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Eliminating Drainage at the Forming Board and Its Effects on Formation and Retention

Michael F. Scholly
Western Michigan University

ELIMINATING DRAINAGE AT THE FORMING BOARD AND ITS EFFECTS ON FORMATION AND RETENTION

by

Michael F. Scholly

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ABSTRACT

The pilot paper machine at Western Michigan University was modified to eliminate drainage at the forming board. This was achieved by inserting a thin plate under the wire, from the breast roll beyond the point of jet impingement. Two different plates were used - one five inches and one ten inches. Data was collected to determine the effects the modifications had on the table's performance and web formation and retention. The following can be concluded from this study: the modifications increased the web's consistency leaving the couch, yielded poorer formation, and had insignificant affects on solids retention. Problems occurred when obtaining samples from the table. This led to some uncertainty to the data.

INTRODUCTION

The objective of the fourdrinier table is to remove as much free water as possible while promoting good formation. The fourdrinier table is the most economical place to remove water and consequently much research has studied this aspect. The promotion of good formation on the table has not received as much attention until recently. In the past, formation was improved through improving headboxes. Recently, more research has been aimed at the deposition and initial dewatering of the stock on the wire.

The forming board is the machine element designed to deal with these aspects. This paper will discuss the design and operation of the forming board and my pilot machine study of how eliminating drainage affects formation and retention.

FORMATION

Formation is defined as the distribution of the fibrous mass of a sheet over its area. The degree of uniformity of fiber dispersion and general appearance of the sheet are covered by the term formation.[1,2]

In general, there are three areas which affect formation. The first are those things which are external to the paper machine and include: stock quality, uniformity, etc. The second category pertains to sound papermaking practice and attention to mechanical details of the paper machine. These include table levelness, rigidity and wet end design. The third category contains those variables that affect turbulence and drainage. These can be controlled on a day-to-day basis and include the controllable headbox variables and the water removal devices. The primary controllable variables of the headbox are: the consistency, the jet velocity to wire speed ratio, the slice geometry, and the liquid level. Water removal devices include the forming board, table rolls, hydrofoils, vacuum augmented foils, suction boxes and the vacuum couch roll. Formation will be influenced by these devices until a consistency of 1.2 to 1.4 percent; where the sheet becomes set. Suction boxes and couch rolls remove water from the sheet at much higher consistencies and therefore do not influence formation.[3]

Turbulence is essential to good sheet formation on the fourdrinier paper machine. It is developed to keep the fibers in suspension and to disperse fiber flocs as they form. The main reason turbulence is necessary is that at commercially used headbox consistencies (0.5% - 1.0%), fibers in suspension do not exist individually. They are present in the form of interwoven networks or flocs of considerable mechanical strength. In the absence of turbulence, fibers will flocculate within milliseconds.[4]

To develop good formation, turbulence is needed until sufficient amounts of water have been removed, and the sheet is set. The forming board is the first place on the table where turbulence can be developed. The forming board's design and alignment with respect to the wire and headbox discharge affect formation. This will be discussed later.

RETENTION

Retention is the retainment of suspended solids on the paper machine wire as the water is being removed. These solids are fibers and generally, fillers. Solids' retention is affected by variables which occur before the paper reaches the dryer section. The furnish, chemical additives, headbox, and drainage elements are all variables that can affect retention.[5,6]

The term drainage element includes the wire and all drainage equipment (e.g. forming board, table rolls, hydrofoils, vacuum boxes, etc.). These elements have a significant effect on retention throughout the entire sheet forming process.

THE FORMING BOARD

History

Forming boards were first applied to bridge the gap between the breast roll and the first table roll. Another reason for their use was to guide the initially drained whitewater into the tray below the wire. For a long time, forming boards were constructed of wood. Today the main structure is stainless steel with the blade material being some form of polyethylene or ceramic.[7]

The objectives of the forming board and its relationship to the jet are: to avoid excessive pressure forming, minimize breast roll pumping, maximize retention and formation and promote good formation.[8]

Design and Operation

There are three basic designs of forming boards: solid top, perforated top, and the bar or cattle crossing type. The solid forming board is commonly used when it is desireable to delay drainage. Perforated type boards are used with drop legs to remove water over their surfaces. The bar type forming boards are now the most commonly used. They consist of one or more bars (or blades). The critical design considerations are: the blade spacing, the blade size, and the blade-to-wire angle.

The blade spacing is often referred to as the open area of the board. The drainage that occurs early on the table is induced by gravity. Therfore, greater open area will cause more drainage on the forming board. The leading edge of each blade must be designed like a hydrofoil to doctor off the water that is draining through the wire.

Blade size has varied greatly. The trend is to have a large first blade with a large nose. This enables the forming board to be moved very close to the breast roll if desired. This first blade rarely exceeds nine inches. The remaining bars are usually much smaller in an attempt to reduce drag. They are rarely larger than four inches.

The blade-to-wire angle can have a significant effect on the performance of the forming board. The board can be placed flush with the wire or sloping up or down. If the forming board slopes upward, then the leading edge of the first blade is lower than the wire. This condition accomodates the pressure pulse of the jet impinging on the wire, but reduces the doctoring at the nose of the blade. This can be used to develop some turbulence, however stock jump can occur on high speed machines. Angling the blade in the other direction will increase doctoring at the leading edge and cause increased drainage at the trailing edge as the blade will operate as a foil. This is used to increase water removal, but excessive wear at the nose of the blade can occur.[9]

Position

The position of the forming board with respect to the point where the jet impinges the wire is also critical. An understanding of the jet flow as it contacts the wire is necessary when considering the position of the forming board. Figure 1 illustrates how the angle of impingement, β , varies depending on the geometry of the slice and the stock velocity. β can be calculated.[10]

When the stock contacts the wire, a portion travels backwards or upstream. This is known as jet back-flow. The amount that travels backwards is equal to: $1/2\,(1-\cos\beta)$. The smaller the angle, β , the smaller the back-flow.

The point where the stock contacts the wire is known as the turbulent region. This region is identified in Figure 1. Turbulence in this region is mainly caused by the angle of impingement, the velocity difference between the jet and the wire, and the jet disturbances developed in the headbox and at the slice. Turbulence in this region is necessary to prevent the occurrence of flocculation, however if excessive, defects in the sheet will appear.[11]

Another important characteristic of the jet flow is the forming pressure developed. This, also, is dependent upon the angle of impingement, β. The forming pressure = h(sine β). Where h is the total head developed in the headbox at the slice. This pressure is the force with which the fiber is being driven into the wire. Forming pressure will therefore affect the drainage rate and solids' retention.

