Development And Validation Of An Improved Drainage Testing Methodology

Frank J. Sutman
Sr. Research Scientist
Hercules Pulp and Paper Division
7510 Baymeadows Way
Jacksonville, FL 32256

Abstract

A flexible pulp drainage testing device was optimized in order to produce accurate laboratory simulations of water removal from newsprint and closed packaging system pulps. The test method was validated by comparing laboratory results to a series of paper machine trials. Laboratory experimental response variables were successfully correlated with total paper machine water removal, retention, and sheet formation on a mill scale. The new test method allows laboratory retention, drainage, and formation product development and process studies to be performed in papermaking systems where conventional tests such as Canadian Standard Freeness are of limited value.

Introduction

Need For An Improved Drainage Test

Industry-accepted Canadian Standard Freeness and Schopper-Riegler Drainage tests for pulp drainage have been used for many years. There is no question that these methods are valid predictors of paper machine wet end drainage in certain situations. It is fairly well accepted that freeness testing does little to predict total paper machine dewatering. In situations where freeness does show a response to chemical treatment, it has been correlated only to wet end drainage.

There are situations where freeness testing fails to yield a significant response, or yields an incorrect response to drainage/retention chemistry. Treatments which result in significant drainage and production increases on the paper machine can give no response whatsoever in traditional drainage tests. Two particular situations where this problem is commonplace are in newsprint and closed recycled packaging mills. High levels of fines, colloids, and dissolved substances interfere with the ability of a freeness test to provide meaningful results.

The high shear level developed during paper machine dewatering causes stock to dewater in a thickening mode. Thickening is defined as dewatering during the gradual consolidation of the web. Ideal thickening is when the instantaneous localized consistency remains constant regardless of the location in the thickness of the consolidating web. The opposite dewatering mechanism is filtration. During filtration, a high solids web or mat deposits on the forming fabric. The remainder of the filtrate from the dilute stock must drain through the formed mat, depositing additional fibers as drainage continues.

Britt Jar retention results have traditionally been used to select treatments for paper machine trials when freeness testing did not yield a response. There was often a reasonable correlation between better Britt fines retention values and improved drainage performance on machine. In 1996, we set out to develop a test which would be able to demonstrate a direct and accurate drainage response in these difficult to treat furnishes. The objective was to produce a test which would predict total paper machine dewatering, not just wet end drainage.

Drainage Testing Literature

Unbehend published a comprehensive literature survey of laboratory drainage testers in 1990. In it, he concludes that "over the years, there seems to be as many drainage testers developed as there were scientists investigating drainage phenomenon". The 44 cited references certainly demonstrate the wide variety of approaches which have been developed. He concluded that no one test satisfied all of the needs of the industry, and that the search for a "perfect" test continued. [1]

Since the review paper, a number of significant efforts to develop new drainage tests have been reported. Wei and coworkers have developed a drainage testing method based upon the specific filtration resistance of pulp pads formed under constant pressure. [2] Specific filtration theory is widely accepted for understanding the dewatering characteristics of filter cakes. Mantar and coworkers reported a variation of using a vacuum-assisted Britt jar for drainage studies. They developed methods to instantaneously calculate specific filtration resistance at points during the drainage versus time curve. [3] Unbehend has commented on the limitations of using the Britt jar approach for drainage studies. [1] Raisanen reported use of a moving belt drainage tester to determining dewatering characteristics of pulp slurries under vacuum. He used high frequency pulsed vacuum to dewater the web. [4] Forsberg and Strom [5] and Krogerus [6] report use of a commercially available unit, the Dynamic Drainage Analyzer (DDA), for laboratory drainage studies. The device measures vacuum-assisted drainage through a relatively coarse wire. Drainage events are inferred by interpreting the shape of the vacuum versus time curve. The DDA is becoming a popular testing tool in Europe. Trepanier described the G/W drainage retention tester as developed by Gess. It measure the change in constant flow rate vacuum as a function of time. Four different rate zones on the vacuum versus time curve were identified as correlating to paper machine dewatering. [7]

