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The Effect of Filler Distribution on Sheet Optical Properties

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THE EFFECT OF FILLER DISTRIBUTION ON SHEET OPTICAL PROPERTIES

by

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INTRODUCTION

It is becoming increasingly important to the paper industry to be able to produce paper with high brightness and opacity. Good formation is also highly important. For these reasons, the industry is investigating the way the fines, fiber, and filler are distributed using the different types of paper machines.

Through this thesis work, it will be investigated how the filler distribution affects the optical properties of a sheet and what filler distribution will give maximum scattering power, brightness and opacity. From this it may be possible to suggest what paper machine variables will give filler distributions with improved optical properties.

LITERATURE REVIEW

Effect of Fillers on Paper

To understand how filler distribution affects opacity and brightness of a sheet, one must first understand why fillers are added and what effect they have on paper properties.

Fillers are added primarily to improve opacity and brightness. They are also added to improve smoothness, printability, softness, absorption, or to impart certain properties in speciality papers.

Paper actually has a very rough surface with many depressions and voids. These voids are caused by the fibers, which have fairly large dimensions compared to the filler particles, entangling together. The filler particles fill in these voids thus giving a smoother surface and better printability.

Of course undesirable effects result from the addition of fillers. The main one is a decrease in strength. The filler does not aid in fiber to fiber bonding and in fact reduces this bonding. Also a decrease in bulk is generally noted upon filler addition. This is because the pigment is heavier than the fiber and thus the weight in-

creases more than the thickness.) A decrease in sizing and a dusting problem are two more undesirable effects of filler addition.(1)

Casey (1) lists factors which affect opacity: they include sheet thickness, the number of individual particles making up the sheet, and the refractive index of these particles.

Davidson (2) found that the major effect controlling opacity when titanium dioxide (TiO_2) was used was the flocculating and crowding together of the TiO_2 particles. The fact that a difference in refractive index was needed was proven by Swanson (2,4). Swanson took cellulose and then surrounded it with clay and/or calcium carbonate ($CaCO_3$) fillers. He found that when the fillers and cellulose had similar refractive index little increase in opacity over the unfilled sheet was noted.

Hemstock (4) experimented with fillers, applying the Kubelka-Munk theory*. He found that fillers of higher refractive indices and with the larger difference between media (air, fiber, and filler) gave the greatest increase in opacity. Hemstock also concluded that the greater the number of particles the more scattering that will take place, thus increasing opacity. Also, fillers with higher refractive index have

* See section on Kubelka-Munk theory

better opacifying and brightening power (4,5,6).

Steele (7) who first applied the Kubelka-Munk theory to paper, also investigated the contribution of the filler type to opacity.

How much the brightness of a sheet improves upon addition of filler depends upon three things: the original brightness of the pulp, the brightness of the pigment, and the particle size of the pigment (1,3). Naturally a filler with a much greater brightness compared to the brightness of the pulp will increase the brightness of the sheet considerably. Also, a decrease in particle size, to a point, gives more scattering of light and an increase in brightness and opacity. The point of maximum brightness and opacity is obtained when the particle size is equal to one-half the wavelength of the incident light. (3)

Retention of Fillers

The theory of filler retention has been described by three main mechanisms; coflocculation, mechanical attachment or mechanical filtration and charge attraction.

The coflocculation theory (8,9,10) is that filler and fibers gather together to form a common floc. This is done in the absence of significant electrostatic forces on both fiber and filler. The mechanical theory of retention (9) is that individual particles may flocculate together by alum and be trapped by the fiber mat. The charge attraction theory (9,11) is based on the fact that in a fiber, filler, alum system, the cellulose and filler because of the alum have opposite electrokinetic charge and attract one another.

There is much disagreement about which mechanism plays the major role in filler retention. Haslam and Steele (8) state that under ordinary conditions coflocculation is the most important means of filler retention. Only 50% was attributed to mechanical attachment while an insignificant amount was attributed to charge attraction.

The charge attraction theory has recently come under heavy criticism. Martin & Willets (11) stated that in a system of fiber and

filler there can be no colloidal attraction because both constituents are negatively charged. Retention in such cases they say was by mechanical filtration. If alum is added, the alum hydrolyzes to positively charged alumina which is absorbed on the negatively charged fibers and acts as "electrostatic cement" for the filler.

Boussu (12) agreed that retention of fillers was not a physico-chemical phenomenon. That meant he thought it was neither a charge attraction nor a coflocculation mechanism, but a filtration process. On the other hand Williams and Swanson (10) believe that retention of fillers in papers containing high opacity pigments, such as TiO_2, is mainly a result of coflocculation.

All of these disagreements point to the fact that the mechanism of filler retention is not perfectly clear and is probably a combination of many mechanisms, each of which is more important than another under certain conditions.

Variables affecting filler retention have been studied extensively. Some of these are pH, amount and concentration of alum present at flocculation, temperature, order of pigment and alum addition, beating, the use of retention aids and specific machine variables such as

machine speed, consistency changes, dandy roll use, etc. Brill and Hecklau (13) studied the effect of changing the amount and concentration of reactants at the time of folocculation. They found that the amount and concentration of reactants present affected the size, resistance to agitation, and resistance to dispersion of the agglomerates and, thus, affected retention. They also found that an increase in temperature reduced retention slightly when starch was present. No change in retention was noted due to starch.

Fraik (14) investigated the following variables affecting retention: the effect of order of pigment and alum addition, and pH control by different alum concentrations in the presence or absence of rosin size. Results showed that pH of the system at the location of pigment addition was the only factor which consistently correlated with retention.

The effect of beating was studied by Hansen (15). He found that beating increased retention. This is probably because beating increases the number of bonding sites due to more surface area available to the filler particles.

Retention aids have been studied by many individuals. Some retention aids are sodium aluminate, polyacrylamides, galactomannans, and

cationic starches. Retention aids increase the amount of filler retained.

Filler Distribution in Paper

The filler distribution in a finished sheet depends on the process by which the sheet is made. The fourdrinier, Twinver-former, Verti-forma and sheet mold machines all give sheets which show different filler distributions. Therefore, each process will be treated separately.

The distribution of filler in paper made on a fourdrinier machine

To better understand how and why filler is distributed in a fourdrinier made sheet of paper, some characteristics of the process must first be discussed.

In a fourdrinier made sheet, the fiber, fines and filler are unevenly distributed throughout the thickness of the sheet. The large fibers are concentrated on the bottom and increasingly smaller fibers toward the top or felt side of the sheet (16,17). These larger fibers at the bottom form a mat which catch the smaller particles, namely the filler and fines. The fines are concentrated mostly in the center of the sheet with a decrease toward the top side and a somewhat larger decrease towards the wire side. This is because as

stated earlier the larger fibers form a mat which catch the fines. Also a large amount of the fines are washed out of the sheet by the water thrown back on the bottom of the sheet by the table rolls. Thus the bottom side of the sheet has practically no fines. The only fines found in the bottom portion of the sheet are ones that are pulled there by the suction during formation of the sheet. The top side is rather void of fines also because the layer below the top of the sheet is the one that holds the fines.

There were many variables studied which affect the amount of filler retained and its distribution throughout the sheet. Hansen (15) studied six such variables; increase of weight, addition of glue, change in speed, consistency changes, amount of beating, and the use of a dandy roll. He found that the retention of filler increased with an increase of weight. When Sveen glue was added to a sheet, the filler content increased about 3½%. When the paper machine was speeded up by 95 fpm there was only an increase of 1½% even with the glue or a decrease of 2% with no glue. In each case, though, the filler distribution was not affected. Filler content increased when consistency was decreased in the headbox. When Hansen changed the consistency an exaggerated

amount he found a difference in filler distribution. The wire side was about the same for thin or thick stuff, but in the case of the lower consistency stock, the content of filler increased more rapidly and less stock was required to form a comparatively dense layer. The change in consistency was very extreme and Hansen believed under normal operating consistencies, no effect on filler distribution would be noted.

Hansen (15) also showed that beating increased the retention of filler, but had no effect on filler distribution. Investigations on the effect a dandy roll had on filler distribution showed that the amount of filler in the central portion and felt side was affected. Some of the filler was carried from the central portion to the felt side of the sheet. Hansen (15) also found that the "wetter" the stock passing the dandy roll, the greater the increase of filler toward the felt side.

Groen (17) also investigated some fundamental aspects of filler distribution. He found that the filler content of the wire side layer depended largely on the degree of beating and to some extent on the total amount of filler in the paper. This, he stated, suggests that

the filler capacity of the extreme wire side layer to be the main factor in determining filler distribution. Other factors he found were machine speed, and filler content. Groen also backed up Hansen in his findings that a dandy roll affected the top layers of filler.