The position of the forming board influences the effect of the angle of impingement, particularly the turbulence and the forming pressure just discussed. The forming board can be positioned so that the jet contacts the wire before the board, at the leading edge, or on top of it.

Allowing the jet to contact the wire before the forming board will "set" the sheet faster, removing a large amount of water. The water is removed by the forming pressure, the force of gravity, and possibly breast roll suction if the L/b ratio is negative. This condition is known as breast roll pumping and occurs when the stock leaving the slice is in contact with the top dead center of the breast roll. The stock is subjected to the suction developed by the rotating breast roll. This suction (P) was shown to be related to the roll speed by Burkhard and Wrist.[12] They found that the suction of a rotating roll to be expressed by the equation: $P = 1/2pU^2$. Where: p is the density of the whitewater and U is the tangential velocity of the roll (or simply the wire speed). Figure 2 is an illustration of the slice geometry with a negative L/b ratio. Fibure 3 is a plot showing the suction developed from the roll velocity. At high speeds, the breast roll suction is much larger than the forming pressure.[13]

Landing the jet before the forming board will reduce turbulence and settle out jet disturbances. The pressures that are present, increase the drainage rate and will reduce solids' retention. Under this condition, the forming board will only act to guide the drained whitewater into the tray.

If the jet lands on the wire at the leading edge a portion of the lower side of the jet will be doctored off. This is generally done to remove the back-flow portion of the jet. With this relationship, the initial violent drainage is significantly reduced, thus improving retention. Most of the jet disturbances developed in the headbox and at the slice will not settle out. These disturbances may result in poor formation of the final sheet.[14]

Allowing the jet to land on top of the forming board eliminates pressure forming and delays drainage. At high jet velocities or large angles of contact, turbulence and jet dis-

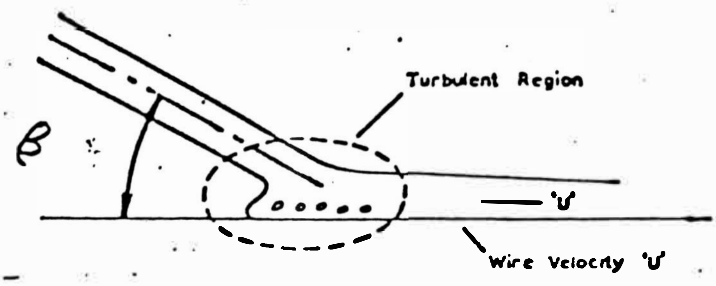


Fig.1

Definition sketch for jet back-flow.

Figure 2

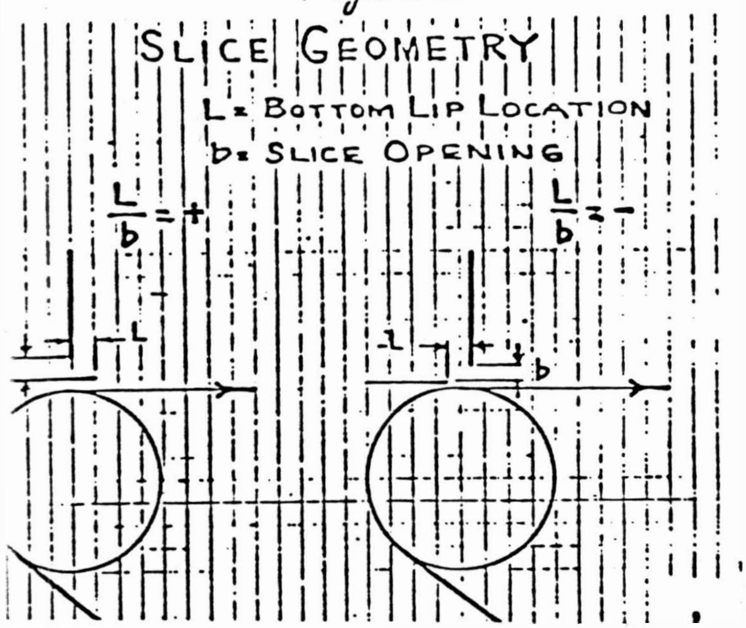
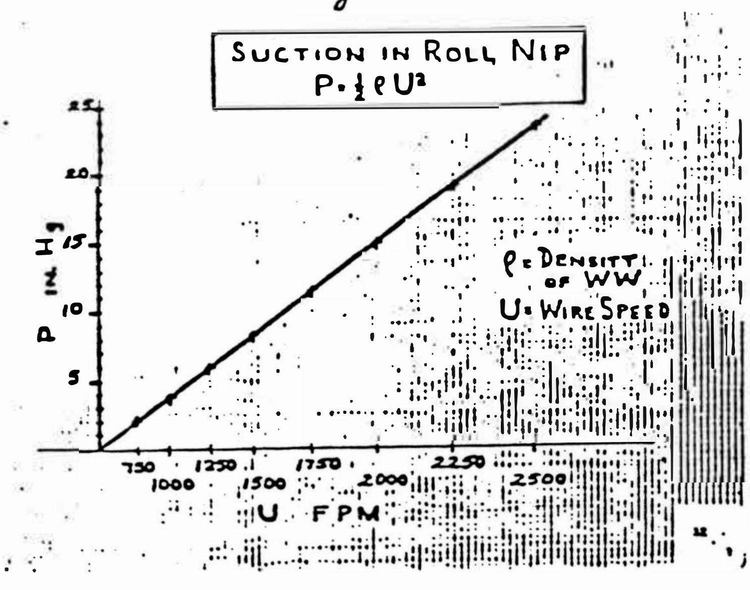


Figure 3



turbances are magnified and it is possible for the stock to jump off of the wire. If the angle of contact and the jet disturbances are small, the forming board can redisperse the fiber and improve sheet formation.

Positioning of the forming board has taken the following approach: If the jet disturbances and turbulence are excessive and promote poor formation, the trend is to move the forming board out or downstream. As hydraulic headboxes have become more common with lower contact angles, formation has been improved by landing the jet at or near the leading edge of the board to increase turbulence.[15]

In general, the forming board has less theory and design behind it than any other part of the fourdrinier. The deposition and initial dewatering of the stock on the wire is one of the most critical aspects of the sheet forming process. An author recently reported that the forming board should prevent dewatering from occurring and it should develop turbulence in the stock for redispersion.[16,17] This coincides with the belief that the sheet should be made on the fourdrinier table and not in the headbox.