Initial Drainage Test Development

The Pulsed Drainage Device (PDD) was developed in the late 1980s. Lin and Schuster have previously reported details of the operation of this device. [8] The PDD is a patented, flexible drainage testing tool. A diagram of the physical setup of the device is contained in Figure 1. Stock is mixed with additives in an upper chamber. At the start of the test, the stock drops through a valve onto the forming chamber wire. A rotating foil is directly below the wire. The foil gives the unique opportunity to provide rapid pressure pulses while drainage is occurring. During the charging of stock to the forming chamber (for about 1 second) an air pad below the wire minimizes drainage. This avoids excessive early drainage due to the kinetic effects of the pulp impinging onto the wire. The filtrate collection chamber below the wire is connected to a vacuum pump. Vacuum may be applied at any point throughout the drainage event. A differential pressure transducer measures the static head of water collected in the lower chamber. This is calibrated to provide the mass of filtrate drained. A second pressure transducer measures the vacuum level in the lower chamber underneath the wire. Both pressure transducers and an event clock are connected to a high speed data acquisition system.

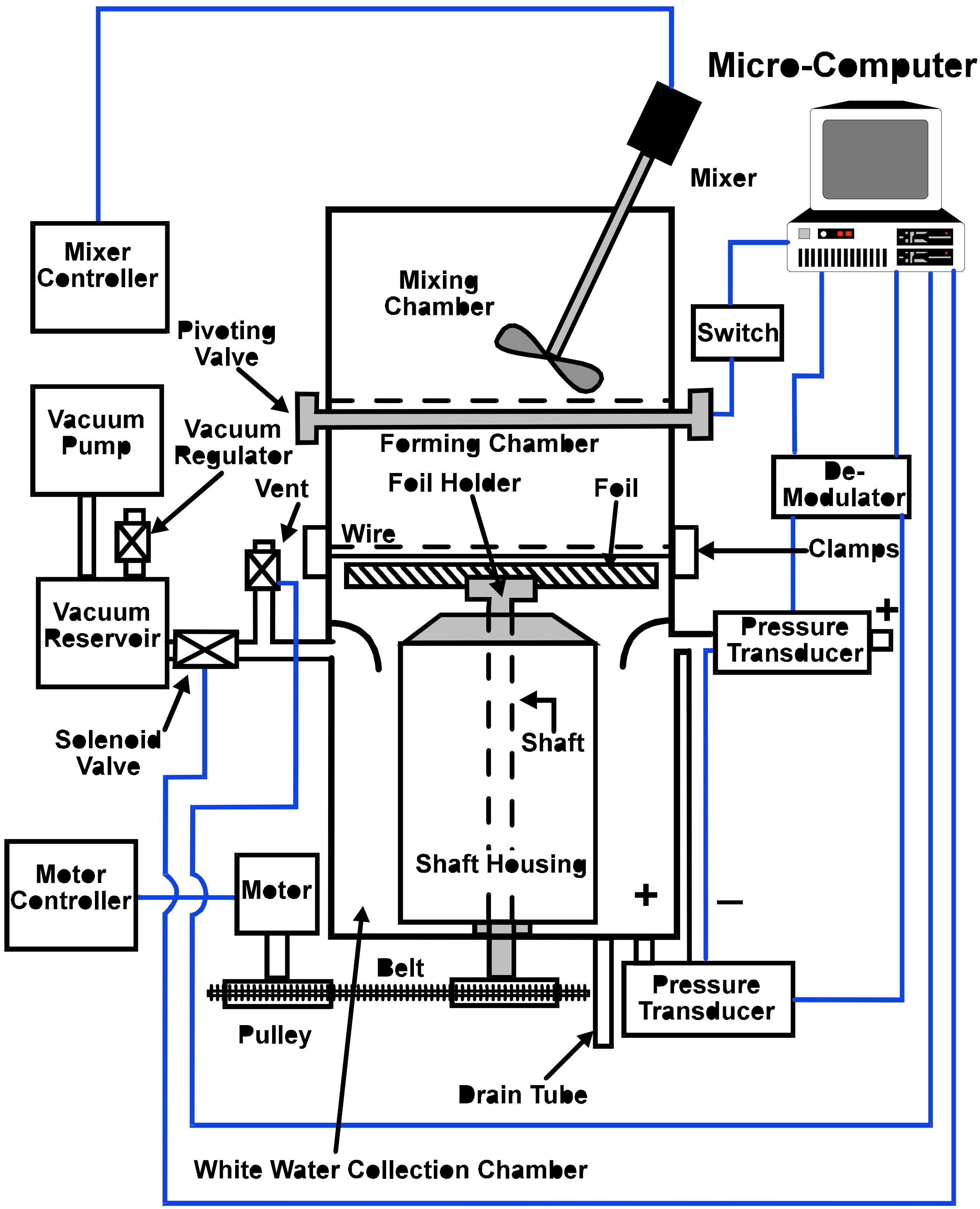
The initial operation of the device was defined to use high volume, relatively dilute stock suspensions. A fine wire similar in mesh to a paper machine forming fabric was used. Gravity drainage, utilizing only the foil, was used for a majority of the drainage curve before vacuum was applied. The combination of high volume, fine wire, and gravity drainage all led to a drainage mechanism which was highly filtrative. The method tended to give similar drainage predictions, or lack thereof, to freeness testing.

