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# The Effects of Wet End Chemical Additives on Recycled Filler Furnish

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THE EFFECTS OF WET END
CHEMICAL ADDITIVES ON
RECYCLED FILLER FURNISH

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Recycled
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Strength
Water Removal

Abstract

Improvements in desired characteristics can be seen from wet end chemical additives and will be accompanied by some degree of negative results in other desired characteristics. Lab work is useful in identifing qualitatively the specific areas where negative and positive effects will be seen. The negative results must then be weighted against the positive gains.

The Britt Jar is a powerful tool for predicting pilot machine behavior and should be used with hand sheet data. Pilot machine data is included as verification of Lab findings.

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## Introduction

For many years members of the Box Board Research and Development Association have listened to and read about the benefits received from wet end chemical additives. Most of these arguments have delt with findings based on virgin fiber. Most member mills have tried various chemicals with mixed results. Some mills reporting good results, while most have not seen all claimed results. Reports dealing with poor results offer such catch-all phrases as "Anionic trash" and "disolved salts" as explanations.

Therefore, it is the main objective of this paper to determine on the pilot machine if any wet end chemical additives are effective when used in 100% recycled filler furnish. Effectiveness is measured relative to: 1) water removal, 2) fine retention and 3) sheet properties, bulk, smoothness, tensile, TEA, internal bond, and stiffness.

To reduce the amount of time in pilot machine trials, a bench evaluation was conducted to screen out the noneffective chemicals in achieving the desired characteristics.

The results are not intended to be an endorsement or nonendorsement of any materials evaluated. The purpose is simply to state that under these conditions this is the result.

## Experimental Procedure - Bench Evaluation

Furnish for the study was selected randomly from bales of waste - news, corrugated and box shop cuttings. Two furnish combinations were used, a three part furnish consisting of equal amounts of all three with a 25% fine content and a two part furnish consisting of three parts corrugated to one part news with a 20% fine content.

Wet and additives were solicited from eleven different chemical companies with the objectives in mind. A total of 49 different single or dual chemical systems were evaluated. Chemicals received ranged from cationic low, medium, high molecular weight polymers to Anionic,low and high molecular weight polymers. Amphoteric, cationic and anionic starches were also included as were nonionic polymers and mineral fillers - Reference Table I, Appendix.

Furnishes were pulped in a commercial size Waring Blender at 2% consistency for 20 minutes. From each batch 40 hand sheets or Britt retentions could be run roughly enough to evaluate only three chemicals. For each batch a "blank" (no chemical added was made).

Handsheets were made following Tappi standard T205 om-81, with a target basis weight of 12#/mft$^2$. A constant turbulence (mixer) was added to the sheet mold to better simulate actual forming conditions. Fine Retention was determined using the Britt Dynamic Drainage Jar following standard procedures with one exception. The white water solids were determined by filtration vs evaporating water in a weighed can. Evaporating the water is more accurate, but it is not practical to tell a machine operator tomorrow where the machine is at today! The error here is small since 95% of the white water will be deposited on the filter pad.

Two drainage measurements were made, the first in the sheet mold was made according to Tappi Standard T221 om 81. This is a measure of time for water to leave the wet sheet on the wire. The better the drainage the lower the time required. The second test is a measure of the volume of white water through the Britt Jar in a fixed time period of 30 seconds. The better the drainage the greater the amount of white water through. Since no pad is formed in the Britt Jar, the sheet mold measure is most likely a better indicator of drainage rate on a paper machine wire.

Moisture contents by weight difference were measured after standard pressing and after one pass through the Noble and Wood Drier held at a constant temperature of 180$^{0}$ F. Both measurements are very sensitive due to the low weight of the handsheets. Stated another way, a .01 gram change in a hand sheet equals 1%. This high sensitivity makes for a high experimental error.

Density is a measure of basis weight divided by caliper.

Stiffness was measured on the Gurly stiffness tester. Using four taber tabs at a time and the five unit weight in the one inch position.

Tensile strength and TEA were measured on the Instron tester.

Smoothness was measured on the Parker Print Surf with the soft backing, 10 kg/cm$^2$ clamping pressure and a head pressure of .63 meters.

The % fine fraction was determined on the Bauer McNett Classifier.

Bench Evaluation Results

Table II, appendix lists the results for all chemicals. Evident was a large variation in the blanks due to variations in raw stock. Due to this variation, all tests in Table II are expressed in a percent increase or decrease from the blank for that batch. Example: Code E, fine retention, 3 part furnish indicates +36.1 at the 22#/ton level. The fine retention for that batch was 61%, adding chemical E increased the fine retention to 83%.

$$\frac{83\% - 61\%}{61\%} = +36.1$$

All tests in tables have been factored for basic weight which ran 12.0#/mft$^2$ ± 2.0 (95% C.L.).

The data in the above form was sent to Chemical Additives Task Force of the BRDA and a consensous was reached to evaluate four chemicals on the pilot machine:

Chemical C on three part furnish was selected for improvements in drainage and retention with very slight strength loss. Chemical E on both furnishes for improvements in retention, density and stiffness. Chemical D on both furnishes for improvements in water removel during pressing and drying, stiffness, mullen and tensile. Dual chemicals A/B on two part furnish for improvements in retention, stiffness, tensile and drainage.

With so many chemicals to evaluate, it was surprising how limited the choices were. In fact, some of the materials gave drainage problems in both the sheet mold and Britt Jar. These chemicals are identified by an asterisk under fine retention table II. Adding these chemicals caused plugging of the wire. The chemicals formed small flocs that were broken down due to shear action, then when the particles passed through the wire, the flocs reformed. Many of these flocs were then trapped between the wire and a coarse screen under the wire, thus plugging the wire. Since not all the material actually went into the white water, no accurate measure of retention can be made.

Data was plugged into a statistical package in WMU's PDP10 computer and analyzed. No over-all correlations were seen between the variables except the most obvious. Such as, the higher moisture content after pressing, the higher the moisture content after drying. This indicates that each chemical must be evaluated on an individual basis. Indeed this was how the materials were selected for further evaluation on the pilot machine. It is also true that improvements in one or more desired properties are always at the expense of one or more other desired properties.

Experimental Procedure Pilot Machine Evaluations

The furnish used was from the same bales of paper used in the bench evaluation.

The chemical additives choosen from the bench work were prepared following precisely manufacturer's guidlines. Five additive levels were choosen, two corresponding to bench levels. Chemical C,a liquid, was diluted to .5% and mixed 30 minutes. Chemical A, a dry powder, was diluted to 1% and mixed two hours. Chemical B, a dry powder, was diluted to .5% and mixed two hours. For chemicals A and B,continuous preparation would eliminate long mixing times. Chemical D, a dry powder, was diluted to 5% and cooked at 200$^{o}$F for 15 minutes. It was then diluted to 1%. Chemical E, a liquid , was diluted to 1% and mixed for 30 minutes. All chemicals were fed into the headbox at the appropriate feed rates.

Stock was dispersed in a pilot scale hydro pulper at 6% consistency and 160$^{o}$F for 20 minutes. The stock also had to be dosed with a small amount of NaOH to help break up the wet strength in the corrugated. After pulping, the stock had to be screened on the Johnson screen with .020" slots. This removed the large plastic and unpulped clumps that remained. It also discarded a good portion of the long fibers which effectively increased the percent fine content over that in the bench work. For the two part furnish % fine content went from 20% in the bench study to 32% on the pilot machine. For the three part furnish it went from 25% to 38%.

The pilot machine was a fourdinier with a deckle of 23 inches and a speed of 100 fpm. The production rate was 150#/hr. Target basis weight was 10#/mft$^{2}$, similar to one ply on a board machine. The pilot machine had two wet press sections held at a constant 85 PLI loading. The main steam to drier header pressure was held at a constant of 20 psi. The sheet was calandard through two nips with a constant loading of 160 PLI.

Moisture measurments were made after the wire on the felt and after pressing using a Gama Moisture Gauge for chemicals A/B, C and D. Measurements for chemical E after the wire and pressing were made on web samples using oven dry method. All measurements for moisture at reel were made by oven dry method as well.

Total acidity was measured and varied slightly from 20 - 15 ppm for all trials.

Britt fine retentions were determined from the same headbox samples used to measure machine fine retentions. The machine white water solids were determined from the first tray. The flow in the second (clear water) tray was very slow and solids settled out readily so no accurate sample could be taken. Also, no sample of the solids from the couch roll could be made. This is a common problem on fourdinier machines and previous work has shown that only 5% of the lost solids will reach the couch roll. Thus, using an estimated constant of .90 in the retention equation should account for these two small errors.

Drainage rate was hoped to be measured by any changes in the dry line on the wire; however, the dry line did not move except when the suction boxes were shut on or off for the entire trial.

Percent fine content in the sheet was determined following standard procedures in the Bauer McNett fiber classifier. The sheet first had to be redispersed in a Williams disintegrator at 1% for 10 minutes. Since all trial paper made dispersed easily, there should be no problem with recycling. The Williams disintegrator is designed to do minimal work on the individual fibers. Breaking down the fiber-fiber and fiber-fine bonds. A total headbox fine content was determined from adding white water solids to fine content found in the sheet.

CSF was also measured on repulped sheet.

Gurly, Stiffness, Parker Print Surf, Tensile TEA, Basic Wt., Caliper and Mullen tests were run on all paper produced.

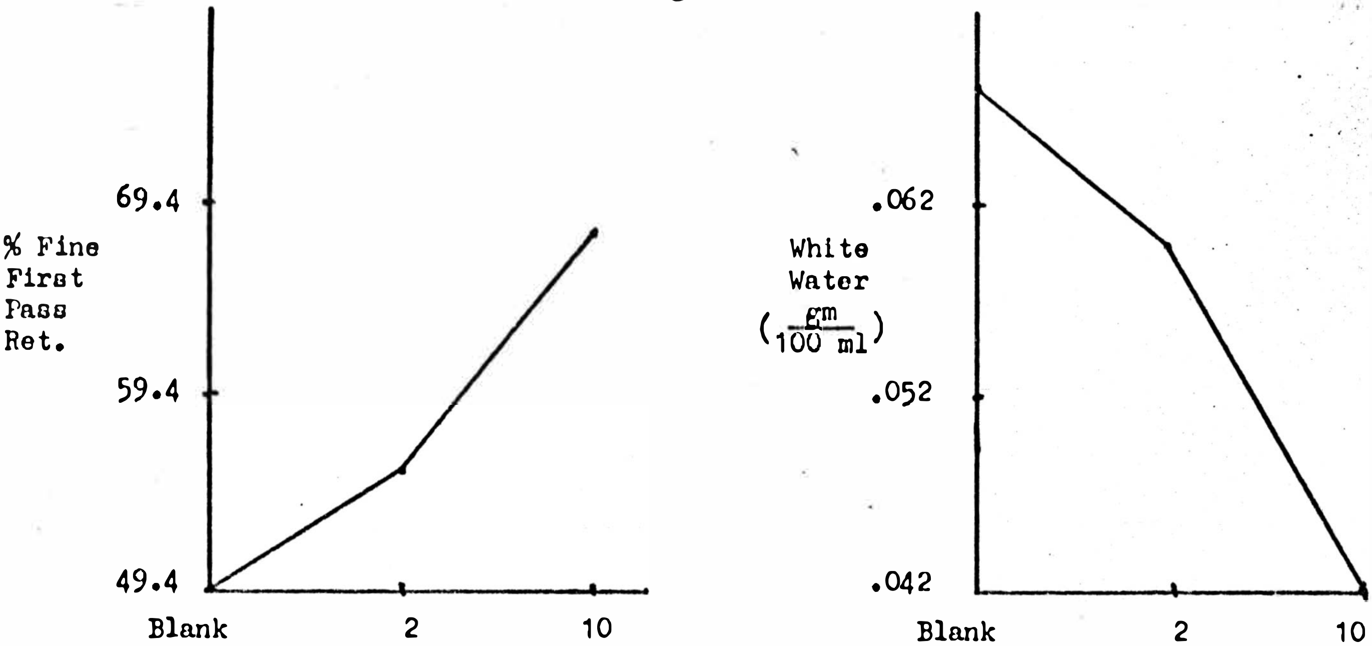
Experimental Results Pilot Evaluations

Table III, appendix lists results for all pilot machine trials. Graph 1 indicates the results for Chemical C choosen for drainage and fine retention. Shown is good improvement in retention with accompanying cleaner white water. Mullen also increase indicating the chemical acted to supplement the natural hydrogen bonding in bridging the fines to the longer fibers. The presence of more paper making fines also provides more potential bonding sites. Negative effects shown in Table III are seen in increased moisture content through the machine and increased density.

Graph 2 indicates results for dual system A/B choosen for strength and retention. Shown are improvements in retention, tensile, Mullen and stiffness. Negative effects shown in Table III were seen in moisture at the reel and density.

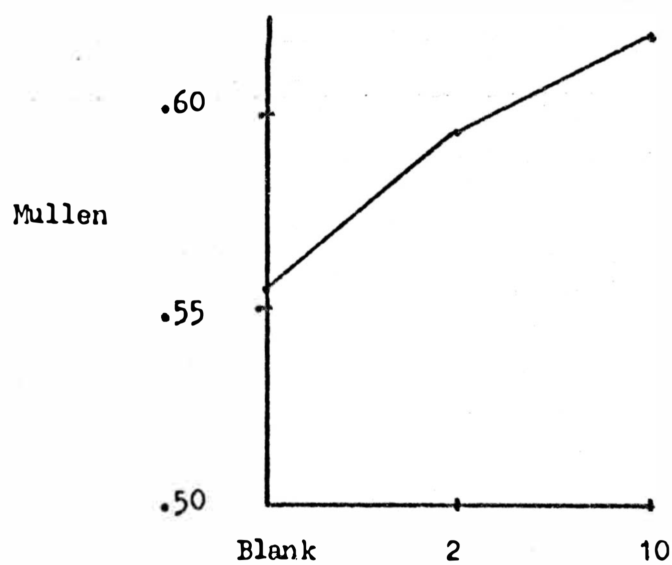
Graphs 3, 4, 5, and 6 summerize results seen with Chemical D choosen for water removal. The results for moisture are varied depending on level of addition and furnish were seen. Negative effects are seen consistently in MD TEA.

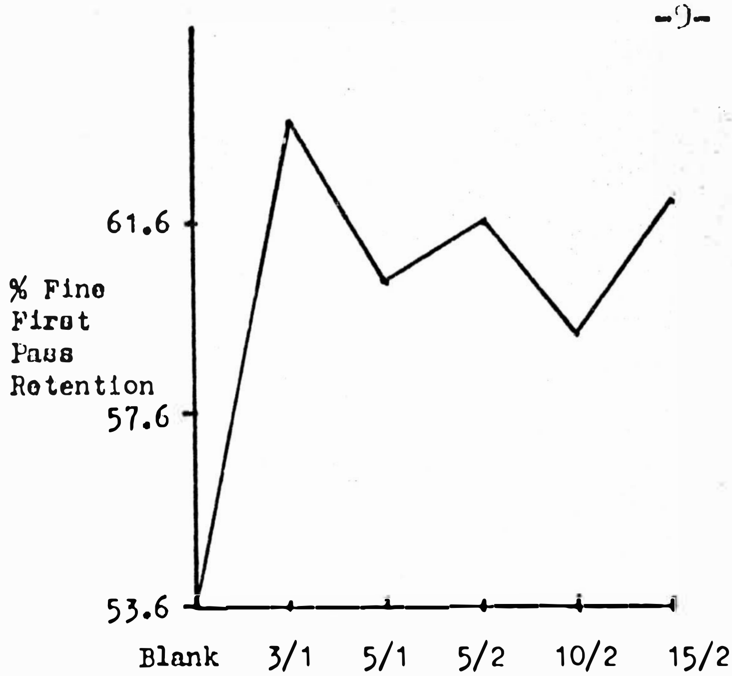
Graph 7 and 8 summerize results for Chemical E, choosen for improvements in density and retention. The results here are again mixed, depending on addition levels and furnish good results are seen in density and retention. Negative results are consistantly seen in water removal.

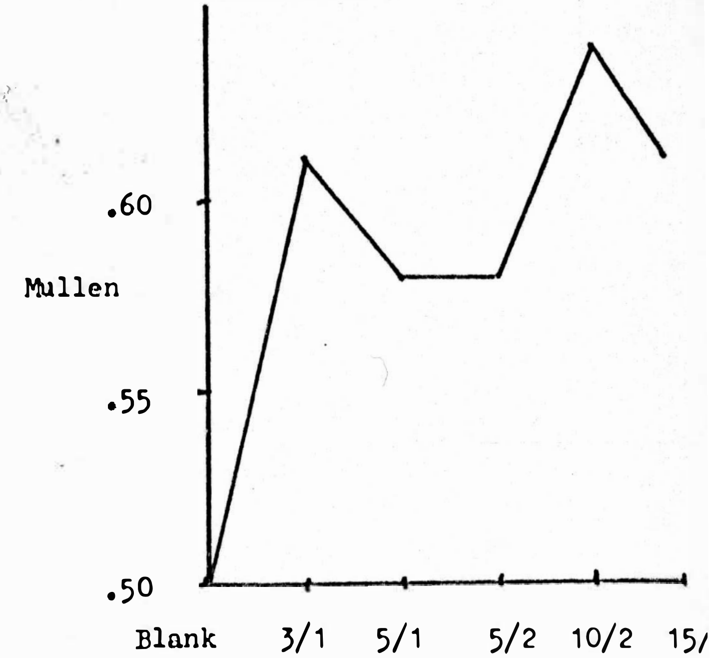



Graph 1
Chemical C
Addition Level (#/Ton*)

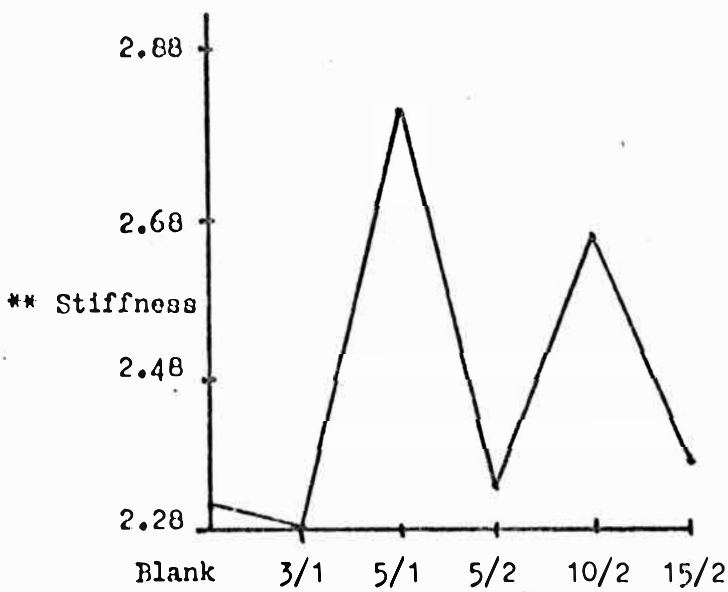
* As Received Basis
** Factored for Basis wt.
*** 3 - Part Furnish
Pilot Machine Trials

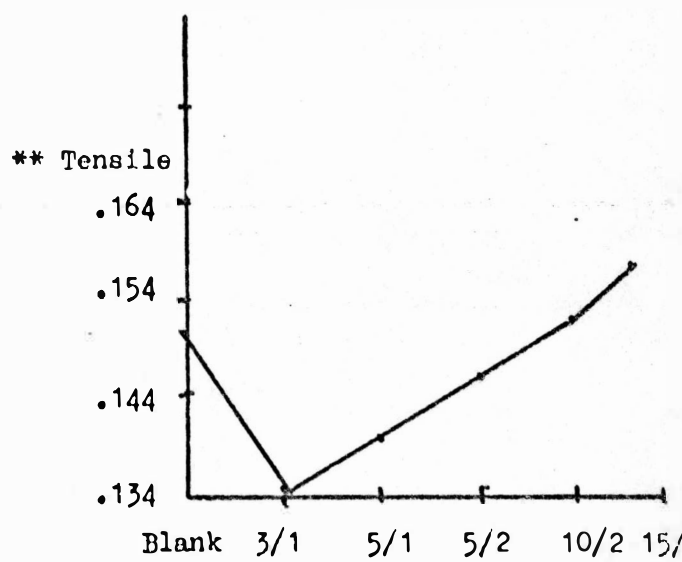




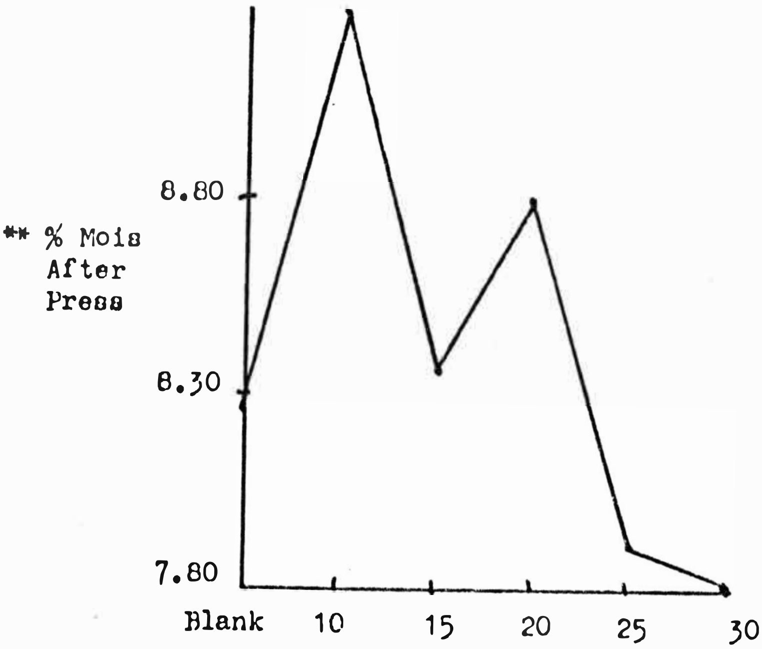



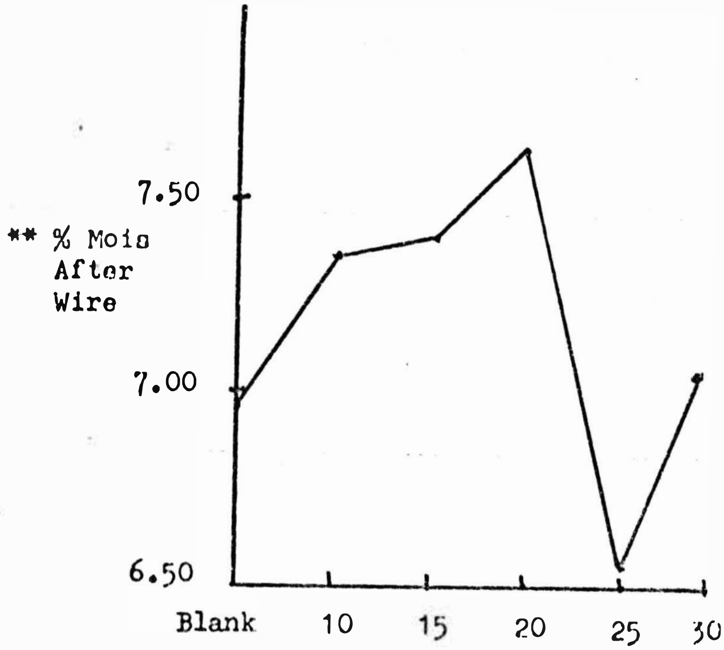

Graph 2
Chemical A/ Chemical B
Dual System
Addition Level (#/Ton*)



