling was applied to develop some of the necessary tools for the analysis of the experimental data. These tools should be of use in future studies of anisotropic permeability, and are also being used as a stepping stone towards developing the improved MIPPS model.

B. Experimental Apparatus and Approach

The permeability measurements were made using the MTS hydraulic system in two configurations, one for lateral permeability and one for transverse permeability measurements. The system for lateral measurements is shown in Figure 6. A disk of paper is pressed between two metal plates, one of which has an inlet port for the injection of fluid. Distilled, deaerated water in a translucent plastic tube is driven by compressed gas at a controlled pressure. The flow rate of fluid into the compressed paper disk is obtained by measuring the motion of the fluid meniscus in the tubing. A mechanical displacement meter indicated the position of the top head with respect to the stationary base; this information was then used to obtain the sheet thickness.

The lateral permeability apparatus constrains fluid to flow radially outward in the plane of the paper. Measurements were made in dry and saturated sheets. In sheets with in-plane anisotropy, dyed water was injected. (For initially dry sheets, the dye was not necessary since the wetted region was clearly distinguishable from the dry zone. Using special data analysis tools, the in-plane permeabilities could be determined from the shape of the resulting dyed region combined with knowledge of the flow rate, viscosity, and sheet thickness.

Transverse permeability measurements were also made with the MTS system in a different configuration, as shown in Figure 7. Fluid at a constant hydraulic head enters the chamber of the upper displacement head. The fluid passes through the drilled bronze plate, enters a felt, passes through the paper, and then exits through another felt and another drilled brass plate. The felts were necessary to provide uniform mechanical pressure (as shown by carbon paper imprints) and uniform hydraulic boundary conditions.

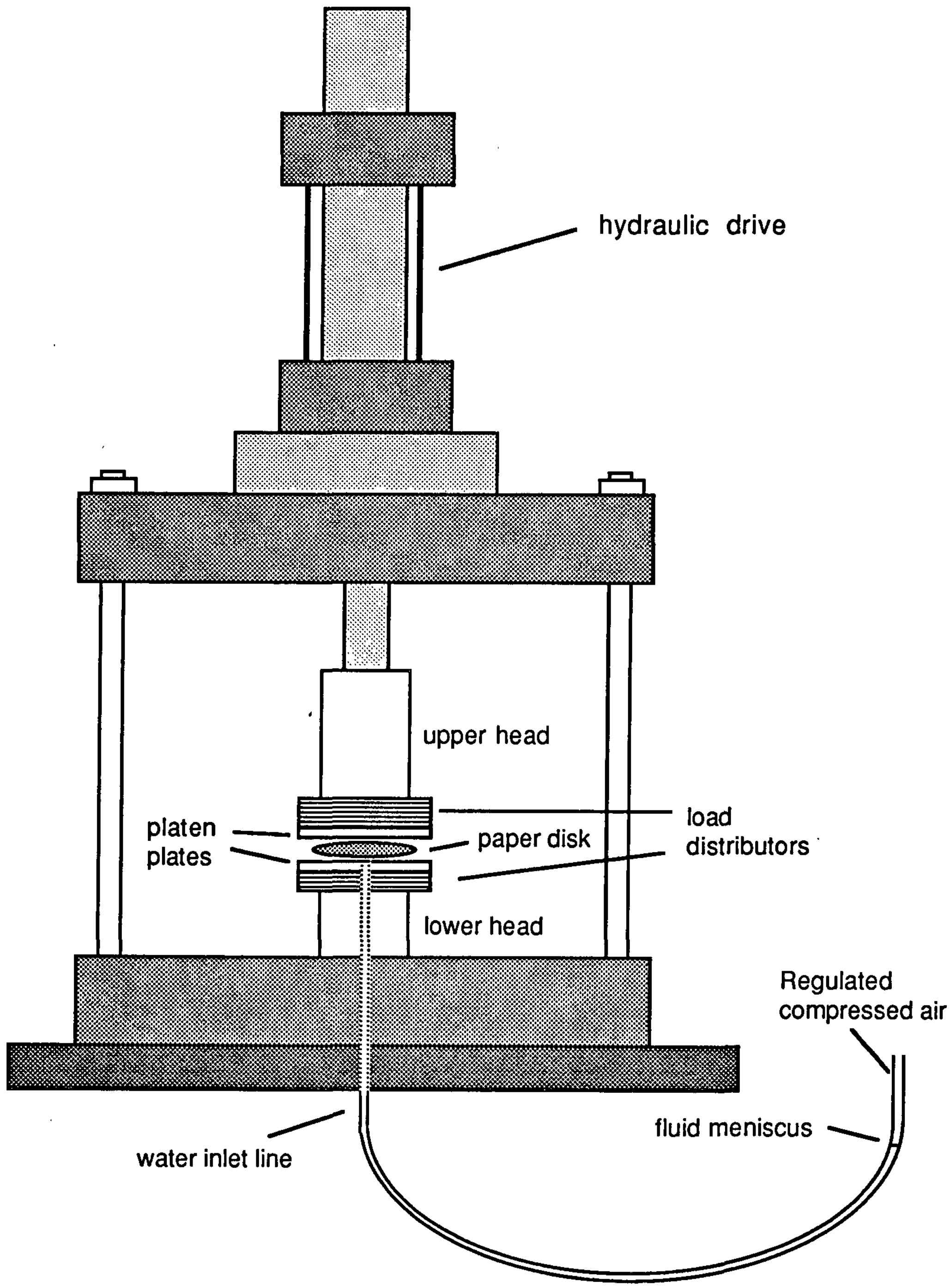

Figure 6. The MTS hydraulic press modified for lateral permeability measurements.

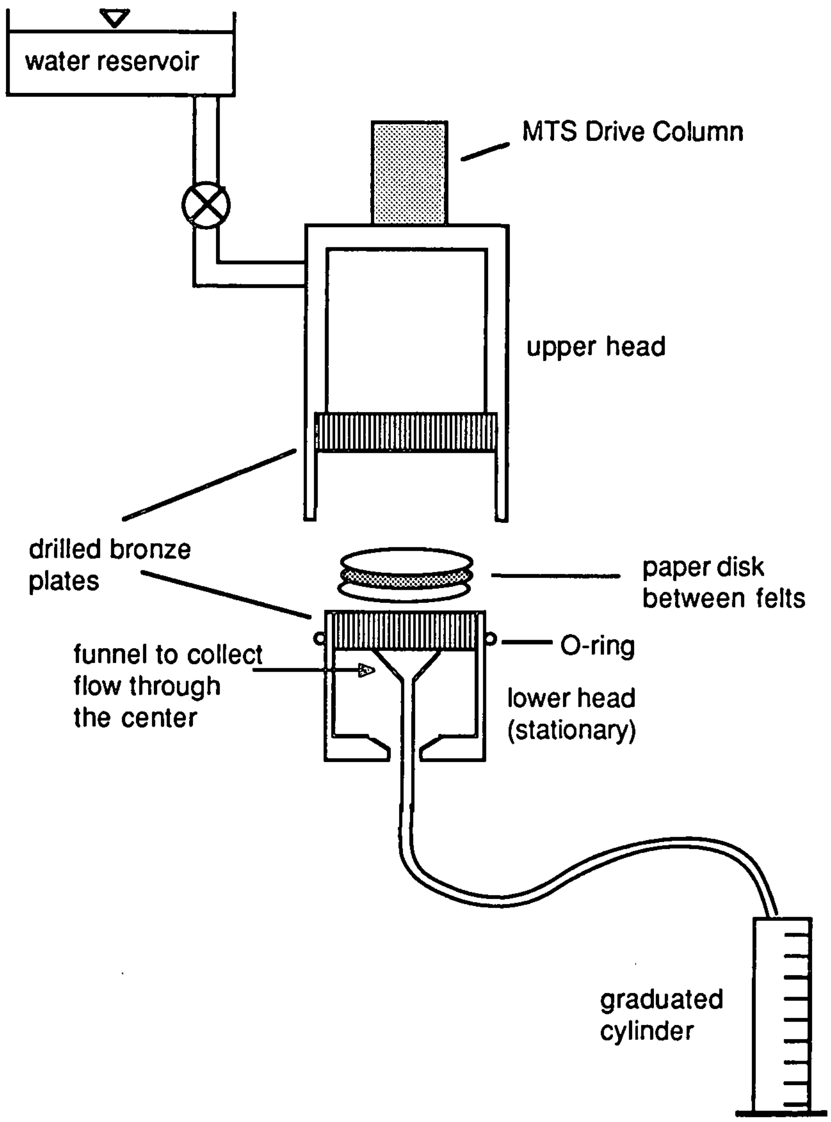

Figure 7. Detail of modifications to the MTS heads for transverse permeability measurements.

C. Results

Measurements were made in samples of linerboard, commercial blotter paper, and a lightweight paper made on a pilot machine at The Institute of Paper Chemistry. Machine-direction permeability was always greater than cross-direction permeability in machine-made papers, with ratios ranging from 1.05 to 3.0. The ratio of lateral to transverse permeability was on the order of 1-2 in most cases, consistent with predictions from simple models of fibrous media.

One set of results is shown in Figure 8. Measurements of both average in-plane and normal permeabilities were made in each of two linerboard handsheets from a common furnish. The observed ratio of lateral to normal permeability ranged from 2.0 at a porosity of 0.73 to 1.2 at a porosity of 0.85.