Method Development

<u>Difficulties With Previous Operation</u>

As described above, early operation of the device led to excessive filtration during pad formation. This led to pitfalls previously observed with other drainage test methods. In a number of cases, treatment with high molecular weight flocculant chemistry would actually cause drainage rates to slow down, when an increase in drainage had been observed on the paper machine. Treatment with non-flocculant drainage aids (i.e. - polyamidoamines and modified polyethyleneimines) usually had no effect on laboratory drainage, but were known to be successful drainage treatments in certain paper machine systems. Due to these limitations, the original method using the PDD was never successfully validated.

Figure 1.
PDD Diagram.



Current Method Description

Several major modifications were made to the original PDD test method. All were designed to increase web consolidation by a thickening mechanism and to minimize filtration effects. The stock volume per test was reduced from 1000 to 250 ml. Tests were performed at the same retained basis weight target as on the paper machine being simulated. This allowed the initial stock to be at or slightly above headbox consistency for packaging grade simulations, and slightly below headbox consistency for newsprint. The wire was replaced with a coarse (40 mesh (approximately 350 micron open area) stainless steel screen. This is much coarser than paper machine forming fabrics, but allowed greatly increased drainage velocities and produced realistic retention values. The foil speed was increased to raise the level of shear experienced by the web during pad formation. Lastly, a moderate vacuum level (10 in Hg (34 kPa) was applied to the vacuum reservoir at the beginning of the test. These modifications reduced drainage times by approximately an order of magnitude, and avoided setting up a filtration event. Drainage times for newsprint stock at 48 gsm are now on the order of 2-3 seconds. Drainage times for recycled packaging stock at 125 gsm are now on the order of 4-5 seconds.

Mass drainage, vacuum, and time data are acquired and averaged into a computer data file at the rate of about 40 averaged data points each second. The mass drainage data are then statistically smoothed to remove the majority of the noise due to vibration and other error influences.