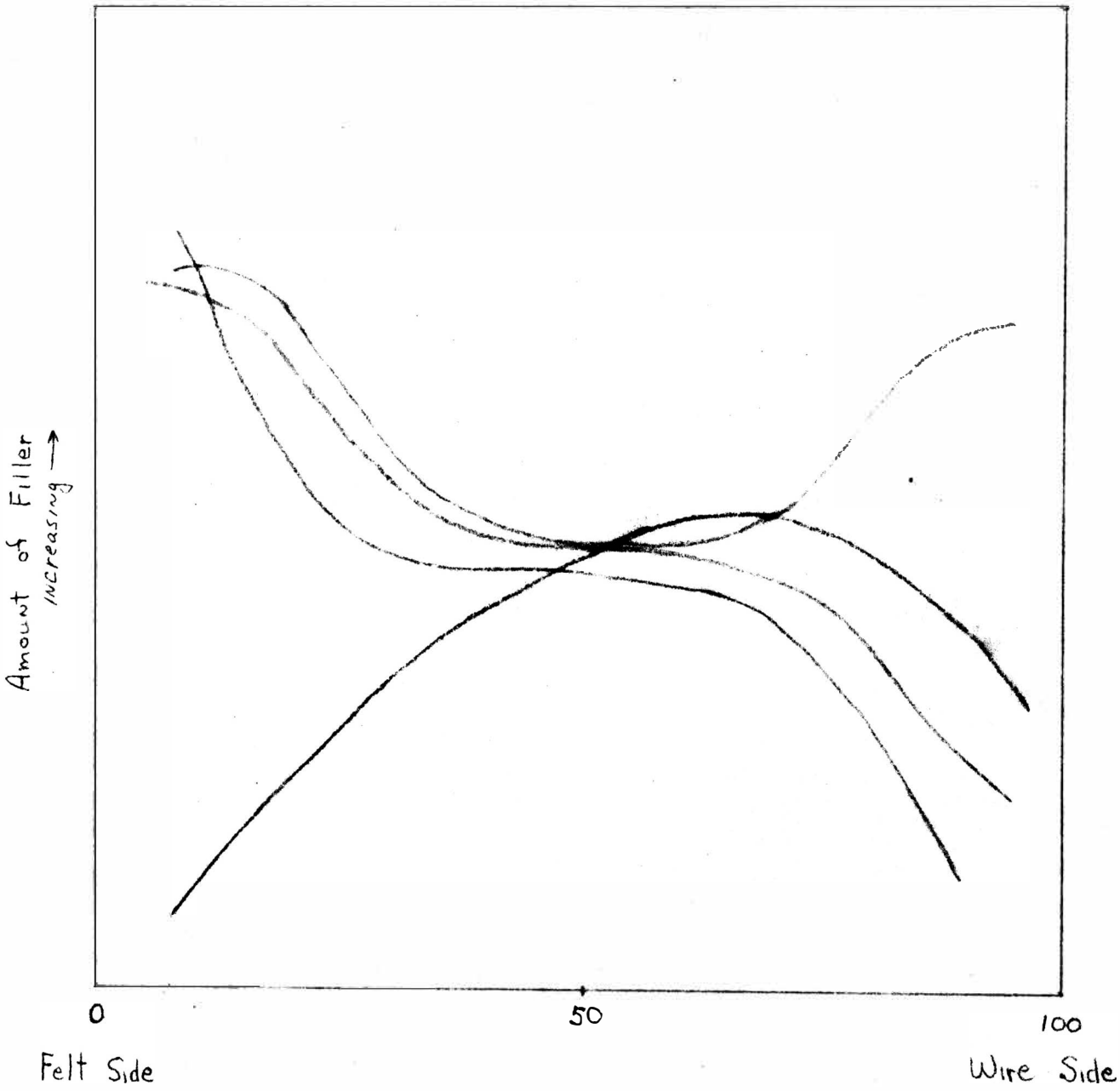
Much work has been done to establish the filler distribution of a sheet made on a fourdrinier paper machine. Studies have been made by Hansen (15), Groen (17), Browning (18), Mack (19), and Whitman, Mays, and Williams (20). These studies have been made by three main methods; sheet splitting, careful abrading, or microtoming.

All the studies gave the type of filler distribution for fourdrinier as shown in Fig. 1. The felt side has a high content of filler, while the wire side a lower filler content. The center of the sheet is fairly constant at an intermediate level.

Although there is agreement on the filler distribution, there is much disagreement what causes this type of filler distribution. Hansen (15) studied this question extensively and came to the conclusion that the low content of filler near the wire side was already fixed immediately after the slurry had been run onto the wire and was an inherent property of paper manufacture. Mack (19), Browning (18), and Heinz's (13)

Fig. 1

FILLER DISTRIBUTION GRAPH



—— Sheetmold

—— Fourdrinier

—— Twinver-former

findings back up Hansen's theory. All three found that table rolls and suction boxes only affect the filler near the wire side of the sheet.

Groen (17) proposed a theory of self-filtration which greatly paralleled Hansen's theory. Groen stated that in any self-filtration three phase system, containing two solid phases of entirely different shape and size, an uneven distribution will result. In the first stage of drainage the large fibers tend to close the coarse openings of the wire. The next layers will contain more filler due to the fiber mat formed in the first stage. The top layers will not have as much filler because the filler particles are not retained by the top layer but by the layers below it.

G. F. Underhay (21) disagreed with Hansen's and Groen's theories. He stated that water is kicked back up from the table rolls. This distrubs the fibers and washes the filler from the wire side. The study made by Whitman, Mays, and Williams (20) supported Underhay. Whitman, Mays, and Williams also thought that the low filler content at the wire side was due to the effect of wire vibration at high speed as well as the hydraulics associated with table rolls. Part of

the disagreement in this area may be due to the machine speed and the effect of its deflectors. High speed machines have different hydraulics than slow speed machines. Also, the newness and type of deflector may affect the filler distribution differently.

Whether the reason is an inherent property as Hansen and Groen stated or whether table rolls cause filler uneveness as Underhay, Whitman, Mays, and Williams insisted, the fact remains that the industry is unable to correct this type of filler distribution with the fourdrinier type machine and thus must seek other methods if more uniform filler distribution is desired.

The distribution of filler in paper made on a British sheetmold

Paper made on a British sheetmold machine is structurely very different from a sheet formed on a fourdrinier paper machine.

A sheetmold handsheet showed a low content of filler at the felt side and increasing considerably through the center of the sheet and decreasing again toward the wire side but with a much larger per cent filler at the wire side than paper made on a fourdrinier machine. (See Fig. 1)

Majewski (22) studied the differences in fourdrinier and sheetmold papers. He cited three reasons for the differences in sheet structure. First, there is no fiber orientation caused by lateral movement between the forming mat (bottom fibers) and the wire. Secondly, the consistency used in a sheetmold machine is much lower than used with a fourdriner machine. This allows for much better dispersion of the fibers. Thirdly, the fines are concentrated more toward the wire side in a sheetmold machine. This was explained by E.R. Finger and Majewski's (23) theory of self-filtration. The large fibers settle more rapidly to the bottom, and become set in position. The much smaller fines are then able to flow with the water toward the bottom of the mesh.

Because of the lack of intermittent suction and release, the fines in a handsheet are concentrated toward the wire side.

The distribution of filler in paper made on a cylinder machine

Groen (17) examined the filler distribution of paper made on a cylinder machine. He stated that the cylinder machine gave sheets with much the same filler distribution as a sheetmold machine. The filler content was low at the felt side and increased considerably through the center of the sheet and again decreased toward the wire side but with a much larger per cent filler at the wire side than paper made on a fourdrinier machine.

This type of filler distribution can possibly be explained by the dynamics of sheet formation on a cylinder machine. During formation on a counter-current cylinder machine, the web is formed and washed off several times. It is finally formed before the cylinder rotates out of the slurry in the vat. This leads to a fairly gentle formation of the web. Also, the suction and release on the web, found during formation on a fourdrinier machine, is not present in either a sheetmold or cylinder machine. This may also lead to the difference in filler distribution.

The distribution of filler in paper made on Twin-wire machines

The twin-wire machines such as the Verti-forma and Twinver-former, are new types of paper machines designed to produce sheets with less two-sideness and with better formation. The Verti-forma has two wires which are mounted vertically. The stock flows down between the two wires and the water is removed by deflectors only (24). In a Twinver-former the two wires are horizontal and the stock flows between them.

The Verti-forma is believed to yield a sheet with the fines more or less symmetrically distributed throughout the sheet (24,25). This is attributed to the new headbox set-up which eliminates much of the turbulent flow, and to the gentle drainage conditions and to no intermittent suction and release action.

Work done at Western Michigan on the filler distribution of a sheet made on a Verti-forma, showed the filler content to be higher on both wire and felt sides and fairly constant at an intermediate level in the middle of the sheet. (See Fig. 1)

Tests on a Twinver-former machine showed a much more uniform sheet over the fourdrinier made paper, but with the filler still concentrated

on the felt side of the sheet (26).

EXPERIMENTAL

INTRODUCTION

The experimental procedure of this thesis work involved making handsheets with a variety of filler distributions, testing them for brightness and opacity, weighing and then splitting and ashing the sheets. This is all fairly basic except for the unique method of filler addition. Filler was added at different stages of drainage and thus different filler distributions obtained.

The object was to determine the effects of filler distribution on the effectiveness of filler in paper.

PREPARATION OF HANDSHEETS

The main problem in performing the experimental work of this thesis, was in distributing the filler in different parts of the sheet. Sheets with the filler concentrated at the wire side, middle, and felt side of the sheet as well as sheets with fairly uniform distribution of filler were desired. To do this a unique methods of filler addition was devised. To obtain a sheet with the filler concentrated on the wire side, the sheetmold (British Standard Sheetmold) was filled with water. The stock was added and stirred, and then the filler added and sheetmold drained. The filler was added as a dilute slurry through a cylindrical container with many small holes punctured in the bottom. This gradually distributed the filler across the sheetmold and did not greatly disturb the surface of the water or sheet.