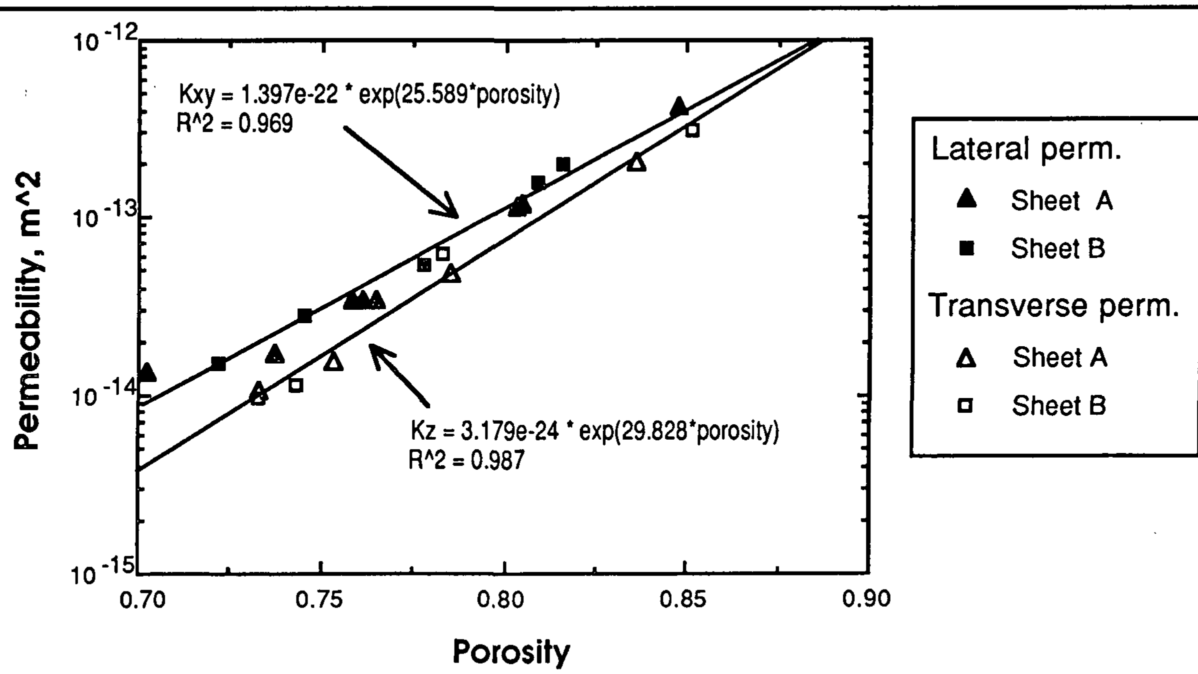

Figure 8. Comparison of lateral and transverse permeabilities in similar linerboard handsheets.

D. Applications

The ratio of transverse to lateral permeability is of interest in a variety of water removal issues. For instance, understanding the anisotropic permeability of paper may provide new insights into crushing phenomena. Crushing is believed to occur when in-plane flows disrupt the paper structure. Higher lateral permeabilities may reduce the in-plane flow resistance of the paper and thus alleviate crushing stresses. Future investigations of the relation between lateral permeability and crushing may be fruitful.

The relationship between anisotropic permeability and wet pressing is also worthy of attention. In the past, anisotropic effects have been ignored due to lack of experimental information. Based on this study, an in-plane permeability on the order of 1.5-2 times the transverse permeability could be used in dynamic models when specific measurements of lateral permeability are unavailable.

Information about the anisotropic permeability of paper is now being applied to the problem of delamination during impulse-drying. This problem can occur when high vapor pressures are generated in sheets of low permeability. With the sudden release of applied mechanical pressure as the sheet leaves the nip, internal vapor pressure can cause the sheet to be split or blown up like an inflated paper bag in some cases. The lateral permeability is believed to play an important role here. Preliminary analysis suggests that a high machine-direction permeability should help to safely relieve high vapor pressure in the nip without sudden delamination. Further work is needed.

In displacement dewatering, a ratio of lateral to normal permeability greater than 1 can help stabilize the gas-liquid interface. Papermaking processes which give rise to higher lateral permeability values may be favored for future displacement dewatering processes.

PLANS FOR NEXT PERIOD:

1. Further explore the potential of displacement dewatering using heated air and superheated steam as the displacing media.

2. Complete the revision of MIPPS to handle two-phase regions and compression of the paper. Validate the improved model using a variety of experimental data.

3. Continue measurements of lateral permeability in a variety of papers.

4. Obtain additional flash x-ray radiographs of impulse drying.

SIGNIFICANCE TO THE INDUSTRY:

Displacement dewatering offers the potential of efficient water removal as well as enhanced control over physical properties such as bulk. Developments in the science of displacement phenomena, especially through numerical modeling, may also lead to improvements in the proven technology of impulse drying.

An understanding of both the lateral (in-plane) and normal permeability of paper may facilitate advances in conventional wet pressing and other water removal processes where two-dimensional flow occurs.

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S L I D E   M A T E R I A L

To The

Engineering Project Advisory Committee

Octoaber 20-21, 1988
The Institute of Paper Chemistry
Continuing Education Center
Appleton, Wisconsin

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Project 3628

RECOVERY BOILER FIRESIDE CORROSION

David C. Crowe

October 20, 1988

Project 3628

RECOVERY BOILER FIRESIDE CORROSION

David C. Crowe

OBJECTIVE:

Understand the mechanism of high temperature corrosion in the recovery boiler so that corrosion control options may be identified.

Costs of Recovery Boiler Corrosion:

- Possible Explosion: Injuries, Fatalities, Loss of Production.
- Inspection, Repairs and Downtime.
- Increasing Insurance Premiums.

Lower Furnace Corrosion Problems:

1. Composite Tube at Air Ports
2. Smelt Spouts, Liquid Level
3. Oxidation/ Sulfidation of Waterwall.

Results to Date:

- The technical literature has been surveyed.

- A tube furnace has been refurbished and a second furnace purchased.
- Preliminary tests of 1018 carbon steel and 304 steel have been completed.

- A corrosion probe for use in an air port has been proposed.

Results Since Last Report:

- Installation of a probe access port in a secondary windbox of a recovery boiler.

- Temperatures in deposits on the back sides of air port tubes have been measured.

Progress:

A probe access port was installed in a secondary wind box.

Progress:

Temperatures were measured in deposits on the backside of secondary air port tubes:

200 - 270 °C (390 - 520 °F)

Progress:

- Temperatures, air flow and deposit accumulation varied considerably throughout the day.

Preliminary Result:

- Frequent rodding, even air flow and stable operation may contribute to lower corrosion rates.

Plans:

1. Design & construction of the corrosion probe.
2. Measure temperatures at other places.
3. Obtain smelt and ash samples.
4. Begin laboratory studies.

Future Activities:

1. Sample smelt and flue gas near air ports and smelt spouts.

2. Document smelt spout problems and relevant corrosion mechanisms.

3. Develop an experimental plan for gas phase oxidation/ sulfidation tests.

Other Potential Activities:

1. Devise a test apparatus which will continuously replenish molten smelt at the corroding steel surface.

2. Develop methods for in-situ corrosion testing.

SIGNIFICANCE TO THE INDUSTRY:

An improved knowledge of corrosion mechanisms in recovery boilers will aid in the design of remedial measures which will extend the operating life and improve safety.

Project 3556

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

David C. Crowe

October 20, 1988

Project 3556

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

David C. Crowe

Objective:

Understand causes of corrosion of carbon steel in kraft liquor, as the basis for developing methods for reducing corrosion damage.

PREVIOUS RESULTS

- Qualification of monitoring methods
- Development of microprocessor-based data acquisition system.
- Liquor corrosivity is more important than grade of carbon steel.
- Fluctuation of corrosion rate could not be correlated with liquor composition changes
- Liquor level cycling increased corrosion rates.
- Effects of various white liquor constituents.

More Recent Results:

1. Further investigation of the effect of velocity using the rotating cylinder electrode and flow loop.
2. Bench testing of improvements to the corrosion monitoring system.
3. Completed study of stress corrosion susceptibility of steel in real mill liquor.

LIQUOR VELOCITY EFFECTS

Objective: To relate corrosion rates to hydrodynamic factors, e.g. shear, Reynolds number.

Technique: Measure corrosion rates under controlled conditions.

Current Objective:

Develop the RCE technique for the study of velocity effects in kraft liquor.

Rotating Cylinder Electrode

Experimental Approach:

1. Measure kinematic viscosity (γ). Calculate Re, τ
2. Measure corrosion rates over a range of potentials.
3. Determine repeatability of tests.
4. Relate corrosion rates to velocity.
5. Compare results with the flow loop.

Fluid Mechanics of the Rotating Cylinder

Three regimes:

Laminar: Very little mass transfer.

Vortex: Intermediate.

Turbulent: $Sh = 0.079\ Re^{0.7}\ Sc^{0.356}$

$$\tau = (f/2)\ \rho\ \omega^2\ r^2$$

$Re = Vd/\gamma$	A ratio of velocity & viscous forces.
$Sc = \gamma/D$	Diffusion layer thickness.
$Sh = kd/D$	Dimensionless mass transfer.

Correlation of Rotating Cylinder and Pipe Loop.

$$\log Re_{tube} = 0.67 + 0.833 \log Re_{cyl}$$

Equate the shear, τ

Equate the mass transfer.