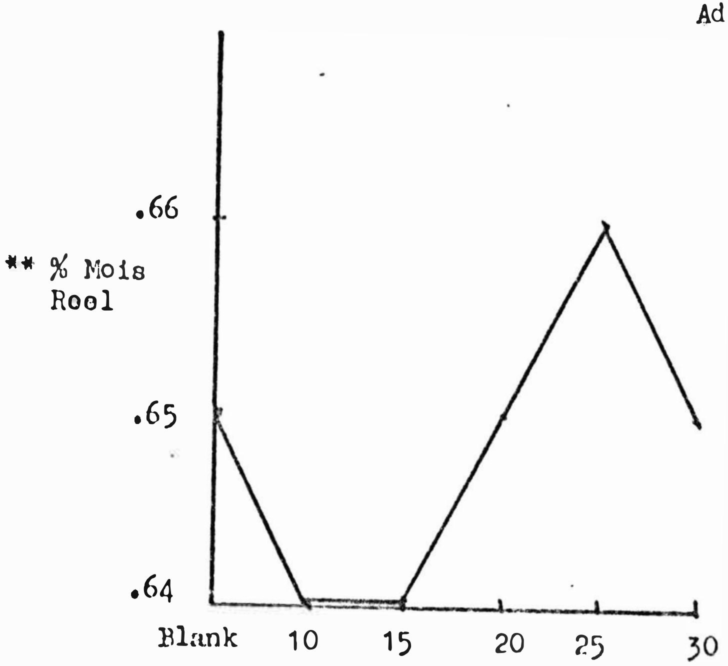



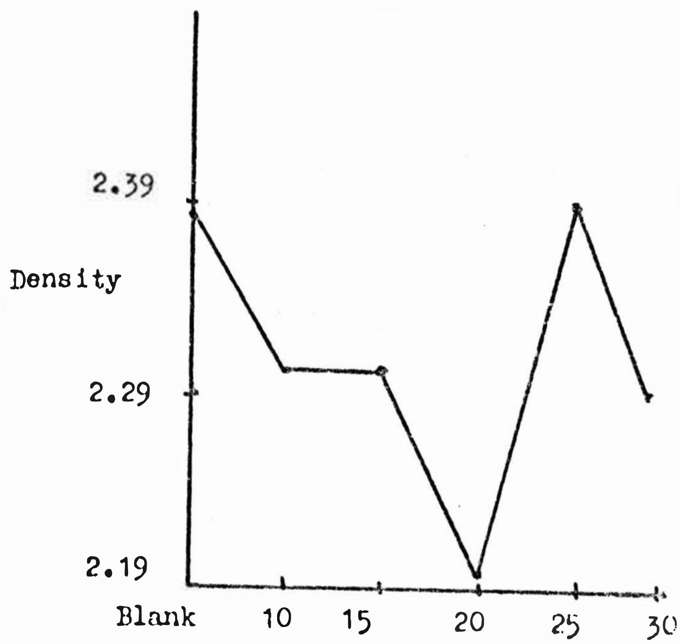

**** All Test Values Factored for Basis wt.
*** For 2 Part Furnish - Pilot Machine Trials
* As Received Basis
** Geometric Mean $=\sqrt{(CD)(MD)}$



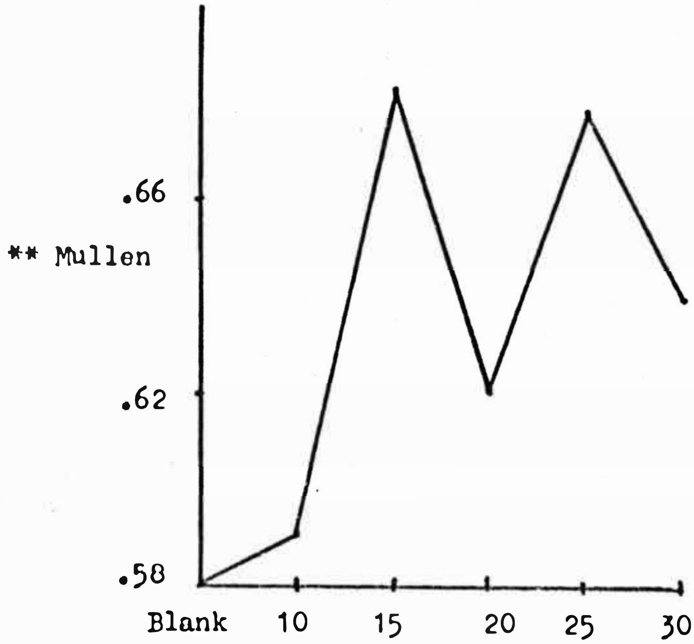



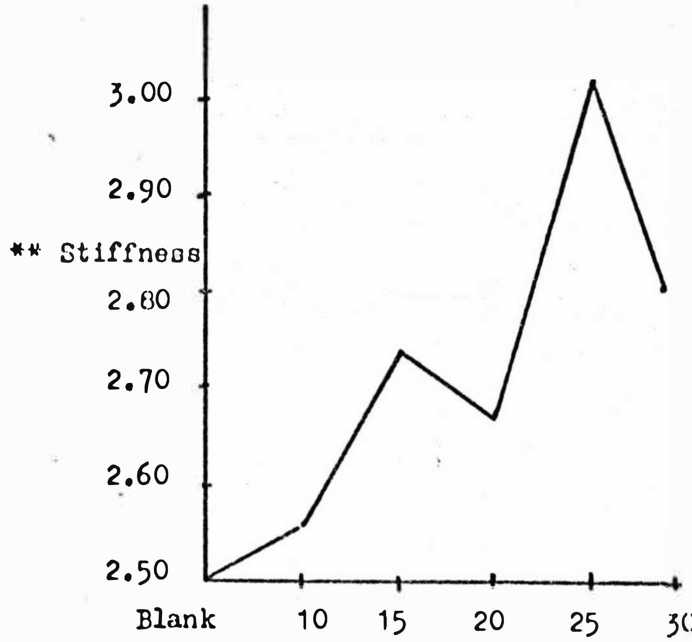

Graph 3
Chemical D
Addition Level (#/Ton*)



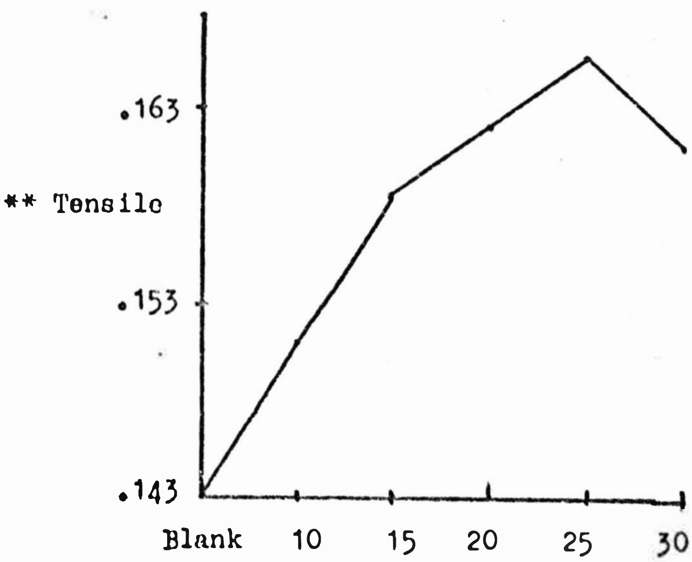

* As Received Basis
** Factored for Basis wt.
*** 2 Part Furnish - Pilot Machine Trials



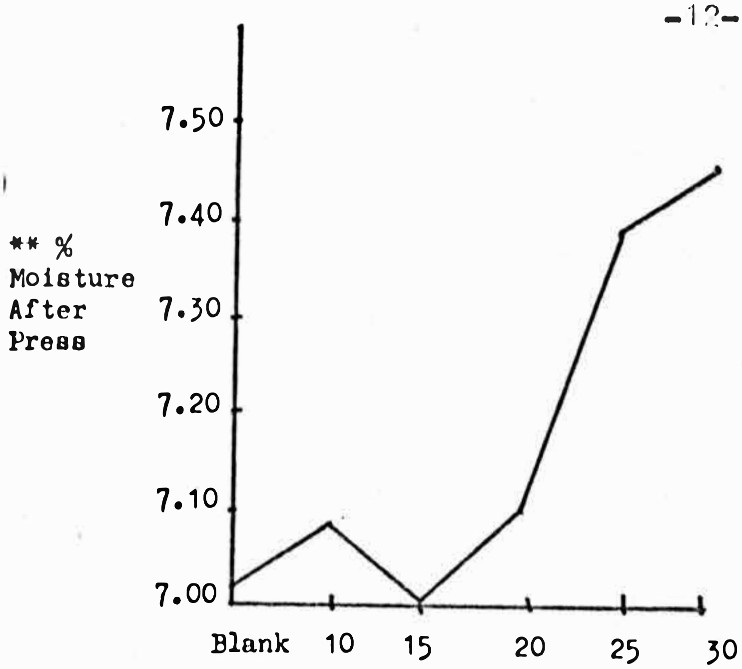



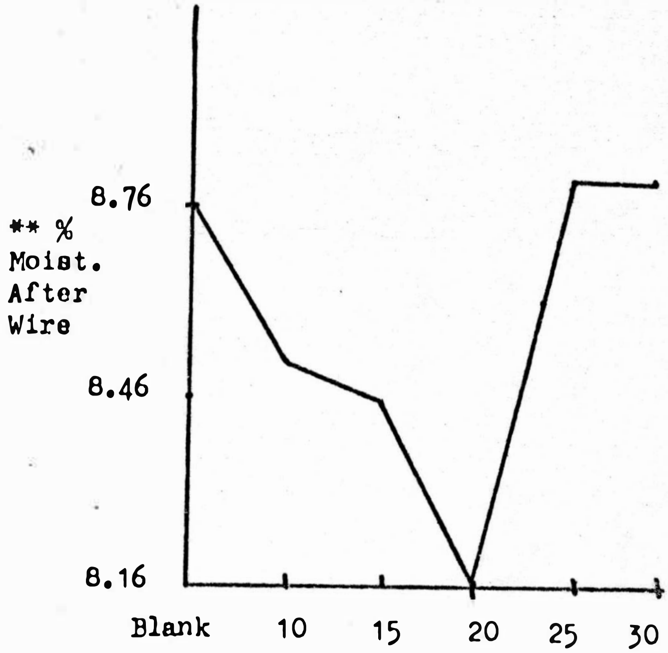

Graph 4
Chemical D

Addition Level (#/Ton*)

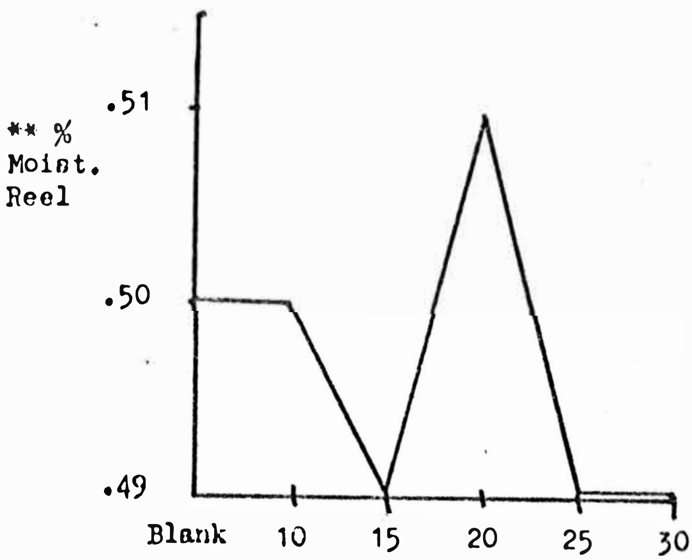


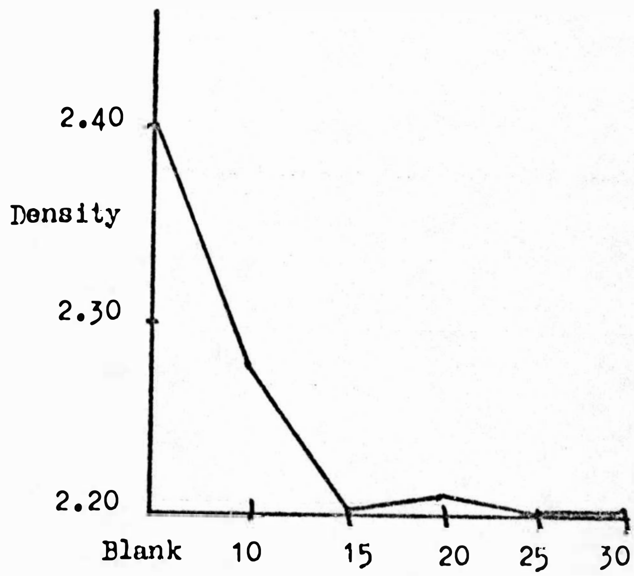

* As Received Basis
**** Factored For Basis wt.
*** 2 Part Furnish Pilot Machine Trials
** Geometric Mean = (CD)(MD)



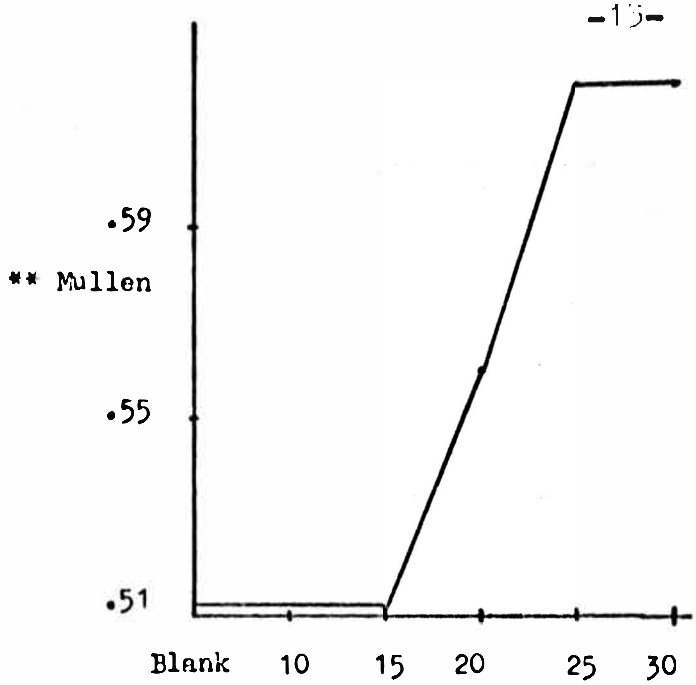



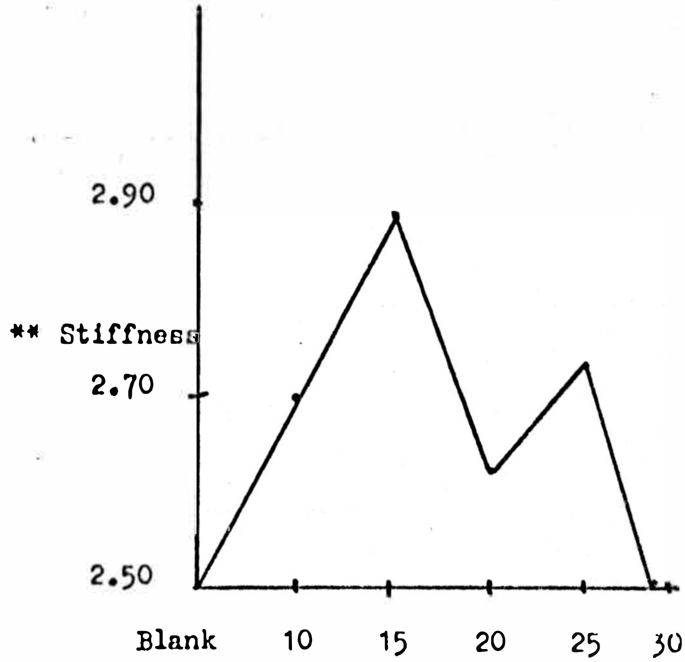

Grah 5
Chemical D
Addition Level (#/Ton*)



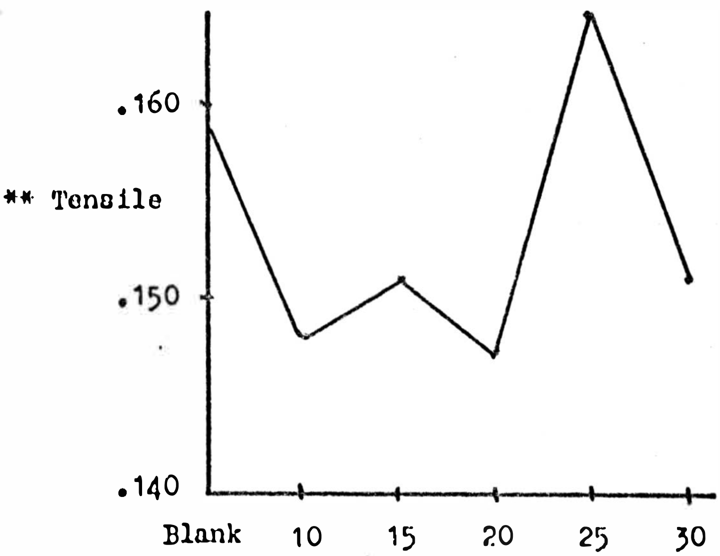

* As Received Basis
** Factored for Basis wt.
*** 3 Part Furnish - Pilot Machine Trials



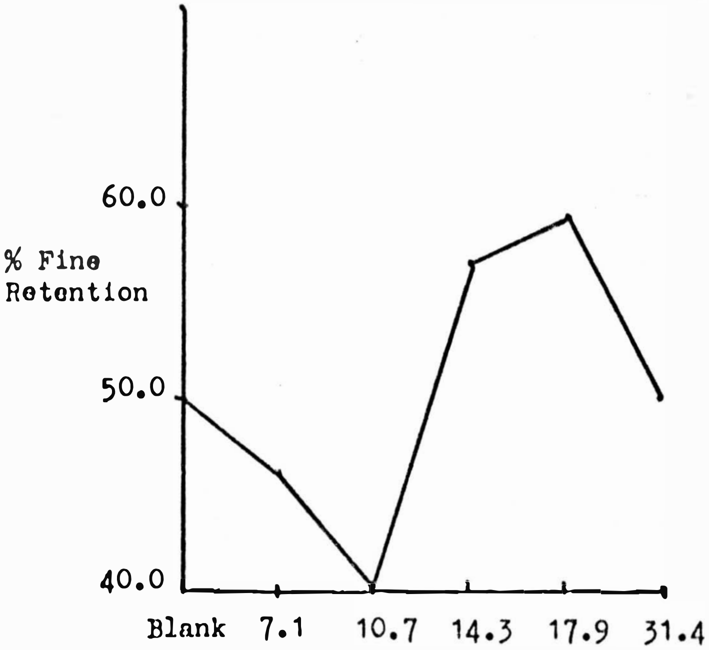



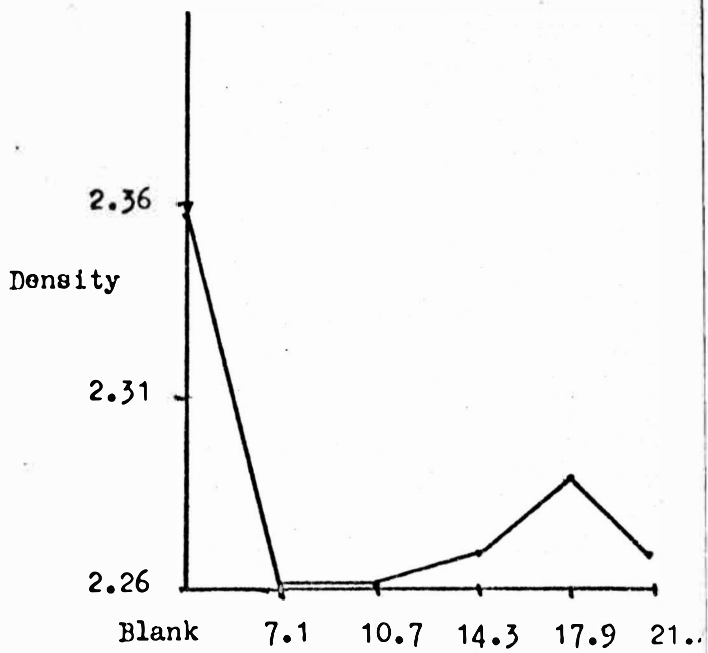

Graph 6
Chamical D

Addition Level (#/Ton*)