To obtain a filler distribution with filler concentrated in the center of the paper the procedure was carried out in the following manner. The sheetmold was filled with water and stock, stirred and then drained one quarter of the way down the sheetmold. At this point drainage was stopped and the filler slurry added. After a short pause, drainage was continued.

To obtain sheets with filler concentrated toward the felt side, the filler was added with the fiber slurry at a much lower position of the sheetmold.

A sheet with fairly uniform filler distribution was obtained by adding filler at the top of the sheetmold, draining the sheetmold one half way, adding more filler, draining to near the bottom, stopping, adding more filler, and then finishing the drainage. (Appendix A gives the complete details.)

The handsheets were then pressed and air dried.

TESTING OF HANDSHEETS

The handsheets were weighed and then tested for brightness and opacity. This also permitted the calculation of scattering coefficients by means of the Kabulka-Munk theory. The I.P.C. Brightness meter, Martin Sweets Co., Automatic model was used to obtain brightness and the Bausch and Lomb Opacimeter to obtain Tappi opacity.

Ash determinations were made on the sheets to obtain total filler content.

SPLITTING OF HANDSHEETS

To determine the filler distribution of the handsheets, the sheets had to be split in quarter sections. This was done by using the Beloit Sheet Splitter.

The Beloit Sheet Splitter consists of two rotating, stainless steel rolls that are chilled by the use of Freon-12. A paper sample is thoroughly soaked in water and then inserted between the two cold rolls. When the rolls are at the proper temperature and rotated at the proper speed the sheet becomes frozen onto both surfaces and thus pulled apart at the sheet center. Each half is then rewetted and the procedure repeated. If one roll is colder than the other or the temperature of the rolls or speed of rotation is not correct, the sheet may become frozen through the entire sheet and will not split. Therefore roll temperature, and roll speed are controlled to obtain the best splits.

After splitting, the sheets were then labeled "one" for the top or felt side quarter of the sheet, to "four" for the bottom or wire side quarter.

ANALYSIS OF HANDSHEETS

To evaluate the optical properties of the handhseets, Kebulka-Munk analysis was used. This was done because the scattering coefficient which is obtained thru this type analysis is a more basic measurement than either brightness and/or opacity. The scattering coefficient is corrected for basis weight of the sheet, brightness and opacity of the pulp used, and for the amount of filler in the sheet.

The basic Kubelka-Munk equation is:

$$R = \frac{(R_g - R_\infty)/R_\infty - R_\infty (R_g - 1/R_\infty)\, e^{SX[(1/R_\infty) - R_\infty]}}{R_g - R_\infty - (R_g - 1/R_\infty)\, e^{SX[(1/R_\infty) - R_\infty]}}$$

Where R - The reflectance of any colorant layer of known absorption and scattering coefficients, "K" and "S"

Rg - Any reflectance

X - Thickness of the colorant layer

R - Reflectance at complete opacity

e - Napierian logarithm - 2.71828

Another equation derived from the Kubelka-Munk theory is:

$$\frac{K}{S} = \frac{1 - R_\infty)}{2R_\infty}$$

The first step in determining the scattering coefficient (27) of the filler in a sheet of paper is to determine the scattering coefficient, S, for an unfilled sheet of the same stock. This is done by measuring Tappi opacity ($C_{0.89}$), brightness (R_∞) and the

basis weight (X) of the unfilled paper. By use of Kubelka-Munk charts, the scattering power (SX) can be found. Dividing the scattering power by the basis weight gives the scattering coefficient of the pulp. Repeating the above procedure at various basis weights and plotting resultant scattering power versus basis weight values, yields a straight line with origin at zero/zero and a slope equal to the value of the scattering coefficient, S, for the unfilled paper.

Using the same pulp for which the scattering coefficient was determined, papers are then prepared at a constant basis weight but containing three or more concentrations of the desired filler between one and ten per cent. Tappi opacity and brightness are measured for each sample and again the scattering power is determined from the Kubelka-Munk charts. The scattering power is then divided by the basis weight to give the scattering coefficient. A plot of these scattering power values versus per cent mineral filler is made. The scattering power intercept equals that of the unfilled paper at that basis weight. The greater the scattering power of the filler, the greater the slope of the line. The scattering coefficient of the filler may then be determined by the following equation:

$$S\ (paper) = S\ (pulp)\ \ C + S\ (filler)\ \ C$$

Where S = Scattering coefficient

C = Concentration

The scattering coefficient of the paper and pulp and concentrations of pulp and filler have already been determined. Thus the scattering coefficient for the filler may be calculated.

After the scattering coefficients are calculated, the filler distribution is determined. This was done by ashing the quarter sheets and thus determining the percent filler in each quarter. Filler profiles were then drawn. Four separate sheets were evaluated for each filler distribution.

SAMPLE CALCULATION

Filled Sheet:

Brightness = 80.5

Opacity = 96.5

Sheet Weight = 2.8058 grams

Basis Weight (25 x 38 x 500) = 103.7 lbs.

Ash Determinations:

% Ash: 1st Quarter = 5.71 1st Quarter = felt side

2nd Quarter = 17.15

3rd Quarter = 27.65

4th Quarter = 49.46 4th Quarter = wire side

Total wt. of ash = 1.7289 grams

Total % filler in sheet = $\frac{1.7289}{2.8058} \times 100 = 10.75\%$

SX coefficient from Kubelka-Munk graph = 6.05

$S = \frac{6.05}{x} = \frac{6.05}{103.7} = .0583$

$S_{pulp} = .0346$

$S_{paper} = S_{pulp\ (Conc.)} + S_{TiO_2(Conc.)}$

$.0583 = .0346\ (.8925) + S_{TiO_2}\ (.1075)$

$S_{TiO_2} = 0.2558$

PRESENTATION AND DISCUSSION OF RESULTS

From Table I, proportion of ash in each layer, the filler distributions of the different samples can be determined. This is graphically illustrated in Figures 1 through 6. Obviously, samples A, B and D (Fig. 1,2 and 4) have similar pigment distributions. Sample A has the filler most heavily distributed toward the wire side and decreasing continuously toward the felt side. The top quarter of the sheet is at a very low level and fairly constant. Sample B (Fig 2) has less filler at the wire side and the filler content does not decrease as rapidly toward the felt side but follows the same basic filler profile as A. The Filler distribution of sample D (Fig. 4) is almost identical to sample B. Sample C (Fig. 3) is slightly different with the filler content at the wire side being lower and fairly constant through the bottom quarter of the sheet. The filler amount then decreases toward the felt side. Although samples A,B,C and D differ from each slightly, they are similar in that the filler content is much higher at the wire side and decreases rapidly toward the felt side.

Samples E and F (Fig. 5 and 6) are very similar and differ greatly

PRESENTATION AND DISCUSSION OF RESULTS

Table 1
Proportion of Ash in Each Layer

sample	total filler,%	fraction of total ash,%
A #8	10.75	
1		5.71
2		17.15
3		27.65
4*		49.46
A #22	11.13	
1		5.51
2		12.22
3		34.16
4		48.10
A #24	12.84	
1		6.20
2		11.65
3		26.07
4		56.06
A #25	11.11	
1		3.58
2		9.32
3		36.15
4		48.64
B #4	6.54	
1		6.23
2		9.78
3		38.37
4		45.59
B #10	10.60	
1		9.64
2		14.08
3		25.82
4		50.44
B #17	11.22	
1		8.19
2		22.99
3		35.40
4		33.40
B #23	14.54	
1		7.78
2		25.00
3		30.75
4		36.48

* 1 is the felt side and 4 is the wire side

Table 1 (cont.)