Rotating Cylinder Electrode Advantages

- small quantities of liquor
- better control of conditions
- uniform surface velocity
- established fluid dynamics
- has been demonstrated in corrosion studies

Applications to Corrosion Studies

Problems:
- may not be diffusion controlled.
- erosion

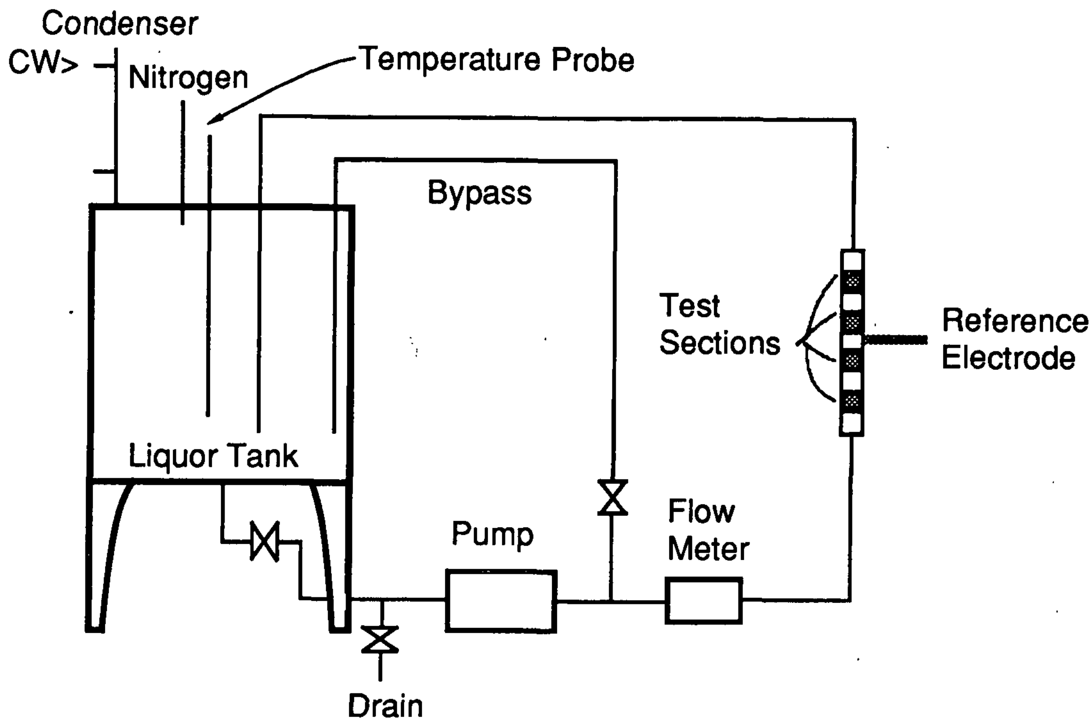
Previous Applications:
- inhibitors for pipelines
- steels in sulfuric acid
- Cu/Ni in seawater
- corrosion of ships' hulls

Pipe Flow Loop:

- duplicates flow in mill pipe systems.
- fluid dynamics established.
- must be carefully controlled, cumbersome.

Progress:

A bypass loop was added to the flow loop to attain lower flow rates.


Condenser
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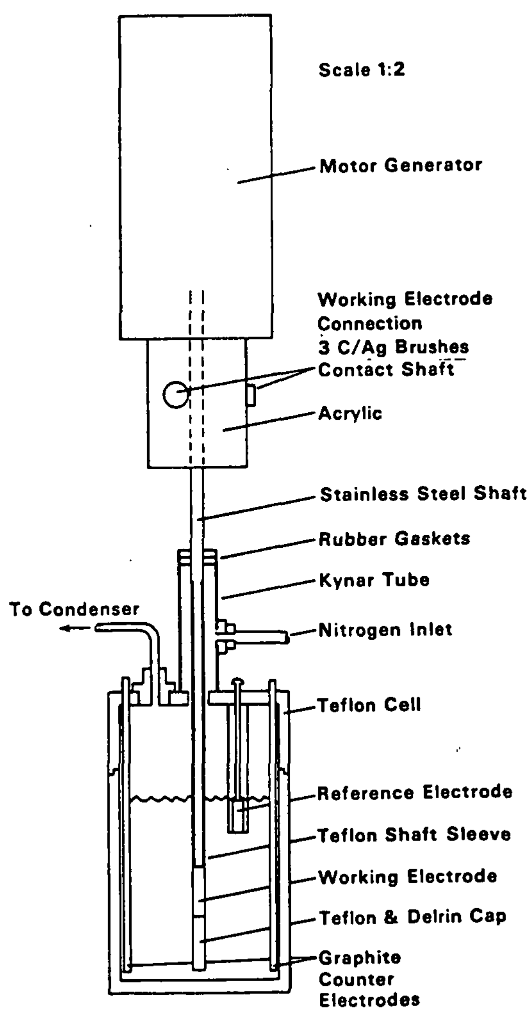
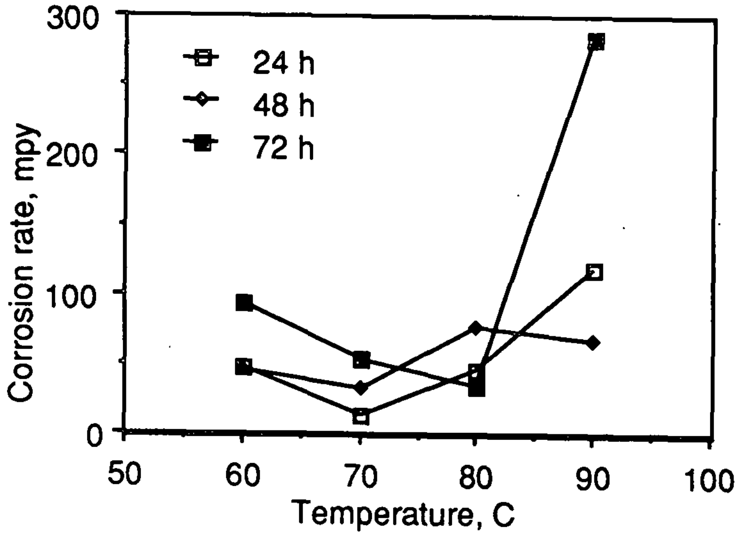
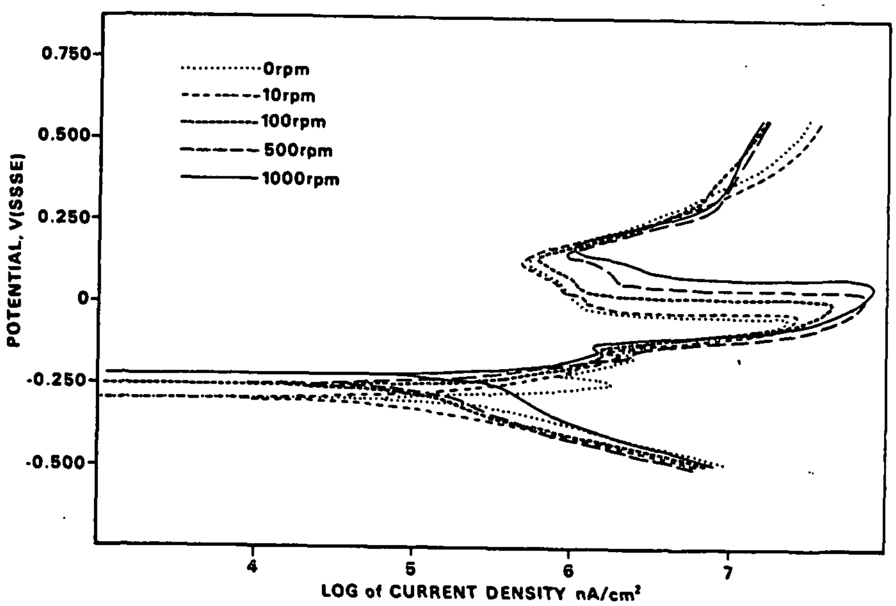
Nitrogen
Temperature Probe
Bypass
Test
Sections
Reference
Electrode
Liquor Tank
Pump
Flow
Meter
Drain


Scale 1:2
Motor Generator
Working Electrode
Connection
3 C/Ag Brushes
Contact Shaft
Acrylic
Stainless Steel Shaft
Rubber Gaskets
Kynar Tube
To Condenser
Nitrogen Inlet
Teflon Cell
Reference Electrode
Teflon Shaft Sleeve
Working Electrode
Teflon & Delrin Cap
Graphite
Counter
Electrodes


300
200
100
0
24 h
48 h
72 h
Corrosion rate, mpy
50
60
70
80
90
100
Temperature, C


0.750
0.500
0.250
0
-0.250
-0.500
0rpm
10rpm
100rpm
500rpm
1000rpm
POTENTIAL, V(SSSE)
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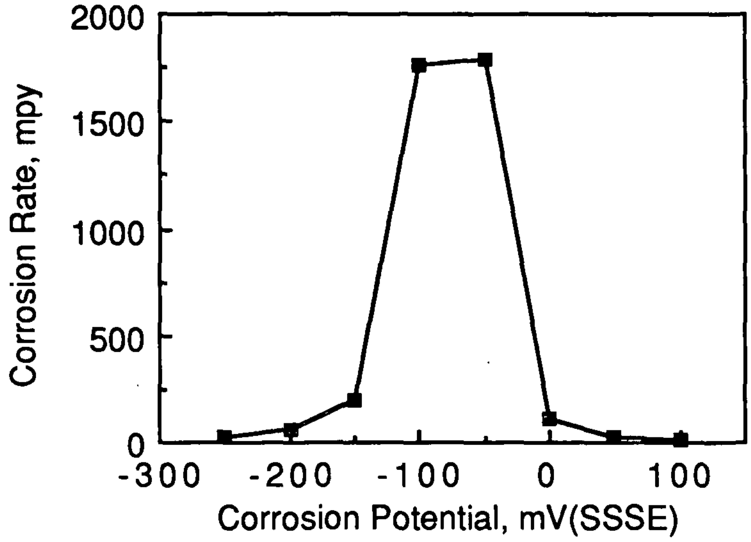
5
6
7
LOG of CURRENT DENSITY nA/cm²


2000
1500
1000
500
0
Corrosion Rate, mpy
-300
-200
-100
0
100
Corrosion Potential, mV(SSSE)

Results Since Last Report:

Further testing with the rotating cylinder electrode and the flow loop showed considerable scatter in measured corrosion rates even when the corrosion potential was controlled.