EXPERIMENTAL DESIGN

The Western Michigan University pilot paper machine was used to study the effects of modifying the forming board. Figure 4 illustrates the fourdrinier section of this paper machine. A hydraulic headbox is used to distribute the water suspension onto the machine wire. The headbox is designed to operate under pressure-forming conditions at the breast roll. Draining into the first collection tray, is the whitewater removed at the point of jet impingement to approximately half of the third bank of foils. The whitewater removed by the remaining foils and table rolls is collected in the second tray. The combined whitewater from these two trays is used for thick stock dilution and the remaining is sent to the sewer. The whitewater from the four flat boxes and vacuum couch are collected in the separator and sent to the sewer.

Significant amounts of water, fiber, and filler are removed between the point of stock impingement on the wire and the first large foil. This condition is illustrated in Figure 5. This excessive drainage early on the machine table may impede both formation and retention.

Modification

My Senior Thesis Project focused on modifying the forming board section of the pilot paper machine to eliminate drainage at the point of jet impingement on the wire. This was accomplished by inserting a plastic plate underneath the wire and against the breast roll. Two different sizes were tested. The plate sizes were five inches and ten inches. Figure 6 shows how the insertion of these plates modified the wet end.

Paper Machine Trials

Two machine trials were run to determine the effects of modifying the forming board. The dates of these trials were February 28 and March 15, 1984. The two trials differed only in the basis weight and the machine speed. The machine speed was used to change basis weight. Both trials had three runs. These runs were as follows:

Run # 1 - The control run; no modification

Run # 2 - Insertion of the small 5 inch plate

Run # 3 - Insertion of the large 10 inch plate

FIGURE 4

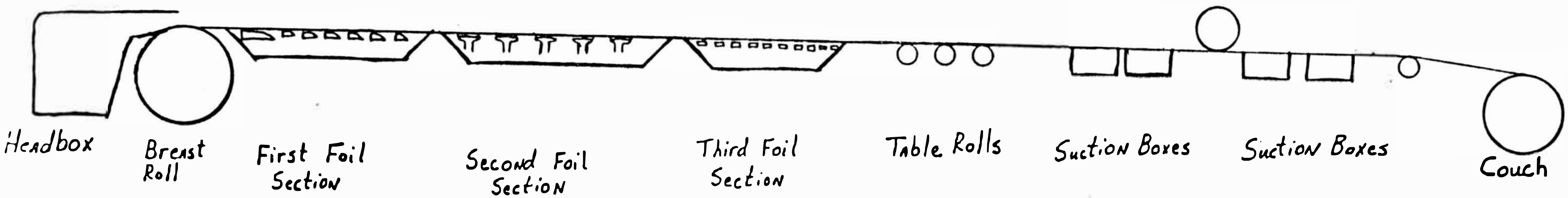

Headbox
Breast Roll
First Foil Section
Second Foil Section
Third Foil Section
Table Rolls
Suction Boxes
Suction Boxes
Couch

FIGURE 5

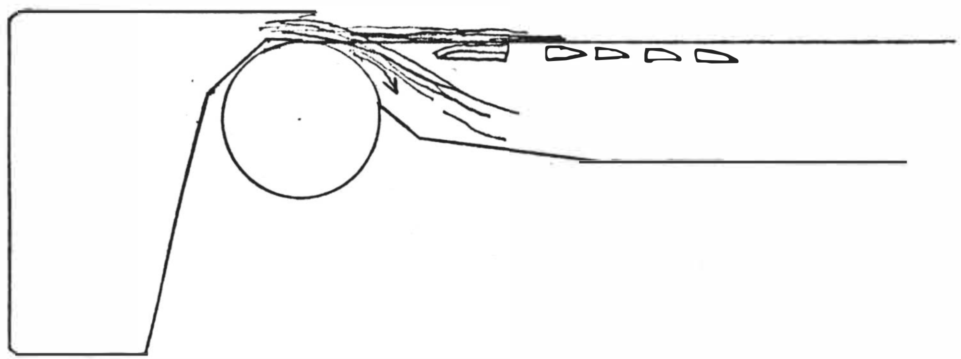
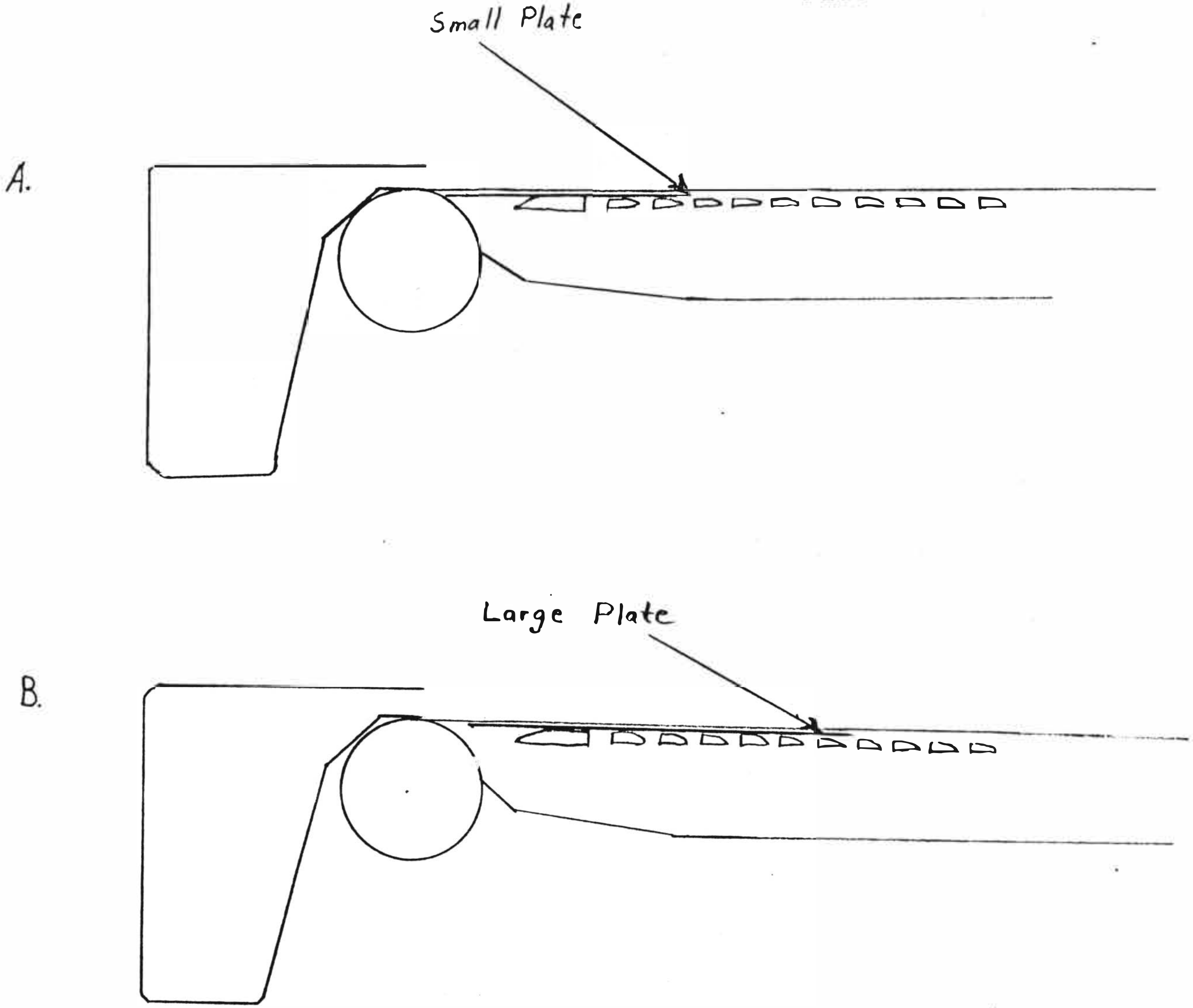