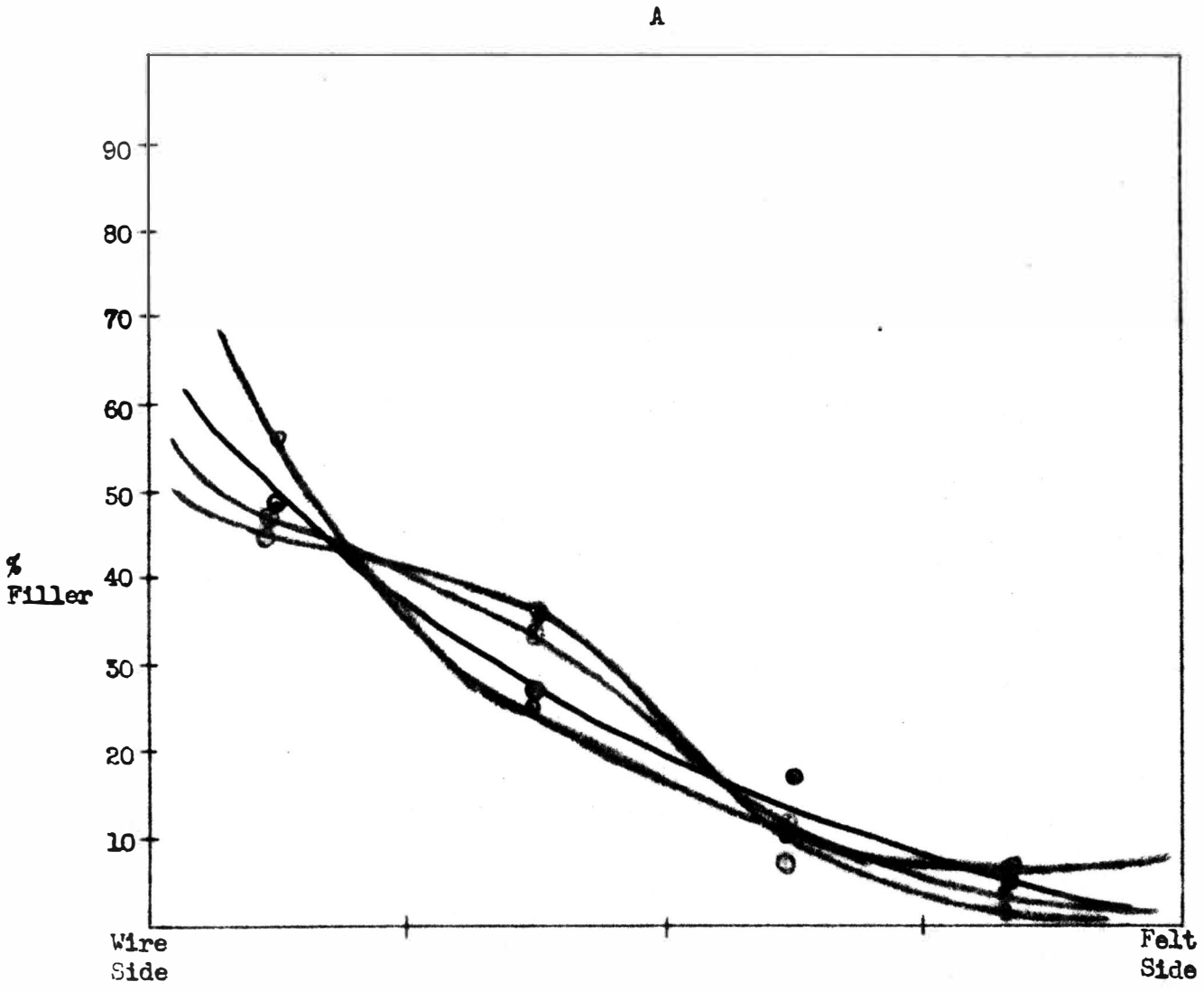
sample	total filler,%	fraction of total ash,%
C #1	14.15	
1		6.12
2		25.41
3		38.45
4		29.99
C #12	9.38	
1		12.84
2		26.73
3		38.22
4		22.19
C #20	11.85	
1		5.57
2		24.32
3		33.59
4		36.50
C #22	11.45	
1		5.86
2		17.77
3		35.00
4		41.35
D #12	9.67	
1		4.22
2		15.56
3		34.00
4		46.10
D #15	8.92	
1		7.04
2		21.25
3		34.81
4		37.11
D #16	7.90	
1		4.43
2		15.52
3		33.88
4		46.34
D #19	7.92	
1		6.09
2		22.84
3		30.61
4		40.44

Table 1 (cont.)

sample	total filler,%	fraction of total ash,%
E #1	11.95	
1		14.72
2		27.26
3		31.39
4		26.61
E #3	13.03	
1		15.86
2		22.67
3		32.86
4		28.59
E #4	12.29	
1		14.04
2		26.89
3		27.76
4		27.24
E #6	12.26	
1		13.43
2		27.06
3		30.43
4		29.05
F #4	12.79	
1		9.67
2		21.56
3		33.42
4		35.33
F #7	13.40	
1		10.62
2		18.05
3		34.40
4		36.91
F #11	16.51	
1		7.06
2		11.06
3		55.53
4		26.33
F #12	12.15	
1		7.57
2		18.71
3		31.28
4		42.42