Progress:

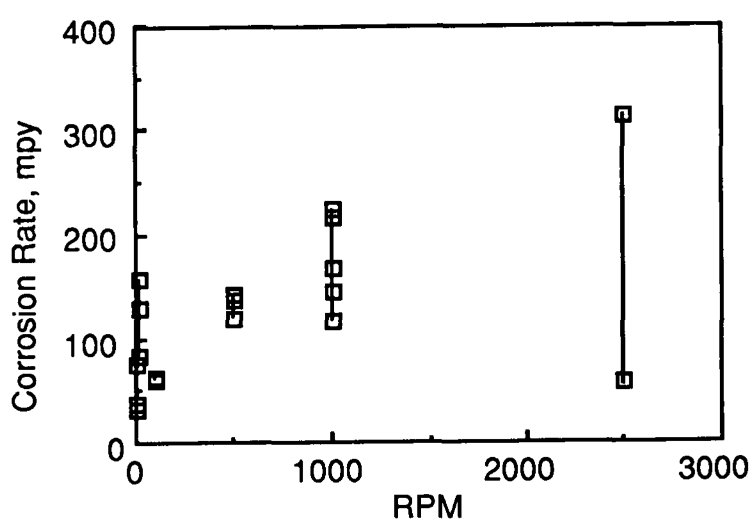
RCE tests were performed at a range of rpm at a controlled potential.

There was considerable variation in measured corrosion rates, even when the potential was controlled.

Table 1

Dependence of Corrosion Rate on Rotation Rate

rpm	C.R.,mpy	v, m/s	Re	τ, N/m^2
0	33, 76, 39	0	0	0
10	158, 129, 83	$4.8x10^{-3}$	83	$5.3x10^{-4}$
100	64, 63, 61	$4.8x10^{-2}$	832	$2.7x10^{-2}$
500	143, 121, 137	0.24	4160	0.41
1000	217,169,118,223,145	0.48	8322	1.34
2500	313, 59	1.20	20805	6.37
3000	-	1.44	24966	8.68



Progress:

Flow loop tests were performed at a controlled potential and at the free corrosion potential.

There was considerable variation in measured corrosion rates, even when the potential was controlled.

Table 2

Flow Loop Results

	Corrosion rate, mpy			
Electrode	**5**	**6**	**7**	**8**
Potential	**-150 mV**	**-150 mV**	**E_{corr}**	**E_{corr}**
Run 1	**158**	**138**	**162**	**155**
			E = -240/-102 mV	
Run 2	**95**	**94**	**271**	**214**
			E = -234/+15 mV	
Run 3	**346**	**285**	**254**	**304**
			E = -145/-85 mV	
Run 4	**83**	**79**	**95**	**82**
			E = -104/-125 mV	

Why so much scatter ?

- differences in surface roughness ?
- differences in original surface film ?

Tewari & Campbell:

Pyrite (FeS_2) - protective in flow.

Mackinawite ($Fe_{(1+x)}$) - non-protective.

Plans for Next Period:

1. Compare corrosion rates measured with the rotating cylinder electrode and pipe loop.

2. Begin tests of stainless steels (304, 316).

SIGNIFICANCE TO THE INDUSTRY

Corrosion monitoring methods may be applied reliably in white liquor systems.

Effects of major liquor constituents on corrosivity of white liquor have been determined.

Some operating parameters which increase corrosion rate have been identified.

Project 3309

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

David C. Crowe

October 20, 1988

Project 3309

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

David C. Crowe

Objective:

To extend the life of paper machine suction rolls through corrosion and corrosion fatigue studies to establish mechanisms that limit lifetime.

Results Since Last Report:

Due to staff changes, no results have been obtained in the last period.

Future Plans:

1. Near threshold fatigue testing in a simulated pit environment.

2. Rotating bending fatigue testing and alternating bending testing in a simulated pit environment.

3. Investigate crack path through suction roll microstructures.

Future Plans (continued):

4. Study the microstructure of weld deposits on repaired suction rolls.

5. Test effects of superimposed mean stresses on crack initiation resistance.

6. Determine the effect of surface finish on crack initiation.

Significance to the Industry:

Near threshold crack growth behavior has been shown to agree with service performance provided that residual stress effects are considered.

Project 3607

EVALUATION OF STRUCTURAL COATINGS FOR
PULP AND PAPER MILLS

David C. Crowe

October 20, 1988

Project 3607

EVALUATION OF STRUCTURAL COATINGS FOR PULP AND PAPER MILL SERVICE

David C. Crowe

Objective:

To rank commercially available paint systems based on their ability to protect structural steel in the aggressive environments found in the pulp and paper mill, especially if applied under less than optimum conditions.

APPROACH

- Precorrode test coupons in mills.

- Clean and coat the coupons under less than optimum conditions.

- Reinstall in the mill and test to failure.

Progress to Date:

Test coupons were installed, uncoated, at mills to pre-rust. They were returned and have been coated after various surface preparations for reinstallation and exposure until failure in:

- Paper machine wet end
- Bleach plant
- Recovery boiler structure

The Coating Systems:

1. Epoxy Amide Primer/ Epoxy Phenolic Topcoat
2. Inorganic Zinc Epoxy Primer/ Chlorinated Rubber
3. Organic Zinc Primer/ High Build Epoxy/ Gloss Epoxy
4. Epoxy Mastic/ Epoxy Phenolic Topcoat
5. Alkyd Primer/ High Build Epoxy/ Gloss Epoxy

The Coating Systems:

6. Rust Conversion Coating
7. Inorganic Zinc Epoxy/ High Build Epoxy/ Vinyl
8. Vinyl Ester/ Vinyl Ester
9. Inorganic Zinc Epoxy Primer/ High Build Epoxy/ Gloss Epoxy
10. Gloss Epoxy

Surface Preparation:

1. Water Wash
2. Wash + Power Tool Cleaning SSPC-SP3
3. Commercial Blast SSPC-SP6
4. White Metal Blast SSPC-SP5
5. New

Results Since Last Report:

Painted panels were inspected after six months mill exposure.

Table 1
Frequency of various performance ranks for each coating system in all mill locations.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure		6				15				7
Poor	1	8		2	1	3				5
Fair	9	7	1	7	4		1		12	5
Good	20		5	5	6	1		5	8	2
Excellent	53	3	9	21	19	12	13	9	62	11
No Observ.	4	5	5	1	1	2			5	1

Table 2
Frequency of various performance ranks for each coating system in bleach plants.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure										
Poor										
Fair										
Good								5		
Excellent	14			4	4	4	13	9	13	2
No Observ.										

Table 3
Frequency of various performance ranks for each coating system in recovery areas.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure						10				4
Poor	1			2	1	3				4
Fair	6			3	4		1		10	4
Good	13			1	2				3	
Excellent	32			15	13	8			41	8
No Observ.										

Table 4

Frequency of various performance ranks for each coating system in paper machine areas.

Performance Rank	Coating System 1	2	3	4	5	6	7	8	9	10
Failure		6				5				2
Poor		8								1
Fair	2	7	1	3					1	2
Good	7		5	4	4	1			5	1
Excellent	7	3	9	2	2				6	1
No Observ.	4	5	5	1		2			5	1

Results to Date:

The one step rust conversion coating (System 6), the chlorinated rubber (System 2) and a single coat of gloss epoxy (System 10) were inadequate, having failed in less than 6 months.

Plans

Inspect the panels in spring 1989.