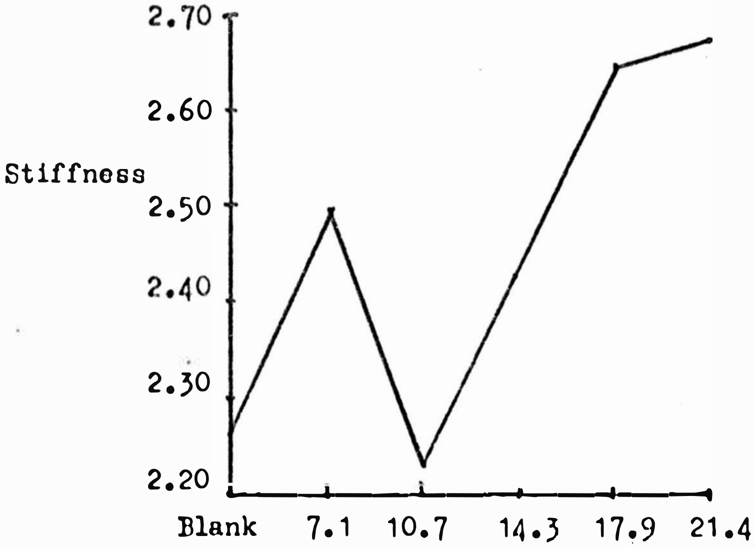


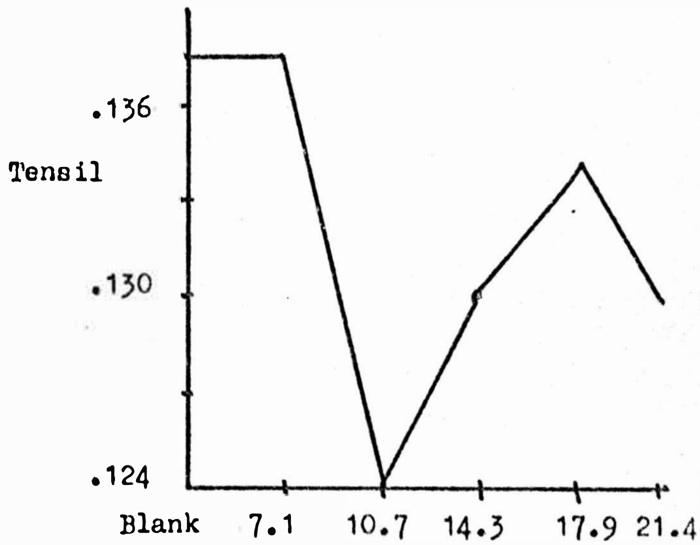

* As Received Basis
**** Factored for Basis wt.
*** 3 Part Furnish Pilot Machine Trials
** Geometric Mean = (CD)(MD)



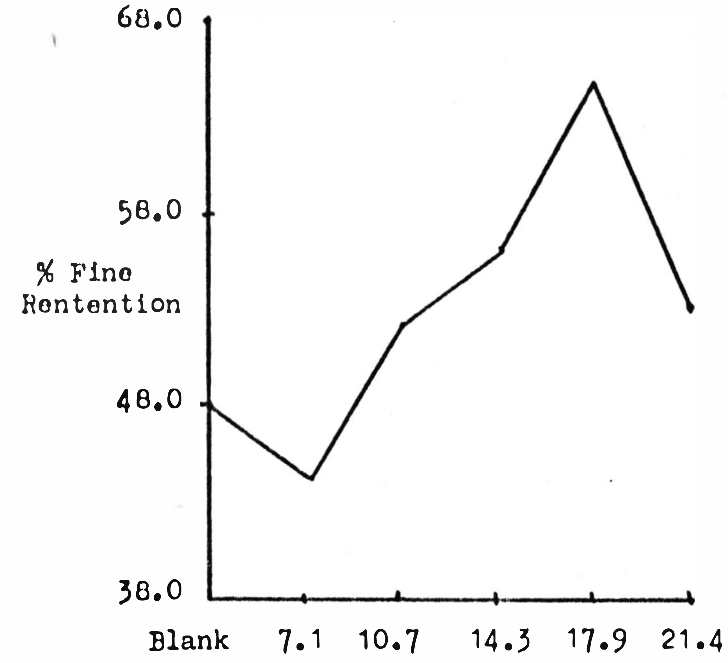



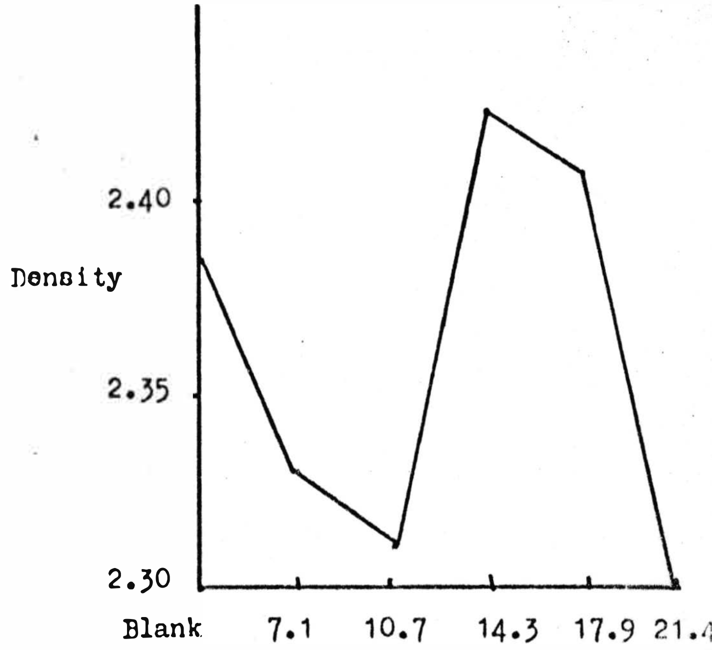

Graph 7
Chemical E
Addition Level (#/Ton*)



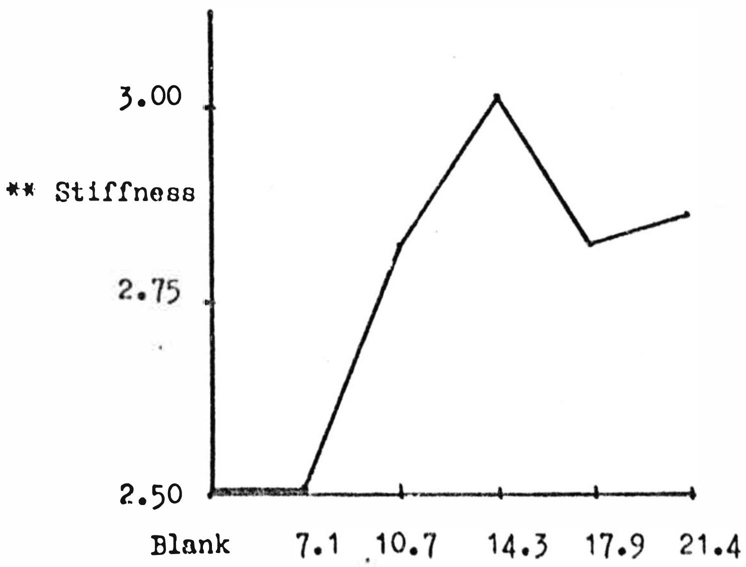

* As Received Basis
** Geometric Means
*** 2 part furnish Pilot Machine Trials
**** All factored for Basis wt.

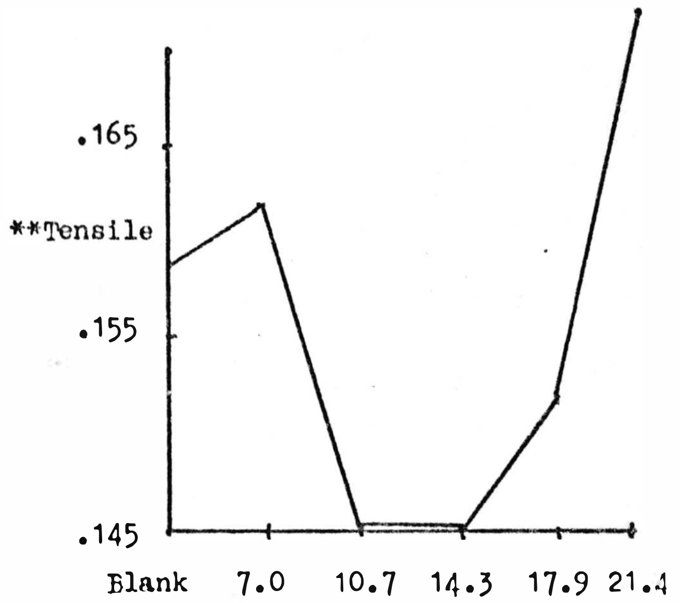



Graph 8
Chemical E

Addition Level C#/Ton*)




* As Received Basis
** Geometric Mean
*** 3 Part Furnish Pilot Machine Trials
**** All Factored for Basi wt.

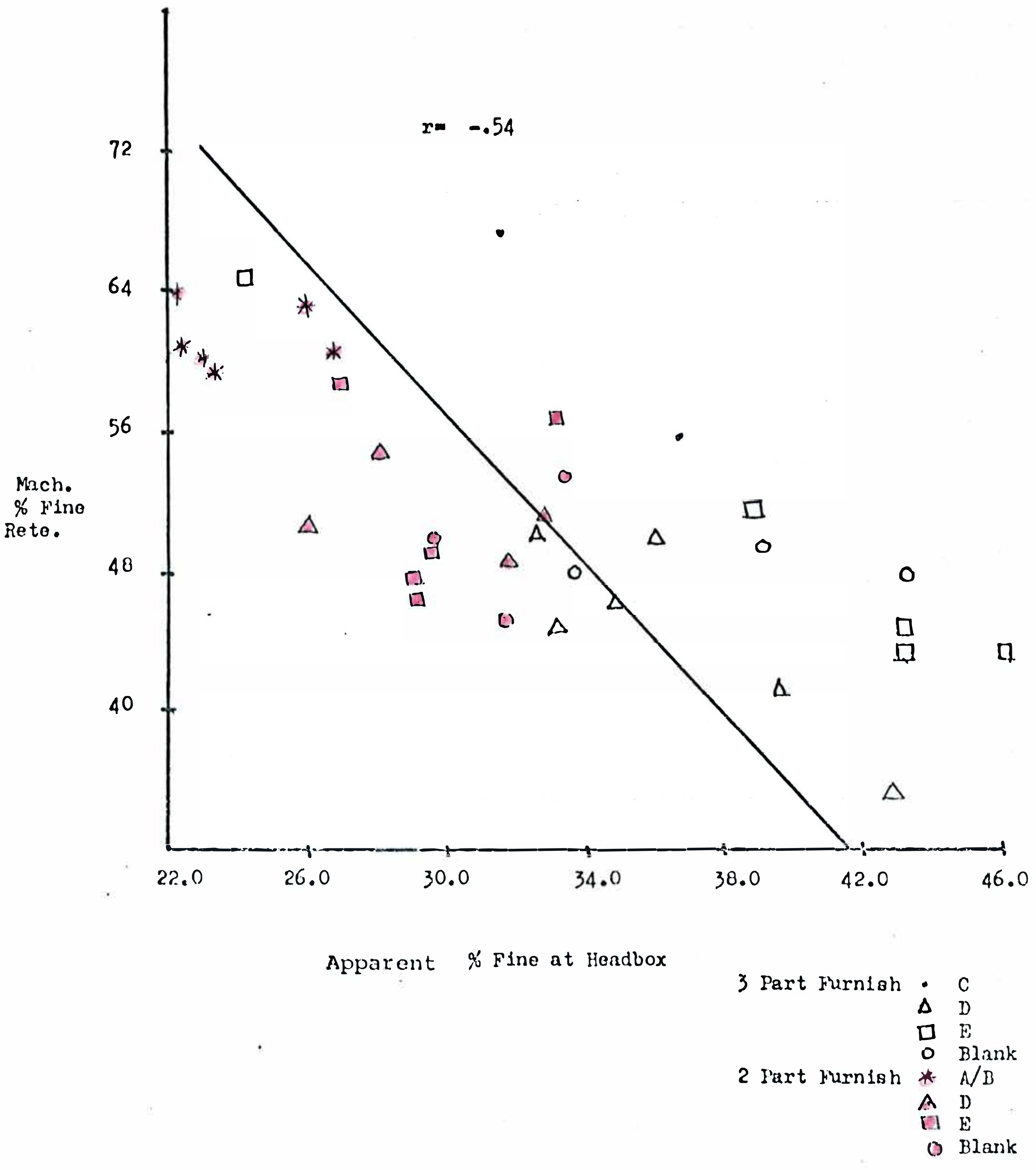
## Discussion of Pilot Results

The data was then analyzed and a number of statistically significant correlations exist. Graphs 9 through 18 summerize these correlations. Noted on these graphs is a small "r". This stands for regression coefficient. Loosely termed r is a measure of how good a linear relationship is between two variables. Stated another way, a r=.50 indicates that 50% of the variation in the dependent variable is related to the independent variable. A r = 1 indicates a perfect direct linear relationship. A r = - 1 indicates a perfect inverse relationship.

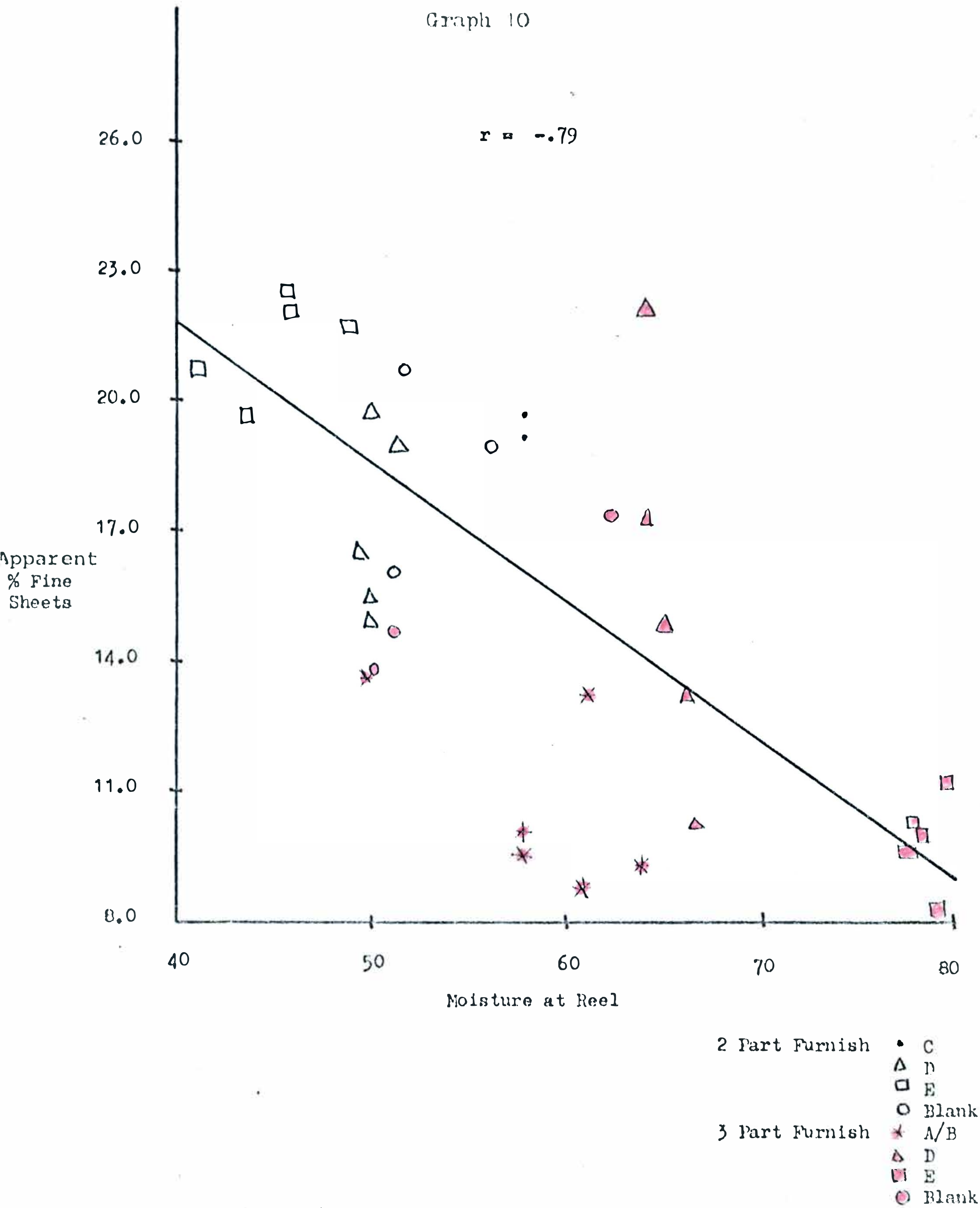
Graph 9 indicates Apparent % Fine Content at headbox. This is due to the lack of sufficient shear forces in the Bauer McNeff Classifier to break the hydrogen bonds formed between the molecules added and the fiber and fines. This is "apparent" in the sheet. Adding the W.W. solids to this gives the apparent headbox fine content. As the chemicals are more effective in bonding the fines to fiber, the average fiber length is seen to increase and the free fine content in the headbox goes down relative to the blank.

This apparent fine content in the sheet has a negative on the moisture at the reel and smoothness. These are indicated by Graphs 10 and 11. These two graphs seem contradictory. However, Graph 12 sheads some light on the mechanism. As the polymers increase the average fiber length, the mobility of the fines is low and they can not move enough on the surface to fill in the void areas. Hence, the sheet becomes rougher. Following this reasoning there should be more void area and hence greater water removal as has been proposed[2]. This argument appears not to be the case as the chemicals added that improved rentention tended to increase density. This helps explain why only Chemical D, with decreased density, showed any sign of improving water removal. It would

Graph 9

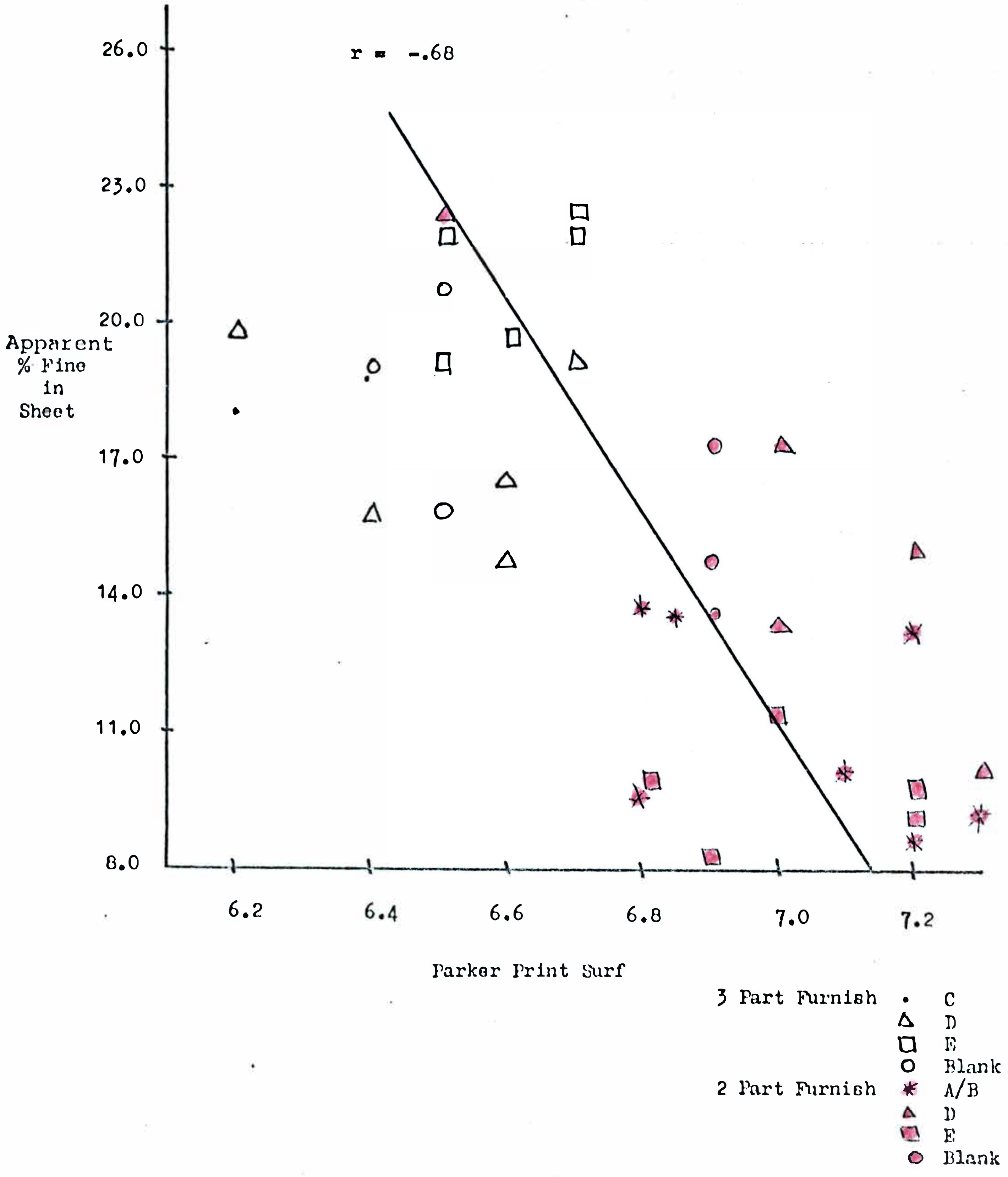

r= -.54
72
64
56
48
40
Mach.
% Fine
Rete.
22.0
26.0
30.0
34.0
38.0
42.0
46.0
Apparent % Fine at Headbox
3 Part Furnish
C
D
E
Blank
2 Part Furnish
A/B
D
E
Blank

Graph 10

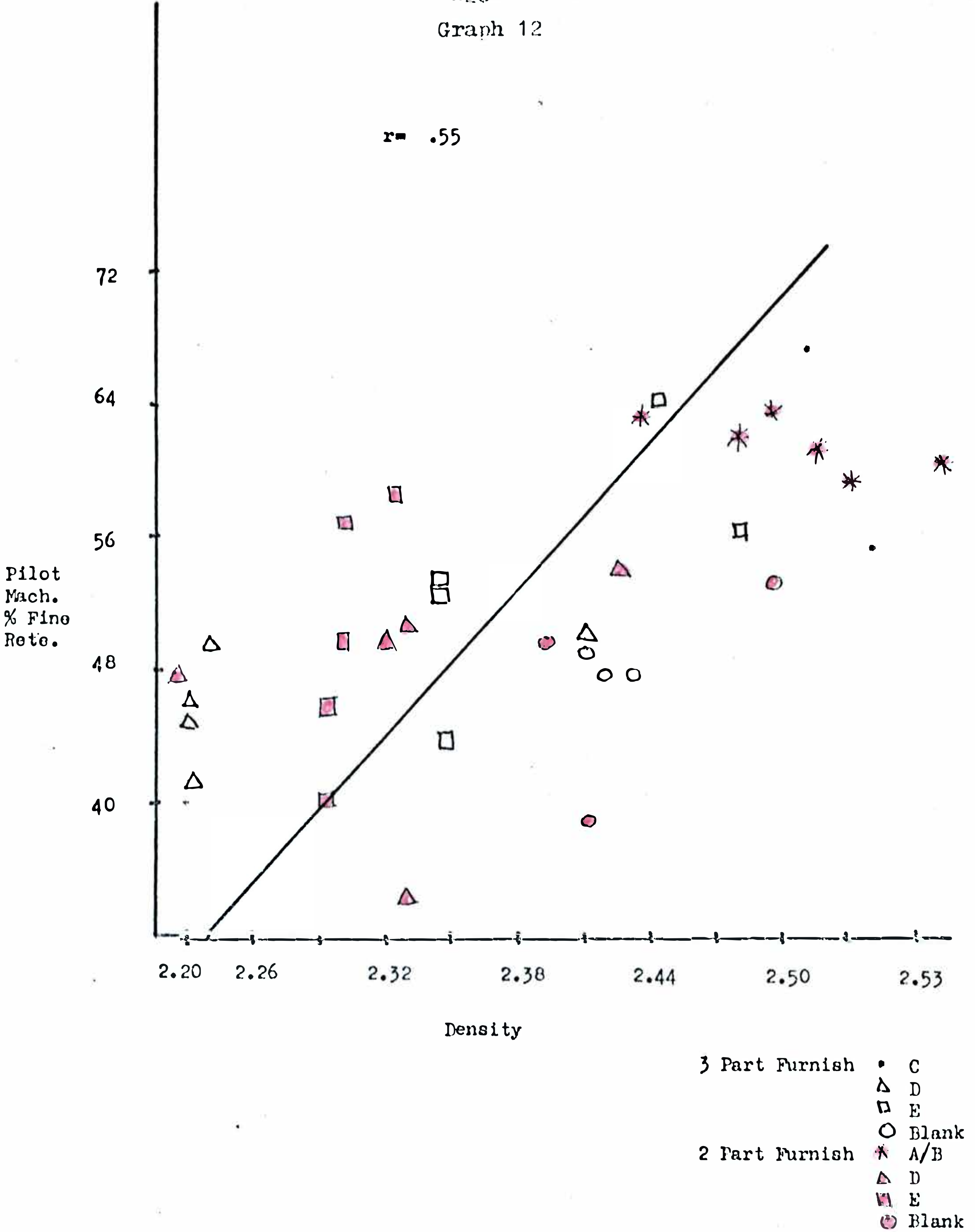



Data factored for Basis wt.