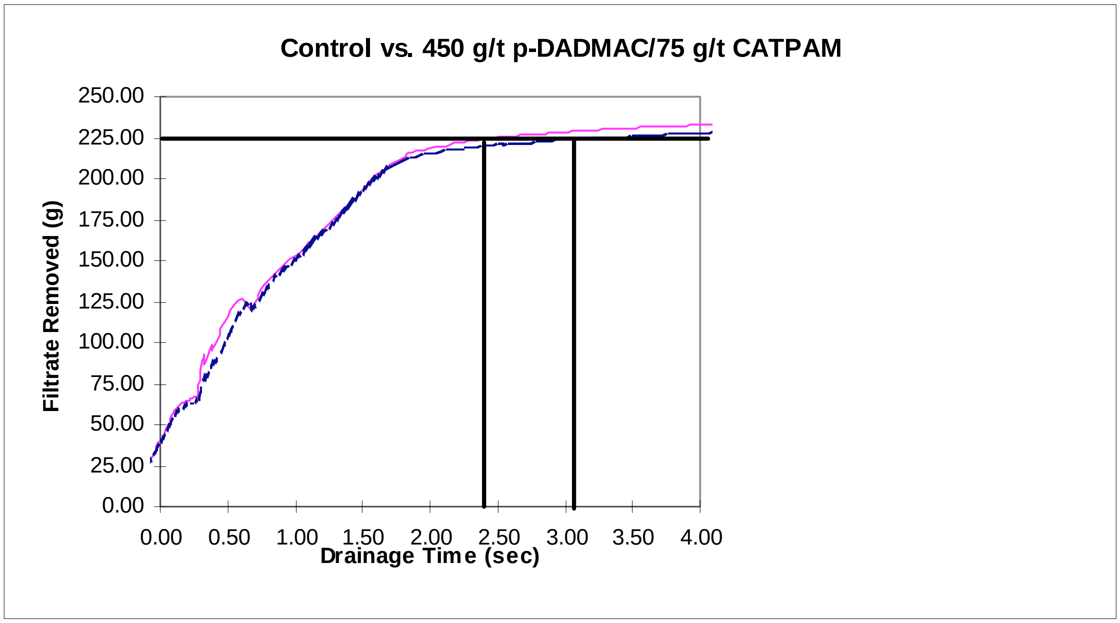
Early in the method development we considered whether single or multiple pass testing would provide a more accurate simulation of systems with a high degree of closure. Multiple pass testing involves reuse of filtrate obtained from a previous pass to dilute thick stock for a subsequent run. Single pass testing was shown to provide good predictive capabilities with the new method.

Response Variables

Two raw drainage versus time curves as collected by the data acquisition system are contained in Figure 2. There is some mass of filtrate registered at the test initiation point due to limited drainage through the wire during the “air hold time”. After the vacuum starts, drainage is quite rapid, with over 80 % of the total mass of filtrate drained during the first two seconds of the test. In the example an untreated control is compared to a dual cationic retention/drainage aid system consisting of a poly-DADMAC followed by a high molecular weight, low charge density cationic polyacrylamide. A considerable effort using statistical analysis determined that the time to reach 90% of the total stock mass drained (i.e. - 225 g out of a 250 g test) provided the best correlation to observed paper machine dewatering behavior while exhibiting the highest testing precision for a given number of replicates. In this case, the untreated drainage time is about 3.1 seconds.

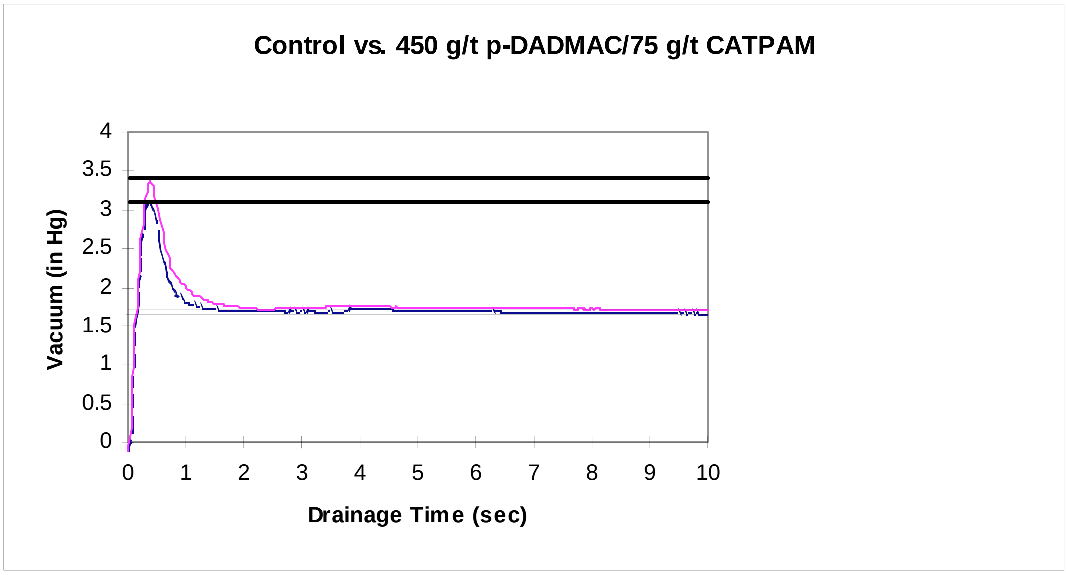
Drainage time with treatment improves to 2.4 seconds. The 90 % drainage time is linearly normalized for differences in retained pad mass within an experiment and defined as the Corrected Drainage Time (CDT).