SIGNIFICANCE TO THE INDUSTRY:

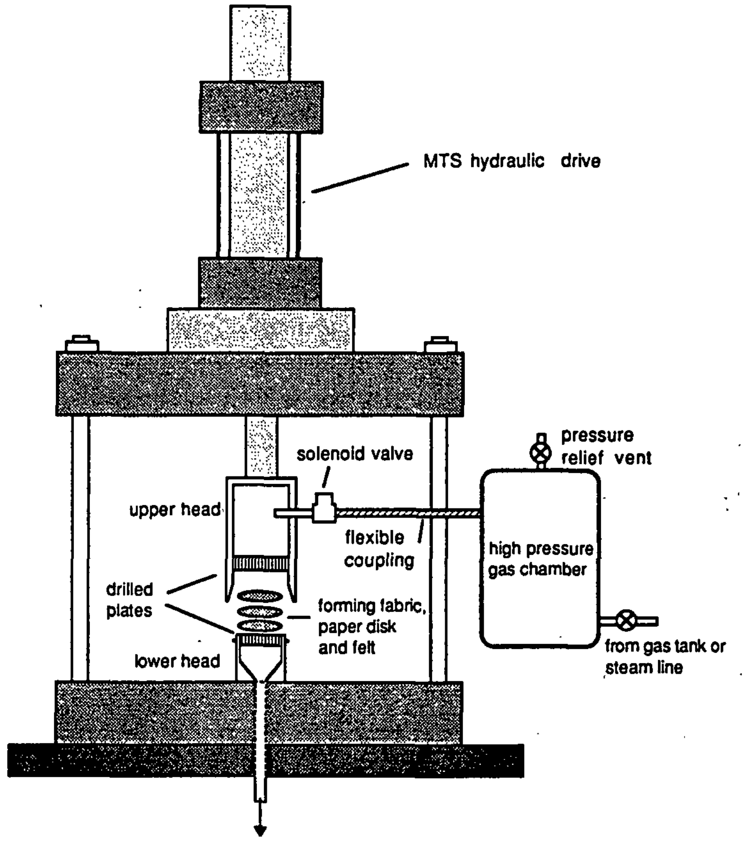
This project will provide mills with an independent assessment of the long-term reliability of structural coatings.

Project 3480

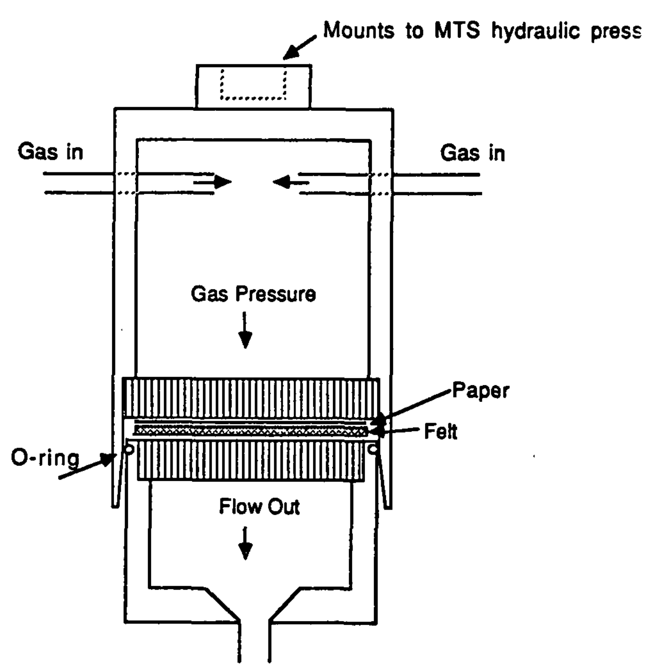
FUNDAMENTALS OF WET PRESSING

Jeff Lindsay
and
Cyrus Aidun

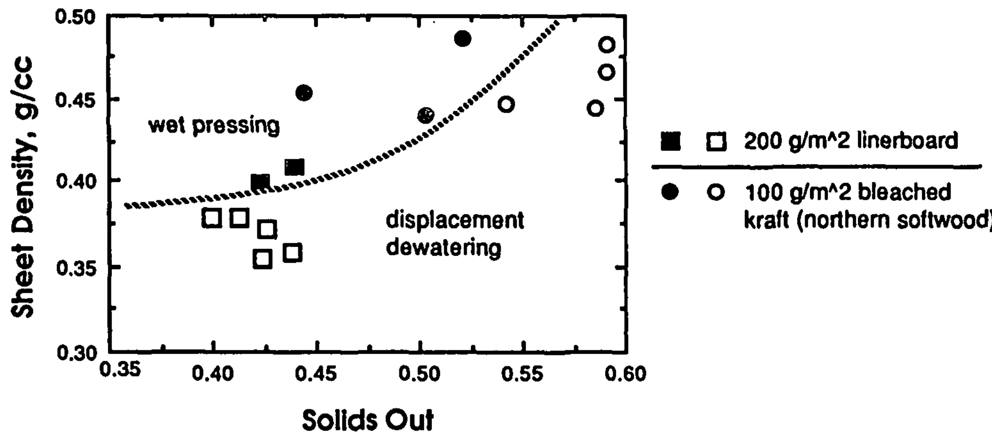
October 20, 1988



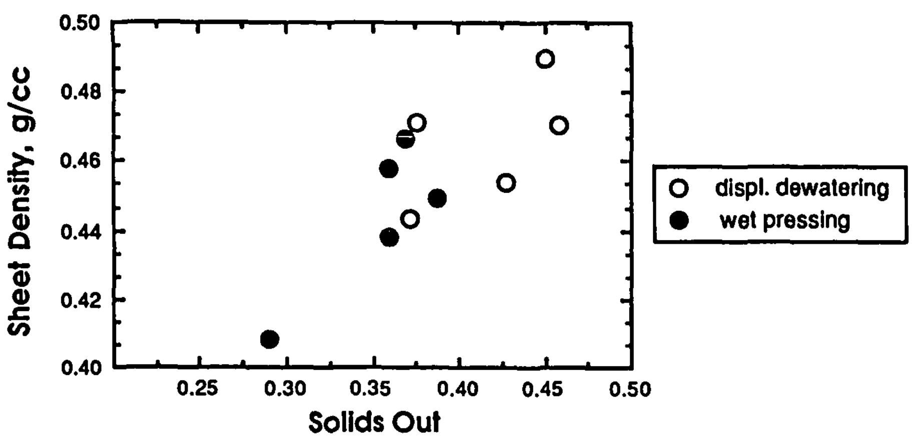
Experimental displacement dewatering device installed in the MTS hydraulic system.



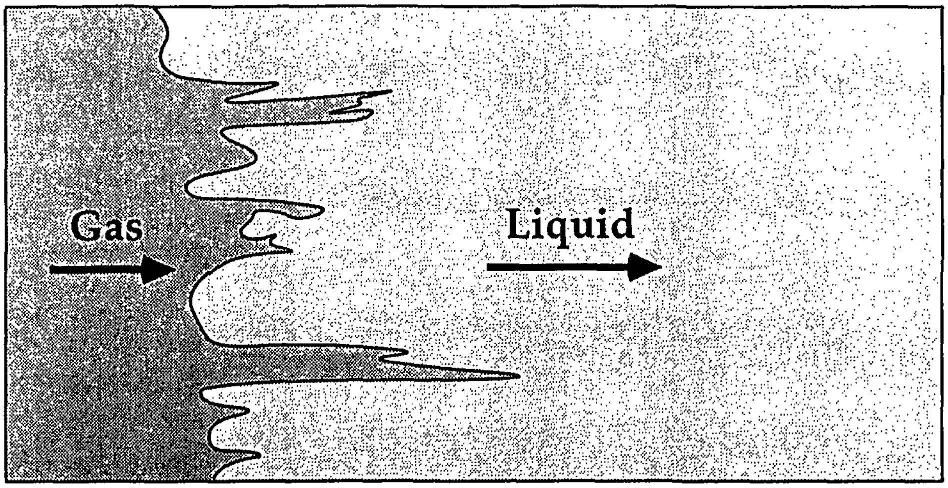
Displacement dewatering equipment (gas supply valves and pressure chamber not shown).



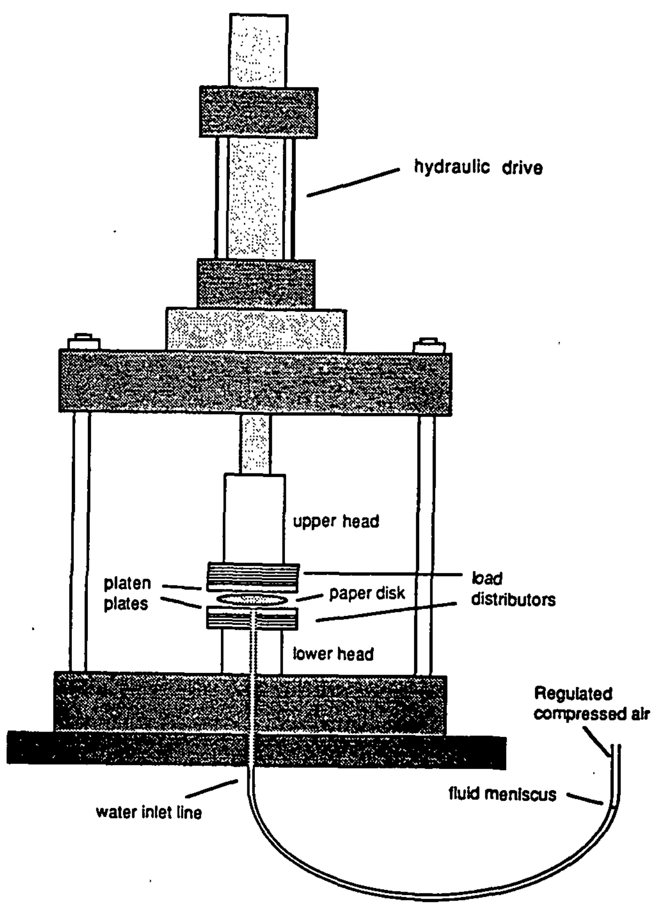
Density-dryness data from displacement dewatering and wet pressing for two furnishes. Nip residence times ranged from 60 to 120 ms, air pressures ranged from 60 to 100 psi, and peak mechanical loads ranged from 200 to 300 psi for the linerboard and from 500 to 650 psi for the bleached kraft handsheets.



