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Western Michigan University

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THE EFFECTS OF RESIDUAL SURFACTANT
ON THE RETENTION OF FINES

By

Steve L. Myers

A thesis submitted
in partial fulfillment of
the course requirements for
The Bachelor of Science Degree

Western Michigan University

Kalamazoo, Michigan

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ABSTRACT

Research was conducted to determine if small amounts of non-ionic surfactants present in the papermaking furnish would effect fine particle retention.

The Britt Jar was used for the first part of this experiment to determine if the surfactant would affect the retention. The surfactant was tested at six different concentrations and no detrimental effects were seen.

Subsequent Britt Jar experiments were used to determine the effects of shear, and the effects of retention aids. These experiments were conducted primarily to see if they were interacting some way with the surfactant. The results showed no interaction.

The final part of the experiment was to use the pilot papermachine to see if the results obtained in the Britt Jar would correlate to the pilot machine. The results from the pilot machine confirmed those found using the Britt Jar.

Therefore one can conclude that these non-ionic surfactants did not effect the retention on the papermachine. Before one would see any retention loss there would be substantial foaming on the papermachine. This contradicts previous theories that small amounts of surfactants would affect the retention.

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OBJECTIVE

The objective of this project was to determine if the use of non-ionic surfactants in the pulpmill or papermill can effect the fine particle retention on the papermachine. Presently many surfactants are used in this industry for washing deinking, flotation deinking, and defoaming. It has been hypothesized that as small amounts of these surfactants find there way into the papermaking furnish, they may reduce retention. The results from this project will be used to try to prove or disprove this hypothesis.

INTRODUCTION

Today environmental problems have pushed recycling upon industry to try to manufacture as many products as possible from recycled material. The paper industry has been recycling for many years already. Some very simple reasons for recycling paper are to hold cutting of virgin wood to a minimum, and to reduce the amount of mass going to landfills (1). Wastepaper use has increased from 12 million tons in 1970 to 15 million tons in 1979, and has since increased to 20 million tons through 1989 (2).

New legislative and economic forces are increasing the amount of recycled paper produced. Economics is a major driving force because the operating cost of producing deinked secondary fiber is usually lower than virgin fiber. The unit capital cost (the capital cost of the mill divided by the daily production rate) for a secondary fiber mill is also less than that of a virgin kraft mill (2). In addition to these economic forces new legislative forces are coming on line. Federal legislation has established recycling goals for the paper industry to meet by 1995, although currently most of the responsibility remains in the hands of states. Most of the new legislation focuses on the requirements of secondary fiber in production of newsprint. Many laws will require newsprint to contain at least 50%

recycled fiber (2).

Surfactants play a major role in both flotation and washing deinking processes used extensively in recycling paper. Typically these surfactants are added to the pulper when defiberizing the secondary fiber. By adding the surfactant or any other chemical into the pulper, they can be applied at higher concentrations, and the mechanical action effectively mixes them into the pulp (3). The surfactants are used to help break up the ink particles, remove them from the fiber surface, and to keep them from redepositing on the fiber again. In the past many fatty acid soaps were used as surfactants. Presently synthetic chemicals are added which are usually non-ionic linear hydrocarbons. Other chemicals which are added to the pulper are: caustic soda to swell the fibers; sodium silicate to buffer the solution, to prevent hydrolysis of soaps, and to act as a sequestering agent; and hydrogen peroxide used to improve the brightness of the pulp (4).

BACKGROUND INFORMATION

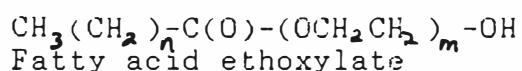
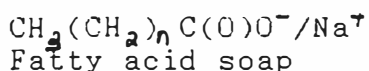
Flotation Deinking

Flotation deinking has become much more common due to difficult-to-remove inks of the polymeric and nonimpact type, UV radiation-cured, and heat set inks, all which have become very popular (4). These inks are almost impossible to remove by washing because of dispersing difficulties, therefore flotation is used to remove the ink. The flotation cell is the heart of the deinking process. It is here that the bulk of the ink is removed from the pulp fibers. Ink is removed by attachment to a small gas bubble, which is introduced into a dilute pulp slurry, typically 0.8% to 1.2% consistency (5). These air bubbles are then allowed rise to the surface removing the ink particles from the fiber.

A flotation cell has three major zones: the aeration, mixing, and separation zones. In the aeration zone, air is added in the correct amount to effectively float the ink particles to the surface. The mixing zone is important in order to maximize both the intensity and frequency of collisions between ink particles and air bubbles (5). In the separation zone the bubble-ink particle can float to the top of the cell to be removed. Two important variables which must be controlled in the flotation cell are the

bubble size and the ink particle size (6). Flotation cells usually work better on larger particles in the range of 30 to 60 microns, while washing works better on smaller particles. Therefore modern deinking mills will sometimes incorporate both flotation and washing deinking to achieve higher efficiencies.

Flotation is most effective on inks that are difficult to disperse such as the polymeric inks mentioned before. In the flotation cell, ink must be stabilized as insoluble, hydrophobic particles. Washing surfactants are designed to disperse the ink particles into small, hydrophilic colloids (4). These types of surfactants reduce the effectiveness of the cell, so instead a "collector" type surfactant is added that gathers the ink particles into large aggregates. The surfactants used in flotation cells are usually fatty acid derivatives, such as these shown below (4).