FIGURE 6



The furnish used was a 50% hardwood, 50% softwood blend refined to 400 Canadian standard freeness in the Claflin refiner. 20% #2 KWW Englehard filler clay was added at the beater along with 5% alum. pH was adjusted to 5.0 with H_2SO_4. The paper machine conditions are summarized in Table I.

Anticipated Effects

Eliminating drainage at the forming board of the pilot paper machine should affect the papermaking process. Depending on what was originally occurring, I anticipated the modifications to have the following effects:

1. increased drainage on the table because sheet sealing was eliminated
2. increased fiber and filler retention due to a delayed, less-rapid drainage
3. improved formation because of a more turbulent, dispersive jet landing on the wire.

DATA COLLECTION AND ANALYSIS

Comparisons of the paper machine runs were made to determine the effects of these modifications. Performance was evaluated by comparing machine wire profiles, fiber and filler retention, and paper properties.

Machine Wire Profiles

Profiles of the paper machine are one of the best ways to evaluate the machine's performance. This method has been successfully used by the paper industry for some time.[18] During the first trial, I had problems with blowing the samples from the wire. The first problem was that the air velocity was insufficient to blow the stock high enough off of the wire for collection. This meant the sample had to be pushed into the container by hand. The second problem arose when samples were being blown off of the wire after the dry line. The web was lifting off of the wire back past the preceding foil.

Higher air velocity was developed for the second trial, but it was also insufficient for raising the stock from the wire. For this second trial, the samples were scooped up from the wire into a special container. This method proved much better than blowing the samples from the wire. Each sample was placed in an air-tight jar and refrigerated until it's concentration could be determined. Figure 7 illustrates the locations of the collected samples.

Fiber and Filler Retention

Fiber and filler retention was calculated after the concentrations of the samples were determined. Retention values were then obtained for each sample taken from the fourdrinier table. Sample concentrations were determined by filtering the stock through low porosity, ashless filter paper and then ashing them. Table II summarizes the percent consistency and ash of the collected samples.

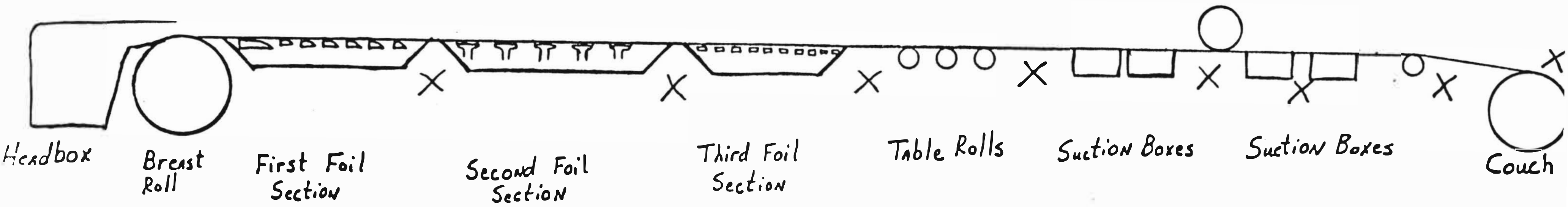
Several samples were taken from the same location to determine the accuracy of these two methods of collection. Ten samples were blown off the wire while producing 40 lb. paper and ten samples were scooped off the wire while producing 80 lb. paper. The consistency data is presented in Table III.

TABLE I

TRIAL MACHINE CONDITIONS

	Trial # 1	Trial # 2
Production Rate (lb./hr.)	160	160
Basis Weight (lb./3000ft^2)	40.0	80.0
Wire Speed (ft./min)	87.6	44.4
Reel Speed (ft./min)	90.8	46.0
Suction Box Vacuum ("H_2O)		
1st Box	0	0
2nd Box	0	0
3rd Box	6.0	7.5
4th Box	2.0	4.0
Couch Vacuum ("H_2O)	15.0	15.0