Figure 2.
Drainage Versus Time Curves - Newsprint.



Vacuum level versus time curves for the same two runs are contained in Figure 3. The vacuum quickly rises to a peak during the early dewatering of the stock. The sharp peak and subsequent drop in the vacuum level occur when the air/water interface starts to break through the forming pad. This behavior is analogous to what happens at the dry line on a paper machine. The control is the data set with the higher peak vacuum level. Note that the peaks on the vacuum curves occur fairly early on the drainage curves in Figure 2. There is a limited and repeatable time delay in the drainage rates registering due to the amount of time it takes the filtrate to drop to the bottom of the lower chamber. The vacuum reading is instantaneous. The slower drainage rate allows the vacuum level to rise to a higher level before the "dry line" occurs. After a period of time, the vacuum level approaches an asymptote. The static vacuum created by the air flow through the pad is defined as the equilibrium vacuum. It is an indication of the porosity of the formed pad. In the absence of differing retention effects (i.e. - changing sheet mass or fines/filler distributions) it was expected to be an indicator of sheet formation.

Figure 3.
Vacuum Versus Time Curves - Newsprint.



Early experiments quickly determined that the equilibrium vacuum by itself was incapable of predicting formation effects of different chemical treatments. Treatments which significantly reduced the CDT usually caused the equilibrium vacuum to decrease significantly, indicating a more open sheet structure and poorer formation. This was regardless of the type of chemical treatment employed. It was determined that another important factor influenced pad porosity. This was the history of the compressive force which the web had experienced. The vacuum reservoir operates at a fixed pressure of 10 in Hg. Slow dewatering treatments or untreated control samples allow the vacuum level underneath the wire to build up to a higher level before the air/water interface breaks through. This compressive force acts to consolidate the forming web which in turn results in a higher equilibrium vacuum level. Conversely, faster dewatering treatments have a relatively lower peak vacuum level which limits the consolidation pressure on the sheet.

It was determined that the ratio of the peak to equilibrium vacuum levels (PEVR) was able to eliminate the bias caused by the differences in consolidation pressure due to different dewatering rates. In analyzing the PEVR, we found we were able to compare the true formation effects of different treatments without confounding the results with the effects of another dependent variable. Another way to consider the PEVR is as an indicator of the web's response to consolidation by vacuum. Lower values indicate a web which will consolidate more for a given vacuum level. A popular viewpoint, which we agree with, is that the floc formation of the wet web is a primary influence on the ability to further dewater the sheet through the high vacuum, pressing, and drying sections of the paper machine. Larger, bulkier flocs retain water better and are more difficult to press and dry. We hoped to be able to demonstrate this link through the following validation studies.