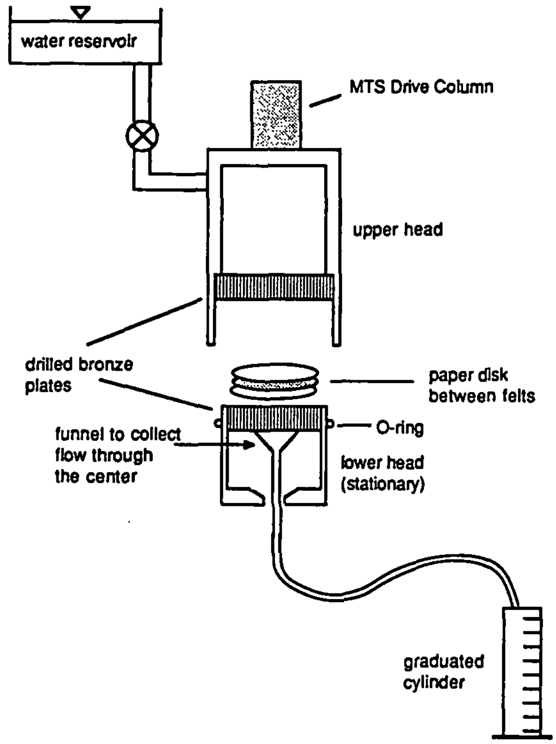
Density-dryness data from displacement dewatering and wet pressing for 125 g/m^2 linerboard.



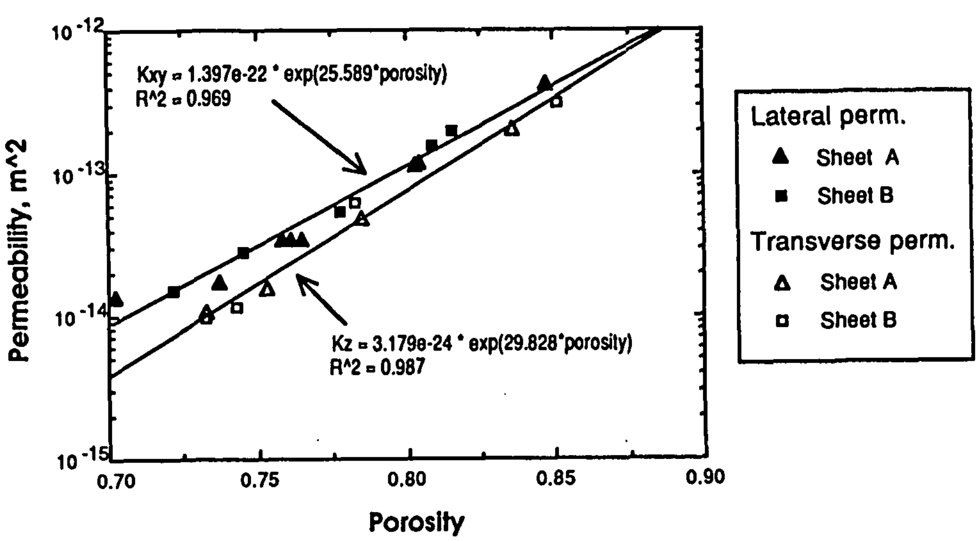
Viscous fingering in a porous medium



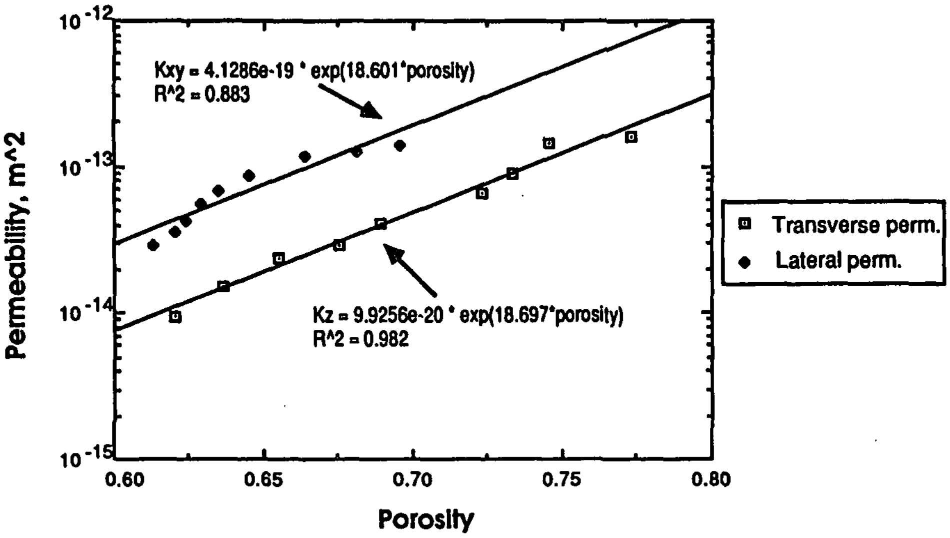
The MTS hydraulic press modified for lateral permeability measurements



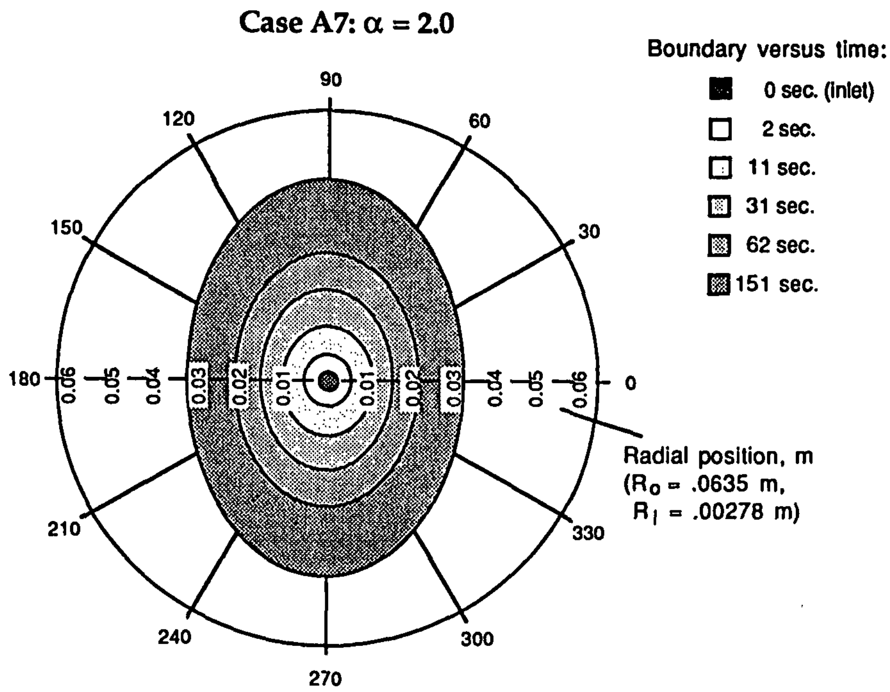
Detail of modifications to the MTS heads for transverse permeability measurements



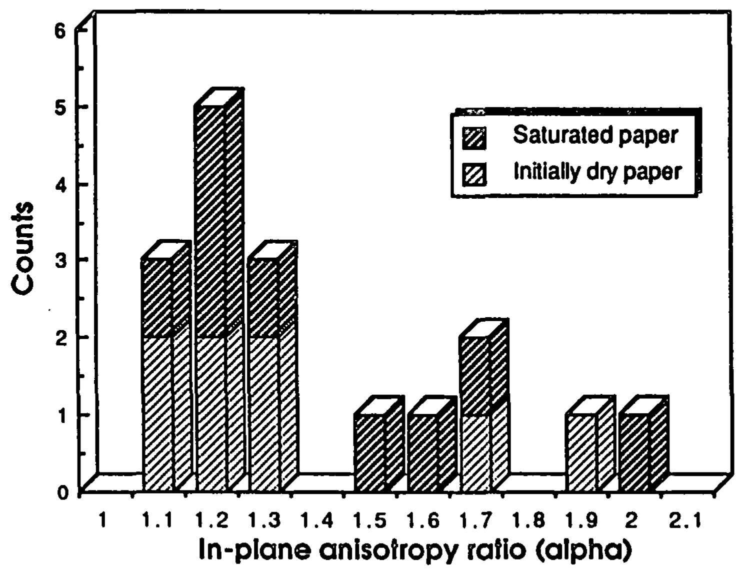
Comparison of lateral and transverse permeabilities in similar linerboard handsheets.



Comparison of lateral and transverse permeabilities in a single sheet of saturated blotter paper. (There is the possibility of a systematic error in measured porosity for the lateral permeability data.)



Predictions of dye boundary growth resulting from lateral injection into a saturated sheet with an in-plane anisotropy ratio of 2.0. $K_x = 1.0 \times 10^{-13}$ m^2, $K_y = 2.0 \times 10^{-13}$ m^2, viscosity = 1.0×10^{-3} Pa-s, and $\Delta P = 1.0 \times 10^5$ Pa.



Distribution of α values in multiple blotter paper samples. Results from initially dry and saturated sheets are shown.

