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The Determination of an Optimum Brownstock Washwater by Laboratory Analysis

Bradley D. Berger
Western Michigan University

THE DETERMINATION OF AN OPTIMUM BROWNSTOCK WASHWATER BY LABORATORY ANALYSIS

BY
Bradley D. Berger

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ABSTRACT:

The optimum displacement of black liquor in a Kraft pulp by a washwater can mean greater chemical recovery, reduced environmental impact, and less evaporator steam consumption. A laboratory apparatus was developed and used to test various washwaters to determine if any were more efficient at displacing the black liquor in a pad of Kraft pulp. These washwaters included tapwater, tapwater with varying amounts of a polyacrylamide polymer, and washwaters collected from various areas of a paper mill. The data generated in this project were used to calculate substance yield, dilution factor, and mobility ratio. There appeared to be no significant difference in the displacement of black liquor by any of the chosen paper mill washwaters. However, it was found that polymer additions at high concentrations significantly increased the displacement of black liquor from a pad of pulp. It was also found that increased temperature of the washwater reduced the effectiveness of the polymer solutions. Washwater, added in smaller aliquots, was more effective than if a large volume was added at one time, in displacing the black liquor.

KEYWORDS: Washing
Displacement
Kraft Pulp
Dilution Factor
Mobility Ratio
Channeling

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INTRODUCTION

Efficient brownstock washing of Kraft pulps is imperative if high solids recovery and low washwater usage are to be achieved. High solids recovery means that more solids can be sent to the recovery boiler, resulting in reduced saltcake loss. The more dissolved solids removed during brownstock washing means that fewer chemicals will be used during the bleaching process. If the bleaching process uses chlorine based chemicals, then reduced chemical usage results in less toxic discharge from the bleach plant. Also, if fewer dissolved solids are sent to the bleach plant, this would probably result in reduced BOD and color in the bleach plant waste water.

When more water is used during brownstock washing, more dissolved solids can be recovered. However, this is not desirable for several reasons. When less water is used for the removal of dissolved solids in the pulp mat, there is a reduced hydraulic load on the evaporators. This reduced hydraulic load results in lower steam useage and, therefore, lower energy costs.

The displacement of the black liquor (containing the dissolved solids) is the key process in the brownstock washing system. The displacement process is used in any type of brown-stock washing system: rotary drum, horizontal belt, diffusion, etc. The washwater used in each system must ultimately be sent to some type of recovery system. If improvement of this dis-placement process can be achieved while maintaining the required dissolved solids removal, then water savings can be realized.

It will be the object of this thesis to compare various mill waste waters as well as freshwater containing a commercially available polymer, to see if any of them are more advantageous at displacing black liquor from a pulp mat. The question being asked is whether a more efficient displacement process can be achieved by using a particular type of wash water.

BACKGROUND AND THEORETICAL

Kraft pulps are well known to be high in color, BOD, dissolved solids, and sodium (1,2). The bleaching units of Kraft mills are increasingly coming under attack because of their high waste loads and toxicity. Improved brownstock washing efficiency can reduce black liquor carryover to the bleaching system. This reduced black liquor carryover improves the quality of the bleaching effluent, as well as reducing the consumption of chlorine based bleaching chemicals.

The removal of the black liquor, which remains in the Kraft pulp stock after pulping, is the reason for brownstock washing. The removal of the black liquor, containing dissolved solids, is achieved in the washing system, by the introduction of fresh water. The lignin compounds that remain attached to the fibers are decolored or removed in the bleaching process.

Displacement

The displacement ratio concept was defined by Perkins, Welsh

and Mappus in 1954 (3). This ratio can be applied to any

$$\text{Displacement Ratio} = \text{D.R.} = \frac{S_v - S}{S_v - S_s}$$

where S_v = % soluble solids in vat liquor
S = % soluble solids in sheet leaving stage
S_s = % soluble solids in shower liquor

stage in the brownstock washing process. It can be used to indicate the efficiency of brownstock washers singly or as a system. The displacement ratio (D.R.) is a method of describing the removal of soluble solids in the pulp mat. If the shower water contained no soluble solids and none were in the pulp mat leaving the brownstock washer, the D.R. would be 1. This would mean that the shower water had completely displaced the black liquor in the pulp mat. In actual practice this is not possible and the displacement ratios are less than one.

There are many factors which affect brownstock washing displacement efficiency. The factors include temperature, distribution of the shower water, and method of application of the the shower water, the thickness and formation of the pulp mat, and the operating variables of dilution factor, stock temperature, air in stock, liquor solids level, fabric mesh characteristics, and amount of fabric fouling (4). In effect, the displacement ratio combines all of these variables, by looking only at the soluble solids going into the brown stock washing system and those soluble solids leaving the system. The displacement ratio enables one to view the entire washing process, not individual variables. However, each of the above factors can influence the displacement process and should be

discussed.

The shower water should be applied as evenly as possible, and at a velocity which does not break up the mat of fibers (5). A too great velocity would lead to interfacial mixing of the washwater and black liquor, which would lower the displacement ratio. The temperature of the shower water should be as hot as possible, but low enough to keep the vat liquor temperature below its boiling temperature in the vacuum leg. This prevents flashing (5).

Ideally, during the Kraft pulping process, the woodstock has been pulped to the point where each fiber has been separated and that no flocs have formed while being pumped to the washing facility. Since neither of the above ideal conditions is possible, the pulp stock which arrives is not of equal consistency and formation.

The pulp mat, formed from cellulose fibers, is an irregular pore structure and this makes it difficult to study the flow of liquids through it (6). The pulp mat has areas of solid cellulose fiber, areas of stagnant black liquor enclosed by fibers, and open areas of freely flowing black liquor (7). Although an ideal mat would have pores of uniform size and resistance to liquor flow, this is not possible in the actual washing operation. A mat of pulp fibers can also be compressed unequally. This would lead to the uneven flow of washwater.

It was found that washing a thicker (greater depth) and more dilute mat of fibers was more efficient as far as dissolved solids removal, but that more water was used in the process to

displace the greater volume in the pulp mat (8). Lee (8) explained this behavior by stating that there was a decrease in the proportion of stagnant liquor and that also there were fewer tortuous pathways which led to less interfacial mixing of the washwater and black liquor.

The dilution factor is a measure of the amount of washwater used per ton of pulp to displace the black liquor in the pulp during the displacement process. Since a main objective of efficient brownstock washing is to use as little fresh water as possible, a low dilution factor is desirable. Although, as stated earlier, better dissolved solids removal is attained at a higher dilution factor, at some point this gain becomes very small, and begins to greatly increase the evaporation costs (5).

The temperature of the pulp stock is normally quite high because it has just left the pulping digester. Hakamaki and Kovasin (9) state that at higher temperature the black liquor viscosity is lower, which means that greater filtration capacity is possible. Therefore, a high pulp mat temperature is desired during brownstock washing.

Air bubbles in pulp stock should be eliminated because they adversely affect pulp washing (10). Air bubbles in a mat of fibers act like a solid, and restrict the flow of liquids. The flow is diverted around the air bubble which clearly decreases the washer capacity.

The fabric mesh is important to the displacement process because if the mesh is too fine, it can restrict the flow of black liquor, and if too large a mesh is used, fibers are lost

through the fabric. The proper size depends on the fiber length and vacuum being pulled during the brownstock washing stage.

Channeling

In order for the ideal 1:1 displacement of black liquor with washwater to take place, there must be no mixing at the interface of the two liquids. Ideal displacement also requires that the washwater flow at a steady and even rate through the pulp mat while it displaces the black liquor.

Interfacial mixing does occur in the actual process and results from diffusion and channeling. Diffusion and channeling are caused by variations in local permeability within the porous pulp mat (11). As stated earlier, the pulp mat has areas of solid fibers, areas of enclosed black liquor, and open areas of freely flowing liquor. The washwater penetrates the open areas at a greater rate, causing interfacial mixing or fingering. The end result is that the areas of enclosed, stagnent black liquor get bypassed and do not get displaced. Lee (11) further states that if the washwater begins to flow more freely through the porous pad of pulp fibers than the black liquor being displaced, the resulting lower pressure drop in these advancing channels tends to increase their growth.

It is the ratio of the mobility of the displaced liquid to the mobility of the displacing liquid in a particular medium which influences the degree of fingering (11). If this ratio is greater than one, then the channeling or fingering growth is accelerated, and when it is less than one, channeling is suppres-

sed.