Lastly, fines retention was calculated through determining the OD weight of the retained pulp pad and the fines content (pass 200 mesh or 76 micron) of the stock. Once dried, the pads can be ashed via normal procedures if ash retention data are a desired test outcome. Additionally, PDD filtrate can be passed through a 1.5 micron pore size filter and subsequently measured for turbidity. We have used this as an indicator of colloidal retention in certain situations. The primary response variables are summarized in Table 1.

Table 1.
Primary Response Variable Definitions.

Variable	**Abbr.**	**Derived From**	**Response Direction**	**Predicts**
Corrected Drainage Time	CDT	Time to reach 90% of mass drained, normalized for differences in retained pad basis weight	Lower value preferred	Wet End Drainage
Peak to Equilibrium Vacuum Ratio	PEVR	Peak value on vacuum versus time curve divided by the asymptotic vacuum value at the end of the test	Lower value preferred	Formation which influences high vacuum and press dewatering, and drying
First Pass Fines Retention	FPFR	Retained pad mass and pulp fines content (<200 mesh, 76 micron)	Higher value preferred	Retention

It quickly became evident that the greatly increased drainage rates and reduced drainage times would require the use of multiple replicates and statistical analysis in order to determine significant differences between treatments. Experimentation led us to adopt the standard practice of requiring five test replicates for each experimental condition. At 95 % confidence, 5 replicates per condition allowed CDT testing precision on the order of 0.1 seconds and PEVR testing precision on the order of 0.03 units.

Method Validation

Validation Approach

Several paper machine drainage/retention trials were selected for both newsprint and closed packaging systems. Situations were sought where an extended trial was going to be performed versus a reference treatment of significantly different chemistry on the paper machine. Different paper machine and pulp types were desired. During the trial, paper machine whitewater and machine chest samples were obtained. These were blended to match headbox consistency and fines content. Trial data were collected and later compared to the results obtained from the PDD drainage test using the same treatments. The laboratory approach was to bracket trial and reference product dosages within dose/response curves. It quickly became apparent that dose/response curves were an essential part of the validation process. Consideration of lab data points only at the mill target dosages was sometimes incapable of detecting significant differences between treatments. Examples of validation studies for both packaging and newsprint paper machines follow.

Packaging Validation Study

Stock was procured during a polymeric drainage aid trial at a highly closed recycled US linerboard mill. The furnish was 100% OCC. The reference program on this 2-ply machine was alum, cationic starch, and a cationic high molecular weight polyacrylamide. The trial program was alum and cationic starch followed by an anionic high molecular weight polyacrylamide. Mill trial results indicated increased paper machine production (25.0 vs. 24.5 T/hr) and speed (1478 vs. 1425 fpm (450 vs. 434 mpm)) when the polymer was switched from cationic to anionic. The mill also noted an improvement in first pass retention when switching to the anionic polymer. It was unclear from mill data whether the production increase was due to improved wet end drainage, improved pressing and drying, or both.

Base ply stock was used for the laboratory study. Dose/response curves were performed for both treatment combinations at a target basis weight of 33 Lb./1000 sq.ft. (158 gsm). Across the dose/response curves, both cationic and anionic polymer produced statistically equivalent CDTs. Dose/response curves for the CDT are displayed in Figure 4. The anionic treatment produced PEVR values which were on average 0.1 units better (preferred) than the PEVR for an equivalent cationic polyacrylamide dose. Dose/response curves for the PEVR are displayed in Figure 5. The anionic polymer produced on average a 5 % increase in laboratory FPFR. Dose/response curves for fines retention are displayed in Figure 6. All points on the graphs were also treated with 10 Lb./ton (4.1 kg/MT) of alum and 15 Lb./ton (6.2 kg/MT) of cationic starch. Both mill and laboratory data demonstrated that the anionic polymer was preferred. However, the cause for the production increase on the machine was unclear.

Figure 4.
Packaging Corrected Drainage Time Dose/Response Curves.