FILLER PROFILE

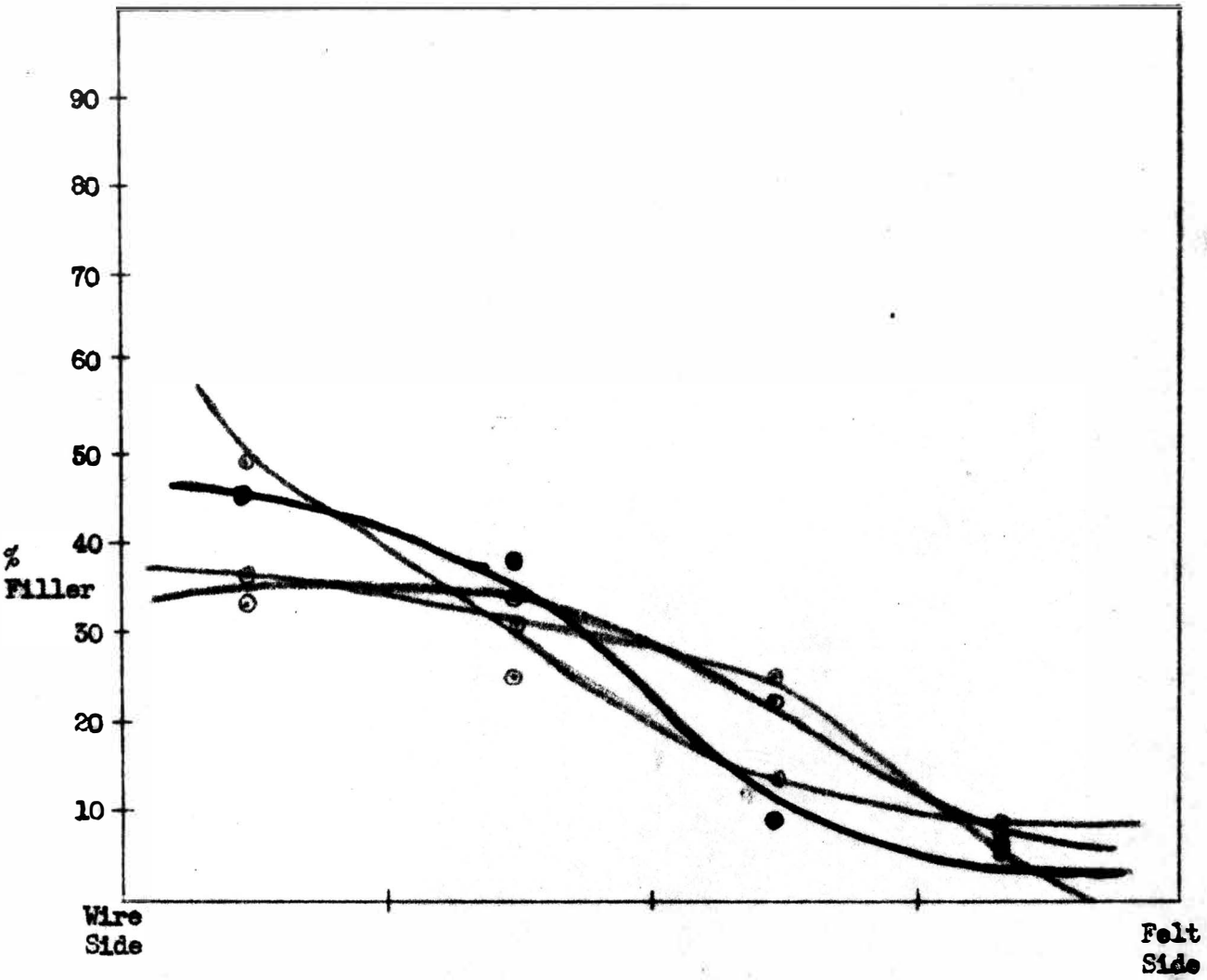
Figure 1



FILLER PROFILE

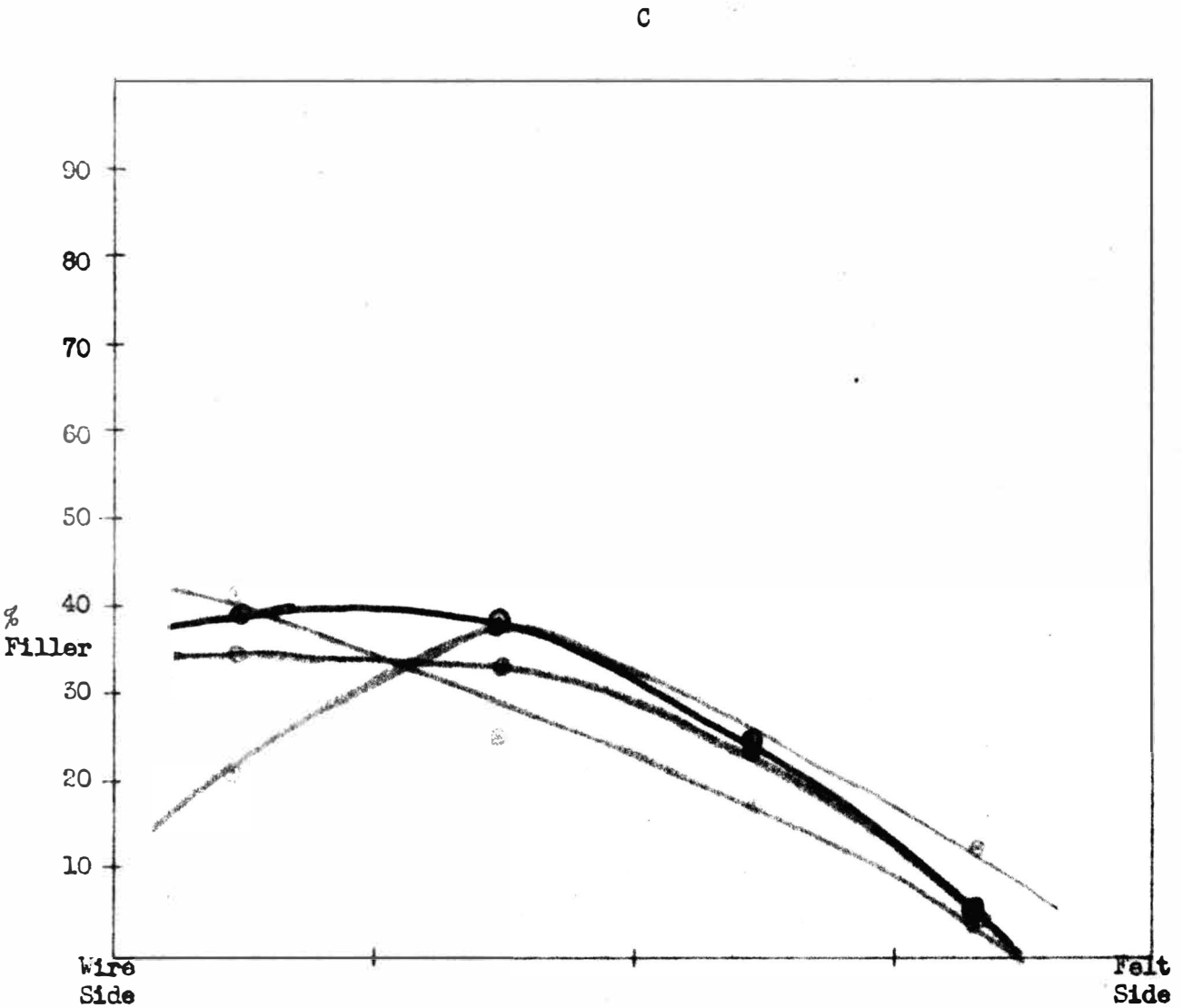
Figure 2

B



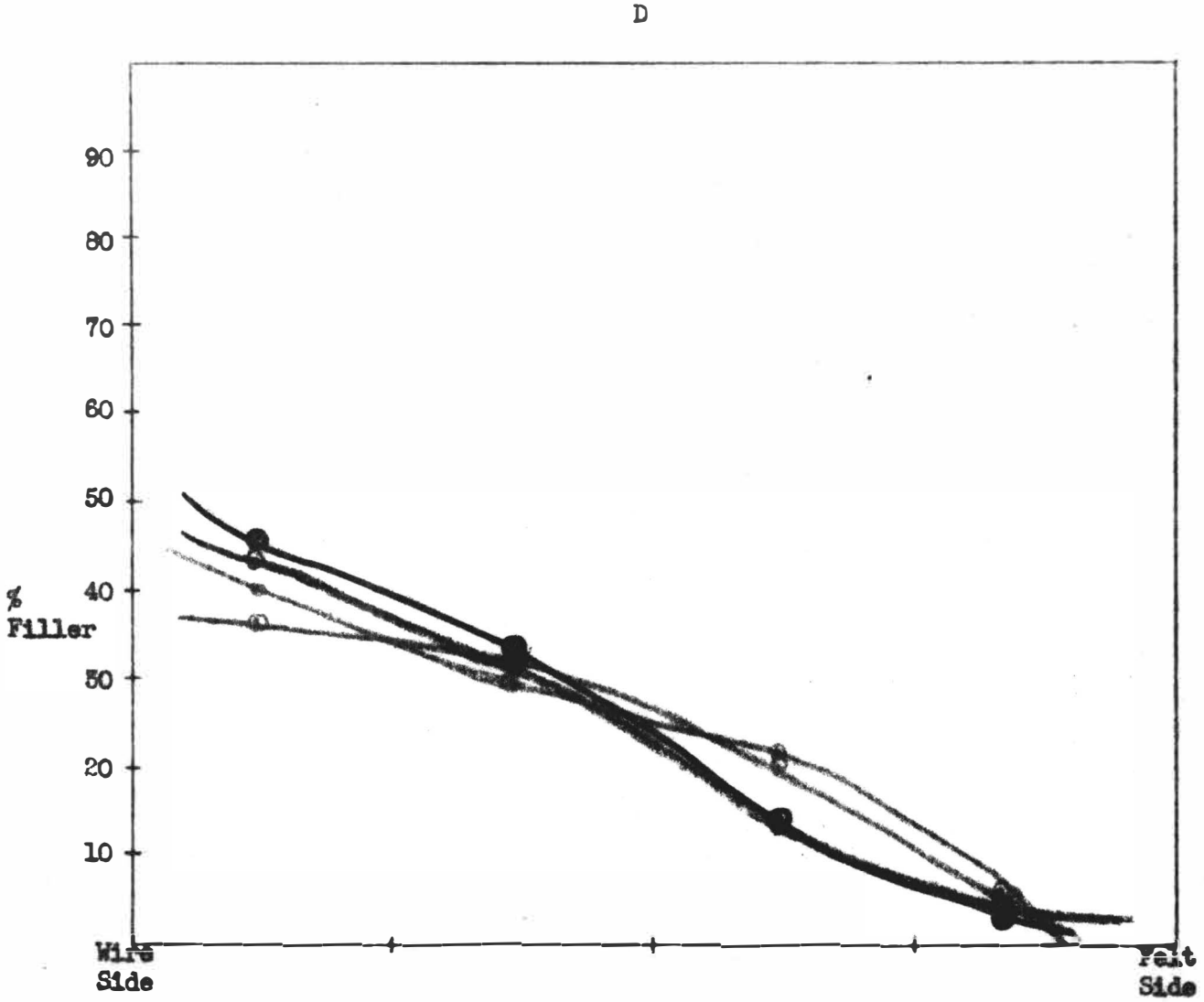
FILLER PROFILE

Figure 3



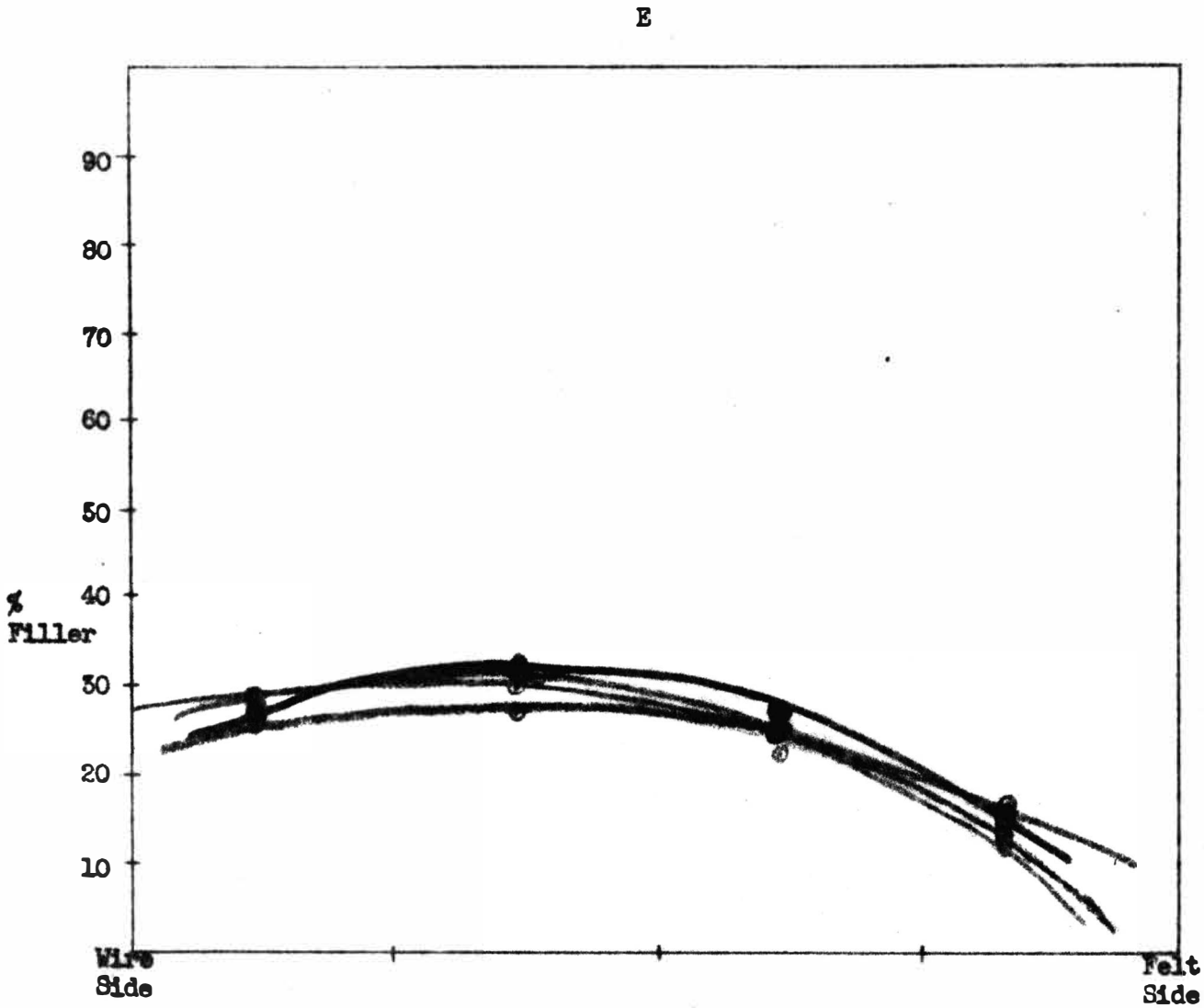
FILLER PROFILE

Figure 4



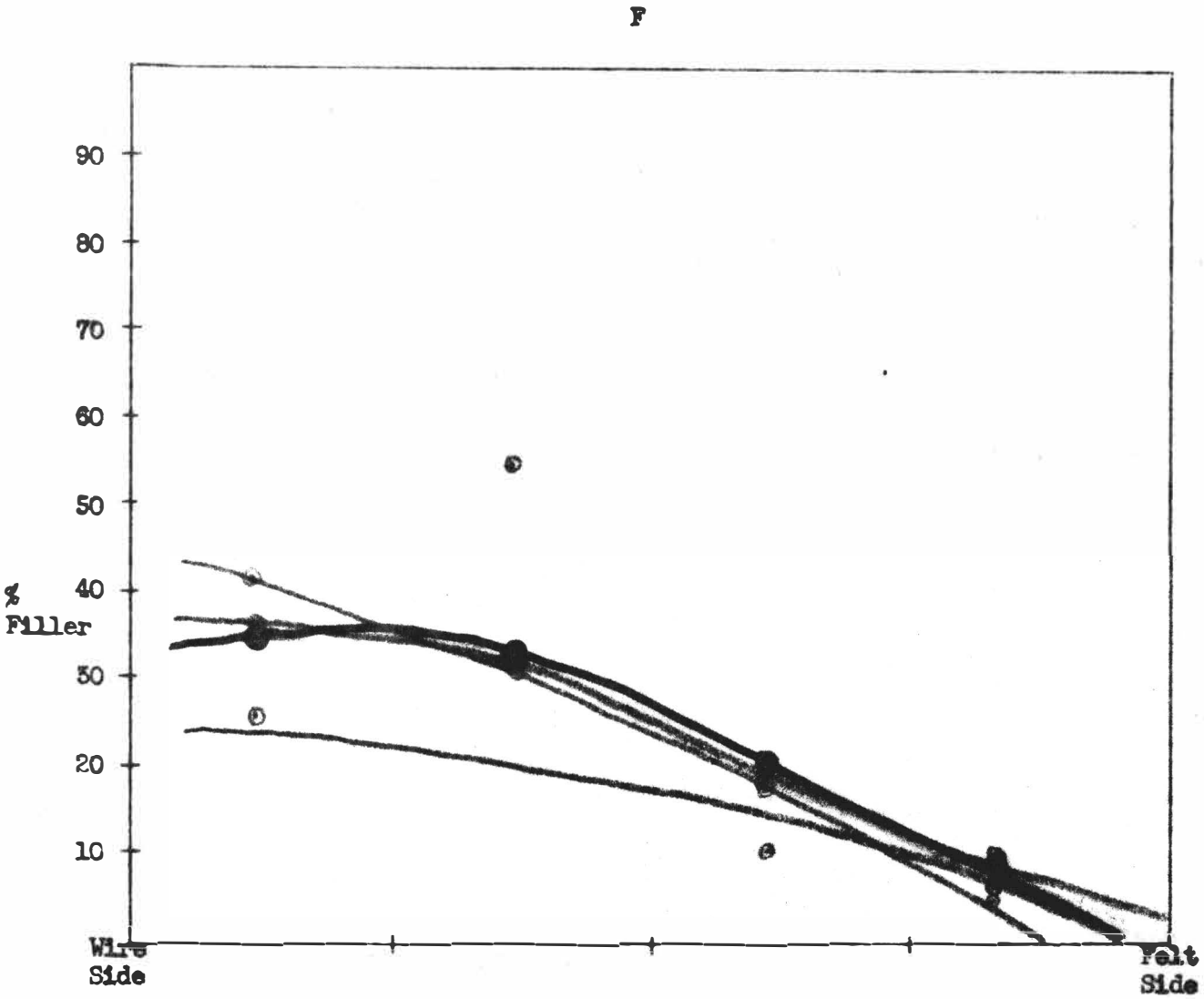
FILLER PROFILE

Figure 5



FILLER PROFILE

Figure 6



from the filler distribution of samples A,B, C and D. Filler profiles of Samples E and F show a much more uniform distribution than the previous samples. The filler content at the wire side is not as high and does not decrease significantly until the top half of the sheet. Even through the top half of the sheet the filler does not decrease as rapidly as the other samples. In short, samples E and F have a much more uniform filler distribution then samples A, B, C or D.

Tables II and III give relative brightness and opacity and scattering coefficient values for each of the four specimens of each sample. Table IV gives the relative brightness and opacity and the scattering coefficient averages of each sample.

To obtain the relative brightness and opacity the original brightness and opacity values were first corrected to a basis weight of 100 lbs. per (25" x 38" - 500) ream. The corrected control values (sheets containing no filler) were set equal to 1.000. The relative values were calculated by comparing the test values against the respective controls (sheets having no filler) with the control value corresponding to 1.000. The scattering coefficients were obtained by the Judd graphical solution.

Table III-Scattering Coefficient Values
Of Whole Handsheets

Sample	S VALUES side 1	side 4
A #8	.2558	.3953
A #22	.2614	.4357
A #24	.2367	.3551
A #25	.1764	.3249