The resistance to the flow of a particular fluid through a medium is determined by the "fluid viscosity and the interaction of the fluid with the permeability of the medium" (11). This resistance can be measured as the amount of time that it takes a known volume of a liquid to flow through a porous medium by itself. This method was described by Foshee, Jennings and West (12), and used by Lee (11). The times can then be used as the mobilities in the mobility ratio to predict whether or not fingering will occur.

The mobility of water can be reduced by the addition of polymers in small amounts. Sandiford (13) and Pye (14) found that oil could be displaced more easily from porous rock if water soluble polymers were added in small amounts to the displacing water. Burcik and Wahond (15) also found that soluble polymers aided displacement, and went on further to state that the viscosity of the water wasn't increased greatly. However, these authors did find that the resistance to the flow of the water and polymer was greatly increased as it flowed though the porous rock. They explained this by saying that the polymer, which is added, forms larger gel-like particles that are more of the size of the pores in the rocks, when forced to go through these pores. The addition of the water soluble polymer was meant to reduce the channeling of the water.

P. F. Lee's work in 1984 (11) stated that microscopic channeling was the primary controlling mechanism of longitudinal mixing during displacement washing. This channeling occured

because the mobility ratio was greater than one, as discussed above. Lee tried to reduce the mobility of the wash water, and thus to reduce channeling by adding varying small amounts of water soluble polyacrylamide. Lee found that with increasing ppm of polyacrylamide, less washwater was necessary for displacement of the black liquor, but the time necessary for displacement increased. He did state that with pure water fingering was to be expected because of the large mobility ratio of water to black liquor.

EXPERIMENTAL PROCEDURE

The experimental design used in this thesis was similar to that used by P.F. Lee (11). Lee's procedure utilized a Buchner funnel as the basic piece of equipment.

In this thesis project a Buchner funnel was also employed as the basic filtration device. A 32 square mesh screen was obtained and placed in the Buchner funnel. This screen is an effort to better duplicate actual washing conditions and to allow the pulp to drain more freely. Appendix I contains a drawing of the apparatus used.

Hardwood Kraft pulp was obtained from the blow pit at the S.D. Warren Company in Muskegon, Michigan and diluted to a total solids consistency of 3.1%. This 3.1% consisted of 1.9% OD fiber and 1.2% dissolved solids.

A pad of pulp, with a consistency of about 7% was formed in the Buchner funnel from the suspension of fiber in diluted Kraft

pulping liquor. These pads were about 2 inches in thickness. An attempt was made to keep the pads as similar as possible in both thickness and density. This was accomplished by using the 3.1% consistency stock to pour into the Buchner funnel apparatus. This stock immediately dewatered to the 7% consistency. A 780ml sample of the 3.1% consistency stock was used for each run. The black liquor was analyzed for total dissolved solids, pH, and viscosity.

Various washwaters were obtained from the James River Corporation in Parchment, Michigan. These wash waters included samples from the Waco saveall, Pusey felt suction, Pusey couch vacuum, and Pusey tray water. Additional washwaters were tapwater, 20% black liquor, and tapwater containing 10 ppm, 200 ppm, and 1000 ppm of Betz 1260, a very high molecular weight polyacrylamide polymer.

Each of these washwaters, in 50 ml volumes, was initially filtered through a No. 2 Whatman filter to determine its mobility in units of time. A vacuum of 635 mmHg was used during these timed drains. Each washwater was also tested for total dissolved solids, viscosity, and pH.

The washwaters in 24.2ml aliquots, were distributed over the top of the fiber pads in the Buchner funnels, by first going through a coarse wire screen to even out the application. The displaced liquor was recovered in aliquots using duplicate sample jars until almost all of the entrained liquor was displaced. A visual determination, based on the color of the displaced liquid, was used to decide when the application of washwater should be

stopped. The quantity of water used affected the displacement ratio and determined the dilution factor. Total dissolved solids were determined for each displaced liquid sample.

The temperature of both the washwaters and Kraft pulp was 65° C except for the 200 ppm run. The washing was done under gravity.

There are many variables which could have been added to this project. These variables include consistency, pad thickness, temperature, varying amounts of agitation of stock, applying vacuums to the Buchner funnel, etc.

The data generated in this project were used to determine if there is an optimum washwater for efficiency and displacement.

The recorded data included 1) the mobility ratios of the washwater with respect to the black liquor, 2) viscosities, 3) the time to drain a specified aliquot through a No. 2 Whatman filter, 4) solids content of each washwater tested and 5) the amount of washwater necessary to displace the black liquor from a pad of pulp. From these data the substance yield and dilution factor were calculated.

A plot of black liquor displaced as a function of the dilution factor will predict the optimum dilution factor. This dilution factor reflects the point at which further washing will result in negligible additional black liquor displacement.

The conclusion reached by Lee (11) was that fingering or channeling could be predicted by the mobility ratio of the displaced to the displacing liquid. This mobility ratio should then be useful in predicting the displacement efficiency of the washwater. This prediction was tested by plotting the dilution

factor as a function of the mobility ratio.

The basic hypothesis for this thesis is that the relative efficiency of a particular washwater can be determined in the laboratory, before actual use in a brownstock washing system. The rating of a particular washwater will be based on mobility ratio, time needed for displacement, dilution factor and substance yield.

RESULTS

The analysis of the various mill waters used as washwaters and the black liquor in the pulp stock can be found in Table I. Figure 1, graphically represents substance yield versus the dilution factor. The calculations used for the substance yield and the dilution factor are found in Appendix II. The actual runs for each washwater tested are contained in Appendix III. The graphs in Appendix III plot mg/l of dissolved solids versus the dilution factor for each sample collected and represent the average of two runs for each washwater, except for those of 1000 ppm and 200 ppm, when only one run was accomplished.

ANALYSIS OF RESULTS

One of the most important aspects of brownstock washing to be considered is that of substance yield as related to dilution factor. The substance yield was described by Lee(8) as the quantity of dissolved solids displaced from a fiber pad divided

TABLE I. WASHWATER DATA

	Temperature	S.S. mg/l	D.S. mg/l	Mobility Ratio	Dilution Factor at 98.5% Yield	pH	Viscosity cP*
20% Black Liquor	65° C	40	2540	3.1	5.8	9.4	8.0
Pusey Felt	65° C	118	572	3.5	5.3	7.6	8.5
Pusey Couch	65° C	494	603	2.1	5.0	7.6	12.0
Pusey Tray	65° C	567	595	2.6	4.9	7.3	12.0
Waco Saveall	65° C	14	570	6.6	4.5	7.7	12.0
Tap Water (large inj.)	65° C	0	300	8.6	5.8	7.5	8.0
1000 ppm	65° C	10	1285	.39	2.7	7.6	13.0
200 ppm	24° C	4	355	.45	3.0	7.6	12.0
10 ppm	65° C	0	345	8.0	5.3	7.6	8.0
Tap Water (each 24.2 ml)	65° C	0	300	8.6	4.4	7.5	8.0
Black Liquor	65° C	450	11800	1.0	---	10.9	8.5

* At temperature given in 2nd column.