Graph 11


r = -.68
26.0
23.0
20.0
17.0
14.0
11.0
8.0
Apparent % Fine in Sheet
6.2
6.4
6.6
6.8
7.0
7.2
Parker Print Surf
3 Part Furnish
C
D
E
Blank
2 Part Furnish
A/B
D
E
Blank

Graph 12


r= .55
72
64
56
48
40
Pilot
Mach.
% Fine
Rete.
2.20
2.26
2.32
2.38
2.44
2.50
2.53
Density
3 Part Furnish
C
D
E
Blank
2 Part Furnish
A/B
D
E
Blank

appear that the increases in density force the fibers to plug the void areas except on the very surface which remains open and rough. Due to the relatively low calandaring and pressing pressure, the sheet is very rough and doesn't relate to smoothness levels on most board machines. This raises the question about validity of the above discussion on multi-ply machines.

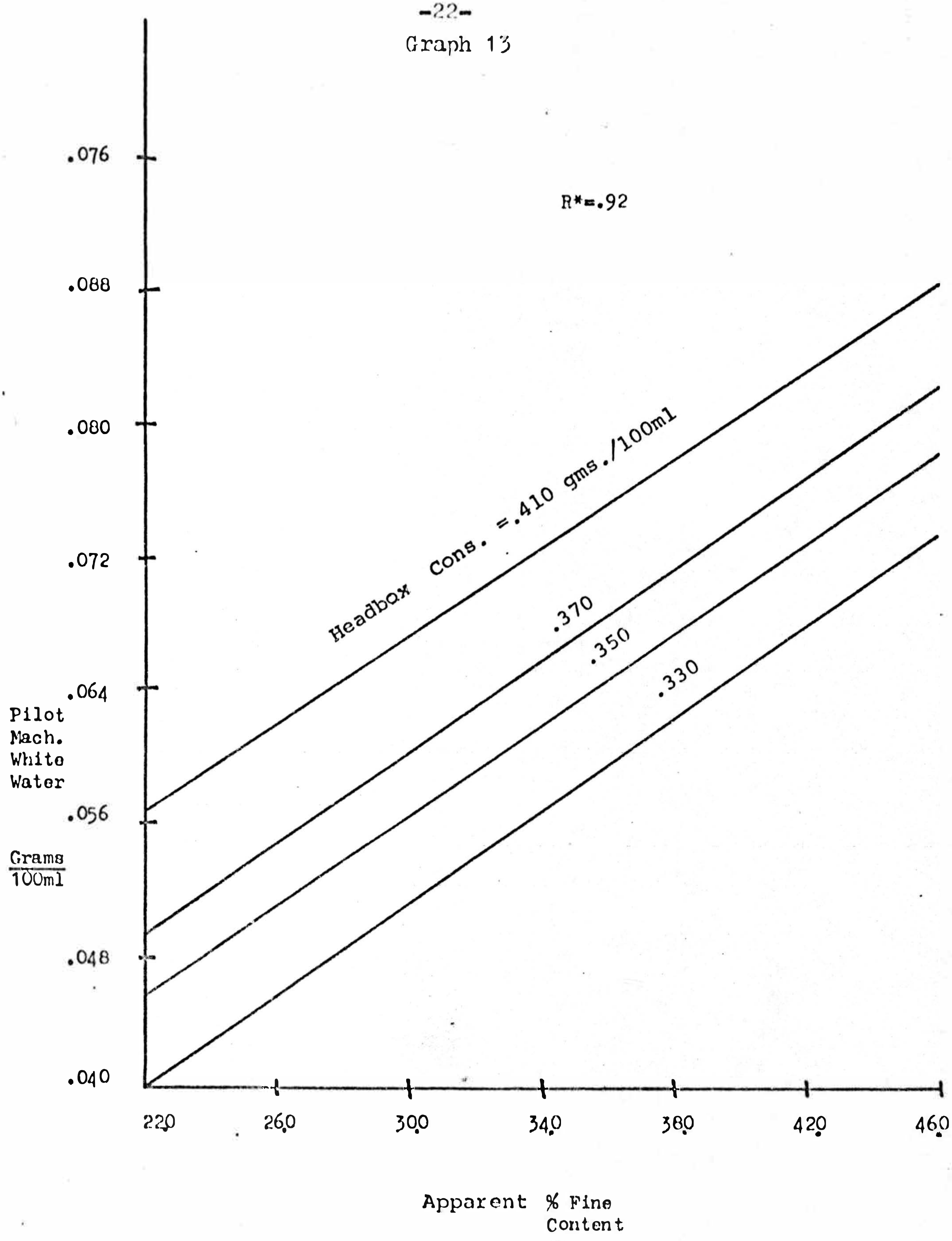
Graph 13 indicates the relationship between apparent fine content and headbox consistency to white water solids. Indicated is that as the the chemicals decreases the apparent fine content or there are decreases in actual fine content in the furnish the W.W. will be cleaner at equal headbox consistency. The importance of controling headbox consistency is seen if cleaner white water is desired. Decreasing consistency means more water and this must be balanced against cleanliness of W.W..

Graph 14 indicates the relationship between apparent fine content and CSF. Due to this relationship CSF was a reasonablely accurate predictor of moisture at the reel, graph 15. It was puzzling that CSF did not relate to moisture after the wire while relating to water removal at pressing and drying.

Graph 16 indicates the relationship beteen moisture after pressing and after the wire. Higher moisture off the wire means higher moisture after pressing.

Graph 17 indicates the volume of material through the Britt Jar is related to CSF.

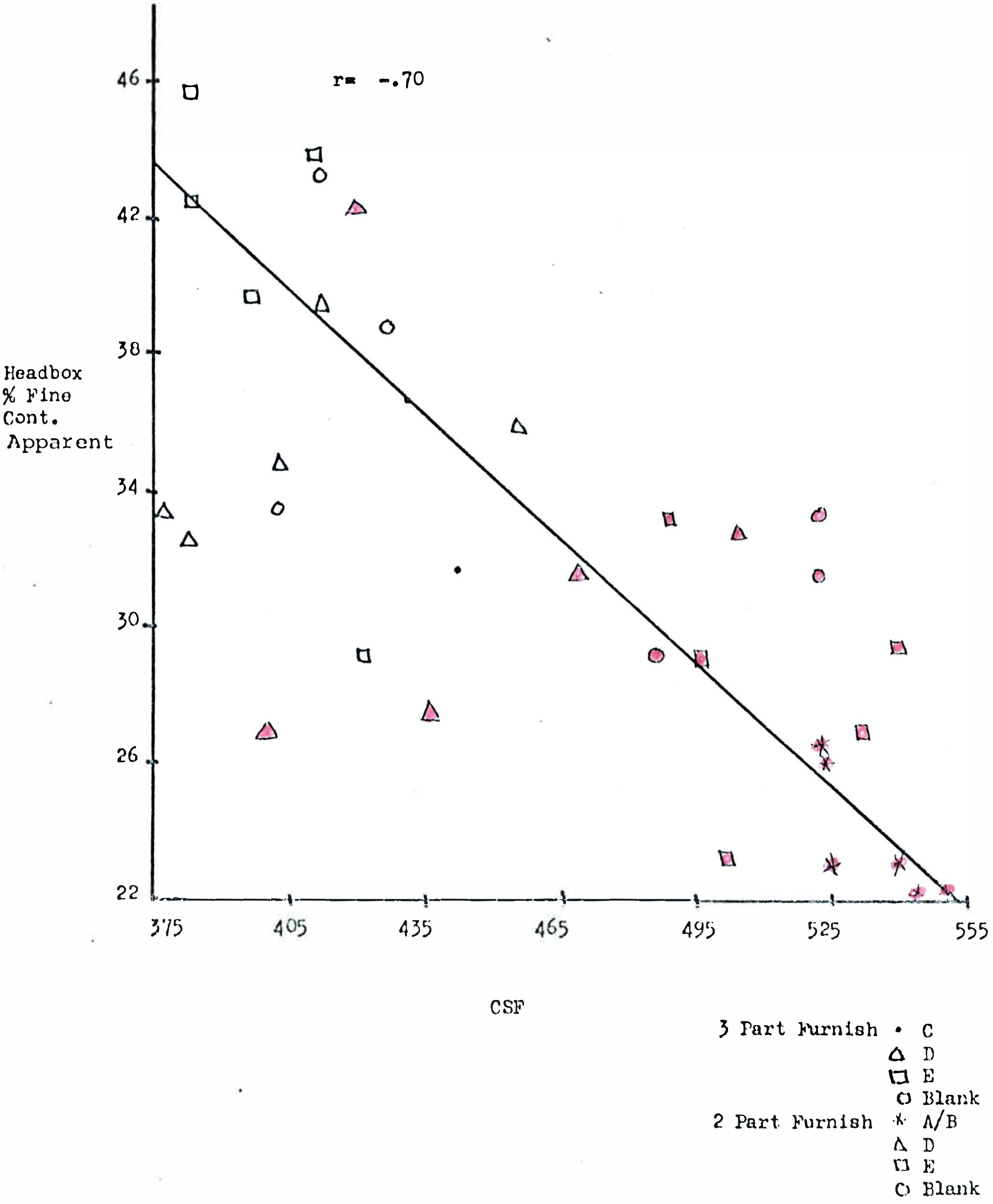
Graph 13



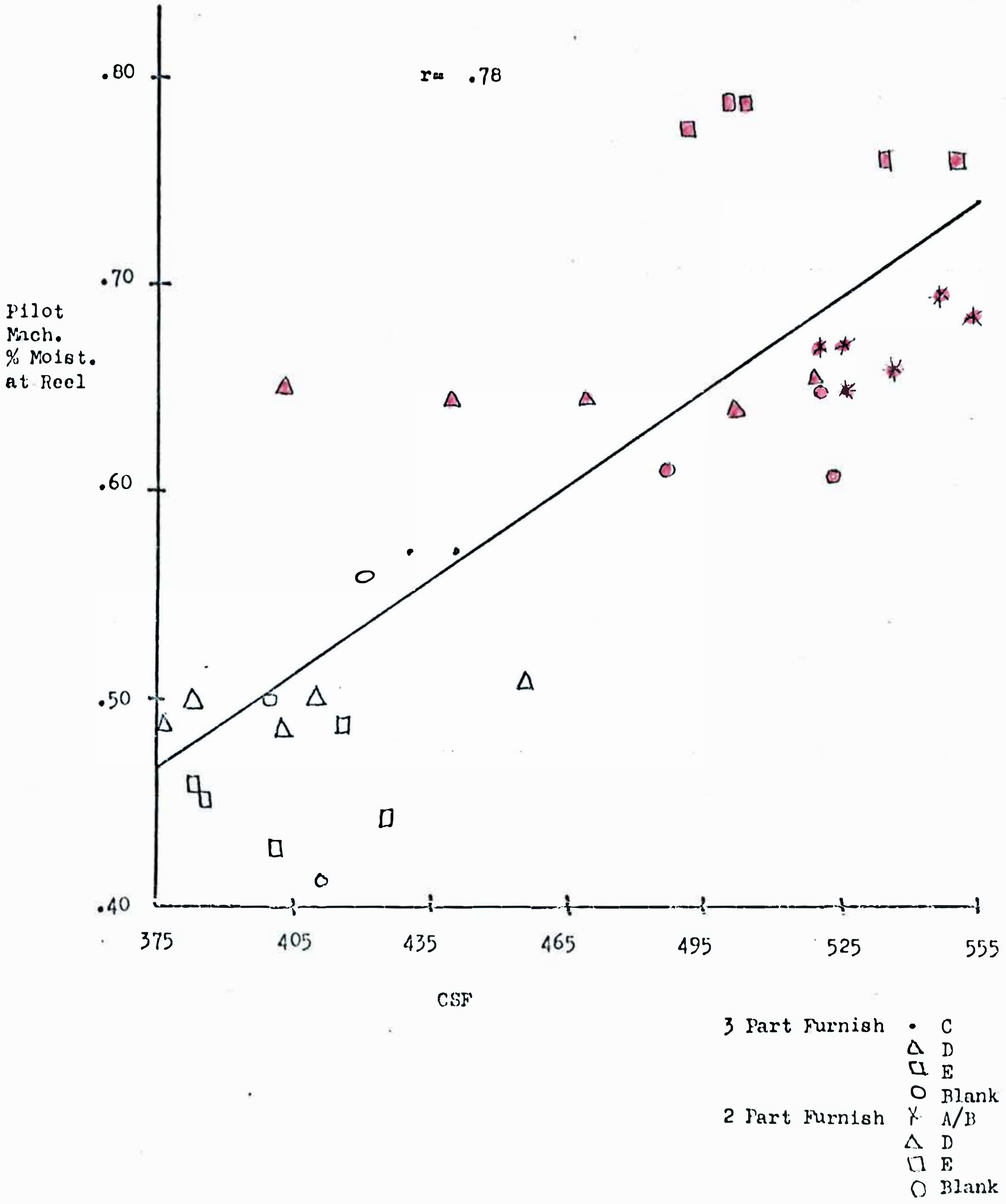

Chemical: A/B, C, D, E

* Multiple Correlation Coef.

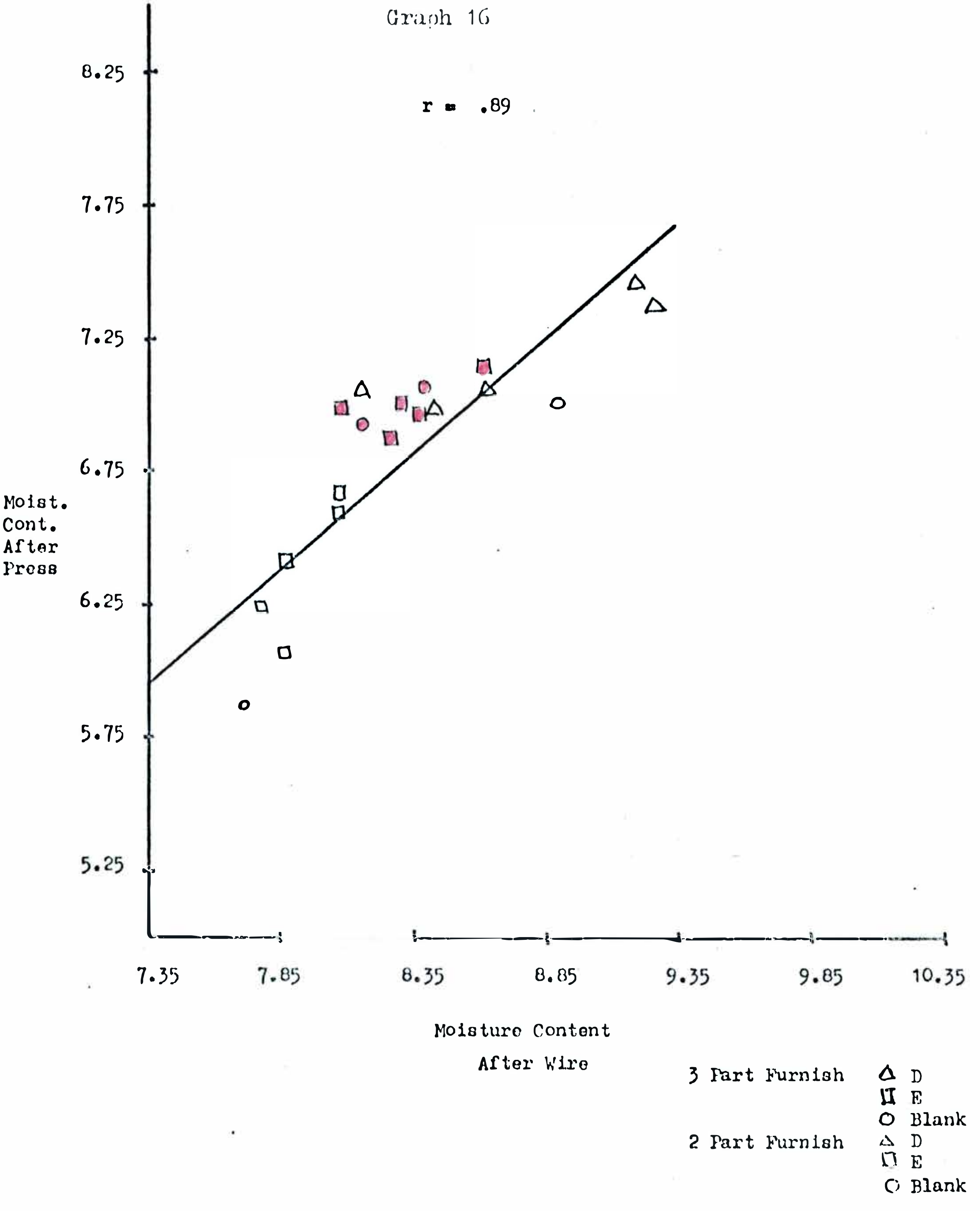
Graph 14


r= -.70
46
42
38
34
30
26
22
Headbox
% Fine
Cont.
Apparent
375
405
435
465
495
525
555
CSF
3 Part Furnish • C
D
E
Blank
2 Part Furnish A/B
D
E
Blank

Graph 15

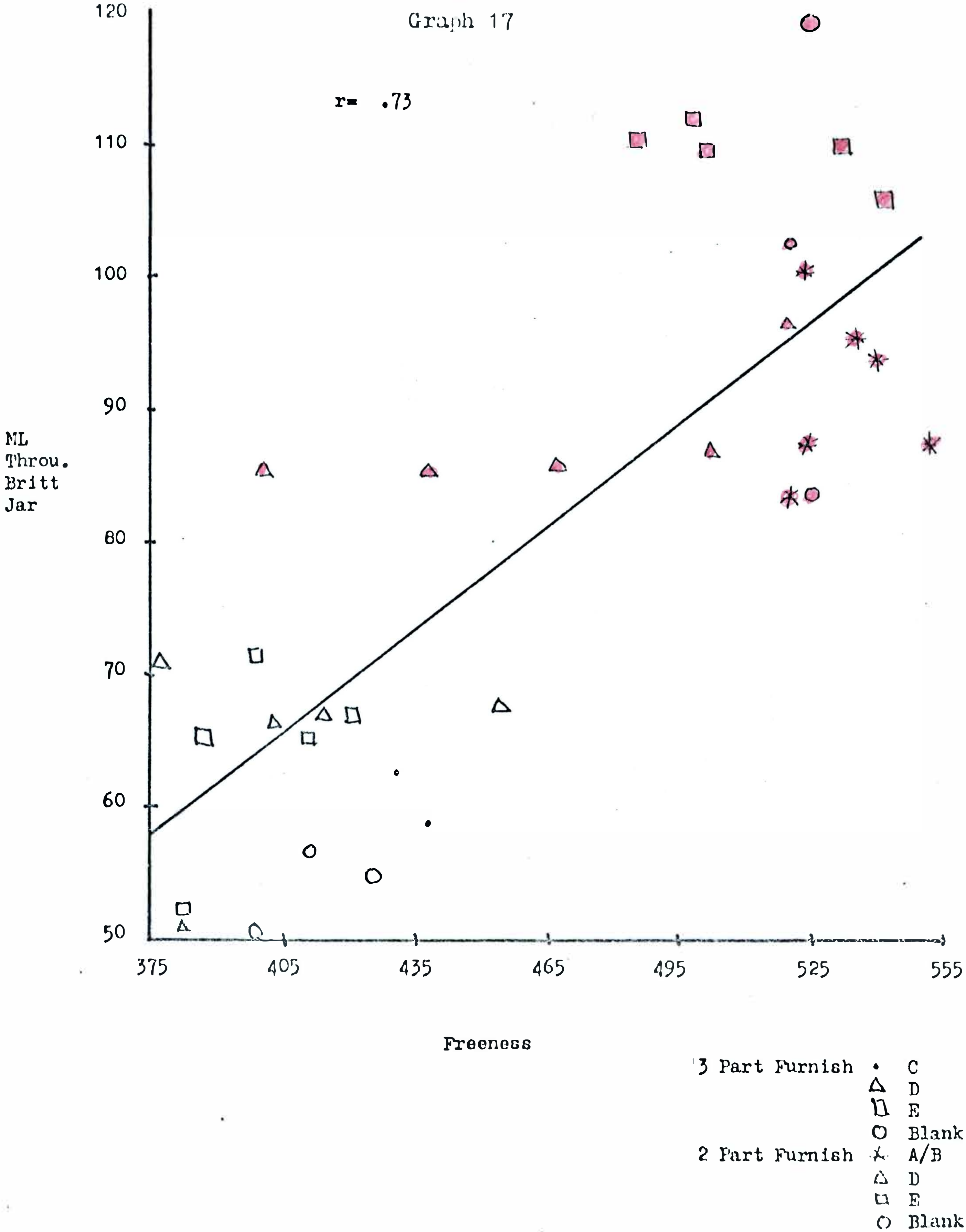

r= .78
.80
.70
.60
.50
.40
Pilot Mach. % Moist. at Reel
375
405
435
465
495
525
555
CSF
3 Part Furnish • C
D
E
Blank
2 Part Furnish A/B
D
E
Blank

Graph 16




Data Factored for Basi wt.