B #4	.3715	.6177
B #10	.2367	.3575
B #17	.2597	.3386
B #23	.2517	.3246
C #1	.2106	.2798
C #12	.3092	.4584
C #20	.2663	.3829
C #22	.2558	.3318
D #12	.3650	.4653
D #13	.3276	.4349
D #16	.3822	.5000
D #19	.4709	.6237
E #1	.3849	.4234
E #3	.3798	.4236
E #4	.3718	.4157
E #6	.2985	.3368
F #4	.4061	.4566
F #7	.3582	.4305
F #11	.3070	.3458
F #12	.3234	.4090

From Table IV it can be seen that the highest values for relative brightness and opacity and scattering coefficients are samples E and F. This can also be seen from Figures 7 through 11. Sample F has slightly higher values than E. After E and F, the values drop significantly with A,B,C and D around the same. Sample C and D have nearly the same scattering coefficients and relative brightness and opacity values. Their scattering coefficients rank 3rd and 4th but their relative brightness and opacity are last or 5th and 6th. Sample A is 2nd in both scattering coefficients and relative brightness and opacity. The scattering coefficients of sample B rate last but its relative brightness and opacity rate 4th, ahead of C and D.

The reason for the discrepancy between the rank of samples in scattering coefficients and relative brightness and opacity is the variance in sheet weights. Sample D had very low sheet weight, while sample C had sheet weights that were higher than the normal. Also D had much higher control values for opacity and brightness. Therefore pigment would make less contribution. The scattering coefficients are corrected for basis weight in a different more basic fashion and therefore should be more heavily relied on.

Table IV

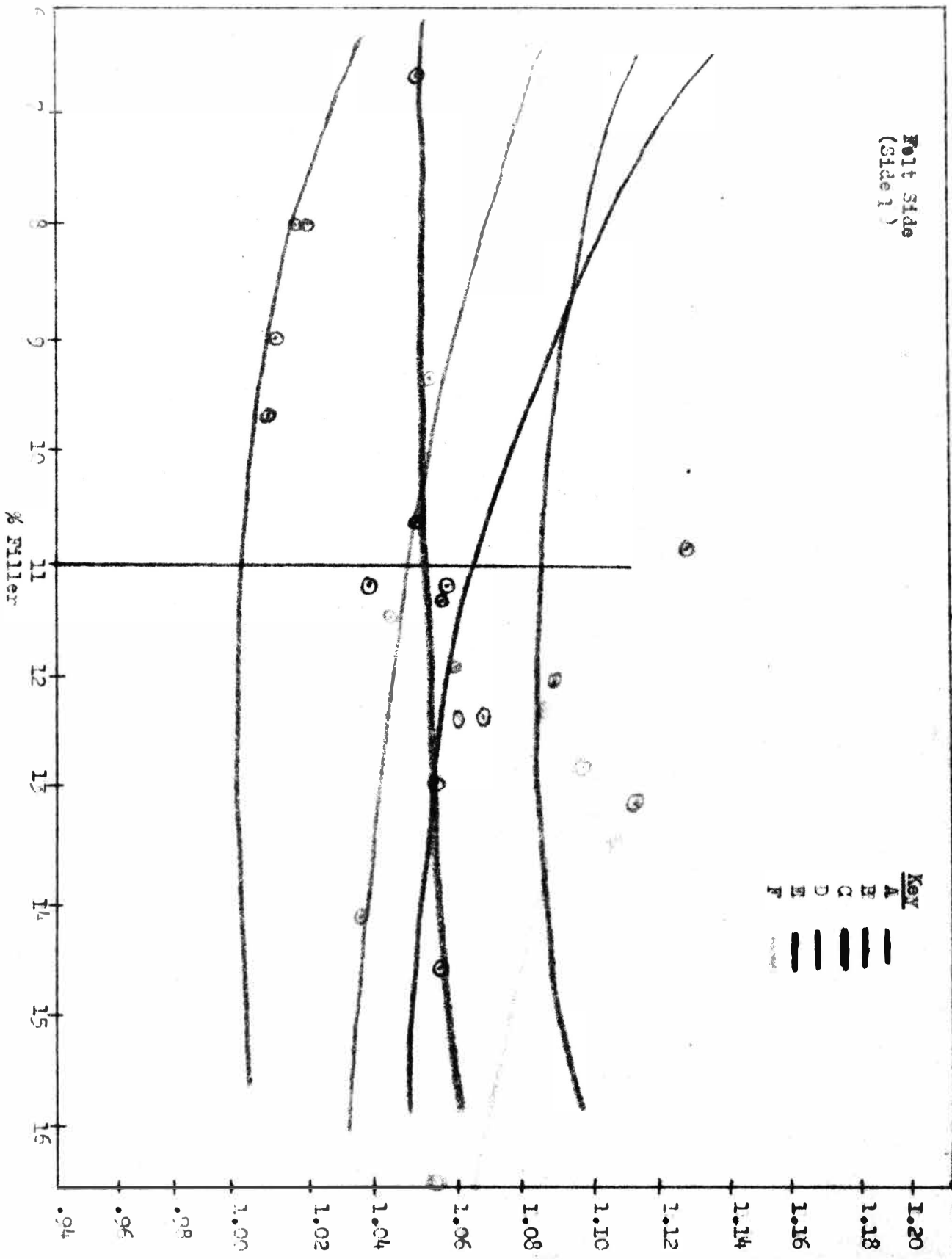
Brightness, Opacity, and Scattering Coefficients
Corrected for % Filler in the Sheet