FIGURE 1. SUBSTANCE YIELD VS. DILUTION FACTOR

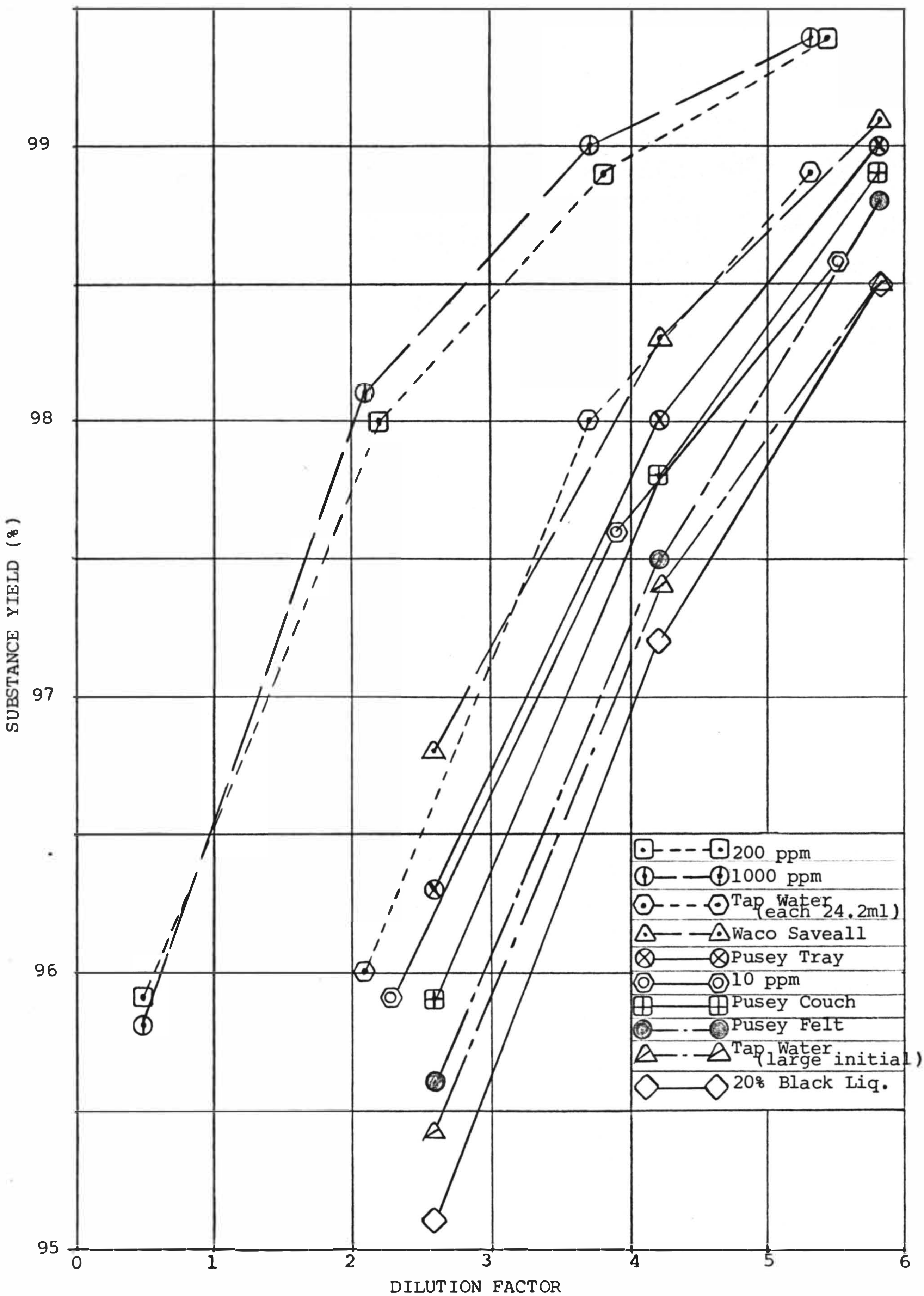
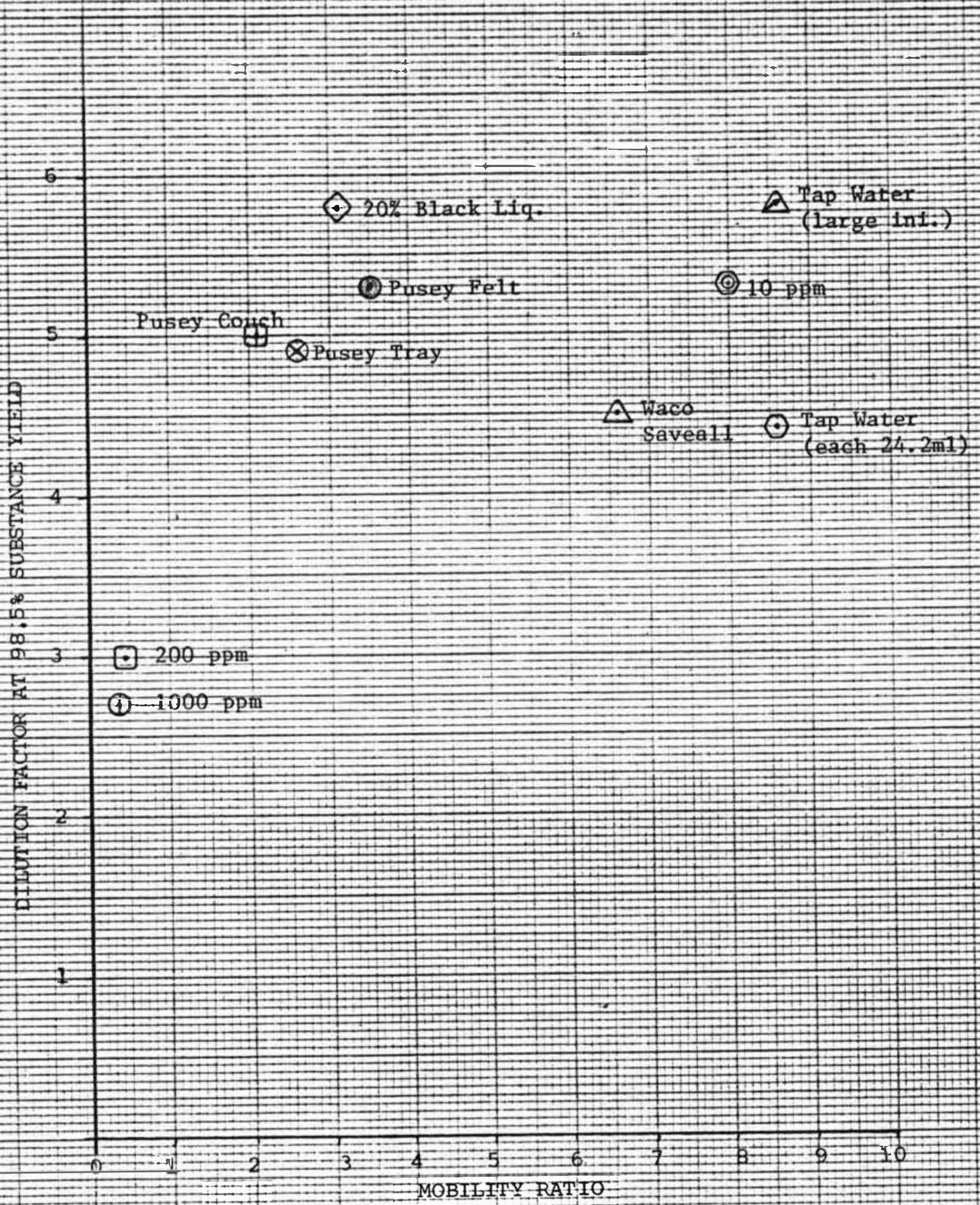


FIGURE 2. DILUTION FACTOR AT 98.5% SUBSTANCE YIELD VS. MOBILITY RATIO



quares to the Inch

by the total amount of dissolved solids that can be removed by displacement. This ratio is then converted to a percent. This equation is listed in Appendix II, along with the other calculations used in this project. Substance yield is equivalent to the displacement as discussed by Perkins, Welsh, and Mappus(3). Both the substance yield and displacement ratio are concerned with the amount, in percent, of the total dissolved solids removed during a one stage washing procedure. In both cases, the addition of any dissolved solids in the washwater is negated. One hundred percent substance yield means that all of the dissolved solids in a pad of pulp that are possible to remove are removed.

The results shown in Figure 1 relate substance yield to dilution factor. Consider the dilution factors for each washwater when the substance yield is 98.5%. These dilution factors can also be found in Table I. These results indicate that the washwaters containing 1000 ppm of Betz 1260 polymer at 65°C and 200 ppm Betz 1260 polymer at 24°C were most effective at removing the black liquor from the pad of pulp.

Since, as given in Table I, these are also the washwaters with a mobility ratio of less than one, Lee's statement that fingering is reduced when the mobility ratio is less than one is substantiated. This result could also be observed through the clear poly pipe extension of the laboratory apparatus. Fingering of channeling was dramatically reduced with the 1000 ppm and 200 ppm polymer washwaters when compared to the other washwaters.

The similarity in the effectiveness of the 1000 ppm and 200

ppm polymer washwaters can be seen in Table I and Figure 1. This similarity indicates that increased temperature has a negative impact on the effectiveness of the Betz 1260 polymer as it relates to displacement of black liquor from a pad of pulp. Whether or not this indication is true for most other polymers is beyond the scope of this project. This is an important aspect that must be considered since brownstock washing usually takes place in the 65° C to 70° C range.

Whereas Lee(11) was able to decrease the mobility of water with a polyacrylamide polymer at 10 ppm, those results could not be duplicated with the Betz 1260 polymer. In Figure 1, it can be seen that the 10 ppm washwater at 65° C had no effect on the ability of tapwater to improve the displacement of black liquor. Much higher polymer additions were necessary.

The individual mill waters, used as washwaters, provide no clear evidence for one being significantly better at washing efficiency than the others. Although there is up to 1.5 dilution factor difference between the various mill waters tested, no clear trend was found. The reduction in mobility ratios in the washwaters high in suspended solids did not result in improved displacement. Apparently, as mentioned by Lee(11), the range of mobility ratio effect is a very narrow band around one. Figure 2, shows the wide range of dilution factors at 98.5% substance yield when the mobility ratios were greater than two.