Graph 17


r= .73
120
110
100
90
80
70
60
50
ML
Throu.
Britt
Jar
375
405
435
465
495
525
555
Freeness
3 Part Furnish
C
D
E
Blank
2 Part Furnish
A/B
D
E
Blank

Pilot vs. Bench Results

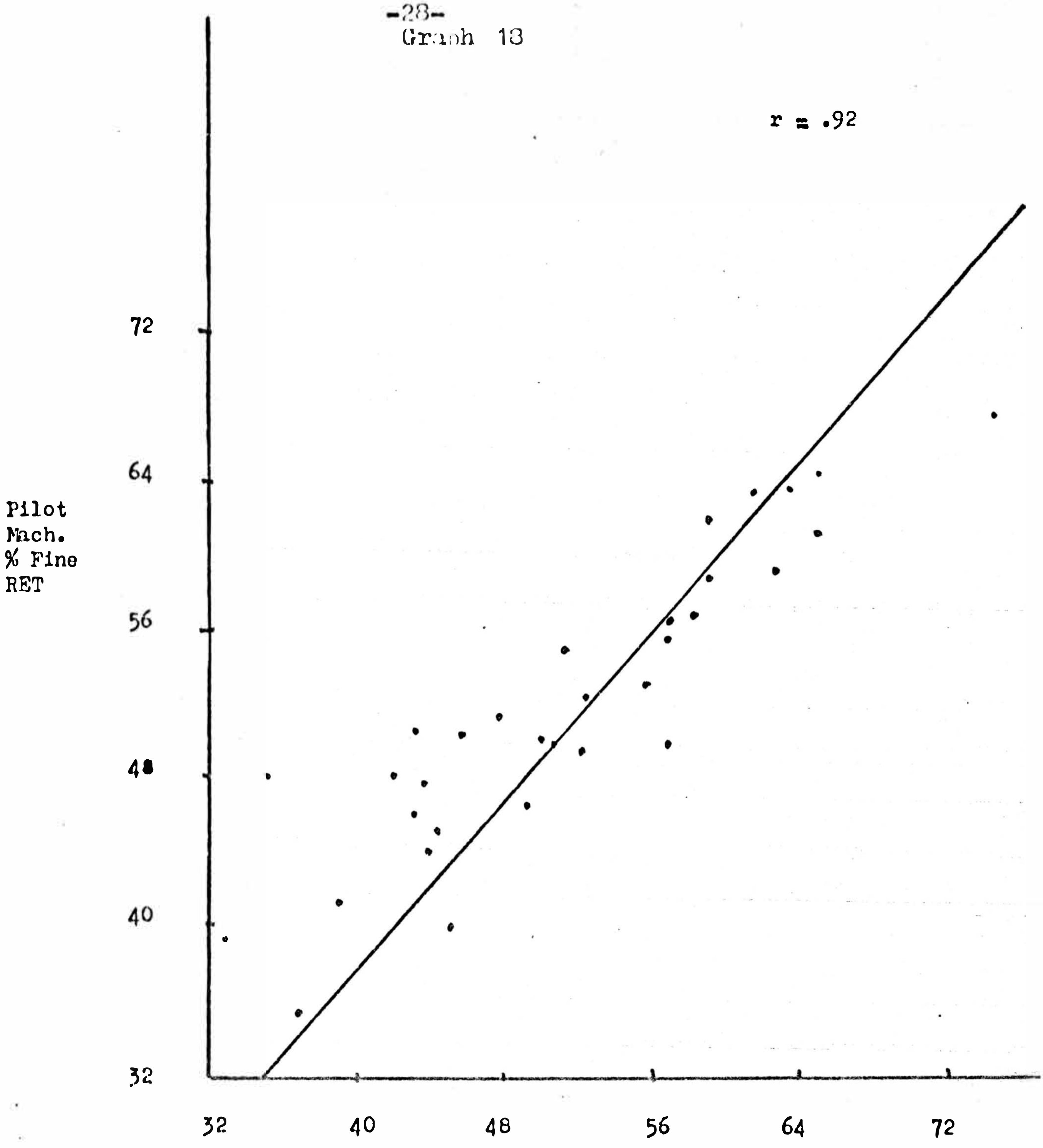
Graphs 18 through 26 indicates the correlation between bench and pilot results. Each comparison is made at equivalent chemical addition levels from the bench results vs. pilot results. Graph 18 indicates how well the Britt Jar predicts pilot machine fine retention. If similar correlation results are seen when comparing to mult-ply forming devise retention, the Britt Jar would be a powerful process tool, and not just a research tool.

The results from the sheet property comparisons are mixed as would be expected. Hand sheets are good predictors for Mullen, moisture after press, moisture after reel,and stiffness, Graphs 19 - 22. While handsheets are poor predictors of Tensile and TEA due to lack of tension forces in the X - Y plane, Graphs 23 and 24.

Moisture after the wire was also not related to sheet mold drainage time, Graph 25. Nothing in the stude related to moisture after wire. In light of Britt's work turbulence and its effect on flocculation in the headbox may explain the lack of any correlation. Handsheets did also not predict paper density. This is probably related to higher pressing and calandaring pressure found on the pilot machine.

It is essential that the raw data for comparison be first divided by basis wt. and the blank. This negates the variation due the raw stock which would otherwise mask the correlations.