sample	Brightness* side 1	Brightness* side 4	Opacity*	Scattering Coefficients side 1	Scattering Coefficients side 4
A	1.015	1.088	1.021	2.55	4.09
B	1.004	1.070	1.010	2.40	3.48
C	.995	1.064	1.012	2.71	3.81
D	.955	1.006	.976	2.69	3.72
E	1.071	1.114	1.075	4.00	4.42
F	1.088	1.144	1.110	4.12	4.98

* all values are relative, corrected so that control=1.00

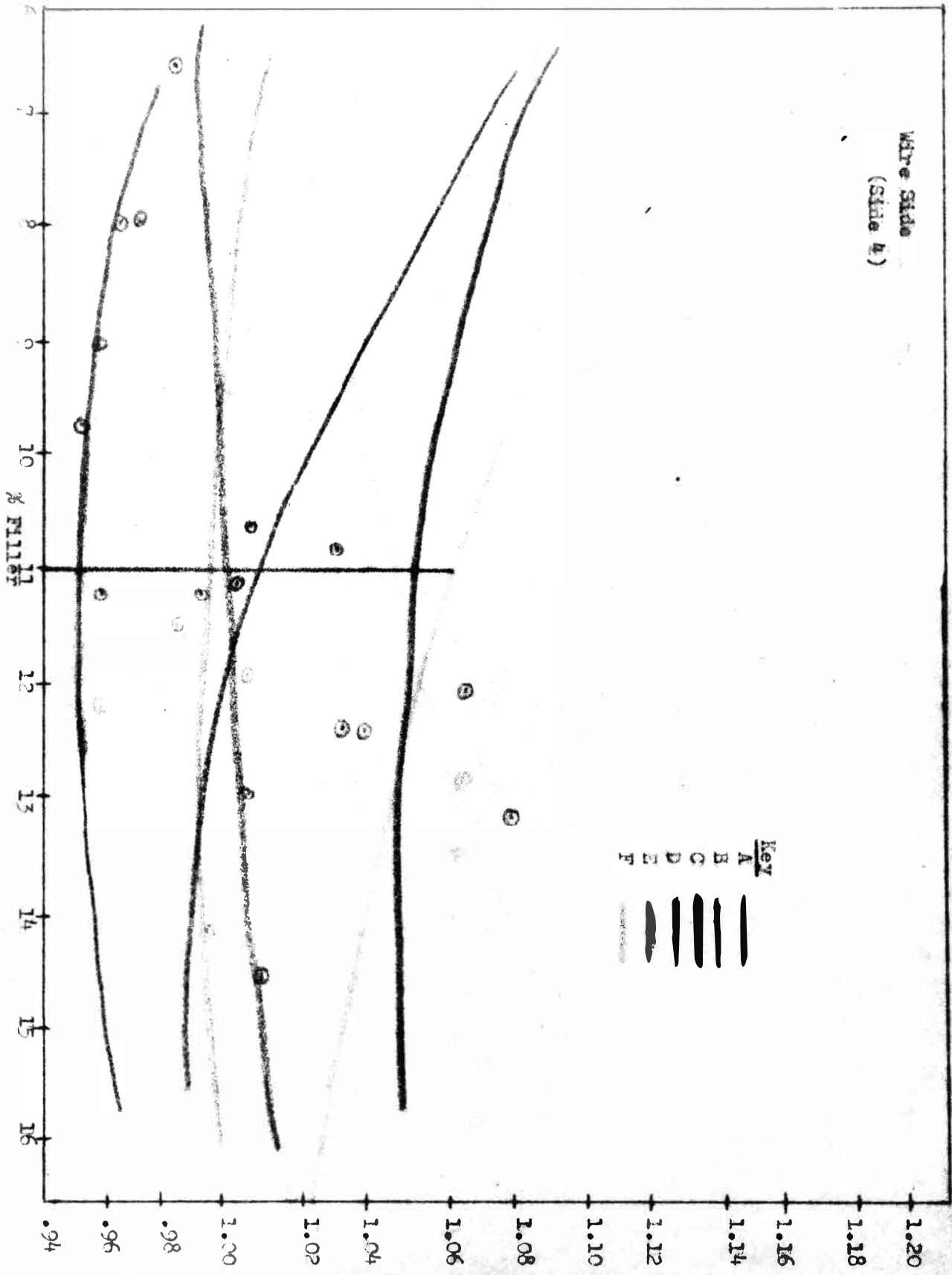
RELATIVE BRIGHTNESS vs. % FILLER

Figure 7



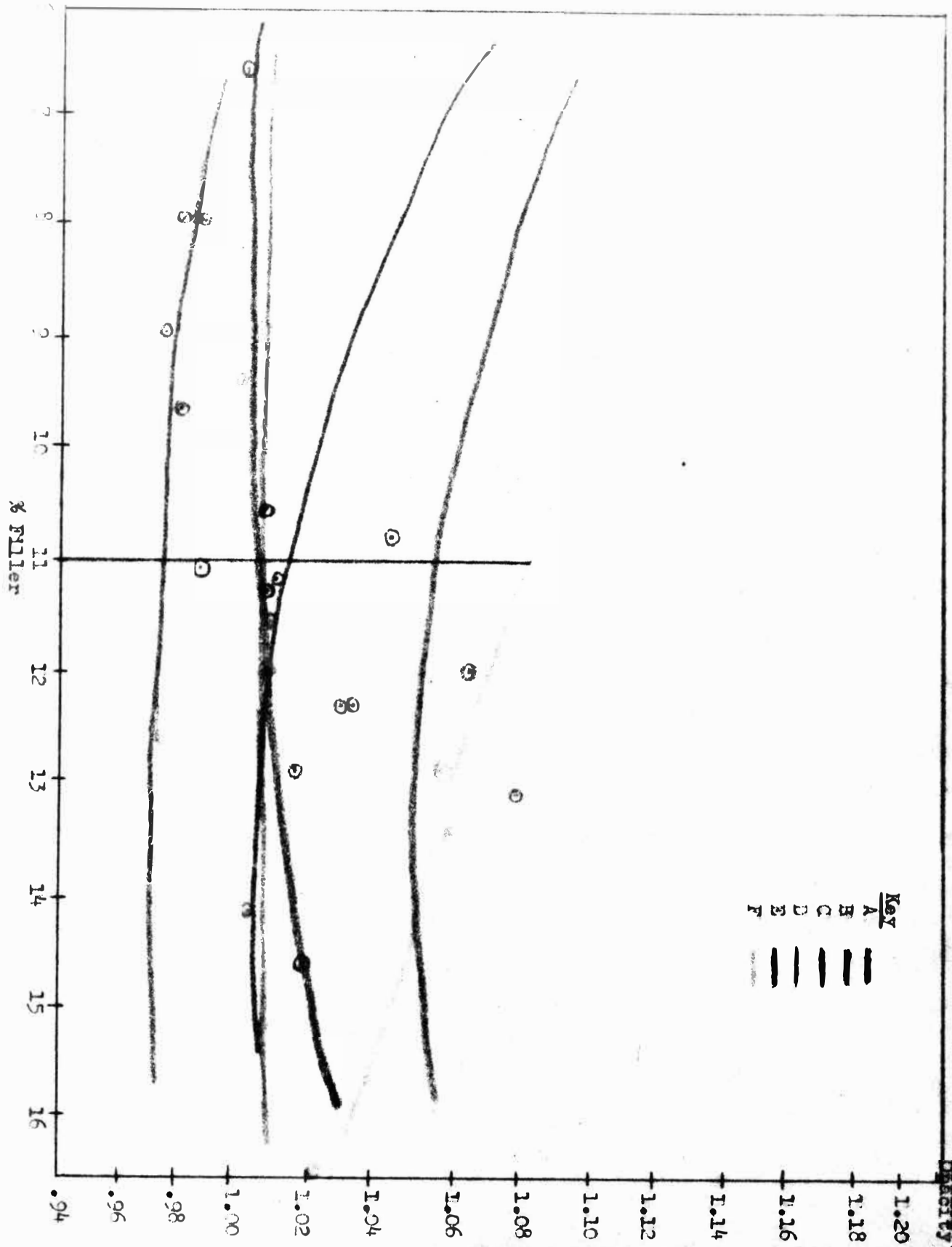
RELATIVE BRIGHTNESS vs. % FILLER

Figure 8



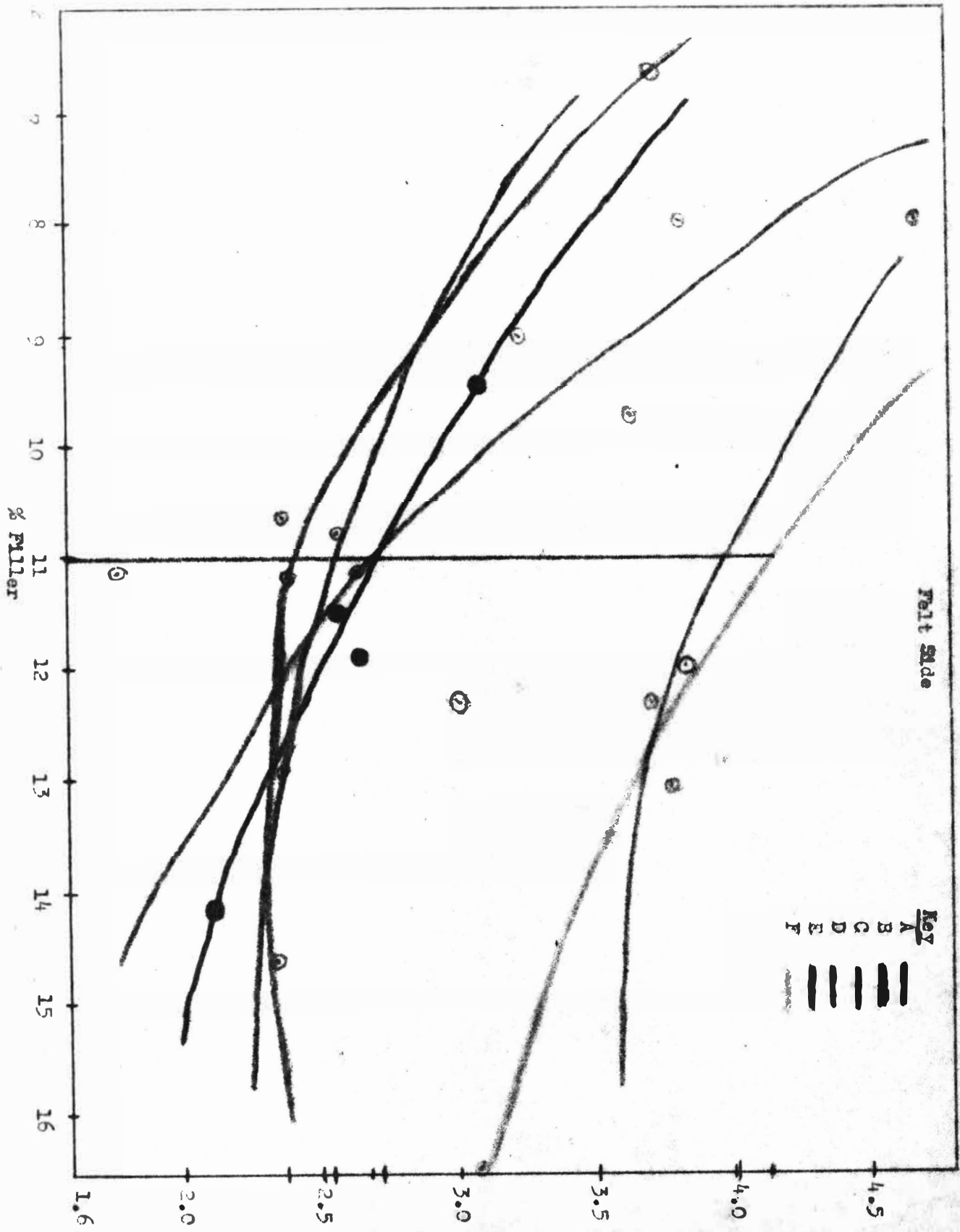
RELATIVE OPACITY VS. % FILLER

Figure 9



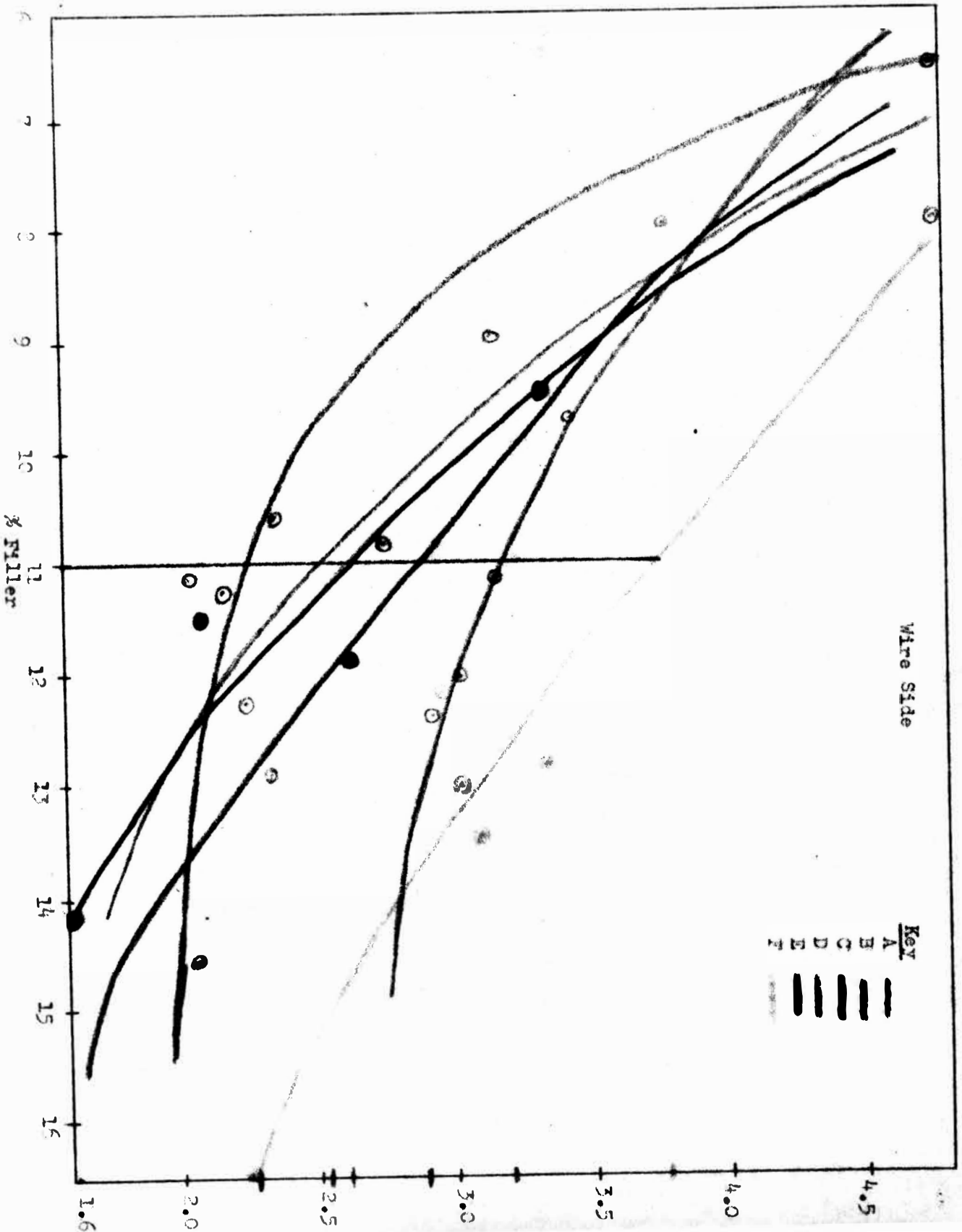
SCATTERING COEFFICIENTS vs. % FILLER

Figure 10



SCATTERING COEFFICIENTS vs. % FILLER

Figure 11



After analyzing the data it is obvious that a more uniform filler distribution gave the best optical properties.

In explaining this, one must remember that decrease in particle size or an increase in number of particles gives better scattering power and thus better brightness and opacity.

The size of particles of filler could have decreased and the number of particles could have increased by the fact that the particles were spread throughout a larger area rather than in agglomerates which would have to form in the smaller area.

Also scattering occurs not only through half or three-quarters of the sheet as in samples A,B, C and D, but throughout the entire sheet. This gives more scattering boundaries and thus a greater scattering power.

Opacity can also be increased by a difference in refractive indices of the two substances. When the filler is distributed throughout a larger area, as is likely the case in a more uniform filler distribution, more filler-cellulose or filler-air interfaces may exist causing increased opacity.

SUMMARY AND CONCLUSIONS

From this work it seems that a more uniform filler distribution gives the best optical properties. The more uniform distribution gives greater scattering among the filler particles and thus higher brightness and opacity values.

I think it could prove highly beneficial to continue this study. A filler distribution with the filler concentrated on the felt side should be studied. Also, filler retention with retention aids as it affects the filler distribution could be studied.

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Appendix A

sample	amount of filler added	distance from top of sheetmold when filler added
A	100 ml*	2 inches
B	85 ml	6.25 inches
C	75 ml	9 inches
D	60 ml	12 inches
E	50 ml	14.5 inches
F	25 ml	2 inches
	20 ml	9 inches
	15 ml	14.5 inches

* 0.4% TiO_2 slurry