From Figure 1, it can be seen that the addition of washwater in more, smaller aliquots was more effective in the displacement of black liquor than if a large volume of washwater was added

initially. The tapwater runs were made by both adding an initial quantity of washwater to reach the minus 2.2 dilution factor and then by adding 24.2ml at each wash starting at a minus 15.7 dilution factor. The graphs for these individual runs can be seen in Appendix III. The run in which the washwater was added 24.2ml at a time appears to be better at displacing the black liquor. A possible explanation for this improved displacement is that once a channel is formed, it continually grows until all of the added washwater has flowed through the pulp mat. Therefore, it is reasonable that the more washwater added in one washing stage would form larger channels and flow through these channels without displacing the black liquor in other areas of the pulp mat. Smaller additions of washwater would not only form smaller channels, but these channels would be able to be closed or filled with black liquor between the washing stages.

There were several observations that were noted during the laboratory procedure. Slower drain times were noticed during the 200 ppm and 1000 ppm runs. One of the original aims for this project was to time each wash and then to compare these drain times. However, since it was considered more important to collect all the displaced liquid, more time than was normally required, was allowed. Accurate timing was, therefore, not possible. Although the observation was made that a slower drain time did occur when the 1000 ppm and 200 ppm solutions of Betz 1260 polymer were used, actual time measurements were not conducted.

Another observation, noted after the 1000 ppm Betz 1260

polymer solution wash, was that the pulp quality was very poor. The pulp felt oily or soapy, and could not be formed into a ball of pulp by squeezing.

CONCLUSIONS

1. Polymer additions, at high concentrations, significantly increased the displacement of black liquor.
2. Increased temperature of the washwater reduced the effectiveness of the polymer solutions.
3. The addition of washwater in smaller increments was more effective in the displacement of black liquor than if a large volume of washwater was added initially.

RECOMMENDATIONS

There are many variables which could be considered in the brownstock washing process. These variables include consistency, pad thickness, temperature, varying amounts of anionic and cationic polymer, etc. Further laboratory work is needed with all the variables if optimization of the brownstock washing is to become a reality.

A study based on the mobility ratio of between .90 and 1.1 might be useful in minimizing the amount of added polymer. Since this study was conducted with hardwood pulp, a similar study using softwood pulp may prove beneficial.

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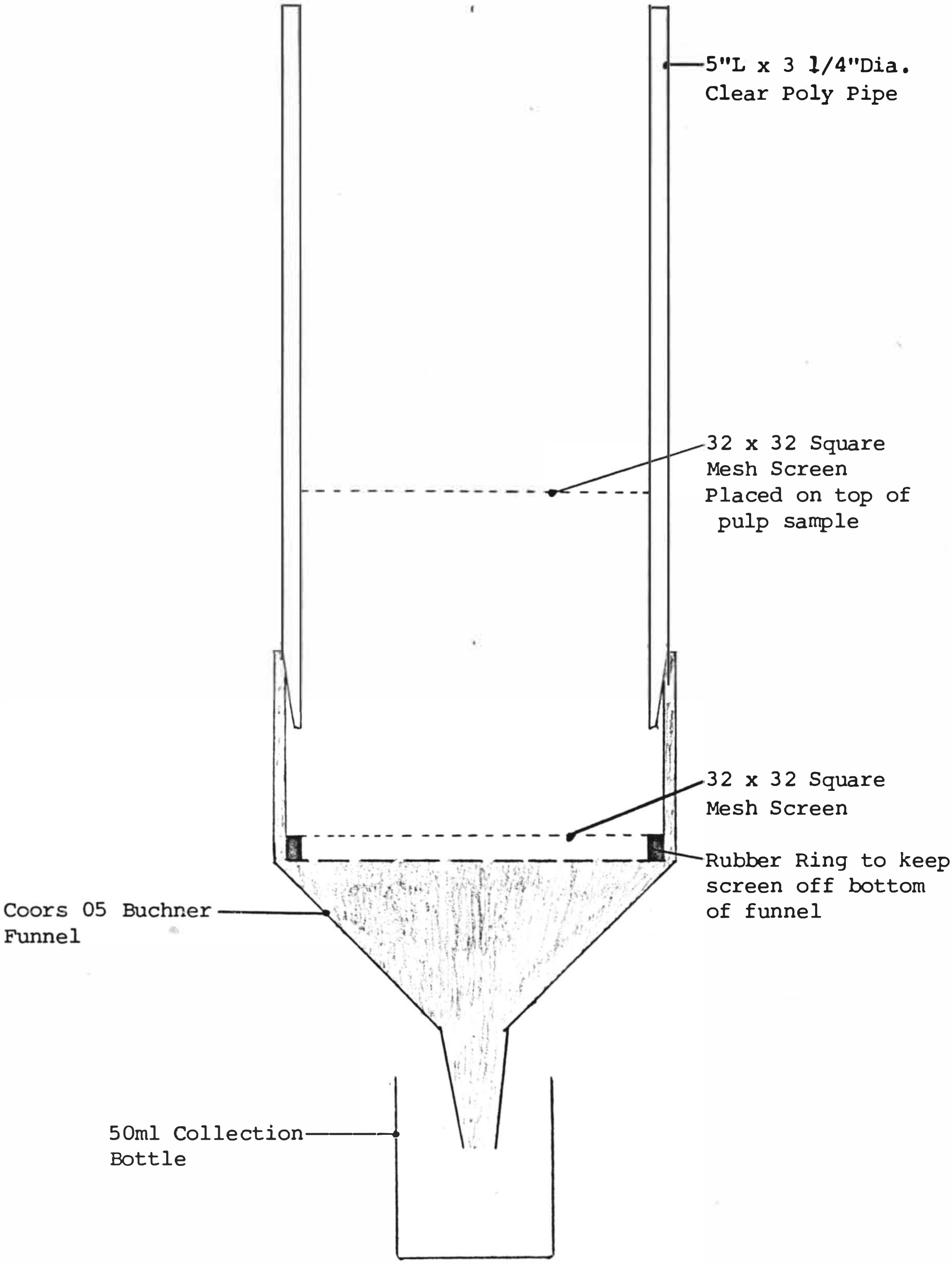
APPENDIX I

LABORATORY APPARATUS

LABORATORY APPARATUS



APPENDIX II

CALCULATIONS

CALCULATIONS

$$\text{Mobility Ratio} = \frac{\text{Time to drain 50ml Black Liquor through \#2 Whatman}}{\text{Time to drain 50ml Washwater through \#2 Whatman}}$$

$$\text{Dilution Factor} = \frac{\text{ml Washwater added} - \text{ml Black Liquor in Pulp pad}}{\text{grams OD fiber in Pulp pad}}$$