Graph 13

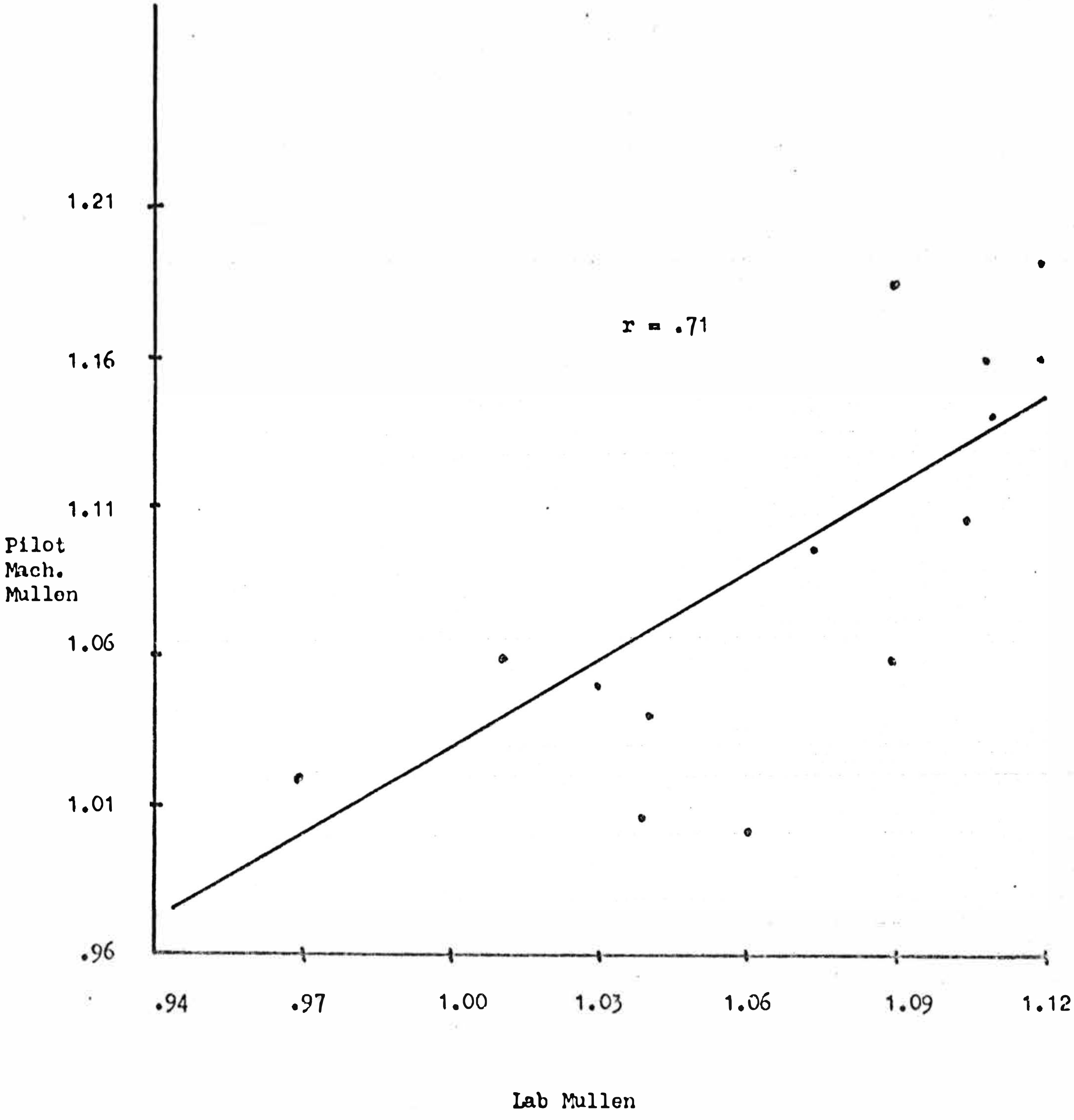



Britt Dynamic Drainage Jar

% Fine Retention - 600 rpm

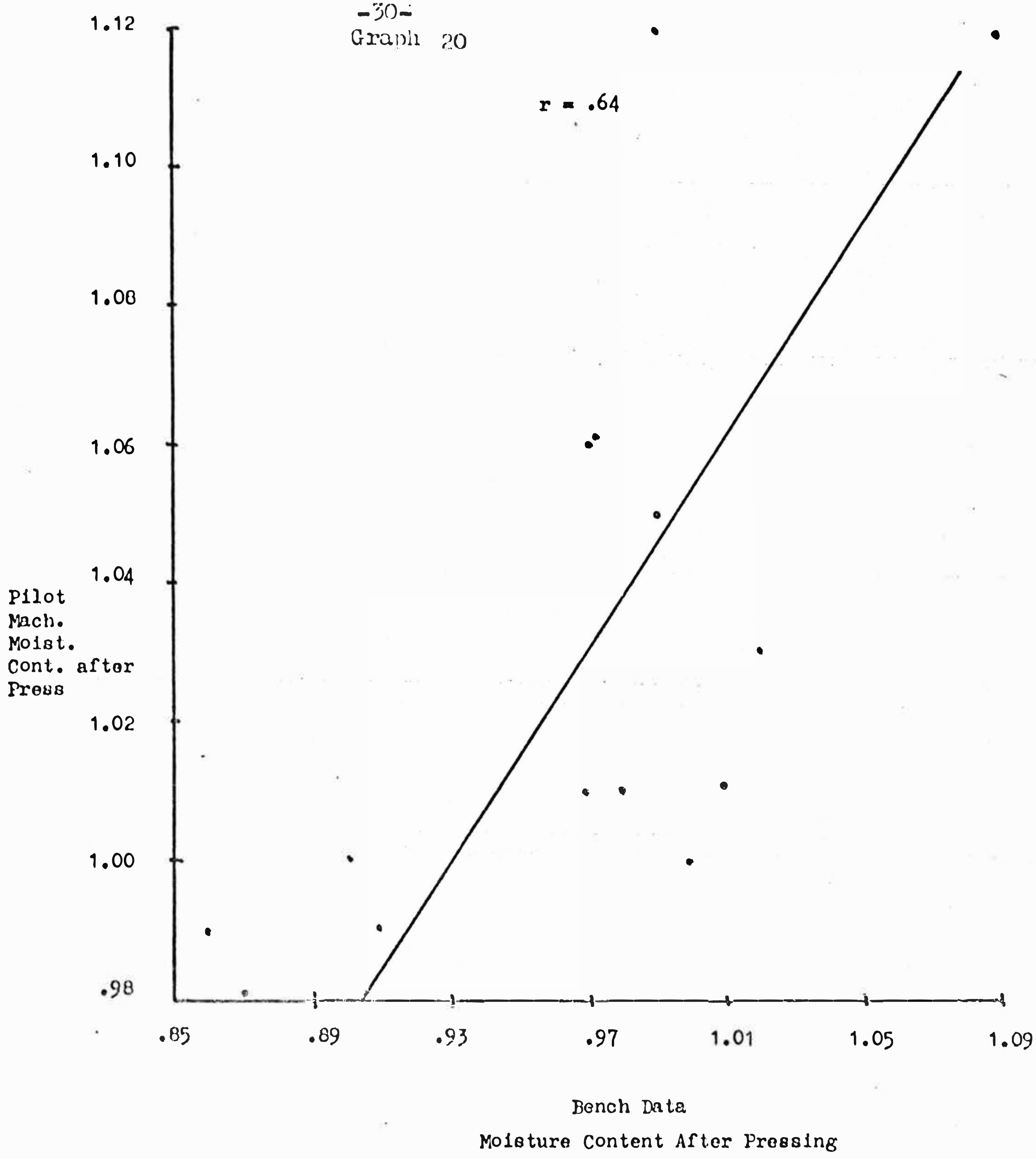
Chemicals; A/B, C, D, E

Graph 19



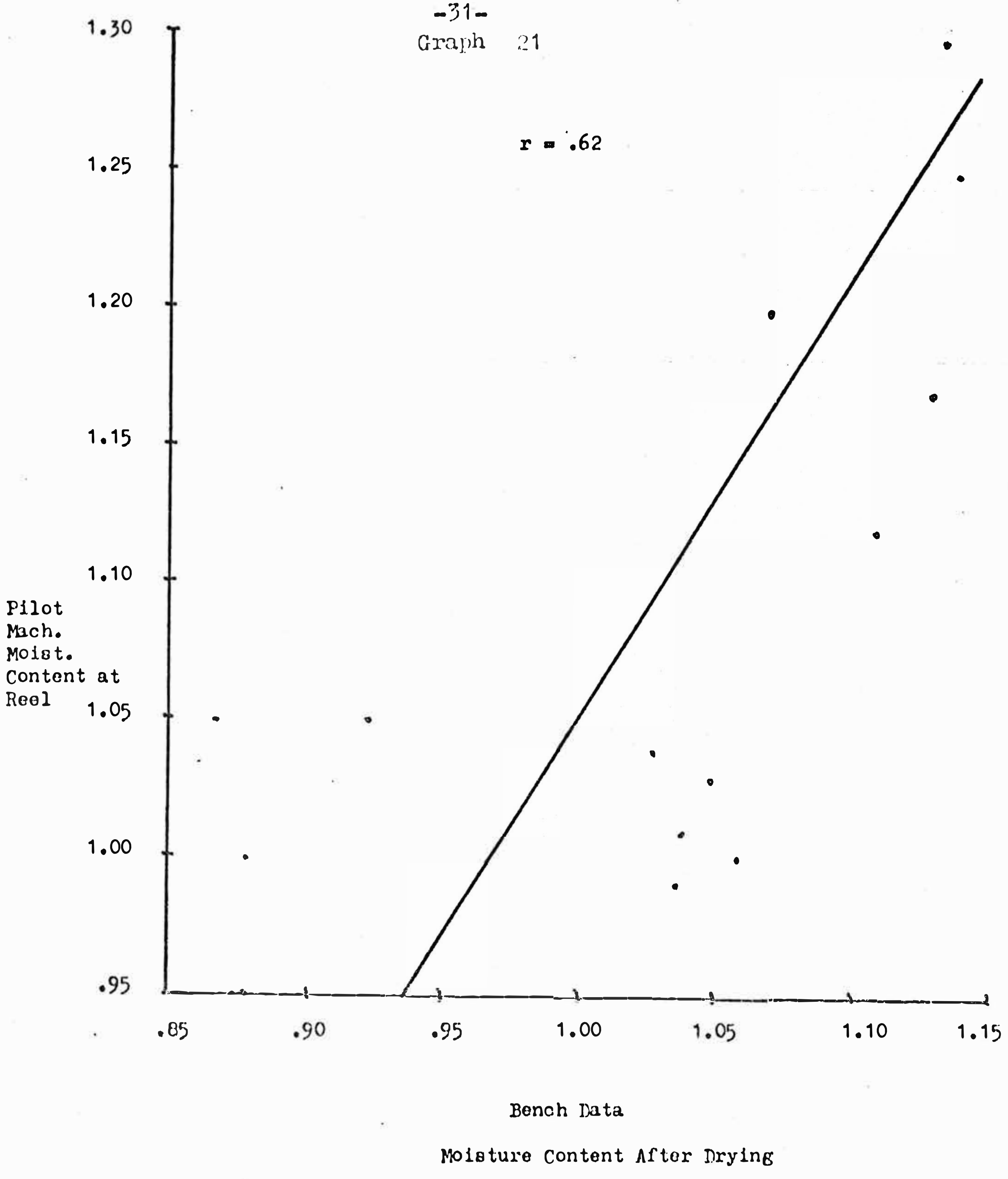

Data Factored for Basis Wt. and Blank

Graph 20



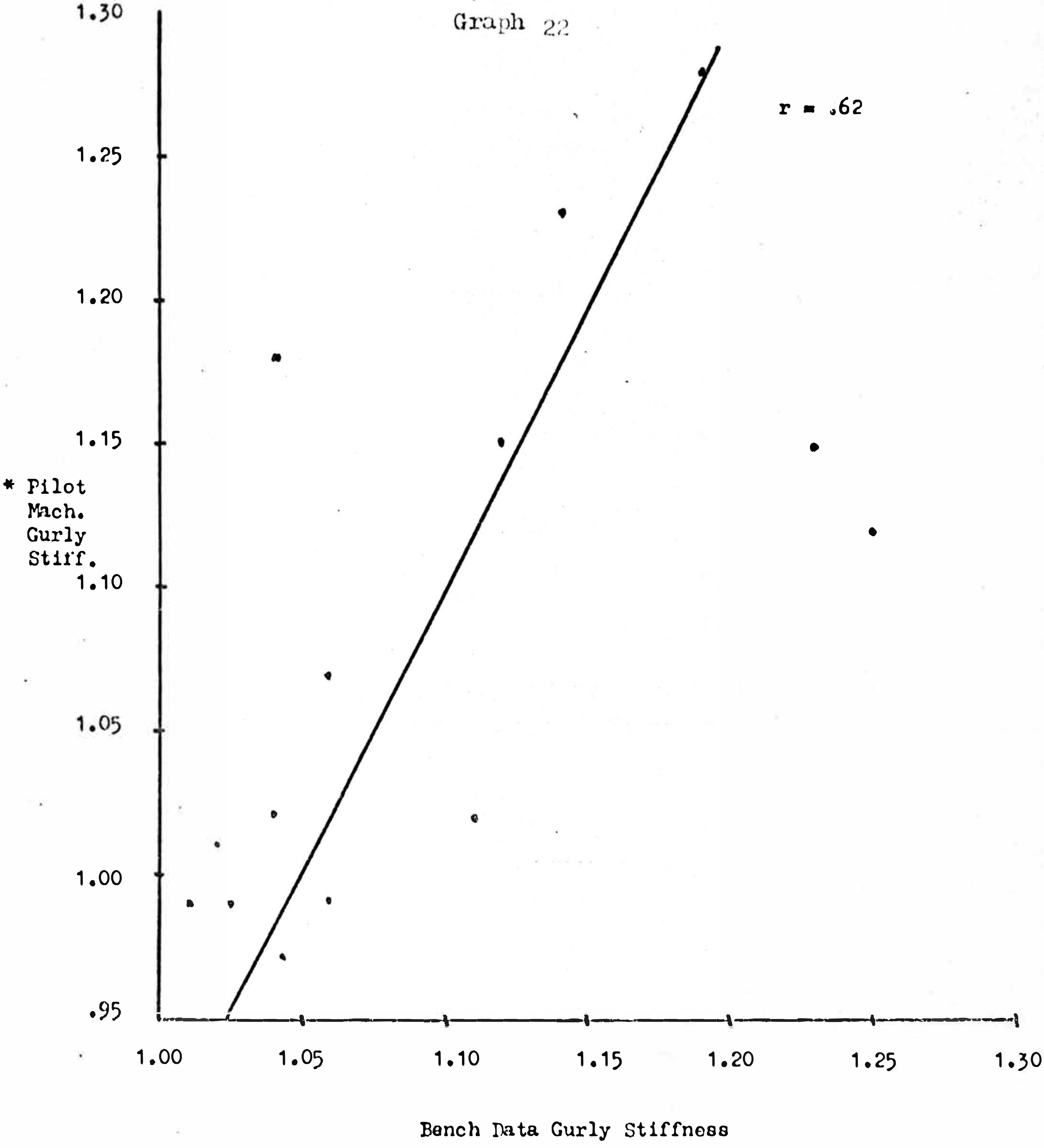

Data factored for Basis wt. and Blank

Graph 21




Data factored for Basis wt. and Blank

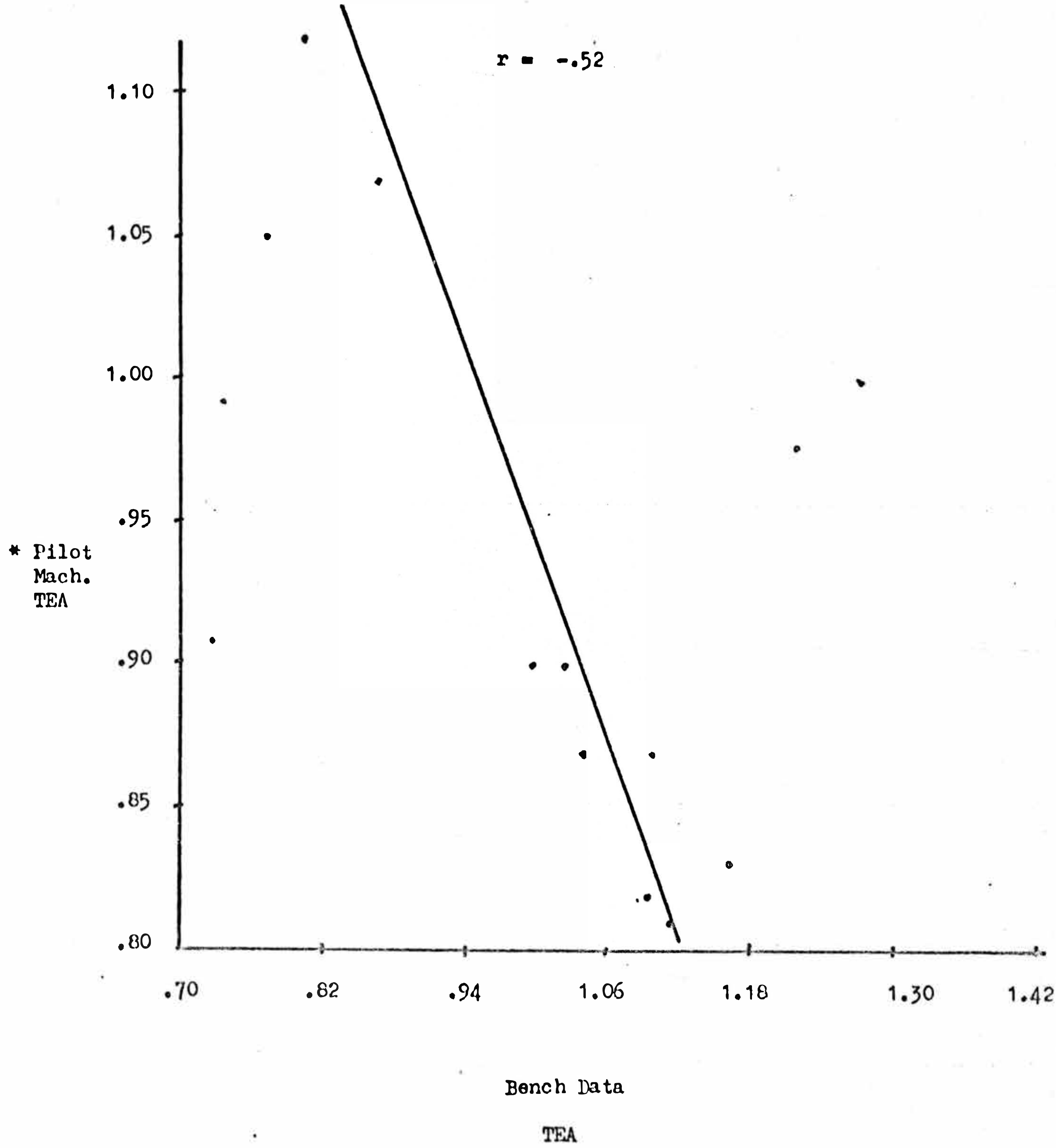
Graph 22




*Geometric mean stiffness $\sqrt{(CD)(MD)}$

Data factored for Basis Wt. and Blank

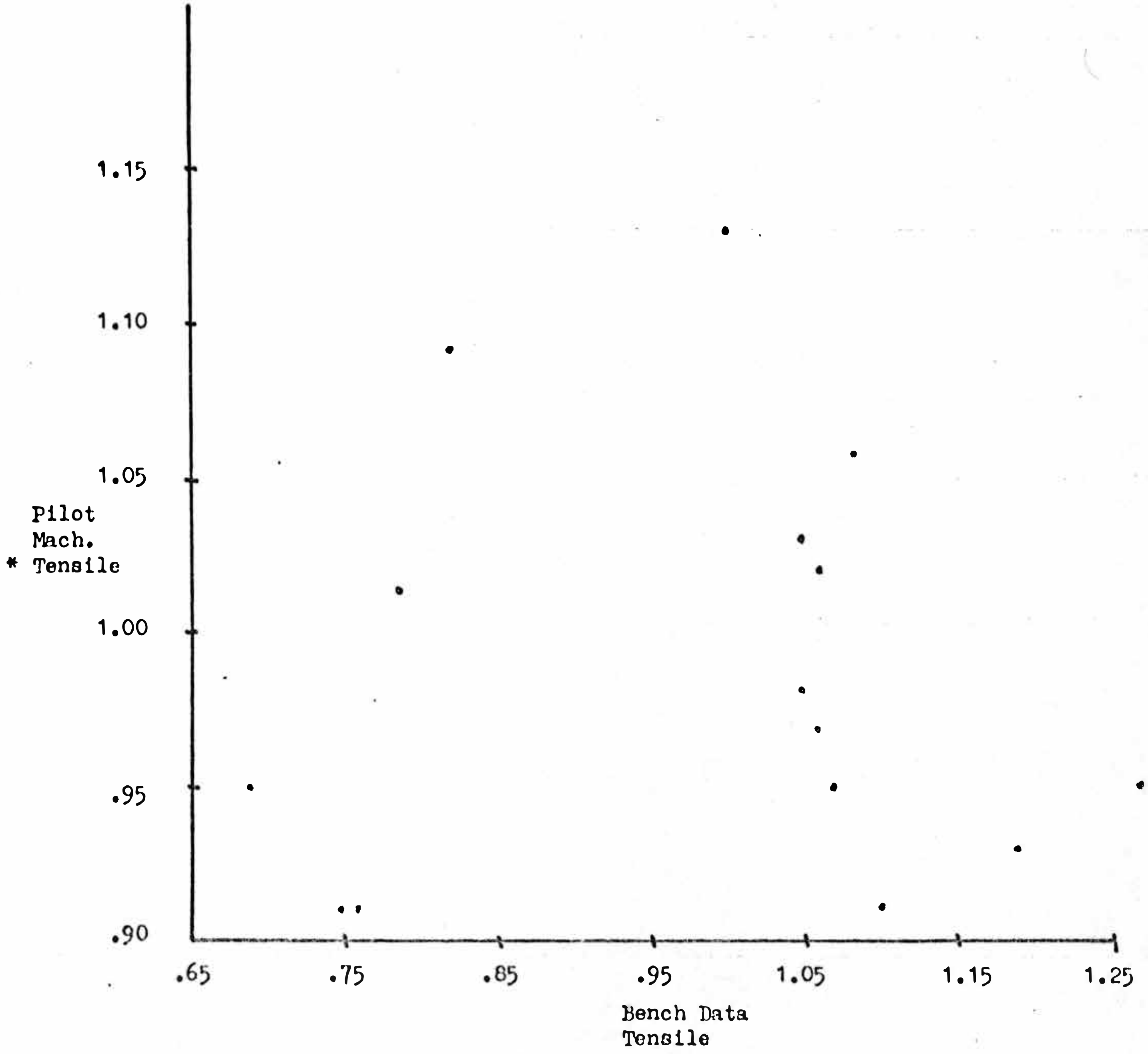
Graph 23




Data factored for Basis wt. and Blank

* Geometric Mean $\sqrt{(CD)(MD)}$

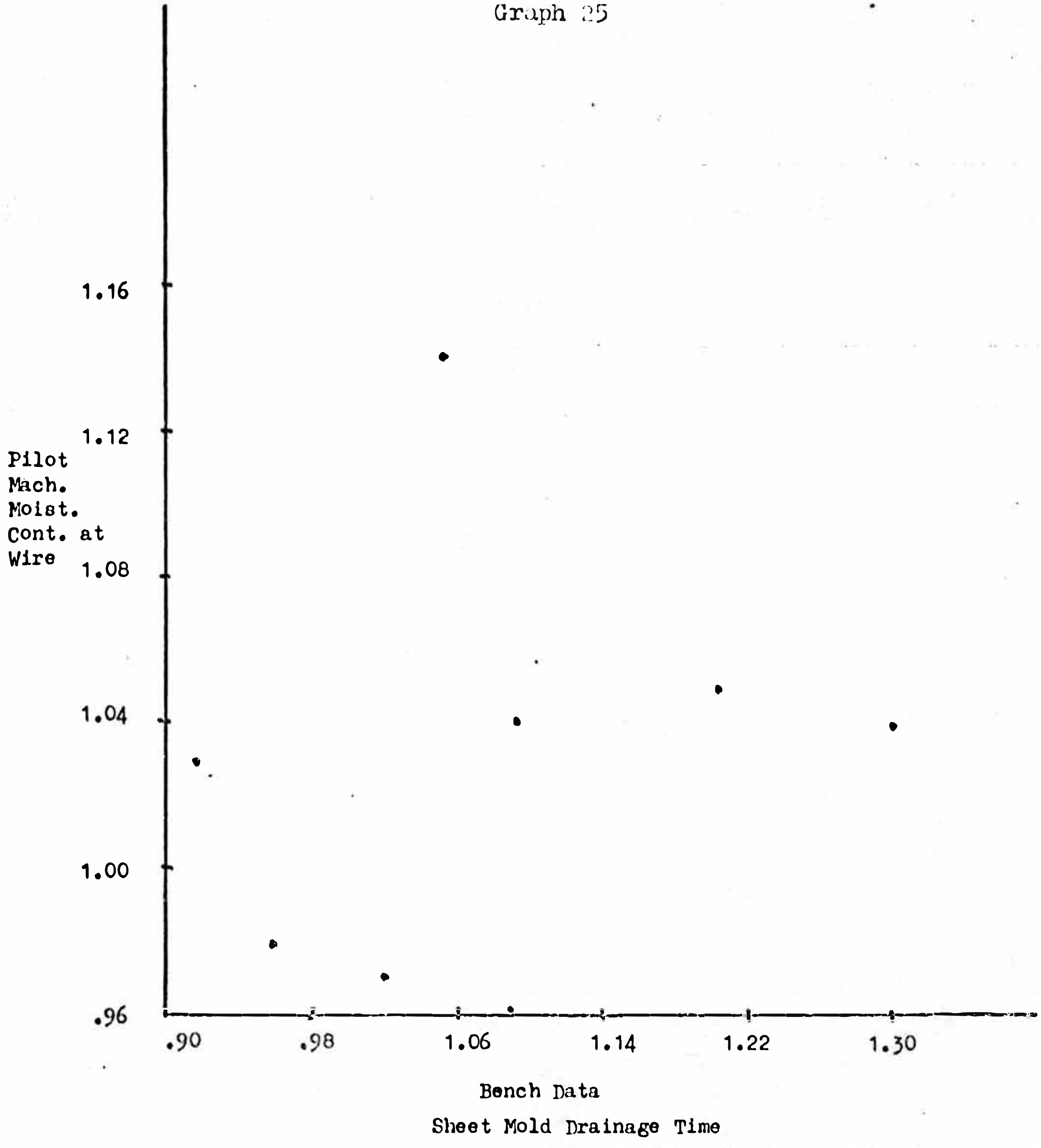
Graph 24




Data factored for Basis wt. and Blank

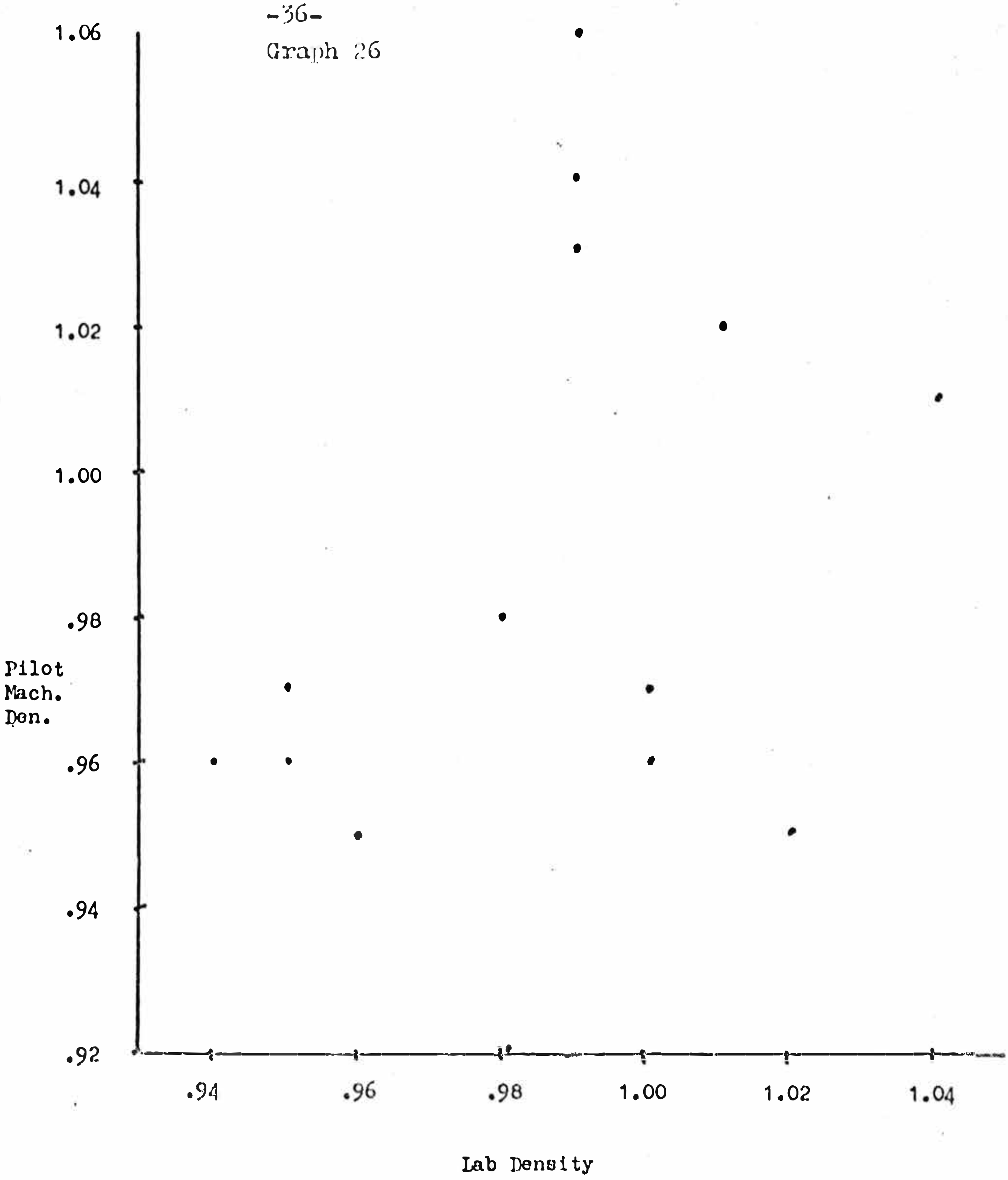
* Geometric Mean $\sqrt{(CD)(MD)}$

Graph 25




Data factored for Basis wt. and Blank

Graph 26




Data factored for Basis wt. and Blank

## Conclusions

Improvements in every desired characteristics can be seen from using wet and chemical additives. Unfortunatly, they do not all occur at the same time and with the same chemical. The benefits gained must be weighed against the negative factors. For example: If the desired characteristic is Retention, this is improved generally at the loss of water removal in pressing and drying. The results do indicate that prescreening chemicals in the lab is effective in evaluating qualitatively these trade-offs, within limitations such as tensile, TEA, density and drainage.

Maintaining optimum addition level is critical in achieving desired characteristics. This is apparently not an easy task due to large variations seen in 100% recycled furnishes. Certainly furnish is a big factor as seen by the consistant differences illustrated between the two part and three part furnishes. Comparing obtimum, dosage for stiffness improvement Chemical C, two part furnish is about 25#/Ton. For the same chemical, three part furnish optimum dosage is 15#/Ton.

The changes within a given furnish such a fine content are not as apparent. It is certainly true that what addition level is the optimum one day may be quite different the next. Causes seem to be many such as: Fine content, organic and inorganic contaminates.

## Recommendations

Continued work with Britt Jar to correlate to an individual machine. The apparatus stirring speed can be varied to simulate turbulence conditions of a particular former. Retention tests should also be performed at the same consistency as individual formers to minimize variations.

This study delt with many chemicals and not much time could be spent fine tunning individual chemicals. This should be done by individual mills based on furnish and machine conditions relative to their operations.

The Britt Jar can provide a quick check by the mill as to whether changes in chemical feed rate are necessary to maintain optimum feed rate. This is a key to gaining maximum benefits from chemical additives. Britt Jar is a part in the picture and when used with hand sheet data,very useful information is gained.

# APPENDIX

Roferences

1) Frankle, N. E., Sheridan, J. L. "The Value of One-pass Retention."
*Tappi,* Vol. 59, No. 2, 84 - 88

2) Britt, K. W., "Physical and Chemical Relationships in Paper Sheet Formation."
Tappi, Vol. 63, No. 9, 77 - 81

3) Britt, K. W., "Mechanisms of Retention During Paper Formation."
*Tappi,* Vol. 56, No. 10, 46 - 50

# Table I

## Chemicals

| Code | Description | Application |
|---|---|---|
| 1 | Cat LMW | Drain. |
| 2 | Cat Resin | Drain |
| 3 | Cat MMW | Drain, Ret |
| 4 | Cat MMW | Drain, Ret |
| 5 | Cat HMW | Drain, Ret, For |
| 6 | Cat HMW | Drain |
| E | Cat HMW | Drain, WR, For, Ret |
| 8 | Cat HMW | Drain, WR, Ret |
| 9 | Cat HMW | Ret, For |
| 10 | Cat HMW | Ret, Drain |
| 11 | Cat HMW | Ret, Drain |
| 12 | Cat HMW | Ret, Drain |
| C | Cat HMW | Ret, Drain |
| 14 | Cat Starch | WR, Stren, For, Den |
| 15 | Cat Starch | WR |
| 16 | Cat Starch | WR |
| 17 | Cat Starch | Ret, Stren |
| 18 | Cat Starch | Ret, Stren |
| 19 | Cat Starch | Ret, Drain |
| 20 | Cat Starch | Stren, For |
| D | Cat Starch | Stren, Ret |
| 22 | Ani HMW | Ret |
| 23 | Ani HMW | Ret, Drain |
| 24 | Ani HMW | Ret, Drain |
| 25 | Ani Starch | Ret |
| 26 | Ani Starch | Stren |
| 27 | Amp Starch | Stren, WR, For |
| 28 | Amp Starch | WR |
| 29 | Mineral Filler | Den |
| 30 | Mineral Filler | Den |
| 31 | Nonionic | Deaerator |
| 32 | - | Stren |
| 33 | - | Stren |
| 34 | - | Deaerator |
| 35 | - | Deaerator |
| 36 | Cat MMW | Ret |
| | Cat HMW | Drain |
| 37 | Cat MMW | Ret |
| | Ani HMW | Drain |
| 38 | Cat MMW | Ret |
| | MMW | Drain |
| A | Ani HMW | Ret, Drain |
| B | Cat HMW | Stren |
| 40 | Nonionic | Ret |
| | Cat Starch | Stren |
| 41 | Amp Starch | Stren, Ret |
| | Amp Starch | Den, For |
| 42 | Amp Starch | Stren, Ret |
| | Ani Starch | Den, For, Wr |
| 43 | Amp Starch | Stren, Ret |
| | Cat Starch | Den, For |
| 44 | - | Stren, Ret |
| | Amp. Starch | Den, For |
| 45 | - | Stren, Ret |
| | Ani Starch | Den, For |
| 46 | Cat Starch | Stren, Ret |
| | Amp Starch | Den, For |
| 47 | Cat Starch | Stren, Ret |
| | Amp Starch | Den, WR |
| 48 | Cat HMW | Ret, Drain |
| | Mineral Filler | WR, Den |
| 49 | Cat HMW | Ret, Drain |
| | Mineral Filler | WR, Den |

Table II

Bench Results

| Code | Furn. | Add Level | Fine Ret. | Drainage | | Moisture | | Den | Stiff. | Mullen | Tensile | | Smo. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Sheet M. | Britt | Press | Drier | | | | Stren. | TEA | |
| 1 | 2 | 1 | -30.0 | +4.8 | -1.7 | -1.5 | -.7 | 0 | +4.2 | +5.8 | -14.5 | -21.5 | 0 |
| | | 10 | -12.0 | 0 | -1.7 | -3.1 | -5.5 | 0 | +9.9 | +5.2 | -23.6 | -33.3 | 0 |
| 2 | | 15 | +1.9 | +1.4 | +7.7 | +3.4 | +4.3 | 0 | 0 | +.6 | -3.7 | -4.2 | 1.2 |
| | | 30 | -1.8 | +4.8 | +16.3 | +1.2 | +2.0 | 0 | +1.0 | +1.6 | -7.6 | -8.6 | 0 |
| 3 | | 5 | +17.8 | -14.5 | -20.0 | +10.1 | +15.2 | +4.3 | -6.2 | +9.2 | -29.7 | -46.9 | 0 |
| | | 12 | +17.8 | -14.5 | -10.4 | +9.8 | +14.3 | 0 | +3.8 | +18.3 | -17.4 | -33.3 | -2.4 |
| 4 | | 5 | 0 | +1.8 | +5.2 | +4.0 | +27.3 | -4.5 | -14.7 | +7.3 | -4.5 | +2.3 | -1.2 |
| | | 12 | -2.2 | +3.6 | +7.0 | +5.7 | +16.7 | 0 | -28.3 | -1.8 | -25.5 | -48.8 | -1.2 |
| 5 | | .2 | -2.0 | +21.3 | -7.4 | -.6 | +8.6 | 0 | -12 | -5.3 | -10.1 | -11.2 | 1.2 |
| | | .6 | +2.0 | +51.6 | 0 | +1.3 | +9.2 | -4.5 | -19.4 | -4.7 | +1.7 | +2.8 | -1.2 |
| 6 | | 2 | -2.0 | -9.7 | -1.6 | +2.1 | +15.3 | 0 | +9.7 | -4.7 | +3.3 | +14.7 | 0 |
| | | 4 | +6.0 | -9.7 | -1.6 | +1.5 | +11.6 | 0 | +6.5 | -4.0 | -3.3 | -4.7 | 0 |
| E | | 11 | +28.0 | -3.5 | -1.7 | +.3 | +12.7 | -4.5 | +1.6 | +2.9 | -24.2 | -28.2 | -1.2 |
| | | 22 | +34.0 | -7.0 | 0 | -1.0 | +14.2 | -4.5 | +3.4 | +4.6 | -30.6 | -35.6 | -1.2 |
| 8 | | 2 | +10.1 | +10.3 | +37.3 | +1.3 | +.3 | 0 | +10.4 | -10.2 | +2.4 | +17.9 | 0 |
| | | 4 | +32.8 | +17.2 | +23.5 | +2.0 | +.4 | 0 | +34.0 | -13.3 | +2.4 | +1.5 | 0 |
| 9 | | .5 | 0 | +3.7 | +14.4 | +1.2 | +2.4 | 0 | +2.9 | 0 | +18.8 | -63 | 0 |
| | | 3.0 | +21.4 | +11.1 | +12.5 | +1.3 | +4.6 | -4.5 | +18.1 | -8.3 | +27.5 | +3.6 | 0 |
| 10 | | 4 | +13.3 | +73.1 | +1.0 | +2.4 | +3.1 | 0 | +5.6 | -4.3 | +26.8 | +33.8 | 0 |
| | | 10 | +35.6 | +150.0 | +2.6 | +2.0 | -.2 | +5.0 | +2.2 | +4.3 | -7.3 | 0 | 1.2 |
| 11 | | 2 | +4.2 | -12.2 | +17.6 | +.2 | +.2 | 0 | +1.6 | -5.7 | -10.0 | -17.1 | 0 |
| | | 5 | +10.1 | -8.2 | 0 | +.2 | +.6 | 0 | -3.4 | -10.3 | -17.5 | -21.9 | 0 |
| 12 | | 2 | -7.1 | -10.2 | -13.5 | +1.4 | +1.4 | +9.5 | -2.7 | -8.1 | -7.5 | -9.8 | -1.2 |
| | | 5 | +5.4 | -8.2 | -21.2 | -.2 | +1.0 | +4.8 | -3.6 | -4.1 | -10.0 | 11.4 | 0 |
| 13 | | 5 | -3.6 | -10.2 | -21.1 | -1.2 | +2.7 | 0 | -2.4 | -3.3 | +2.5 | -6.7 | 0 |
| | | 10 | -12.5 | -12.2 | -14.4 | -1.3 | +3.6 | +4.8 | +1.7 | -21.1 | -7.5 | -4.4 | 0 |
| 14 | | 5 | * | +6.0 | +7.4 | +1.2 | -.7 | 0 | +24.7 | +7.6 | +15.2 | +7.3 | 0 |
| | | 20 | * | +10.4 | +6.5 | +.7 | +.3 | 0 | +12.9 | +8.5 | +15.2 | +10.3 | 2.4 |
| 15 | | 10 | +21.7 | +3.4 | -6.8 | +1.6 | +11.4 | +10.0 | -4.0 | +6.3 | +14.8 | +21.3 | 0 |
| | | 40 | +6.4 | +5.7 | -31.8 | +.7 | +5.2 | +10.0 | +3.2 | +14.1 | -1.3 | -6.4 | 0 |
| 16 | | 2 | +33.3 | +104 | +36.4 | +2.0 | +1.6 | +4.5 | +1.3 | 0 | -19.6 | -30.6 | 0 |
| | | 8 | +46.0 | +246 | +38.6 | +1.6 | +2.0 | +4.5 | +7.6 | -18.1 | -30.4 | -35.9 | 0 |