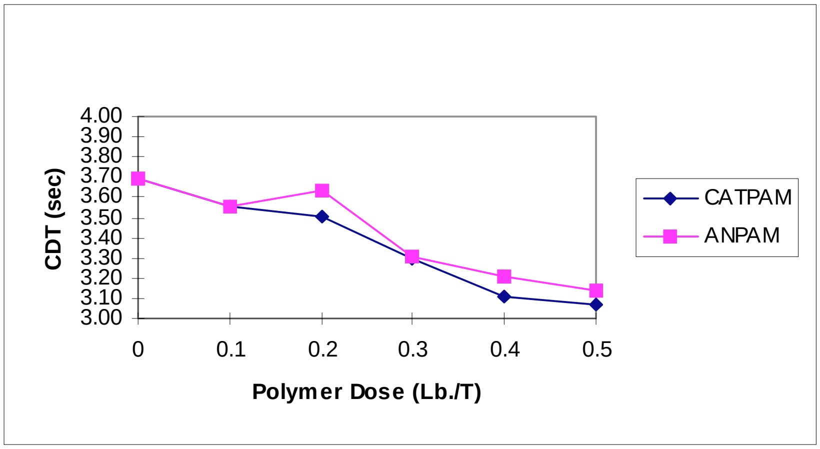


Figure 5.
Packaging Peak/Equilibrium Vacuum Ratio Dose/Response Curves.

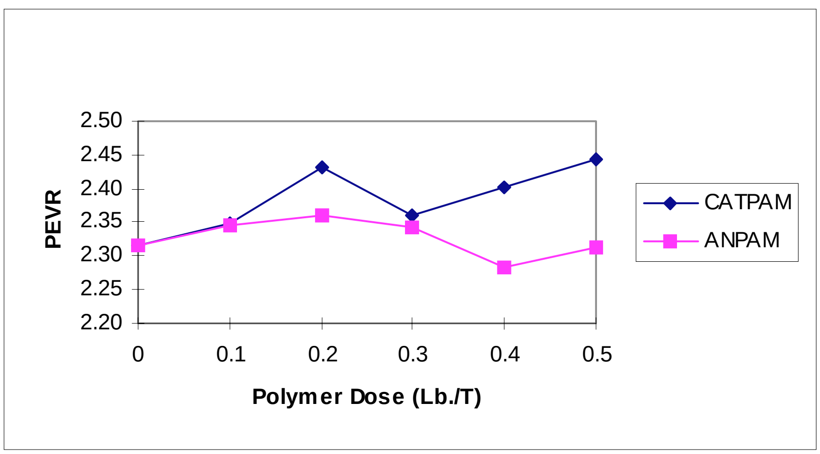


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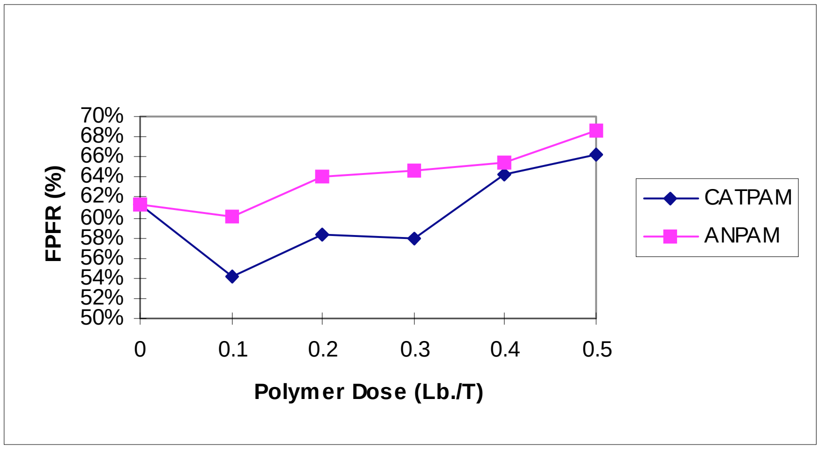
Figure 6.
Packaging Fines Retention Dose/Response Curves.