FIGURE 7



X – Sample Locations

TABLE II

Sample Taken After	TRIAL # 1 % Consis	TRIAL # 1 % Ash	TRIAL # 2 % Consis	TRIAL # 2 % Ash
		Run # 1		
Headbox	.467	29.9	.636	29.6
1st Foil	1.30	21.0	1.11	23.6
2nd Foil	1.98	20.6	2.27	21.4
3rd Foil	3.90	17.5	3.37	21.3
Table Rolls	4.09	17.3	4.01	19.0
2nd Box	4.15	17.8	4.25	20.2
3rd Box	9.41	13.0	13.2	14.6
4th Box	----	12.0	----	13.0
Couch Roll	17.3	11.5	19.5	14.3
		Run # 2		
Headbox	.467	29.9	.659	29.6
1st Foil	1.09	22.0	1.13	22.2
2nd Foil	1.72	20.3	2.33	20.6
3rd Foil	4.23	17.8	3.37	20.5
Table Rolls	4.52	16.6	3.74	20.6
2nd Box	3.83	19.2	4.19	21.2
3rd Box	11.6	12.1	14.6	13.6
4th Box	18.1	11.4	23.3	12.2
Couch Roll	18.4	11.2	26.1	12.6
		Run # 3		
Headbox	.467	29.9	.758	27.4
1st Foil	.790	24.4	.961	23.7
2nd Foil	1.63	20.4	2.18	20.0
3rd Foil	4.19	17.4	3.24	21.2
Table Rolls	3.86	16.7	3.60	22.3
2nd Box	4.04	15.0	3.86	20.1
3rd Box	11.3	11.9	12.6	15.3
4th Box	16.2	10.4	23.5	13.0
Couch Roll	17.3	10.2	26.5	12.9

TABLE III

Consistency Data for the Two Sampling Methods

at the Same Location

40 lb. sheet blown off % consis.	80 lb. sheet scooped off % consis.
3.76	3.14
3.88	3.28
3.82	2.90
4.21	3.04
4.06	3.55
3.81	3.74
3.93	3.43
4.17	3.08
3.72	3.54
3.48	3.62
$\bar{x}$ = 3.88	$\bar{x}$ = 3.33
standard deviation = 0.21	standard deviation = 0.27

Paper Properties

The paper was conditioned and tested at TAPPI Standard conditions— 50% relative humidity and 73°F. The paper was tested for machine and cross-machine direction tensile, tensile energy absorption and optical formation. This formation test consisted of a helium laser, a photo cell and an x,y plotter to record the variations in the sheet's opacity. When graph paper was used in the plotter, a standard deviation was computed from determining the average voltage output. Appendix A describes the operation of this formation tester. Table IV summarizes the results of the tensile and formation testing. The tensile testing was also used to indicate differences in formation. Better formation should result in high tensile strength but also smaller differences between the machine and cross machine directions.

Trial #1 — 40 lb. Basis Weight

As shown on Table II and Figures 8 and 9, it appears that the modifications had small or insignificant effects on the performance on the table. The tensile and formation testing indicated that the best sheet formation was obtained during the control run, when no modification was made to the forming board.

Trial #2 — 80 lb. Basis Weight

Table II and Figures 10 and 11 indicate that the modification had no significant effect on the table until reaching the flat boxes. More water was removed at the flat boxes when either of the plates were installed. The web leaving the couch had a consistency of approximately 26% with the modified forming board, as opposed to 19.5% for the control run. Filler retention was lower for the modified forming board however. As with the 40 lb. paper trial, formation was found to be the best when no modification was made to the forming board.

RESULTS AND CONCLUSIONS

The forming board plays a key role in forming the sheet. It's design, alignment and location with respect to the wire and headbox jet are critical. Eliminating drainage at the forming board was studied on the Western Michigan University pilot paper machine.

The data previously discussed suggests the following:

1) since a higher couch consistency was achieved by modifying the forming board, sheet sealing caused by initial rapid drainage presently occurs on the pilot paper machine while producing heavier weight paper.

2) the modifications yielded poorer formation than the control run. This may suggest that not enough turbulence was generated by the modified forming board.

3) the modified forming board did not significantly change solids retention.

TABLE IV

Tensile Testing (Tensile Strength, Kg/Tensile Energy Absorbtion,Kg/cm)

40 lb. Basis Weight	Control	5" Plate	10" Plate
Machine Direction	6.5/.022	5.5/.015	5.0/.016
Cross Machine Direction	2.9/.024	2.5/.021	2.5/.020

80 lb. Basis Weight	Control	5" Plate	10" Plate
Machine Direction	12.2/.030	11.8/.028	10.6/.026
Cross Machine Direction	5.1/.033	4.8/.031	5.0/.033

Formation Testing (Standard Deviations)

40 lb. Basis Weight	Control	5" Plate	10" Plate
	4.11	4.44	4.84

80 lb. Basis Weight	Control	5" Plate	10" Plate
	4.40	4.83	6.75

Figure 8

Machine Profiles - Trial #1 (40 lb basis weight)