| Code | Furn. | Add Level | Fine Ret. | Drainage Sheet M. | Drainage Britt | Moisture Press | Moisture Drier | Den | Stiff. | Mullen | Tensile Stren. | Tensile TEA | Smo. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 2 | 5 | +7.5 | +3.4 | -2.4 | 0 | -.4 | 0 | +.8 | -4.6 | 0 | +9.9 | 0 |
| | | 15 | +13.4 | +3.4 | -2.0 | -.1 | +7.6 | 0 | -7.5 | +9.2 | 0 | +8.7 | 0 |
| 18 | | 5 | +7.5 | +12.1 | -4.2 | -.3 | -.7 | 0 | -12.3 | 0 | +10.0 | +18.1 | 0 |
| | | 15 | +13.4 | +5.2 | -.8 | 0 | -4.3 | 0 | -6.7 | +9.2 | +15.0 | +19.9 | 0 |
| 19 | | .5 | +14.9 | +14.8 | -2.0 | +1.4 | +3.4 | 0 | +7.5 | +13.3 | -16.3 | -14.4 | 0 |
| | | 1.8 | +35.8 | +29.6 | -.8 | +1.0 | +2.6 | 0 | +5.3 | +18.8 | -31.6 | 125.8 | 0 |
| 20 | | 2 | +32.7 | +20.3 | -2.6 | +.6 | -.1 | 0 | -14.9 | +8.6 | -13.7 | -6.4 | 0 |
| | | 3.5 | +36.5 | +25.9 | +.9 | +1.0 | +1.3 | 0 | -8.8 | +14.1 | -2.6 | 0 | 0 |
| D | | 10 | +1.9 | +4.7 | 0 | -2.0 | -13.4 | 0 | +7.6 | +11.9 | +3.1 | 0 | +1.2 |
| | | 30 | +25.0 | +7.8 | 0 | -1.2 | -12.3 | 0 | +6.4 | -3.2 | 0 | -1.7 | +1.2 |
| 22 | | 1.3 | +2.0 | +132 | -5.8 | -.7 | +1.3 | 0 | +1.6 | +18.9 | -19.7 | -32.9 | 0 |
| | | 2.0 | +12.0 | +329 | -6.6 | +1.3 | +2.8 | +11.1 | -12.7 | +18.9 | -24.6 | -33.9 | +2.4 |
| 23 | | .5 | +17.8 | +27.0 | -11.3 | +.7 | +1.6 | +5.0 | +2.0 | -12.1 | +4.9 | -11.5 | +1.2 |
| | | 3.0 | +22.2 | +1370 | -14.8 | +.6 | +2.0 | +5.0 | -7.8 | -1.3 | +12.2 | +16.7 | +1.2 |
| 24 | | .5 | +17.7 | +3.9 | -11.3 | 0 | +1.1 | 0 | -19.8 | -14.7 | +2.8 | +1.9 | +1.2 |
| | | 4.0 | +17.7 | +11.5 | -23.5 | 0 | +1.3 | 0 | -4.8 | 0 | +2.4 | +1.0 | +1.2 |
| 25 | | 2 | * | +86.6 | -5.6 | +.1 | +1.3 | 0 | -2.4 | -4.3 | -15.2 | -20.1 | +3.6 |
| | | 8 | * | +308 | +3.7 | +.3 | +2.0 | +9.1 | -11.2 | -17.9 | -3.0 | -2.9 | +4.8 |
| 26 | | 20 | +23.1 | +3.7 | -1.8 | -1.3 | +1.2 | 0 | 0 | +16.4 | +7.9 | 0 | 0 |
| | | 40 | +26.9 | +1.9 | -1.8 | -1.0 | +1.0 | 0 | -11.0 | +21.1 | -7.9 | -10.1 | 0 |
| 27 | | 5 | -14.0 | +14.8 | -7.4 | +2.6 | +11.6 | 0 | +15.8 | +10.6 | -1.9 | -7.2 | 0 |
| | | 20 | +4.7 | +31.1 | +8.5 | +4.3 | +.7 | 0 | -3.4 | 0 | +7.6 | +7.2 | 0 |
| 28 | | 10 | * | -7.5 | -1.0 | +2.3 | -.6 | 0 | +9.2 | -.8 | -9.1 | -2.9 | 0 |
| | | 40 | * | +4.5 | +3.7 | -.6 | +1.2 | 0 | +2.0 | -1.7 | -6.1 | +2.5 | +1.2 |
| 29 | | 60 | -2.0 | 0 | -20.2 | -1.3 | -6.0 | 0 | +4.3 | -13.5 | 0 | -1.4 | 0 |
| | | 100 | -6.0 | 0 | -10.1 | -.4 | -5.2 | -4.5 | +14.6 | -11.1 | -11.4 | -3.6 | 0 |
| 30 | | 60 | -7.5 | 0 | -4.2 | 0 | -3.0 | -4.5 | +12.4 | 0 | -9.4 | -3.1 | 0 |
| | | 100 | -10.4 | +3.1 | -.8 | -2.3 | +1.0 | -4.5 | +6.5 | -3.2 | -1.5 | -2.3 | 0 |
| 31 | | 2 | +5.3 | +5.2 | +27.5 | +.1 | 0 | +4.5 | +1.6 | -5.1 | 0 | +1.7 | 0 |
| 32 | | 5 | +26.5 | +12 | 0 | +.7 | +4.7 | +4.5 | +1.7 | -6.3 | -24.7 | -31.3 | 0 |
| | | 20 | +28.1 | +149 | +19.3 | +2.3 | +1.6 | +4.5 | +8.6 | -2.1 | -23.2 | -27.6 | 0 |
| 33 | | 20 | +5.8 | -5.5 | +3.2 | +1.2 | 0 | +15.0 | -5.1 | +4.5 | +12.9 | +11.7 | +1.2 |
| | | 60 | +5.8 | -5.5 | +7.4 | +1.2 | +1.4 | +10.0 | -11.4 | +9.0 | +22.6 | +20.9 | 0 |

| Code | Furn. | Add Level | Fine Ret. | Drainage Shoot M. | Drainage Britt | Moisture Press | Moisture Drier | Den | Stiff | Mullen | Tensile Stren. | Tensile TEA | Smo. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34 | 2 | 1.0 | +6.4 | 0 | -1.4 | +1.3 | +1.1 | +5.0 | -1.6 | +2.7 | +1.8 | +6.3 | 0 |
| 35 | | .6 | +1.4 | +10.3 | +58.8 | +.2 | -1.0 | 0 | +2.7 | -2.1 | -14.6 | -11.0 | 0 |
| | | 1.0 | +10.2 | +10.3 | +76.5 | -1.1 | +1.0 | 0 | +2.8 | +5.1 | -4.9 | +1.0 | 0 |
| 36 | | .5/.75 | -27.1 | +11.8 | +1.8 | +.4 | +1.6 | +5.0 | +4.0 | 0 | +4.6 | -264 | +1.2 |
| | | .5/2.0 | -35.4 | +2.0 | +6.9 | +.8 | +1.8 | +5.0 | +1.6 | +8.1 | +9.8 | +6.5 | +1.2 |
| | | 1.0/.75 | -27.1 | +3.9 | +19.0 | +.5 | +2.3 | +5.0 | +2.0 | +16.2 | +2.4 | -20.2 | +2.4 |
| 37 | | .5/.75 | -14.6 | +83.6 | +44.8 | +8.7 | +26.1 | +9.1 | -17.5 | -13.4 | +25.7 | +58.4 | +3.6 |
| | | .5/2.0 | -14.6 | +189 | +41.4 | +12.3 | +22.4 | +9.1 | -14.6 | -18.3 | +8.6 | + .7 | +5.6 |
| | | 1.0/.75 | -4.2 | +93.4 | +48.3 | +4.3 | +18.3 | +9.1 | -25.7 | -5.3 | +17.1 | +12.5 | +3.6 |
| 38 | | .5/.75 | +20.8 | +38.9 | +51.7 | +3.6 | +9.6 | 0 | -7.2 | 0 | +12.5 | -26.1 | +2.6 |
| | | .5/2.0 | +39.6 | +115 | +81.0 | +4.0 | +12.3 | 0 | -4.7 | -11.9 | +12.5 | -30.4 | +1.2 |
| | | 1.0/.75 | +52.1 | +29.6 | +87.9 | +4.3 | +13.4 | 0 | -2.4 | -11.9 | +18.1 | -1.5 | +2.6 |
| A | | 3/1 | +23.8 | -1.8 | +20.8 | -.4 | +10.3 | 0 | +6.0 | +9.8 | +12.1 | +9.5 | 0 |
| B | | 3/2 | +27.0 | +5.5 | +18.8 | -.2 | +4.1 | 0 | +14.7 | +13.9 | +7.3 | +9.8 | 0 |
| | | 7/1 | +12.7 | -15.7 | +13.9 | 0 | +3.6 | 0 | +2.0 | +26.6 | +5.1 | +4.5 | +3.5 |
| | | 7/2 | +15.9 | -13.4 | +15.8 | +.3 | +2. | 0 | +12.4 | +18.7 | +7.7 | +3.9 | +3.5 |
| 40 | | 2/1 | +6.3 | -3.0 | +9.9 | +2.0 | +12.3 | +4.5 | +7.1 | +13.2 | +9.3 | +1.7 | 0 |
| | | 8/1 | +11.1 | +10.7 | +3.0 | +2.2 | +18.4 | 0 | +6.3 | +8.9 | -6.7 | -7.2 | 0 |
| 41 | | 10/10 | +5.8 | +1.6 | +11.7 | +2.0 | +7.6 | 0 | -8.4 | +15.2 | -5.7 | -13.7 | 0 |
| | | 20/10 | +5.8 | +6.6 | +9.6 | +2.4 | +11.2 | 0 | +2.5 | +4.3 | -3.8 | -13.0 | 0 |
| 42 | | 10/10 | +12.8 | +62.3 | +13.8 | +5.2 | +21.8 | 0 | +5.7 | +5.2 | -9.4 | -18.8 | 0 |
| | | 20/10 | +12.8 | +61.3 | +10.6 | +11.6 | +22.4 | 0 | +9.2 | +6.0 | -9.4 | -21.7 | 0 |
| 43 | | 10/10 | * | +156 | +21.3 | +1.6 | +4.7 | +9.1 | -2.3 | 0 | -8.3 | -22.6 | +3.5 |
| | | 20/10 | * | +108 | +17.0 | +2.3 | +8.9 | +4.5 | +9.4 | 0 | -19.4 | -22.3 | +1.2 |
| 44 | | 10/10 | +46.0 | +14.8 | +30.7 | +1.8 | +1.4 | +10.9 | -16.7 | +12.2 | 0 | +.3 | +3.6 |
| | | 40/10 | +48.0 | +3.3 | +31.8 | +2.4 | +6.7 | +5.0 | -17.3 | +10.6 | +13.1 | +24.5 | +2.4 |
| 45 | | 10/4 | +49.0 | +95.0 | +34.1 | +.6 | +12.8 | +5.0 | +33.2 | +10.6 | +24.2 | +22.0 | +1.2 |
| | | 40/4 | +50/8 | +77.7 | +38.6 | +.9 | +11.4 | +5.0 | +17.6 | +16.3 | +11.3 | +9.3 | +1.2 |
| 46 | | 10/10 | * | +3.6 | -8.0 | +2.4 | +.3 | 0 | -8.6 | 0 | 0 | 0 | 0 |
| | | 20/10 | * | +8.9 | -6.5 | +4.8 | +.2 | 0 | -5.0 | -2.7 | -8.7 | -15.4 | 0 |
| 47 | | 10/4 | +20.5 | +114 | +6.5 | +3.7 | -.1 | 0 | +1.4 | -10.1 | -17.4 | -26.0 | +3.6 |
| | | 20/4 | +21.8 | +255 | +8.3 | +3.5 | +1.3 | +4.5 | +17.9 | -27.6 | -10.9 | -22.6 | 0 |
| 3 | | 2/60 | +13.8 | +6.2 | -4.6 | -.2 | +1.2 | 0 | +22.6 | -12.1 | +5.3 | +8.7 | 0 |
| | | 4/60 | +39.7 | +1.5 | -14.7 | -.3 | -.4 | -4.5 | -3.2 | -6.0 | +10.8 | +18.6 | +1.2 |
| 49 | | 11/60 | +25.9 | +4.6 | +6.4 | +.2 | -1.4 | 0 | +6.5 | -5.4 | +9.7 | +16.4 | +1.2 |
| | | 22/60 | +32.9 | +20.0 | +5.5 | -.7 | -.6 | -4.5 | +5.3 | -13.4 | +8.6 | +13.2 | 0 |

Table II cont.



| Code | Furn. | Add Level | Fine Ret. | Drainage Sheet M. | Drainage Britt | Moisture Press | Moisture Drier | Den | Stiff. | Mullen | Tensile Streng. | Tensile TEA | Smo. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 1 | 0 | 0 | +4.0 | +.6 | +16.1 | 0 | +1.2 | -1.9 | +1.3 | +2.6 | +1.3 |
| | | 10 | +3.3 | -4.3 | +9.3 | +6.1 | +31.7 | 0 | +17.5 | -20.2 | +15.8 | +31.1 | 0 |
| 2 | | 15 | -1.6 | +4.3 | 0 | +.1 | +5.0 | +21.1 | -9.6 | +5.3 | +2.4 | +14.9 | +1.3 |
| | | 30 | -3.2 | +16.5 | 0 | +1.5 | -1.6 | +15.8 | -2.4 | +14.7 | +2.4 | +6.9 | 0 |
| 3 | | 5 | +11.3 | +8.6 | +12.3 | +2.2 | +1.7 | +4.3 | +9.8 | 0 | -4.4 | -17.0 | 0 |
| | | 12 | +12.9 | +47.4 | +6.7 | +.5 | +15.5 | 0 | -10.8 | 0 | -13.3 | -34.3 | -2.4 |
| 4 | | 5 | +1.6 | +1.4 | +5.5 | -4.8 | 0 | 0 | -6.2 | -10.4 | +6.7 | +26.9 | 0 |
| | | 12 | +4.8 | -7.0 | +11.0 | +1.3 | +1.8 | +5.0 | -39.4 | -8.3 | +5.4 | +15.4 | 0 |
| 5 | | .2 | -18.0 | -3.3 | -10.7 | -1.6 | -5.7 | -5.0 | -13.8 | +4.6 | -5.8 | -23.0 | -1.2 |
| | | .6 | -37.7 | -3.7 | 0 | -1.0 | +2.2 | 0 | -13.8 | +4.6 | -21.1 | -30.4 | -1.2 |
| 6 | | 2 | -13.1 | -.9 | +6.7 | +3.7 | +25.9 | | +6.9 | -15.4 | -33.9 | -3.7 | 0 |
| | | 4 | 0 | -.9 | +18.7 | +1.3 | +20.5 | 0 | -14.1 | -13.5 | -32.7 | -7.4 | 0 |
| E | | 11 | +22.8 | +26.7 | +48.0 | +1.8 | +11.7 | -8.7 | +19.3 | +3.6 | -17.3 | -19.2 | 0 |
| | | 22 | +36.1 | +31.0 | +40.0 | +.9 | +6.9 | -8.7 | +20.1 | +1.1 | -23.7 | -23.7 | 0 |
| 8 | | 2 | +27.8 | +3.2 | +17.4 | +1.6 | +2.7 | 0 | +4.4 | -10.2 | +4.4 | -12.3 | +1.2 |
| | | 4 | +31.5 | +15.9 | +15.8 | +.7 | +3.6 | -4.5 | +13.3 | -13.2 | +13.3 | -22.9 | +1.2 |
| ) | | .5 | 0 | -10.1 | +2.5 | +1.3 | +2.0 | +15.8 | -11.2 | +24.0 | +2.4 | -20.7 | 0 |
| | | 3.0 | +24.1 | +32.4 | +27.5 | +1.8 | +3.7 | +21.1 | +23.7 | +12.0 | +2.4 | -26.4 | 0 |
| 10 | | 4 | +19.4 | +29.5 | -5.5 | -.7 | +2.8 | +5.3 | -27.1 | -3.9 | +4.8 | +34.2 | 0 |
| | | 10 | +21.0 | +19.7 | +6.8 | -1.3 | -1.1 | +15.8 | -10.3 | -5.3 | -19.5 | -19.5 | +5.0 |
| 11 | | 2 | +5.6 | -17.6 | +26.3 | +1.2 | +13.3 | 0 | -8.6 | -6.4 | -6.1 | -8.9 | +1.2 |
| | | 5 | +14.8 | -15.9 | +31.6 | +2.3 | +31.3 | +4.5 | -12.3 | -8.7 | -9.7 | -14.3 | 0 |
| 12 | | 2 | +4.8 | -28.6 | -26.3 | +1.2 | +2.3 | 0 | -13.2 | +9.4 | -12.1 | +9.9 | 0 |
| | | 5 | +16.1 | -26.9 | -13.0 | +3.4 | -.7 | 0 | +11.3 | +18.8 | +6.1 | 0 | 0 |
| C | | 5 | +4.8 | -27.7 | -27.5 | +.6 | -3.4 | 0 | +5.9 | +11.5 | +6.1 | +13.9 | +2.4 |
| | | 10 | +22.5 | -19.3 | -6.3 | -1.3 | +.2 | 0 | -2.0 | +3.1 | +6.1 | +33.9 | +1.2 |
| 14 | | 5 | +1.8 | +18.9 | +17.5 | -.4 | +1.2 | +4.5 | -14.3 | +19.8 | -8.5 | -40.2 | 0 |
| | | 20 | +4.6 | +35.8 | +41.3 | +1.3 | +6.7 | +4.5 | +3.7 | +27.0 | 0 | -5.0 | 0 |
| 15 | | 10 | +12.2 | +3.4 | +66.7 | -.5 | +2.3 | +4.5 | +16.8 | +10.0 | -37.5 | -32.1 | +2.4 |
| | | 40 | +18.9 | +5.7 | +42.4 | -.1 | +3.1 | +9.1 | +20.3 | +15.5 | -31.3 | -28.7 | +2.4 |
| 16 | | 2 | +25.7 | +124 | +57.6 | +7.6 | +19.4 | 0 | +5.2 | -27.6 | -21.4 | -31.4 | +2.4 |
| | | 8 | +18.9 | +246 | +13.0 | +11.6 | +31.7 | 0 | +3.6 | -4.2 | -19.8 | -21.6 | +2.4 |
| 17 | | 5 | +10.8 | +6.0 | +2.0 | -.3 | -1.4 | 0 | -3.7 | +7.0 | -6.9 | -11.9 | 0 |
| | | 15 | +16.2 | +8.3 | -1.0 | 0 | +1.5 | +4.3 | -.9 | +7.0 | -13.9 | -18.1 | +1.2 |