Paper machine reel samples were obtained from both the cationic and anionic polymer treatment periods. These samples were analyzed for mass density distribution via an Ambertec Betaradiograph Formation Tester. Each test consists of a 20 x 20 grid of 400 data points on a 3.5 mm spacing. The measurement resolution is 1.0 mm in diameter. Each test was performed in duplicate. At equal average basis weight, the standard deviation of mass distribution for the cationic polymer was 19.7 gsm. The standard deviation for the anionic polymer sample was 15.3 gsm. This indicated that the anionic polymer treatment resulted in significantly better formation, which most likely developed improved dewatering through the press and dryer sections. This study stressed the importance of considering all laboratory experimental responses in reaching a conclusion. An incorrect conclusion would have been reached if only the wet end drainage predictor (CDT) were considered.

Newsprint Validation Study

Stock was obtained from a multi-machine Canadian newsprint mill. The mill contains both top wire and high speed gap formers producing standard newsprint from a mixture of TMP, CTMP, and deinked pulps. A trial poly-DADMAC/high molecular weight low charge density cationic polyacrylamide powder (CATPAM) two component system was run mill-wide against a competitive reference treatment of a blend of a modified polyethyleneimine and a high molecular weight low charge density cationic polyacrylamide emulsion. Information from the mill indicated a 12 % increase in productivity with fewer breaks during the trial period. Fines retention and sheet formation were essentially equivalent for both the trial and reference conditions.

Laboratory dose/response curves at a target basis weight of 30 Lb./3000 sq.ft. (48.8 gsm) indicated that the p-DADMAC/CATPAM system could be optimized to provide the fastest CDTs. This was consistent with mill observation. Laboratory data also indicated that the PEVRs for the two treatments were statistically equivalent in the dosage range bracketing the trial conditions. Lastly, the PDD data demonstrated equivalent fines retention for both treatment systems. Both the paper machine trial and the laboratory evaluation identified the p-DADMAC/CATPAM system as being preferred for increased drainage and production.

Current Applications and Limitations

Three validation studies were completed with different newsprint mills. Five validation studies were completed with different packaging mills including both fourdrinier and cylinder machines.   In all cases the new method correctly simulated the on-machine response of different drainage chemistries. The method is now being used for new product development and drainage aid selection work for specific customer applications. Several successful drainage aid trials have been run on both newsprint and packaging machines as a result of product recommendations made by the new method.

Basis weight cannot be run lower than 45-48 gsm. Below this weight the PDD is unable to form a cohesive pad. The method may be used to model formation of single plies of multiply board at the single ply basis weight, providing that the low basis weight constraint is met. In fact, this approach is preferred in the modeling of heavyweight multiply grades such as those produced on cylinder machines. We use the method when drainage is the primary treatment objective and when experience dictates that freeness testing will not produce a meaningful response. Britt jar testing remains an efficient tool to screen materials where retention is the primary treatment objective.

Summary

A new drainage test was developed which avoids the previous pitfalls of excessive filtration during pad formation. The PDD test is useful to predict drainage, total paper machine dewatering, formation, and retention responses for different chemical treatments. It has been validated using furnish and data from paper mill trials throughout North America. The method is being applied to both new product development and process research studies in the laboratory. The PDD is also being used to make product recommendations for specific mill drainage trial applications. Due to the speed of the test, the method requires that a number of replicates be performed for each experimental condition. It is moderately labor intensive. Freeness and Britt jar testing remain efficient product screening tools in stock systems where reasonable test responses can be obtained from these devices.   The new PDD method gives a more complete picture of the combined retention, drainage, and formation response on the paper machine than previously obtainable. It can be used in systems where standard test methods do not yield significant responses, or yield incorrect responses to treatment.

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The important contributions of Rick Hobirk to this project are gratefully acknowledged. Rick collected the majority of the data upon which this paper is based, and suggested the concept of using the peak to equilibrium vacuum ratio as an indicator of sheet structure and formation. The contributions of Dean Gudlauski, Paul Arvanetes, and Bill Cronin in collection of field data and samples for the validation studies are appreciated.

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