STATUS REPORT

ON

FUNDAMENTALS OF WET PRESSING

TO THE

ENGINEERING PROJECT ADVISORY COMMITTEE

Cyrus K. Aldun
October 20, 1988

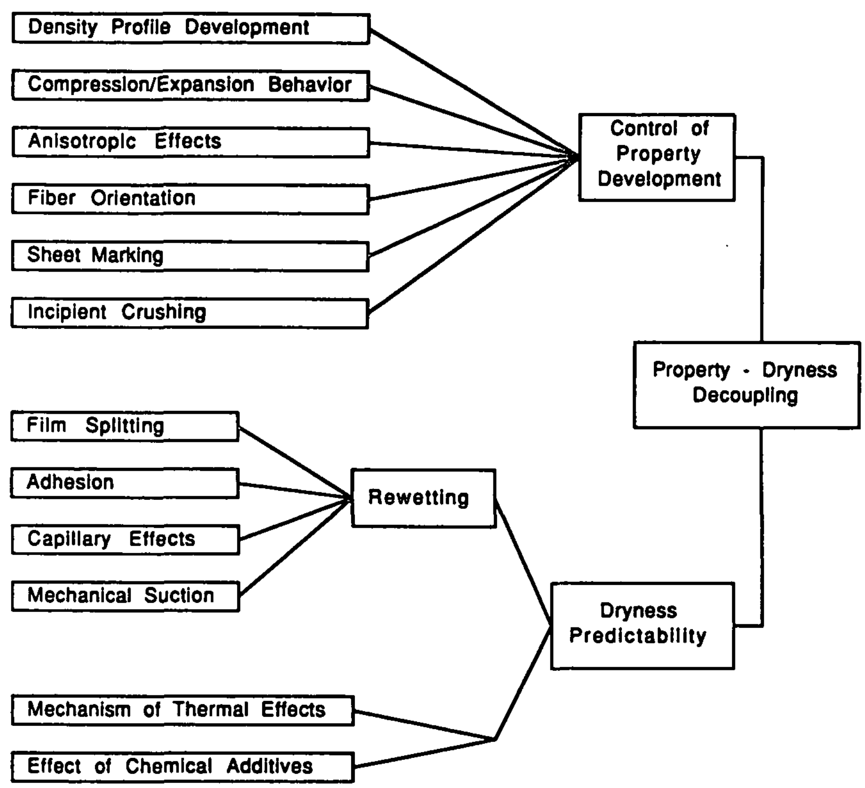
OBJECTIVE

To Improve the Performance of *Wet Pressing*:

Water Removal

Property Development

FUNDAMENTAL ISSUES



APPROACH

Fundamental understanding of web consolidation through direct measurement and observation.

Development of realistic models for detailed understanding and explanation of experimental observations.

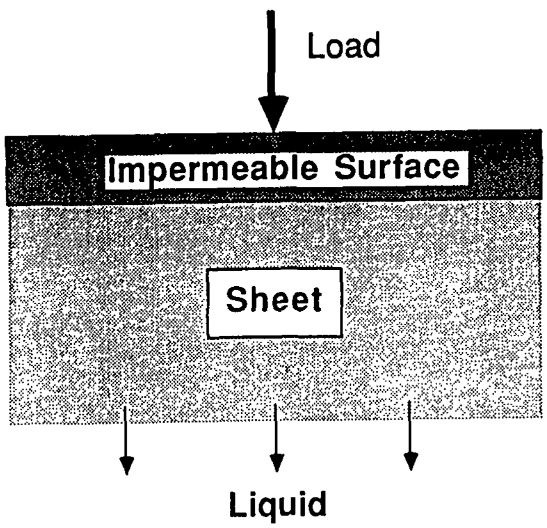
Application of fundamentals to understand and improve the commercial wet pressing processes.

CRITICAL ASPECTS OF WET PRESSING:

PROPERTY DEVELOPMENT

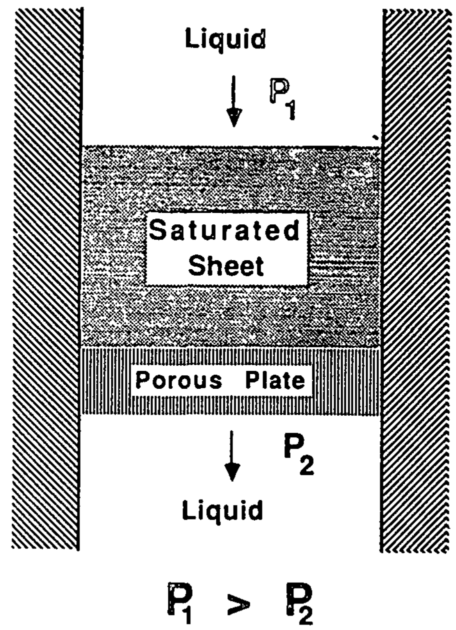
OR

DEWATERING ?



Hypothesis :

Larger density at the lower portion is attributed to the larger fluid velocity in that region

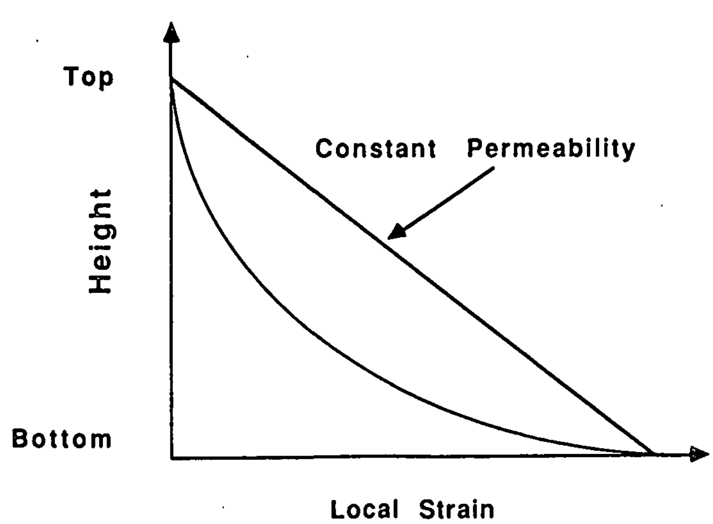


MODEL

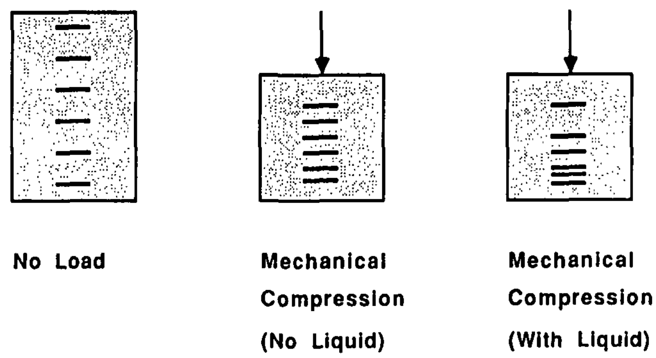
Poroelastic constitutive relations (Biot, 1941).

Equilibrium relations for solid and fluid displacement :

- momentum and mass balance



DENSITY DISTRIBUTION IN A DEFORMABLE POROELASTIC MATRIX



(After Caro et al., 1984)

CONCLUSIONS

The Velocity gradient is not responsible for the density profile development.

Fluid flow in a deformable porous matrix results in nonuniform (nonlinear) strain distribution, which in turn result in a nonuniform density profile.

Local strain increases in the flow direction.

PLANS FOR THE NEXT PERIOD :

1. Design and construction of an experimental roll press.
2. Study the compression/expansion behavior of a partially saturated fiber bed.
3. Measure the stress-strain response of a saturated fiber bed in presence of fluid flow.
4. Formulate a constitutive relation and a model for consolidation of an anisotropic saturated fiber bed layer.

Project 3576

FIBER AND PAPER PERFORMANCE ATTRIBUTES IN
PROCESS SIMULATION (MAPPS)

Gary Jones

October 20, 1988

Process Simulation

- Addresses some industry needs
- Traditional approach using material and energy balances
  - great for overall design
  - lacks detail on product performance

- MAPPS Performance Attribute System
  - Predicts development of fiber and sheet properties throughout process
  - Incorporates more fundamental process knowledge
  - Better representation of what process units do
  - Supplements mass and energy balances

Paper Industry Goals

- Improved Quality (End-Use Performance)
- Lower Costs (Capital and Production)

New Products and Technology

- Papermachine design, coaters, impulse drying polymers, wet end chemistry, calendering techniques

- New pulping and bleaching technology

New Sensor Development

Industry Needs

- Better Understanding of Fundamentals

- Predictive tools - models and simulators
  - process design and improvement
  - new process development

- Better process control
  - utilize new sensors
  - provide logic linking sensors to process

Examples

Chemical Pulping and Bleaching

Conventional Simulation	PAT Simulation
dissolves lignin and cellulose, consumes chemicals	reduces absorption coefficient
	increases fiber flexibility
reduces kappa	increases fiber bonding
consumes energy	affects fiber strength and density
	affects fiber composition
	sheet properties

Refiner

Conventional Simulation	PAT Simulation
converts components	also
consumes energy	changes fiber length and width distribution
	increases surface area and flexibility
	may reduce fiber tensile strength
	handsheet properties changed
	dissolved extractives reduces absorption

Paper Machine

Screening and Cleaning

Conventional	PAT's
mixing and splitting	detailed particle retention
fiber and water	fiber distributions changed
	surface area and CSF changed
	handsheet properties changed