Sample Calculation:

```
  780ml Sample
 - 15g  OD fiber
 -510ml Free draining Black Liquor
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  255ml Black Liquor remaining in Pulp pad
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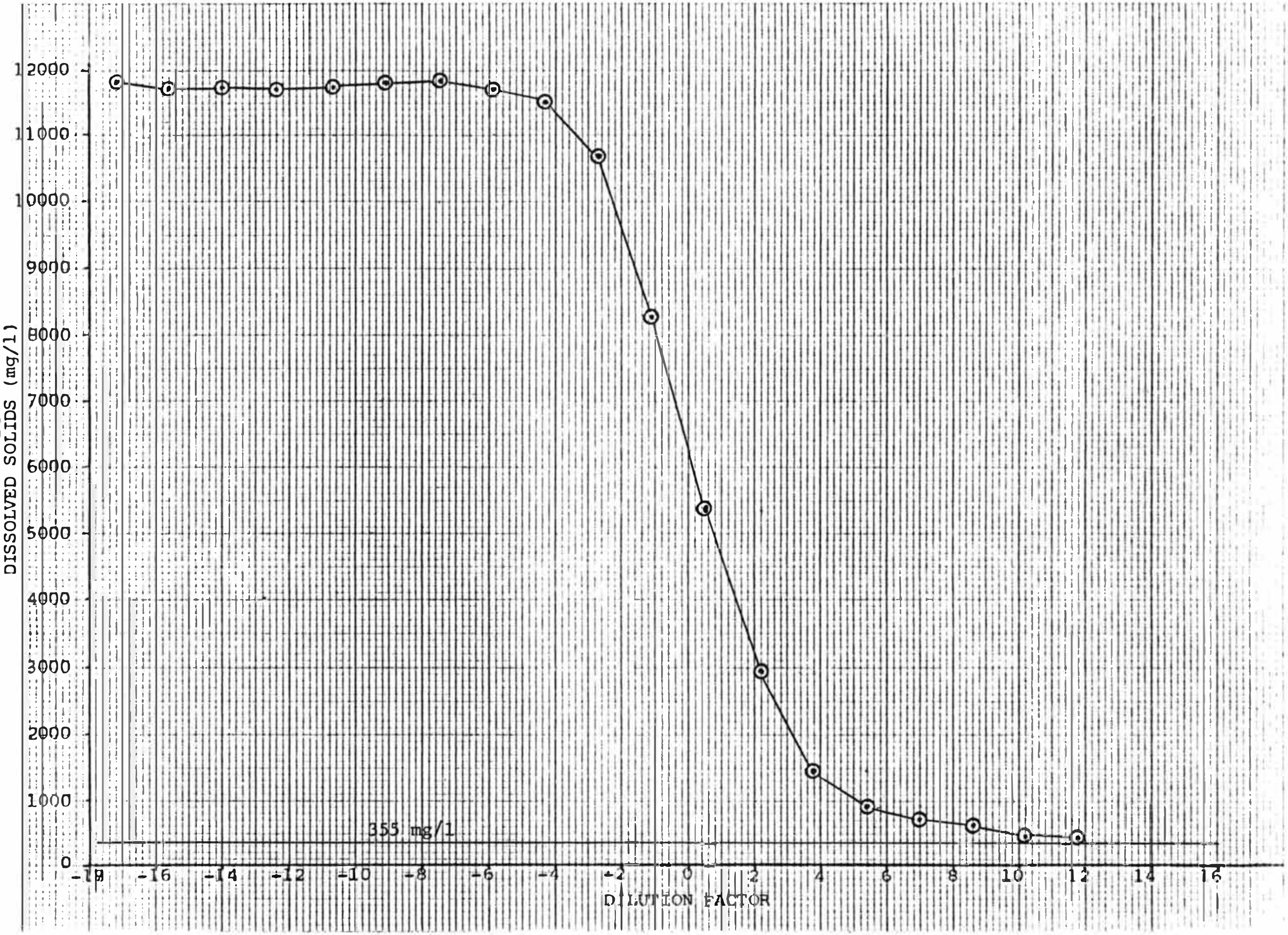
therefore: $$\text{D.F.} = \frac{\text{Xml washwater added} - \text{255ml}}{\text{15g}}$$