Solids Concentration

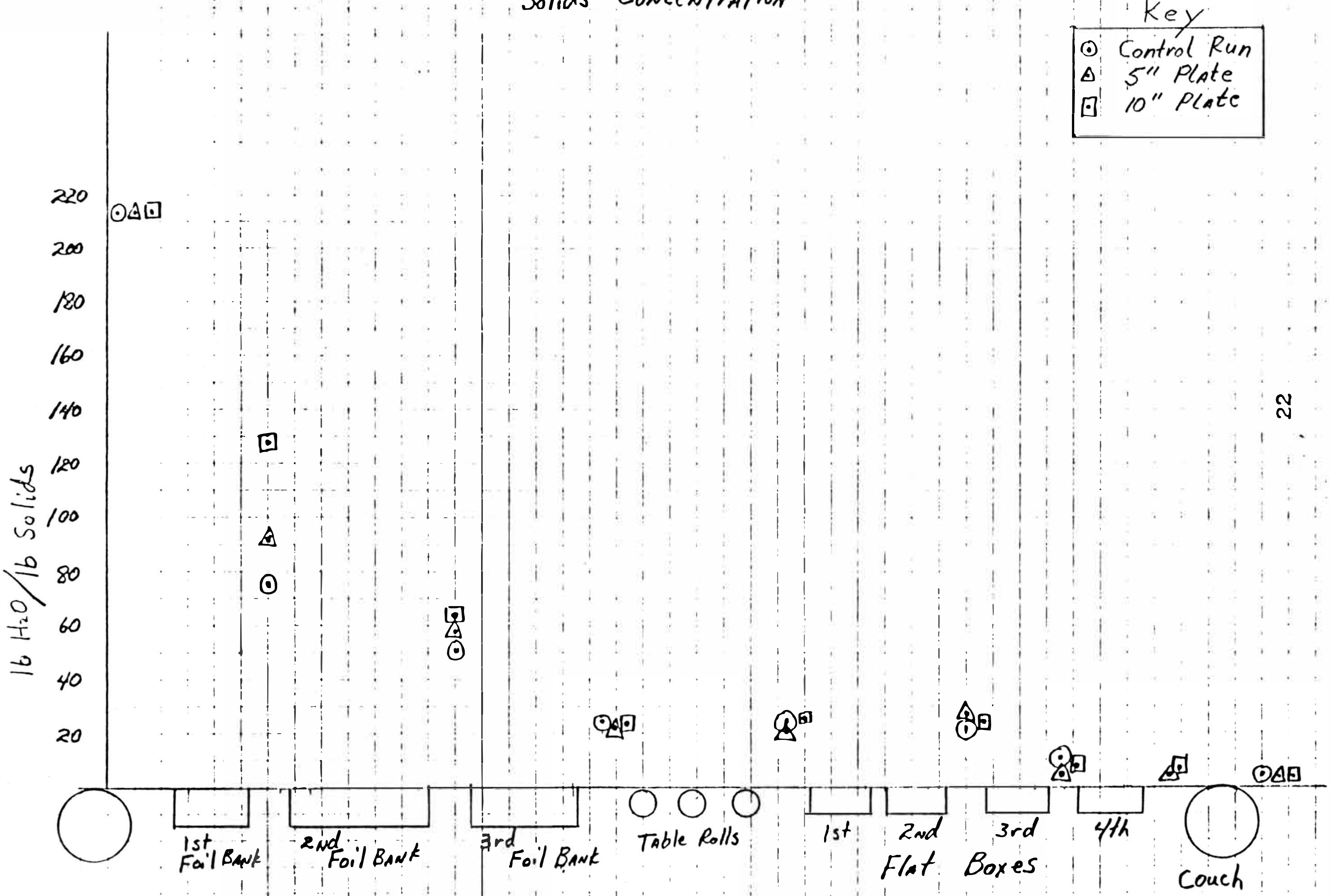


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Figure 9

Machine Profiles - Trial # 1 (40 lb basis weight)

Filler Concentrations

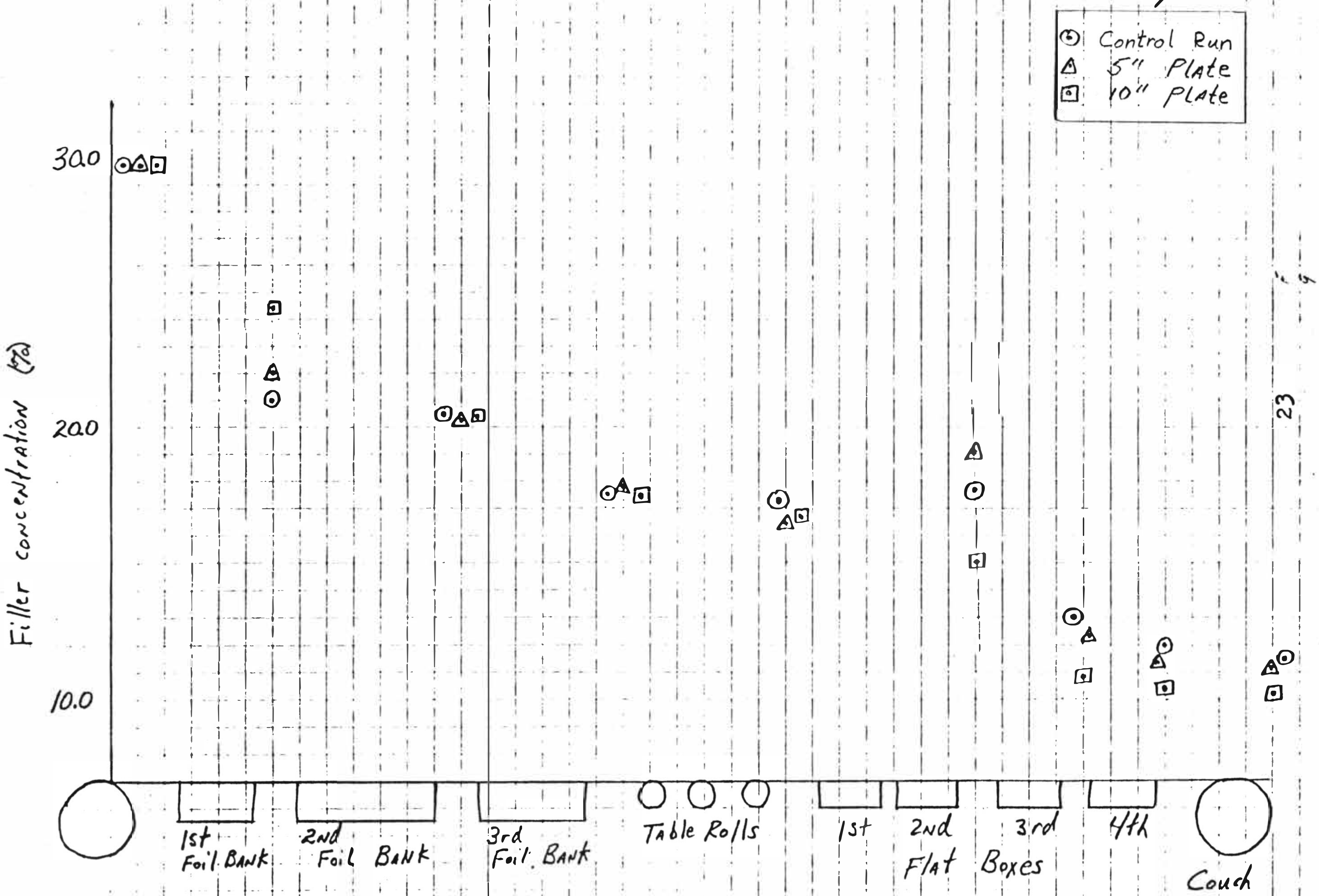

Figure 10

Machine Profiles - Trial #2 (80 lb basis weight)