| Code | Furn. | Add. Level | Fine. Ret. | Drainage Sheet M. | Drainage Britt | Moisture Press | Moisture Drier | Den | Stiff. | Mullen | Tensile Stren. | TEA | Smo. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | 3 | 5 | +10.8 | +6.0 | 0 | +1.3 | +7.2 | 0 | -3.1 | +5.3 | -3.9 | -15.3 | 0 |
| | | 15 | +13.5 | +7.3 | +3.0 | +1.8 | -2.1 | 0 | -2.2 | +2.6 | -4.7 | -18.1 | 0 |
| 19 | | .5 | +20.2 | +16.8 | -6.0 | +.8 | +3.6 | 0 | +13.6 | +9.5 | +5.3 | +11.6 | +1.2 |
| | | 1.8 | +22.9 | +26.3 | -7.0 | +2.0 | +6.2 | 0 | +26.4 | +12.9 | +7.6 | +8.3 | +2.4 |
| 20 | | 2 | +12.3 | +27.4 | +6.1 | +.4 | +2.3 | 0 | +17.3 | -4.3 | +18.5 | +24.5 | 0 |
| | | 3.5 | +17.8 | +44.2 | +7.2 | +1.2 | +2.7 | 0 | +28.4 | +6.9 | +32.2 | +14.6 | 0 |
| D | | 10 | +2.7 | +.8 | -4.1 | -1.5 | -13.1 | 0 | +4.2 | +8.8 | +8.6 | +6.7 | 0 |
| | | 30 | -2.7 | +7.0 | -6.2 | -.8 | -12.9 | 0 | +24.8 | +8.8 | +21.7 | +18.2 | 0 |
| 22 | | 1.3 | +19.7 | +63.2 | +29.3 | +.6 | +9.6 | +5.5 | +1.6 | -2.9 | -14.3 | -26.5 | +1.2 |
| | | 2.0 | +19.7 | +259 | +32.0 | +1.8 | +12.2 | +11.1 | 0 | -1.4 | -7.1 | -21.4 | 0 |
| 23 | | .5 | +6.5 | -6.8 | -1.4 | +1.3 | +5.8 | +5.0 | 0 | 0 | +11.9 | +20.7 | 0 |
| | | 3.0 | +8.1 | +12.1 | -9.6 | +.8 | +4.2 | +10.0 | 0 | -4.2 | +4.8 | +1.2 | 0 |
| 24 | | .5 | +21.0 | +81.7 | +11.0 | +2.6 | +2.3 | 0 | -21.2 | -5.2 | -2.4 | +8.1 | 0 |
| | | 4.0 | +25.8 | +234 | -2.7 | +3.8 | +1.6 | +15.0 | -20.3 | -9.4 | -9.5 | -23.2 | 0 |
| 25 | | 2 | +3.7 | +297 | +29.0 | +.5 | +4.6 | +9.5 | -8.6 | -13.4 | -4.3 | -9.7 | +8.6 |
| | | 8 | +21.1 | +534 | +61.9 | +.4 | +3.2 | +9.5 | -9.1 | -18.6 | -8.7 | -12.3 | +8.6 |
| 26 | | 20 | -4.1 | +5.3 | -13.4 | -1.0 | +14.4 | 0 | +8.8 | +1.7 | +7.4 | +1.3 | +1.2 |
| | | 40 | +1.4 | +7.4 | -11.3 | -.8 | +12.3 | 0 | -5.6 | +.9 | +7.4 | +9.6 | +1.2 |
| 27 | | 5 | +5.1 | +18.5 | +5.4 | +6.7 | +12.4 | 0 | +24.0 | +16.1 | -6.3 | +5.1 | 0 |
| | | 20 | +17.9 | +31.2 | +10.7 | +3.7 | +5.7 | 0 | +19.7 | +25.5 | 0 | +7.8 | 0 |
| 28 | | 10 | +7.3 | +20.8 | +33.3 | +2.0 | +4.2 | +4.5 | -8.8 | +6.2 | -8.5 | -27.4 | 0 |
| | | 40 | +8.5 | +10.5 | +35.9 | +.7 | +5.3 | +4.5 | -24.3 | +19.6 | 0 | -13.3 | +3.6 |
| | | 60 | 0 | 0 | -26.0 | -1.1 | -4.3 | 0 | +12.9 | -1.7 | 0 | -1.3 | 0 |
| | | 100 | -5.4 | 0 | -14.0 | -.8 | -4.0 | 0 | +13.5 | -13.1 | +1.6 | +2.3 | -1.2 |
| 30 | | 60 | -2.7 | -11.6 | -6.0 | -1.0 | +.8 | 0 | +11.3 | -6.1 | -1.3 | +.6 | 0 |
| | | 100 | -5.4 | 0 | -2.0 | -.8 | -4.6 | 0 | +19.6 | -14.0 | +.6 | 0 | 0 |
| 31 | | 2 | 0 | +11.1 | -10.3 | 0 | +1.2 | 0 | +13.1 | -5.1 | -1.3 | 0 | +2.4 |
| 32 | | 5 | +18.9 | -5.5 | +16.7 | +4.6 | +11.4 | +4.0 | +7.6 | -10.4 | -6.7 | -8.3 | 0 |
| | | 20 | +20.2 | -1.8 | +16.7 | +8.2 | +10.3 | +4.0 | +6.4 | -9.8 | -7.6 | -13.4 | 0 |
| 33 | | 20 | +3.8 | -2.3 | +1.9 | +1.3 | -2.7 | +4.5 | +6.7 | 0 | +60 | +1.7 | +2.5 |
| | | 60 | +6.4 | +2.3 | +1.8 | +1.4 | -.4 | +9.1 | +1.4 | +13.0 | +21.2 | +26.8 | +1.3 |
| 34 | | 1.0 | +3.4 | +.7 | +1.3 | +.7 | +1.6 | +4.5 | +1.6 | 0 | +.7 | +5.4 | +1.2 |
| 35 | | .6 | 0 | +15.9 | -10.5 | +6.7 | +13.1 | 0 | +1.3 | -8.3 | +.6 | +1.3 | +2.4 |
| | | 1.0 | +7.4 | +46.0 | +54.4 | +.6 | +1.2 | 0 | -1.9 | +5.1 | +.2 | +1.6 | 0 |

Table II cont.



| Code | Furn. | Add Level | Fine Ret. | Drainage Sheet | Drainage M. Britt | Moisture Press | Moisture Drier | Den | Stiff. | Mullen | Tensile Streng. | Tensile TEA | Smo. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | 3 | .5/.75 | -11.1 | +28.3 | -5.8 | +2.0 | +.3 | 0 | +2.8 | 0 | -2.4 | -4.1 | 0 |
| | | .5/2.0 | -5.6 | +31.8 | -4.3 | +.7 | +1.3 | +4.5 | -29.6 | -14.9 | -4.8 | -17.7 | 0 |
| | | 1.0/.75 | +3.7 | +25.9 | -2.9 | +4.3 | +8.7 | 0 | -13.3 | 0 | -7.3 | -19.8 | 0 |
| 37 | | .5/.75 | -14.8 | +28.3 | -14.4 | +4.6 | +6.6 | 0 | 0 | -5.9 | +12.2 | +24.3 | +2.4 |
| | | .5/2.0 | -16.7 | +72.5 | -15.9 | +3.2 | +7.2 | 0 | -19.3 | -11.8 | +10.1 | +18.8 | +4.7 |
| | | 1.0/.75 | -7.4 | +300 | -8.7 | +4.1 | +8.4 | 0 | -35.3 | -11.8 | +12.2 | +7.3 | +4.7 |
| 38 | | .5/.75 | +24.4 | +276 | +56.5 | +1.7 | +4.1 | 0 | -1.3 | -1.1 | -10.5 | -19.8 | +2.6 |
| | | .5/2.0 | +46.3 | +591 | +56.5 | +.9 | +1.3 | 0 | +2.4 | 0 | -13.6 | -22.7 | +3.8 |
| | | 1.0/.75 | +42.6 | +242 | +65.2 | +2.1 | -.1 | 0 | +5.0 | -7.4 | -12.6 | -24.8 | +1.3 |
| 39 | | 3/1 | +1.3 | +28.7 | +16.9 | -1.3 | -.6 | 0 | +3.1 | +21.1 | +2.2 | +1.5 | 0 |
| | | 3/2 | +7.6 | +36.2 | +9.6 | -1.9 | 0 | 0 | -3.7 | +10.0 | -3.4 | -2.7 | 0 |
| | | 7/1 | +2.5 | +4.9 | +36.1 | +.6 | +2.0 | +4.5 | -.7 | +10.5 | -7.0 | +14.1 | 0 |
| | | 7/2 | +10.1 | +8.1 | +31.3 | +1.3 | +2.3 | +4.5 | -3.8 | +10.5 | -13.2 | -10.0 | 0 |
| 40 | | 2/1 | -3.8 | +10.3 | +16.9 | 0 | +.8 | +4.5 | +3.2 | +15.3 | -3.8 | -9.7 | 0 |
| | | 8/1 | -2.5 | +25.2 | +15.7 | -.2 | +3.1 | +4.5 | +4.6 | +17.0 | -4.2 | 0 | 0 |
| 41 | | 10/10 | * | -5.7 | +7.0 | +3.3 | +27.8 | +4.0 | -3.4 | +8.9 | +13.3 | +18.4 | +6.1 |
| | | 20/10 | * | +12.1 | +7.0 | +1.6 | +1.3 | +4.0 | -2.6 | +1.8 | +23.1 | +36.4 | +6.1 |
| 42 | | 10/10 | +12.8 | +15.2 | +13.6 | +1.8 | +2.3 | +4.0 | +20.7 | +1.8 | -6.3 | -5.5 | +3.3 |
| | | 20/10 | +15.3 | +22.0 | +7.8 | +4.3 | +21.6 | +4.0 | +16.3 | -6.3 | -9.7 | -11.5 | +1.1 |
| 43 | | 10/10 | * | +1.0 | +7.7 | -1.2 | +.7 | +9.1 | +10.4 | -20.6 | -9.6 | -9.5 | +10.0 |
| | | 20/10 | * | +16.2 | +10.6 | +2.6 | +5.4 | +4.5 | +11.4 | -19.6 | -16.1 | -23.7 | +10.0 |
| 44 | | 10/10 | * | +14.8 | +80.3 | +.6 | +2.3 | +5.0 | +3.0 | +11.1 | 0 | 0 | +3.5 |
| | | 40/10 | * | +3.3 | +66.7 | +1.4 | +3.7 | +5.0 | +4.1 | +21.3 | +1.3 | -2.7 | +2.2 |
| 45 | | 10/4 | * | +256 | +10.3 | -.6 | +2.7 | +18.2 | +4.6 | -20.6 | -19.4 | -30.5 | +8.8 |
| | | 40/4 | * | +281 | +81 | -1.3 | +3.8 | +18.2 | +3.4 | -9.8 | -11.1 | -20.9 | +6.3 |
| 46 | | 10/10 | +12.2 | +5.6 | +23.8 | +1.3 | +3.1 | 0 | -3.4 | -3.1 | +1.3 | +2.9 | 0 |
| | | 20/10 | +9.8 | +5.6 | +41.3 | +2.0 | +3.4 | 0 | -3.7 | 0 | +1.3 | +6.2 | 0 |
| 47 | | 10/4 | * | +129 | +82.5 | +1.4 | +3.6 | 0 | +4.1 | -17.5 | -15.0 | -25.6 | +7.5 |
| | | 20/4 | * | +118 | +79.4 | +1.2 | +1.2 | +4.3 | +1.6 | -9.4 | -17.5 | -24.3 | +6.3 |
| 48 | | 2/60 | +23.9 | -4.9 | +3.2 | 0 | -.5 | 0 | +3.4 | -.1 | -15.4 | -37.0 | 0 |
| | | 4/60 | +28.4 | +3.1 | +6.4 | +.1 | -.2 | -4.5 | -7.2 | -9.2 | -9.6 | -23.9 | 0 |
| 49 | | 11/60 | +22.4 | +5.7 | -14.9 | -.6 | -.6 | -4.5 | +3.8 | +1.8 | -17.3 | -36.6 | 0 |
| | | 22/60 | +34.3 | +11.3 | +23.4 | -.1 | -.7 | -4.5 | +3.8 | +10.1 | +5.8 | +12.9 | 0 |

| Chemical | Add Level #Ton | Furn. | Mach. Fine Ret. | Britt Fine Ret. | Headb. Cons. | Mach. W.W. Cons. | Britt W.W. Cons. | CSF | % Fine Sheet | Britt ML Throu | % Mois. After Wire |
|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 0 | 3 | 49.4 | 52.3 | .347 | .068 | .064 | 425 | 19.1 | 55 | (7.38) |
| C | 2 | 3 | 55.4 | 56.9 | .348 | .060 | .058 | 431 | 19.5 | 63 | (7.80) |
| C | 10 | 3 | 67.7 | 74.6 | .336 | .042 | .033 | 440 | 19.0 | 57 | (7.66) |
| - | 0 | 2 | 53.6 | 56.9 | .361 | .056 | .052 | 521 | 13.9 | 67 | (8.83) |
| A/B | 3 /1 | 2 | 63.5 | 61.7 | .328 | .040 | .042 | 525 | 13.7 | 84 | (8.80) |
| A/B | 5 /1 | 2 | 60.3 | 59.3 | .324 | .043 | .044 | 523 | 13.2 | 101 | (8.68) |
| A/B | 5 /2 | 2 | 61.3 | 65.0 | .325 | .042 | .038 | 525 | 10.1 | 88 | (8.60) |
| A/B | 10 /2 | 2 | 39.3 | 63.0 | .324 | .044 | .040 | 536 | 9.5 | 93 | (8.75) |
| A/B | 15 /2 | 2 | 62.1 | 59.4 | .332 | .042 | .045 | 551 | 9.3 | 86 | (8.82) |
| A/B | 15 /3 | 2 | 63.5 | 63.5 | .328 | .040 | .040 | 545 | 8.6 | 94 | (9.97) |
| - | - | 3 | 47.9 | 35.3 | .404 | .071 | .088 | 400 | 16.1 | 50 | 8.88 |
| D | 10 | 3 | 50.5 | 43.2 | .366 | .061 | .070 | 383 | 15.6 | 51 | 8.63 |
| D | 15 | 3 | 45.2 | 44.4 | .352 | .065 | .066 | 376 | 14.7 | 71 | 8.43 |
| D | 20 | 3 | 50.0 | 50.8 | .374 | .063 | .062 | 456 | 19.2 | 68 | 8.16 |
| D | 25 | 3 | 46.5 | 49.4 | .399 | .072 | .068 | 402 | 16.7 | 67 | 9.24 |
| D | 30 | 3 | 41.5 | 39.0 | .360 | .071 | .074 | 410 | 19.9 | 68 | 9.20 |
| - | 0 | 2 | 39.2 | 32.9 | .354 | .068 | .075 | 520 | 17.4 | 103 | 8.14 |
| D | 10 | 2 | 35.0 | 36.9 | .326 | .067 | .065 | 519 | 22.2 | 97 | 9.28 |
| D | 15 | 2 | 51.0 | 47.5 | .362 | .056 | .060 | 503 | 17.3 | 87 | 8.34 |
| D | 20 | 2 | 48.2 | 43.7 | .348 | .057 | .062 | 467 | 15.1 | 86 | 8.81 |
| D | 25 | 2 | 54.8 | 50.9 | .385 | .055 | .062 | 436 | 13.4 | 86 | 7.90 |
| D | 30 | 2 | 50.7 | 45.7 | .379 | .059 | .065 | 399 | 10.2 | 86 | 7.80 |
| - | 0 | 3 | 48.0 | 42.0 | .423 | .095 | .106 | 411 | 20.7 | 57 | 7.71 |
| E | 1.1 | 3 | 43.8 | 43.8 | .271 | .090 | .090 | 383 | 31.7 | 52 | 7.85 |
| E | 10.7 | 3 | 52.4 | 52.4 | .365 | .075 | .075 | 382 | 22.3 | 65 | 8.06 |
| E | 14.3 | 3 | 56.2 | 56.9 | .423 | .080 | .073 | 397 | 19.7 | 71 | 7.86 |
| E | 17.9 | 3 | 64.5 | 65.5 | .496 | .076 | .074 | 421 | 18.9 | 66 | 7.74 |
| E | 21.4 | 3 | 53.1 | 55.6 | .360 | .076 | .069 | 410 | 21.9 | 65 | 8.04 |
| - | 0 | 2 | 50.0 | 50.9 | .435 | .064 | .064 | 485 | 14.7 | 120 | 8.38 |
| E | 7.1 | 2 | 46.0 | 43.3 | .384 | .061 | .064 | 501 | 8.9 | 110 | 8.37 |
| E | 10.7 | 2 | 40.0 | 45.2 | .360 | .063 | .058 | 496 | 11.4 | 114 | 8.60 |
| E | 14.3 | 2 | 56.8 | 58.5 | .391 | .066 | .064 | 490 | 10.4 | 112 | 8.25 |
| E | 17.9 | 2 | 58.7 | 58.7 | .384 | .062 | .062 | 532 | 10.5 | 110 | 8.05 |
| E | 21.4 | 2 | 50.1 | 50.9 | .324 | .063 | .062 | 541 | 9.7 | 105 | 8.21 |

Table III

Pilot results

| % Mois. After | % Mois. | Den-sity | Mul-len | Park Print Surf. | Stiffness CD | Stiffness MD | Tensile CD | Tensile MD | TEA CD | TEA MD | Total % Fine |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6.23 | .56 | 2.38 | .56 | 6.4 | 1.55 | 3.20 | .10 | .20 | .16 | .08 | 38.7 |
| 6.53 | .57 | 2.51 | .64 | 6.2 | 1.53 | 3.21 | .11 | .17 | .14 | .07 | 36.7 |
| 6.43 | .57 | 2.48 | .59 | 6.4 | 1.46 | 3.18 | .11 | .19 | .15 | .10 | 31.5 |
| 7.26 | .63 | 2.46 | .50 | 6.8 | 1.78 | 2.97 | .11 | .20 | .18 | .10 | 33.4 |
| 7.26 | .65 | 2.41 | .50 | 6.9 | 1.52 | 3.43 | .10 | .18 | .15 | .08 | 25.9 |
| 7.17 | .67 | 2.54 | .61 | 7.2 | 2.12 | 3.80 | .10 | .20 | .17 | .08 | 26.5 |
| 7.11 | .67 | 2.48 | .58 | 7.1 | 1.54 | 3.51 | .11 | .19 | .15 | .09 | 23.0 |
| 7.22 | .66 | 2.50 | .58 | 6.8 | 1.90 | 3.71 | .11 | .21 | .16 | .09 | 23.1 |
| 7.27 | .68 | 2.45 | .64 | 7.3 | 1.60 | 3.50 | .12 | .21 | .16 | .10 | 22.0 |
| 8.10 | .69 | 2.39 | .61 | 7.2 | 1.65 | 4.47 | .12 | .22 | .16 | .11 | 21.8 |
| 7.02 | .50 | 2.40 | .51 | 6.5 | 1.70 | 3.97 | .12 | .21 | .16 | .09 | 33.7 |
| 7.08 | .50 | 2.28 | .51 | 6.4 | 1.63 | 3.88 | .11 | .20 | .14 | .07 | 32.7 |
| 6.99 | .49 | 2.20 | .50 | 6.6 | 1.78 | 4.06 | .12 | .19 | .15 | .07 | 33.2 |
| 7.10 | .51 | 2.21 | .56 | 6.7 | 2.05 | 4.05 | .12 | .18 | .17 | .07 | 36.0 |
| 7.39 | .49 | 2.20 | .62 | 6.6 | 1.84 | 3.76 | .13 | .21 | .20 | .07 | 34.7 |
| 7.46 | .50 | 2.20 | .62 | 6.8 | 1.96 | 3.92 | .12 | .19 | .17 | .08 | 39.6 |
| 6.95 | .65 | 2.38 | .58 | 6.9 | 1.73 | 3.61 | .12 | .17 | .16 | .10 | 31.6 |
| 7.37 | .64 | 2.30 | .59 | 6.5 | 1.82 | 3.59 | .12 | .19 | .16 | .08 | 42.8 |
| 7.41 | .64 | 2.30 | .69 | 7.0 | 2.07 | 3.64 | .12 | .21 | .16 | .10 | 32.8 |
| 7.66 | .65 | 2.19 | .62 | 7.2 | 1.91 | 3.72 | .12 | .22 | .16 | .09 | 31.5 |
| 6.56 | .66 | 2.39 | .68 | 7.0 | 2.27 | 4.09 | .12 | .23 | .15 | .08 | 27.8 |
| 7.04 | .65 | 2.29 | .64 | 7.3 | 2.03 | 3.83 | .13 | .20 | .17 | .07 | 25.8 |
| 5.87 | .41 | 2.39 | .50 | 6.5 | 1.53 | 3.96 | .12 | .21 | .18 | .08 | 43.2 |
| 6.44 | .46 | 2.33 | .52 | 6.5 | 1.65 | 3.75 | .12 | .22 | .18 | .07 | 45.9 |
| 6.61 | .46 | 2.31 | .52 | 6.7 | 1.60 | 3.61 | .11 | .19 | .18 | .10 | 42.8 |
| 6.08 | .43 | 2.45 | .55 | 6.6 | 2.04 | 4.56 | .11 | .19 | .19 | .07 | 38.6 |
| 6.25 | .44 | 2.41 | .54 | 6.5 | 1.89 | 4.15 | .11 | .21 | .20 | .08 | 24.2 |
| 6.66 | .49 | 2.30 | .53 | 6.7 | 1.72 | 3.79 | .12 | .25 | .20 | .08 | 43.0 |
| 7.08 | .61 | 2.36 | .51 | 6.9 | 1.55 | 3.29 | .11 | .17 | .19 | .08 | 29.4 |
| 7.00 | .79 | 2.26 | .52 | 6.9 | 1.75 | 3.56 | .11 | .17 | .16 | .08 | 28.9 |
| 7.14 | .79 | 2.26 | .48 | 7.0 | 1.53 | 3.26 | .09 | .17 | .14 | .09 | 28.9 |
| 6.85 | .77 | 2.27 | .50 | 6.8 | 1.60 | 3.65 | .10 | .17 | .19 | .09 | 33.3 |
| 6.98 | .76 | 2.29 | .51 | 7.2 | 1.98 | 3.56 | .10 | .18 | .16 | .08 | 26.6 |
| 6.95 | .76 | 2.27 | .50 | 7.2 | 1.70 | 4.20 | .10 | .17 | .16 | .08 | 29.2 |

Table III cont.

## Abbreviations

| | | |
|---|---|---|
| Add. | - | Additive |
| Amp. | - | Amphoteric |
| Ani. | - | Anionic |
| Cat. | - | Cationic |
| Con. | - | Conditions |
| Den. | - | Density |
| Drai. | - | Drainage |
| For. | - | Formation |
| HMW | - | High Molecular Weight |
| LMW | - | Low Molecular Weight |
| Mach. | - | Machine |
| MMW | - | Medium Molecular Weight |
| Ret. | - | Retention |
| Smo. | - | Smoothness |
| Sta. | - | Starch |
| Stiff. | - | Stiffness |
| Str. | - | Strength |
| W.R. | - | Water Removal |

Equations

$$\text{Mach. \% Fine Ret.} = \left[ 90 \left( 1 - \frac{WW_c}{H_c \cdot F_p} \right) \right]$$

$$\text{Britt \% Fine Ret.} = \left[ 1 - \frac{WW_c \left( V_t / V_{ww} \right)}{H_c \cdot F_p} \right] 100$$

$F_p$ = Fines portion
$H_c$ = Headbox cons. g/ 100 ml
$V_t$ = Total volume intially in Britt Jar
$V_{ww}$ = Volume through Britt Jar
$WW_c$ = White Water cons. g / 100 ml

$$\text{Drain. time} = \frac{d_s( r - 25)}{55}$$

$d_s$ = measured drainage time
r = basis wt. g / $m^2$