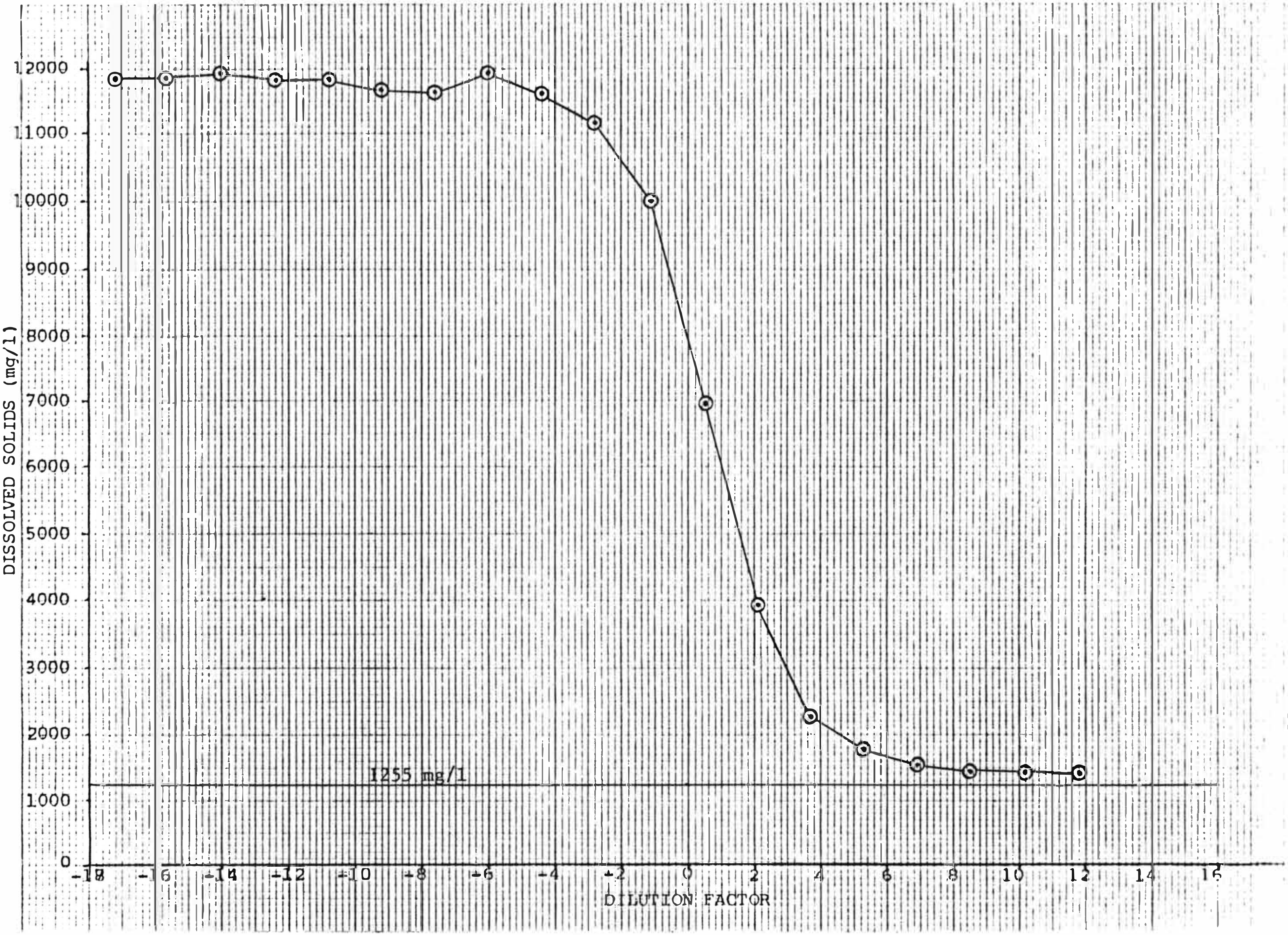
APPENDIX III

GRAPHS FOR ALL WASHWATERS

DISSOLVED SOLIDS VS. DILUTION FACTOR

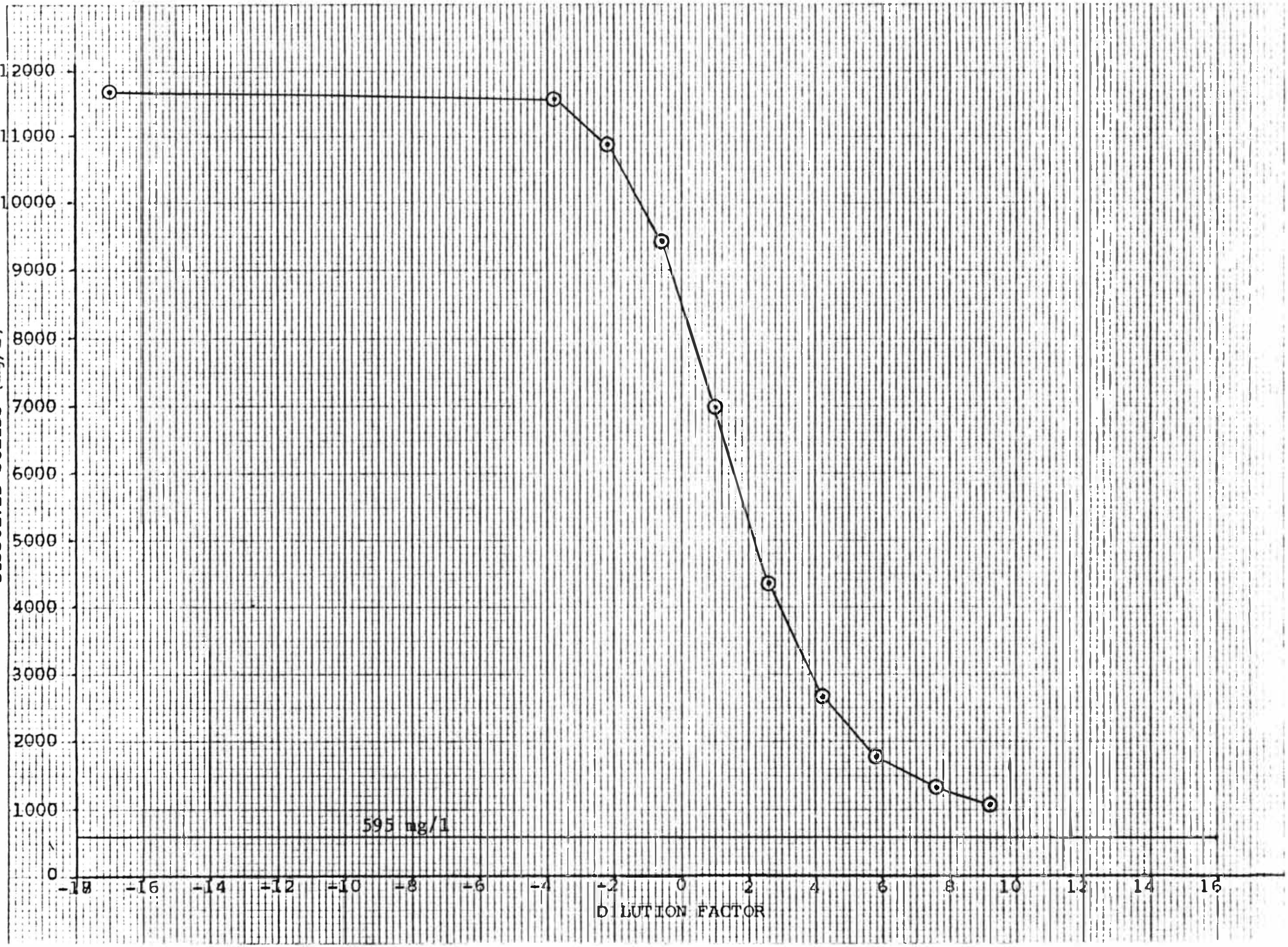


DISSOLVED SOLIDS VS. DILUTION FACTOR 200 ppm BETZ 1260

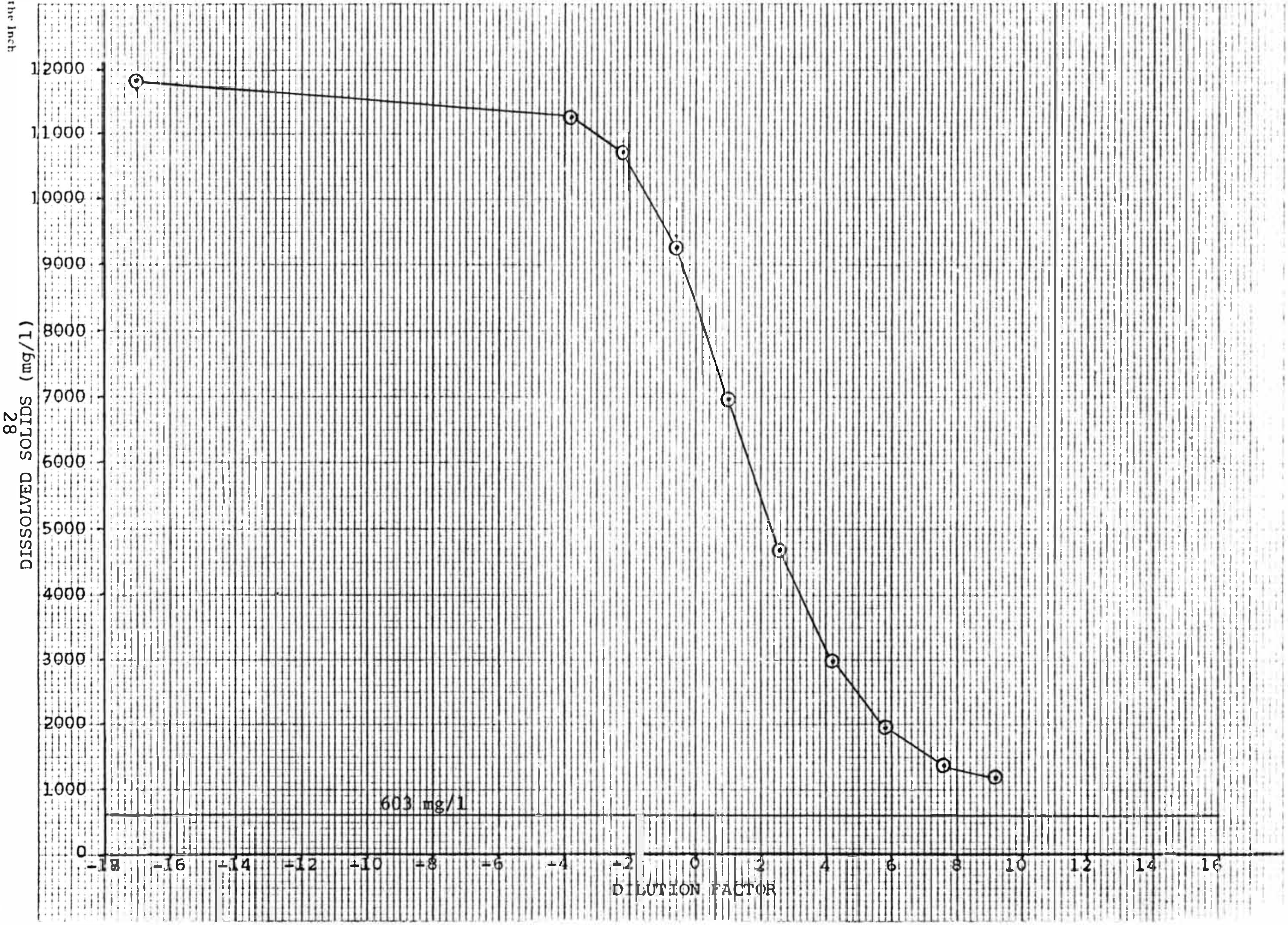


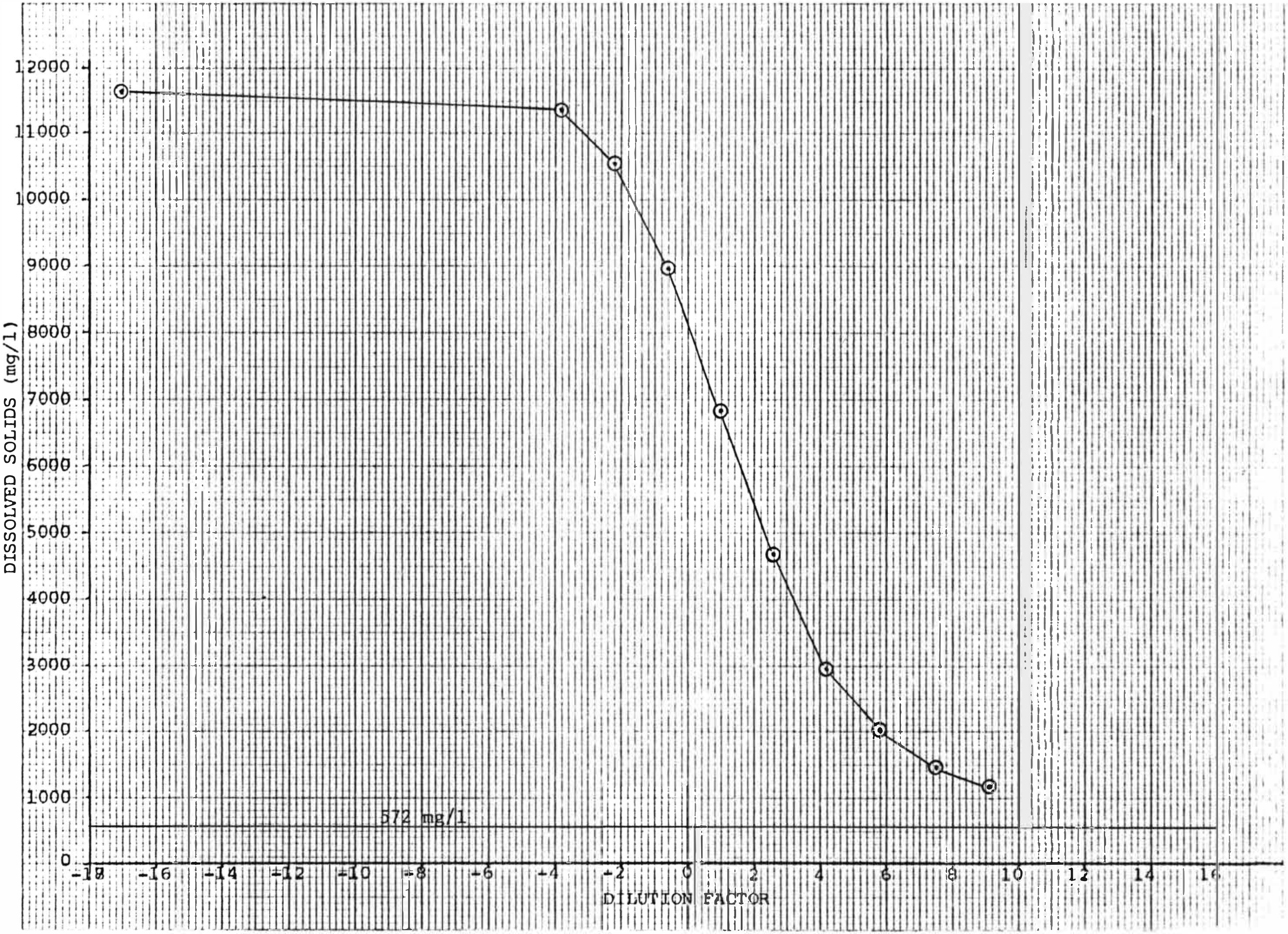