Solids Concentration

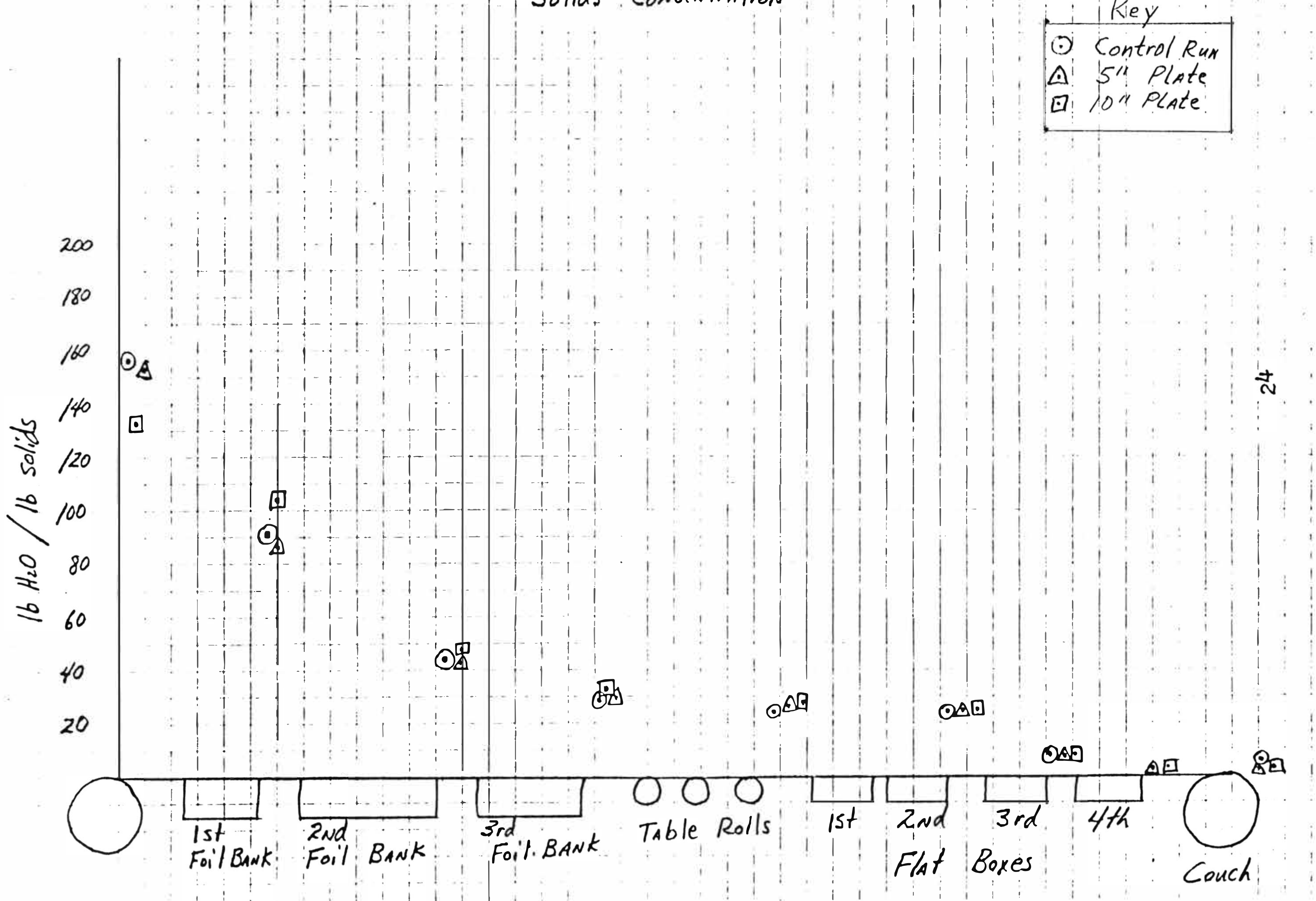

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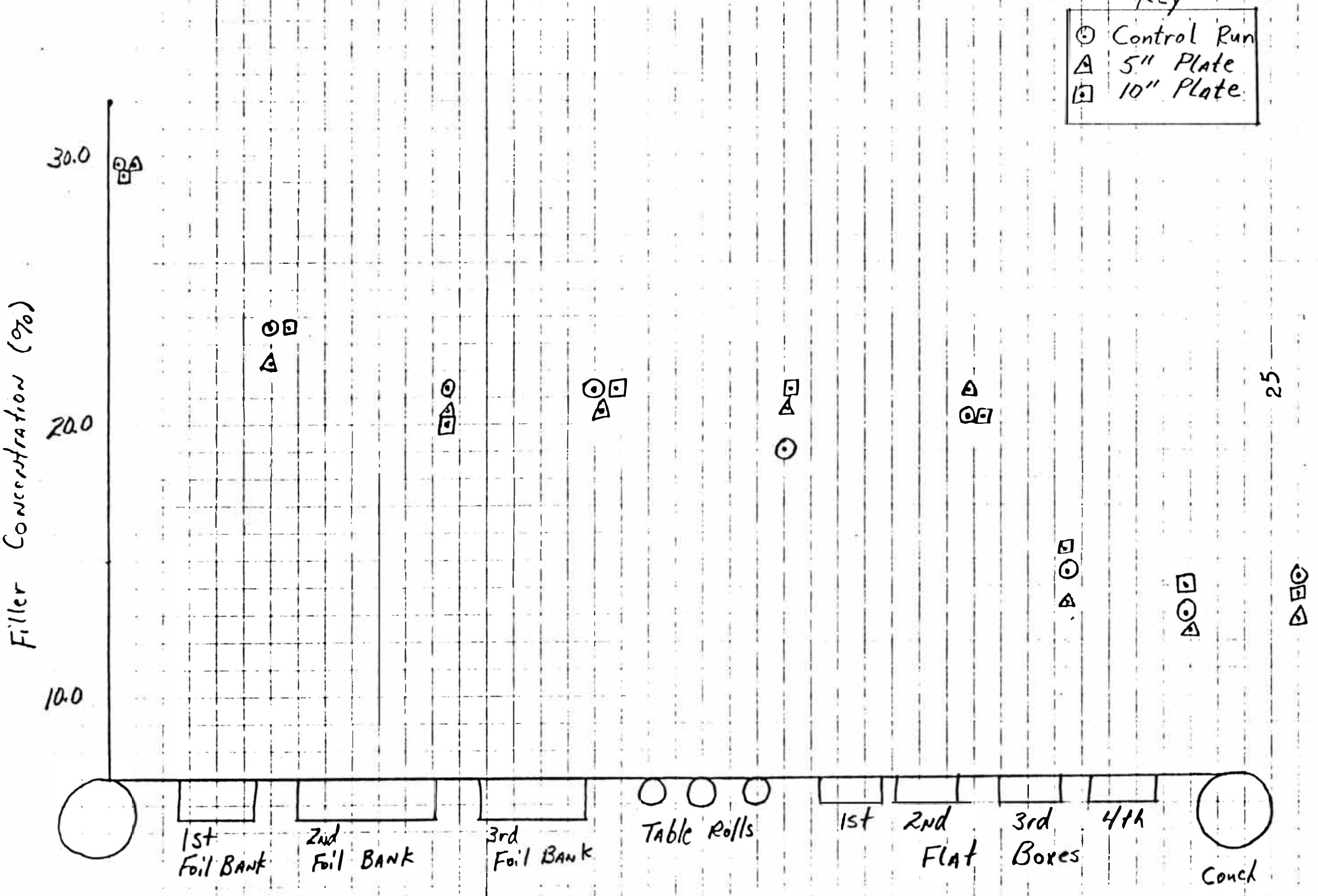
Figure 11