Stock Tank

Conventional	PAT's
mixes components	mixes attributes
	surface area, length, width
	density, strength, modulus

Drying

Conventional	PAT's
Removes water	Creates hydrogen bonds
Consumes steam	Increases sheet tensile and modulus
	Collapse fibrils

Wet Pressing

Conventional	PAT's
Removes water	Increases potential bonded area (densifies sheet when dry)

Calendering

Conventional	PAT's
--------	Bulk densification
	Surface densification
	Break "bonds"
	Reduce tensile and modulus
	Affects scattering and brightness
	Reduces density variations

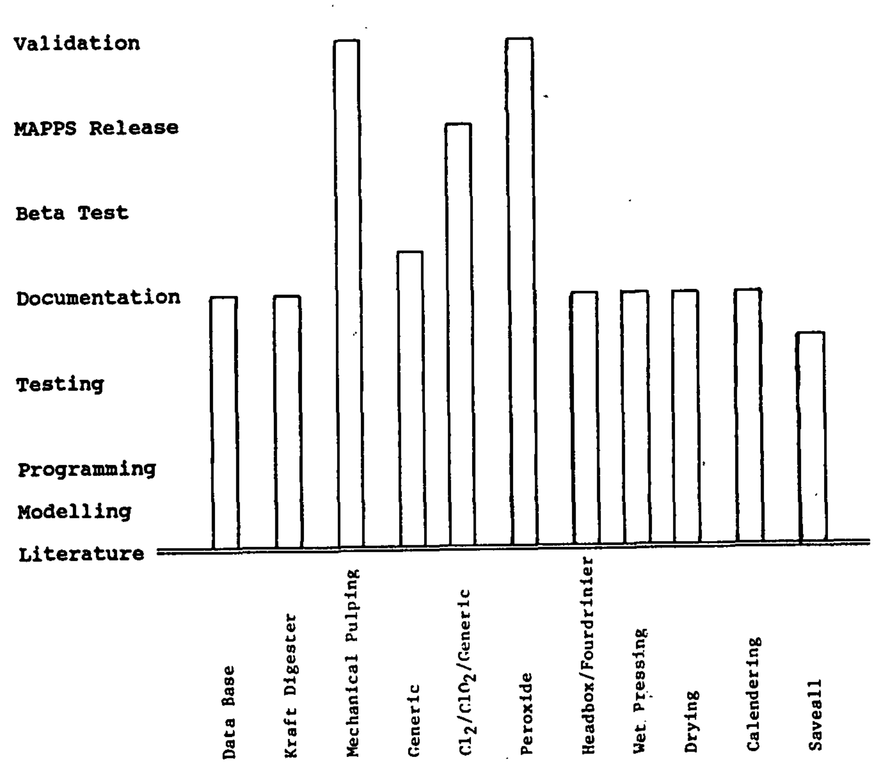
PAT System Process Flow

Wood Yard	Pulping	Bleaching	Stock Prep	Sheet Forming	Pressing	Drying	Calender

```
                              chlorine
                  kraft ---> ClO2        screen
species                      alkaline    clean     headbox    wet     can     multi-
data    -->       generic--> generic --->       -> four    --> press   drier   nip
base                                     refine    drinier    or              calender
                  mechan-    hydrogen    mix         or      generic          stack
                  ical   --> peroxide    broke     generic
                                         recycle
                                         repulp

chips ---------> fibers ---------------->  network   ------->     paper
```

Status of PAT System Development



Performance Attributes

- New Modules Developed
- Significant number of modules modified
- Attribute list expanded
- Flowsheets developed
- Limited testing
- Validation underway

New Modules Using PAT's

- Head Box and Fourdrinier Wire Section (FOUR01)
- Single Wet Press Nip (WPRESS)
- Calendering Nip or Stack (CALEND)
- Stream Initialization Block (WOOD02)
  - Pulping, Bleaching
  - Paper Streams

New Modules (cont'd)

- Property Block (PROPS)
- PAT Initialization Block (PAPSIM)
- Separator Block (SEPAR3)

New Property Models

- Fiber Basic Data
- Computes fiber length and width distributions from statistical parameters
- K-factor model
- Hydrodynamic Specific Surface Area
- Canadian Standard Freeness
- Potential Bonded Area before wet pressing

New Property Models (cont'd)

- Potential Bonded Area after wet pressing
- Actual bonded area
- Light Absorption Coefficient
- Change in absorption coefficient
- Brightness
- Anisotropy ratio
- Formation (bond density variation)
- Directional Properties
  - Elastic moduli C_{11}, C_{22}, C_{33} (MD,CD,ZD)
  - Directional tensiles ZX,ZY,ZZ
  - Directional compressive strength
  - Edgewise compressive strength

Property Models (cont'd)

- Surface Properties (gloss and roughness)

Special Utility Routines

- Computes length and width statistics from paper stream composition

- Computes distribution statistics given correlation matrix and distribution type

- Added Weibull fiber length distribution option

Summary of New Module Features

Wet Press Module

- Single nip continuous wet pressing operation
- Calculates rate of water removal from web
- Uses dynamic compressibility model

  - treats compressible mat as a Kelvin body responding to a compressive stress

$$M_{out} = M_{in} - M_{in}*(P/C)(1. - e^{(t/\tau)})$$

P = maximum nip pressure

C = wet web compressive modulus

t = nip residence time

τ = dewatering time constant

τ = function of web flow resistance and initial moisture content

- web flow resistance is a function of CSF, basis weight and moisture content

C = exponential function of initial moisture content and independent of species and freeness

C also a function of basis weight for machine-made webs

PAT's:

Potential Bonded Area S_b increases through compressibility model

Thermodynamics:

Adiabatic, outlet pressures are atmospheric

Wet Press Model based on

- Caulfield, Wegner, Young (main dewatering model)
  - water removal is dominated by transfer from the cell wall
- Wahlström and Sweet (introduce basis weight dependence)

Calendering Module

- Multiple-nip calender stack

- Determines the following:

  - bulk reduction through nip intensity factor
  - surface densification through heat penetration
  - change in bond area and bulk properties depends on relative extent of heat penetration
  - surface properties based on "surface" densification

. Contributors

- Ron Crotogino - bulk reduction as a function of nip intensity factor, NIF

NIF = function of calendering speed, nip load, roll radius and paper moisture and temperature

* nip temperature depends on approach to equilibrium

* approach depends on roll temps, wrap arrangement, speed and sheet properties and basis weight

. Contributors (cont'd)

- Charles and Waterhouse

Bulk properties such as modulus, tensile and burst increase with increasing densification to a maximum then decrease with increasing densification

- Gradient calendering involves short time, high temperature treatment which has little effect on bulk properties but influences surface properties significantly

Surface Properties

- Sheffield roughness increases from 10 to 350 as surface bulk increases from 1 to 2.3

- Gloss decreases exponentially with surface bulk

- Brightness depends on absorption and scattering coefficients
  - scattering increases with increasing surface bulk

Headbox and Fourdrinier Module

- Headbox
  - Based on Kerekes equations in Tappi J.
  - *Potential flow theory*

Given:	Calculates:
• Pressure	
• Slice height	• Deflection Angle
• Pond height	• Contraction coefficient
• Machine speed	• Jet velocity
• Lip extent	• Drag ratio
• Slice angle	• Initial slurry head

• Wire Section

Input data:

- Machine dimensions
- Forming section length
- Number of each drainage element
  - table rolls, foils, wet vacuum boxes, dry vacuum boxes
  - dandy roll not yet implemented
- Foil length and angle
- Table roll diameter
- Wet vacuum pressure
- Dry vacuum pressure

Input data:

- Wire diagonal length
- Trim fraction
- Orientation angle
- Stretch in open draws, %

Optional data:

- wire resistance
- first pass particle retention
- diameter of suspended material
- density of suspended material

Model Output:

- Basis Weight Profile
- Drainage rate profile
- White water consistency profile
  - after forming board
  - after foil section
  - after table roll section
  - vacuum foil or wet box section
  - high vacuum dry box section

Model Output:

- **Web**
  - **fiber and moisture content**
  - **surface area, CSF and PAT's**

- **White water**
  - **fiber content and consistency**
  - **surface area, CSF and other PAT's**

- **Sheet anisotropy ratio**

- **Formation parameter**

Model Basis:

- **Elaborate filtration and particle separation process controlled by local pressure drop and flow resistance**

  *** entering slurry split internally into three substreams**

  - **slurry above (inlet consistency and fiber content)**
  - **mat (retained fibers and suspended particles)**

    *** mat consistency remains constant**

    *** gains fibers from slurry**

    *** losses fibers to white water**

  - **white water**

Retention:

- based on extension of Estridge model
- depends on each particle (component) in slurry
- computed at each drainage element

Local drainage rate

- In forming section based on Victory model
- Remainder based on model of Pires and Springer
- Uses Darcy and Taylor filtration equation with maximum pressure constraint (iterative solution)
- Local filtration resistance is a function of
    * pressure drop
    * mixture consistency
    * turbulence level

Model Verification and testing

- Debugging, robustness
- Paper machine model - literature data (Springer, Pires)
- Calendering model - Crotogino data

Model Testing and Verification

- Full mill system - newsprint mill data
  - stone groundwood mill
  - kraft mill
  - two different papermachines
- Flowsheet development
- Beta test version