DISSOLVED SOLIDS VS. DILUTION FACTOR 1000 ppm BETZ 1260

DISSOLVED SOLIDS VS. DILUTION FACTOR   PUSEY TRAY WATER



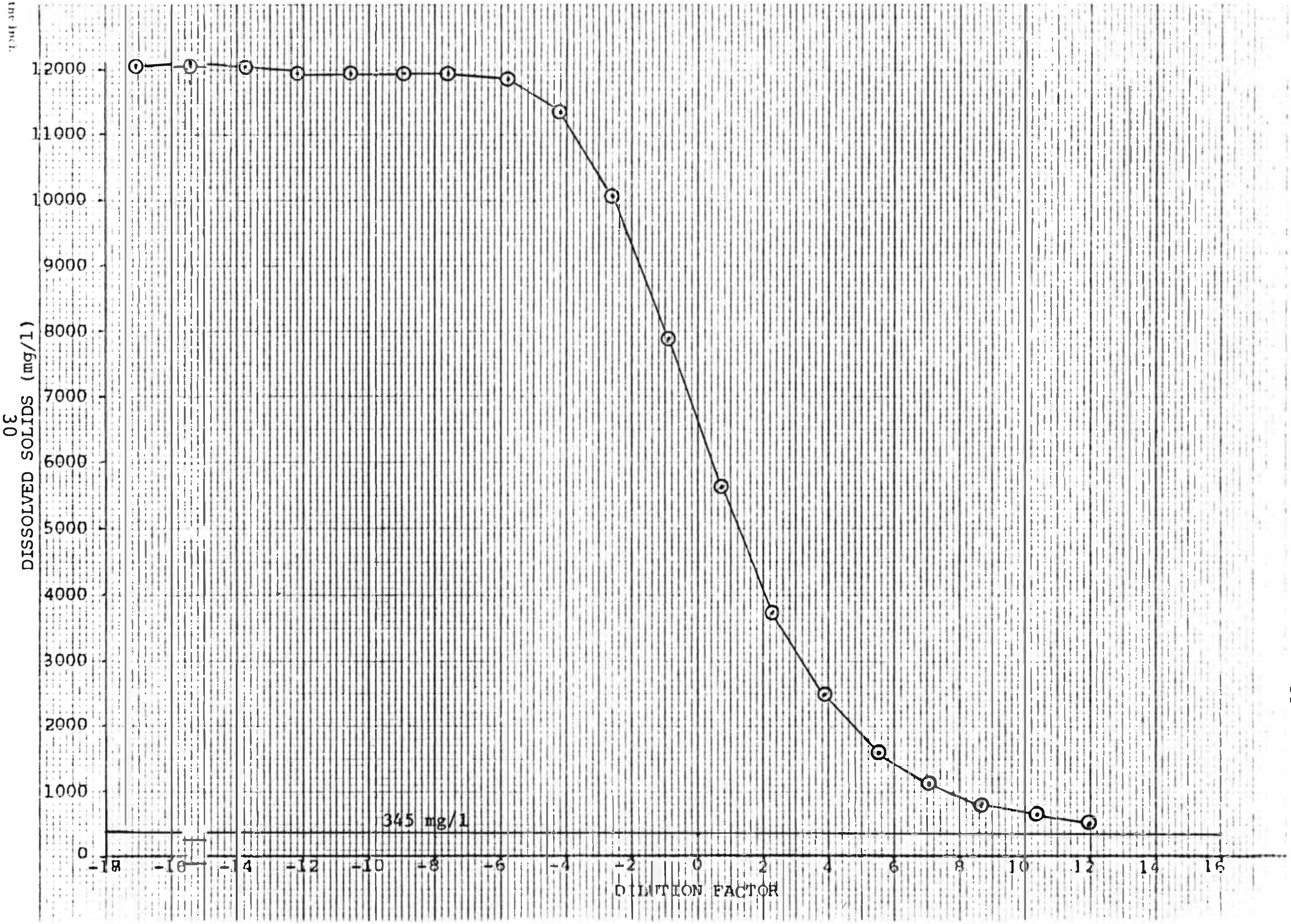
DISSOLVED SOLIDS VS. DILUTION FACTOR   PUSEY COUCH VACUUM



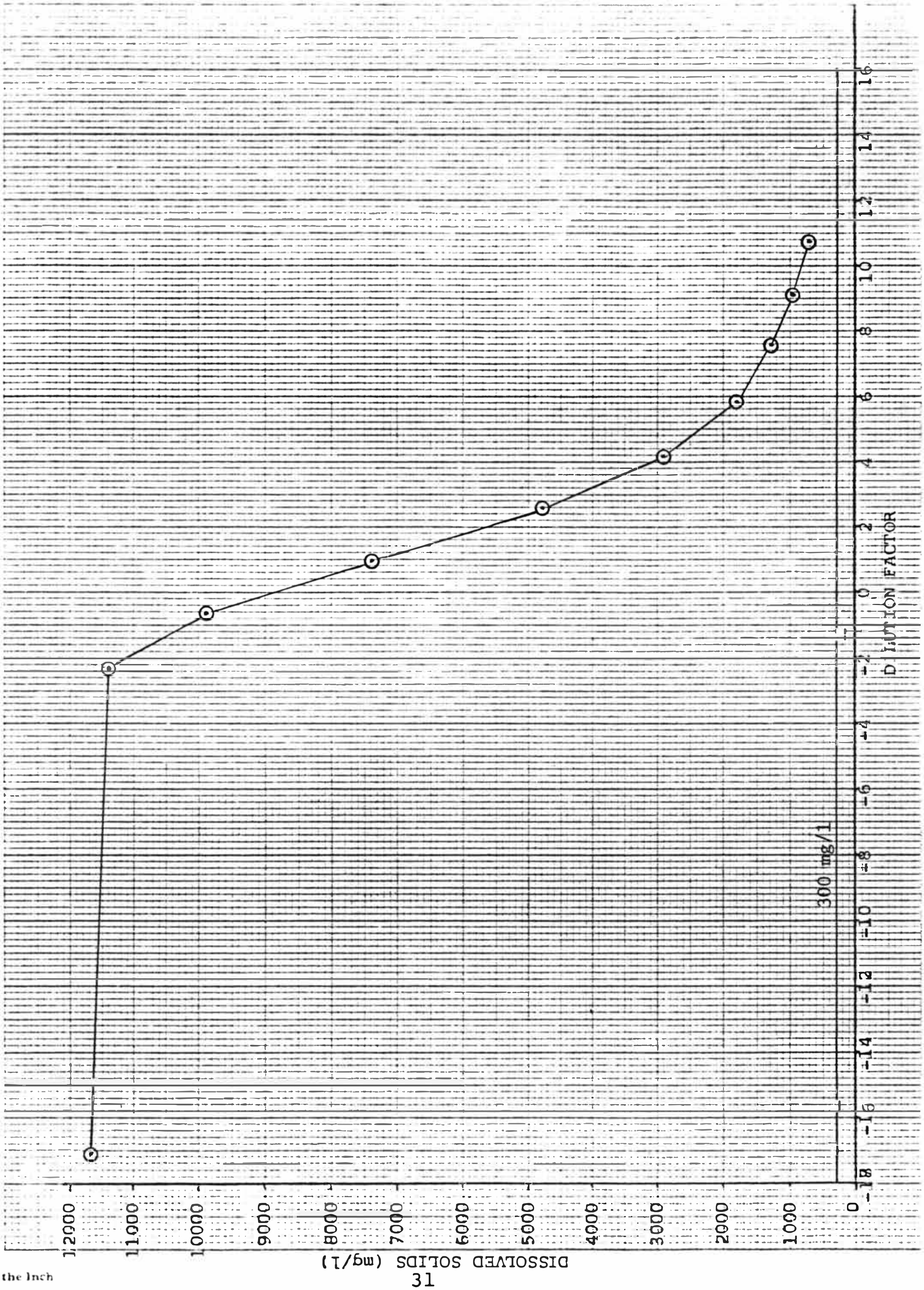


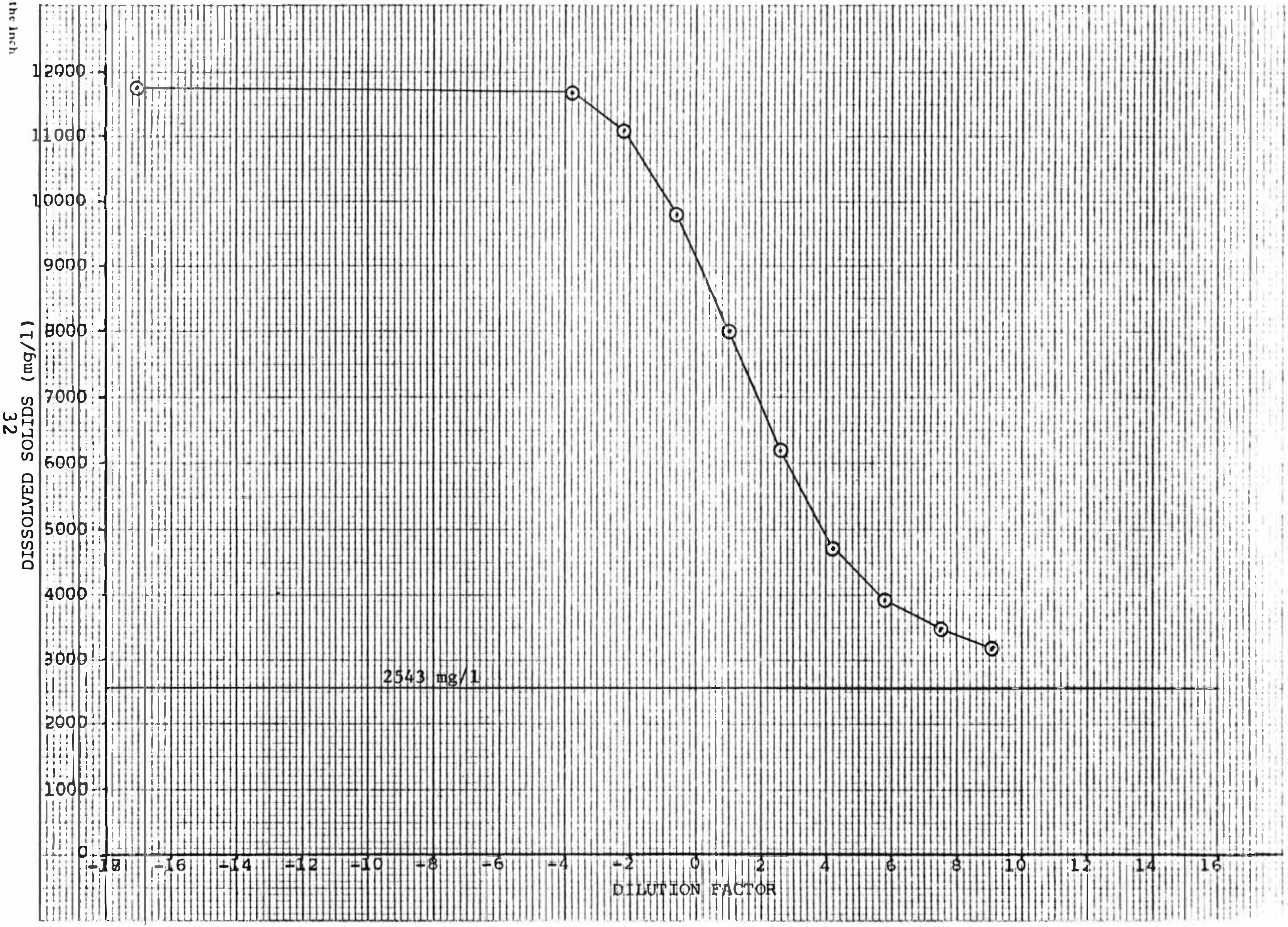
DISSOLVED SOLIDS VS. DILUTION FACTOR PUSEY FELT SUCTION