Machine Profiles – Trial #2 (80 lb basis weight)

Filler Concentrations



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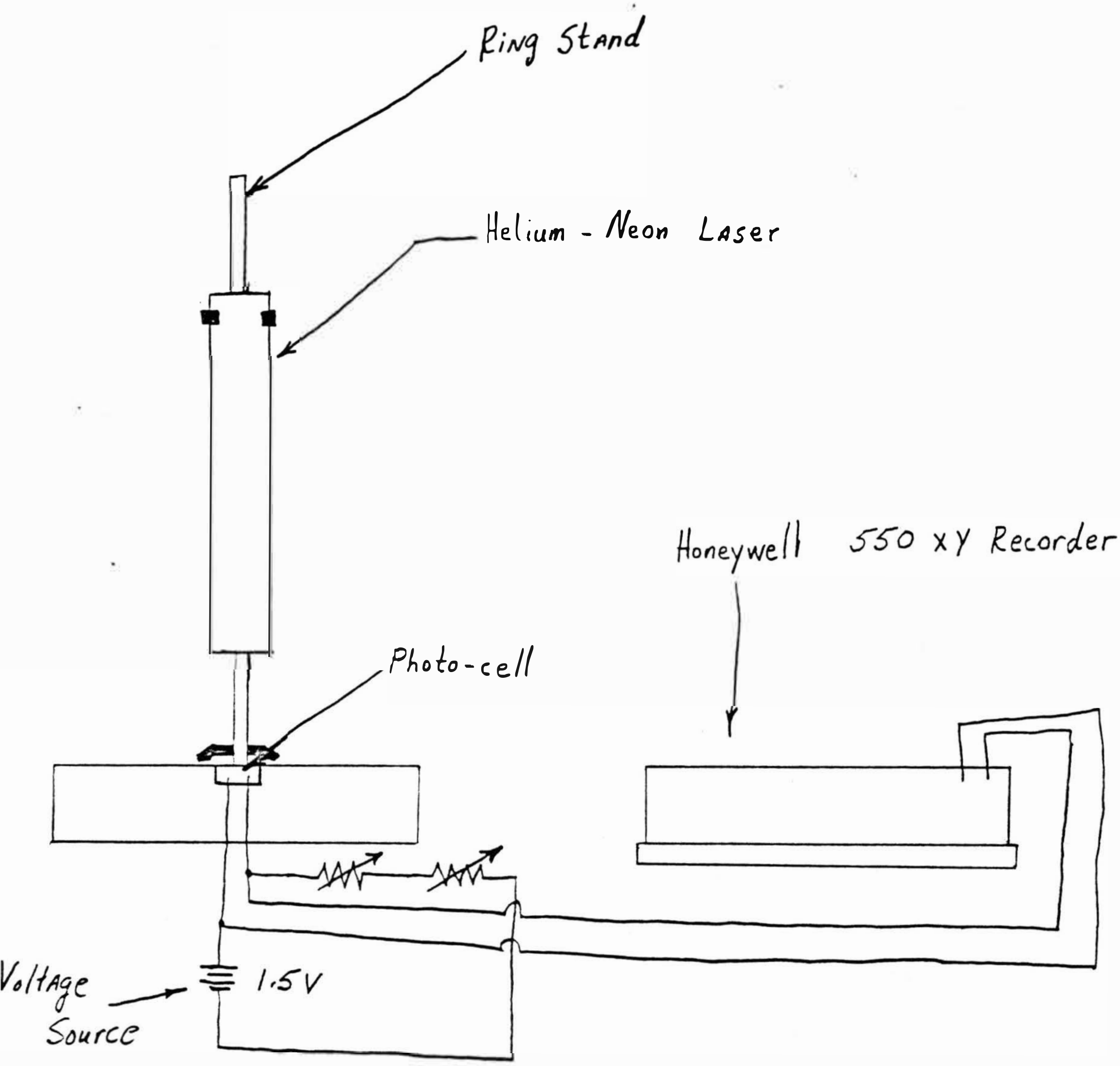
APPENDIX A

Use and Operation of an Optical Formation Tester

To quantitatively measure formation of paper produced for my thesis project, I used a formation tester that has been used in other senior thesis projects. This tester operates on the principle that as the amount of light emitted through a sheet of paper changes, the voltage drop across the photocell will change in the same proportion. The amount of light passing through the sheet is a function of its mass. This formation tester is, therefore, designed to pull a piece of paper over the photocell that has a beam of light shining on it and to continuously record the voltage across the photocell.

Figure 12 illustrates the set up of this formation tester. A laser supported on a ring stand shines a beam of light directly onto a photocell that is connected to a 1.5 volt source, some resistors, and a Honeywell XY Recorder. This recorder holds a piece of graph paper on its face while the pen travels at a preset rate in the x direction. The voltage is recorded on the y axis. A piece of paper is placed over the photocell and connected to the recorder pen so that it moves at the same speed as the pen. As the paper travels over the photocell, the amount of light transmitted through the paper changes due to variations in sheet formation and is recorded on the graph paper. Figure 13 is an example of the voltage recorded when a piece of paper was passed over the photocell at 0.05 inches per minute. The peak voltages, highs and lows, are then averaged and the standard deviation is computed. The standard deviation is a measure of the formation. A high standard deviation suggests poor formation.

FIGURE 12



Ring Stand
Helium - Neon Laser
Honeywell 550 XY Recorder
Photo-cell
Voltage Source
1.5V

FIGURE 13