DISSOLVED SOLIDS VS. DILUTION FACTOR 10 ppm BETZ 1260



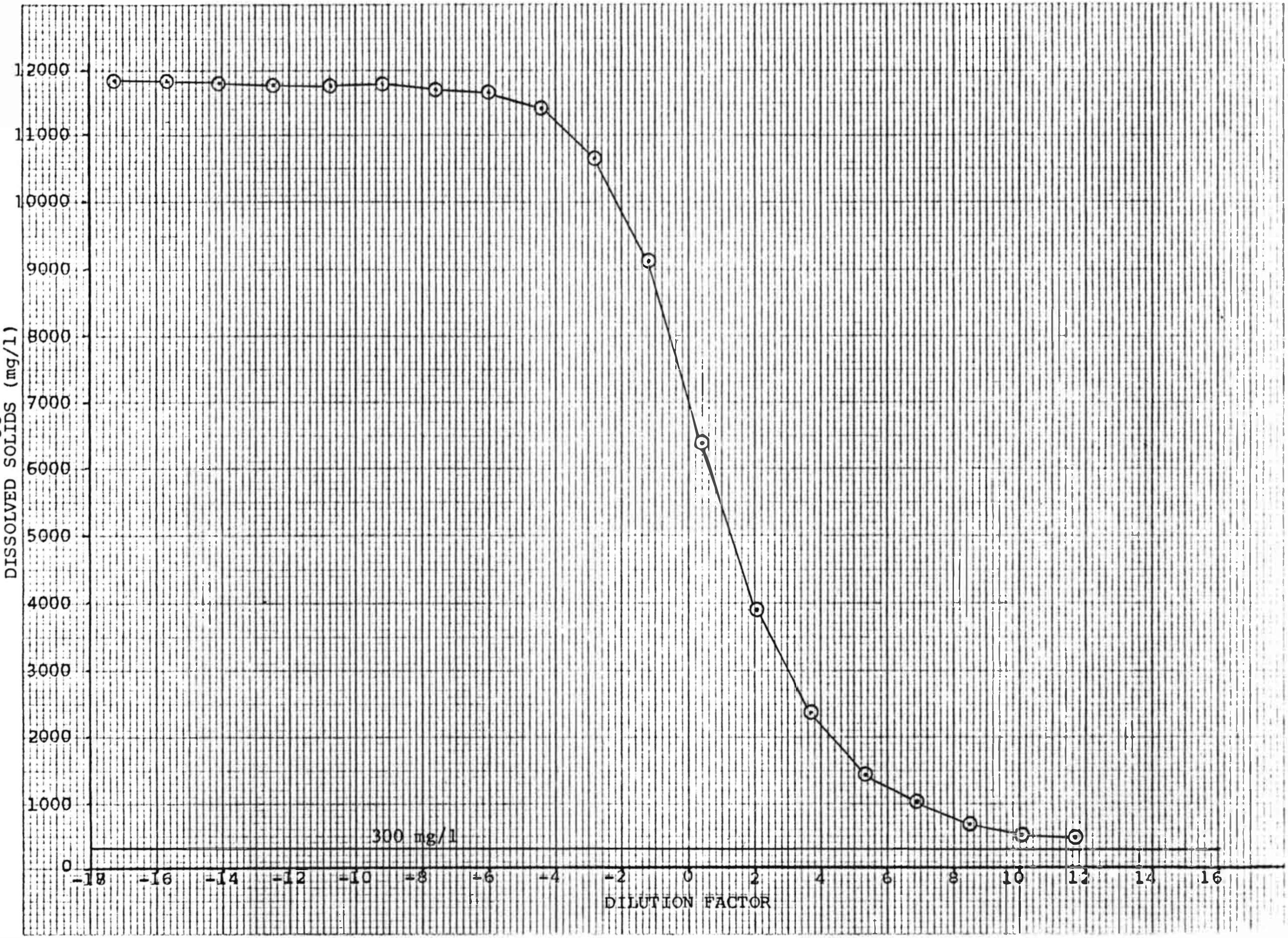
DISSOLVED SOLIDS VS. DILUTION FACTOR TAPWATER (large initial)





DISSOLVED SOLIDS VS. DILUTION FACTOR 20% BLACK LIQUOR

DISSOLVED SOLIDS VS. DILUTION FACTOR TAPWATER (each 24.2ml)



DISSOLVED SOLIDS VS. DILUTION FACTOR WACO SAVEALL