These surfactants may be added dry 0.7% to 1.0% on pulp weight. Soaps are soluble as added but are made insoluble from calcium ions. The resultant insoluble soaps and ink collect preferentially at the gas bubble solution interface and are floated to the top of the cell (4).

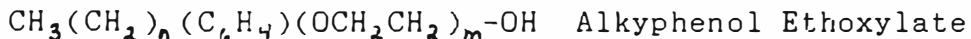
Washing and Thickening

Washing is defined as preferential rinsing of

undesirable particles from the pulp (4). In deinking washing involves dispersing the ink particles to a small enough size so that they can be removed by rising through a fiber mat. The most common type of washers are gravity deckers, sidehill screens, and dewatering screws. Along with any washing system there must be a clarification system to remove the ink from the water which was removed from the stock. To maximize yield and to minimize clarification costs, a side stream containing only part of the effluent may be clarified, and the rest is used for dilution for the washing. This equilibrium of fiber, ink, and chemicals must be carefully balanced in order to maintain high ink removal efficiencies and pulp quality (4). After the washing stage, usually there is a thickening stage. The only difference between washing and thickening is that in the latter nothing is removed from the system. After these stages the deinking process is complete, from here the pulp can be bleached if necessary or blended to make up the furnish for the papermachine.

In a mill incorporating both flotation and washing, washing usually follows the flotation stage in order to remove the small ink particles. In most washing systems ink is removed as colloidal particles smaller than 30 microns(6). A low foaming surfactant is added to stabilize the ink particles and to keep them from agglomerating. A popular class of surfactants for this application has been

ethoxylated alkyphenols shown below (4):



These surfactants are typically 100% active liquids applied in the pulper at 0.5% to 0.75% of pulp weight. They can also be added just prior to the washing stage. As one might expect in a deinking system incorporating both flotation and washing there is going to be a conflict of surfactant mechanisms. For flotation one would like large particles hence the addition of the fatty acid soaps, which reduces washing efficiencies. If a washing sequence follows, dispersants are added to create small particles, making flotation efficiencies poor. Even if the washing surfactant is added at a different point in the system, such as just prior to the deckers or presses, the recirculation of the effluent back to any stage prior to flotation can cause dispersant concentration to build up (4).

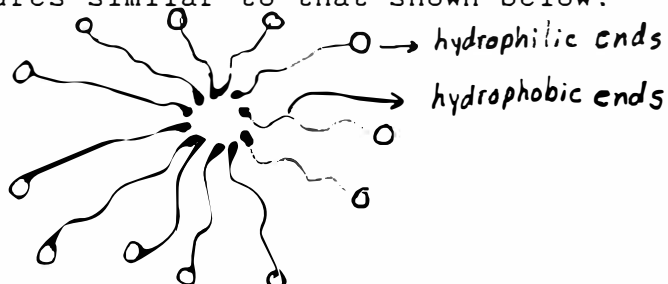
To overcome these problems of the combination systems, products have been designed specifically for use in these systems. These chemicals are called "displacement-collectors" or displectors. They are usually proprietary formulations of alkoxyated fatty acid derivatives containing some of the physical properties of both dispersants and fatty acid collectors (4).

Surface Active Agents:

Surfactants that are used as wetting agents, detergents, suspending agents, emulsifying agents, are association colloids (7). It should be noted that some of the newer surfactants out on the market today do not associate, but these will not be discussed here. Association colloids are substances whose molecules aggregate spontaneously in a given solvent to form thermodynamically stable particles of colloidal dimensions (micelles). Surfactants are used extensively throughout the paper industry. Besides their use in deinking already described they can be used for (7):

- Pulp washing (liquor penetration, defoaming)
- Pulp fluffing (lower surface tension)
- Paper softening (lower surface tension)
- Defoaming and antifoaming
- Absorbency improvement
- Pitch control
- Felt washing and conditioning
- Corrosion inhibition
- Sizing
- Yankee dryer adhesion control

Association colloids are named as such because they form micelles. It is thought that these micelles have structures similar to that shown below.



The hydrophobic (water hating) ends of the molecule try to escape the liquid phase while the hydrophilic (water loving)

ends try to stay in the liquid phase and spherical structure results (7). The micelle formation depends on the delicate balance between interactions as well as the solvent properties and the concentration of the surfactant in the solvent. The concentration above which micelle formation occurs spontaneously is called the critical micelle concentration (CMC). The micelles can then solubilize materials that are ordinarily insoluble in water.

Surface Activity

The addition of surfactants to water causes a dramatic lowering of the surface or interfacial tension, even when present in vanishingly small concentrations (7). This occurs because the liquid system seeks to decrease its energy. Thus, the molecules of the surfactant will quickly migrate to the surface of the liquid.

The surface tension of water plays a major role in the inter-fiber bonding and early strength developments of the web being produced on the papermachine (8). As water is removed from the sheet its high surface tension pulls the fibers and fines very close together and allows them to bond. If this surface tension is lowered the fibers and fines will not be pulled together as tightly. As a result a drop in fines and pigments retention may be noticed on the papermachine, as well as a reduction in strength of the final sheet.

Defoaming Surfactants

Defoamers are used extensively on the papermachine. Foam on the papermachine will cause many problems such as pinholes, drainage instabilities, and low porosity. Commonly these defoamers are added haphazardly to the wire pit. It is sometimes thought that the defoamer will adversely affect the retention on the machine if present in high enough concentrations.

It appears for a surfactant type defoamer to work, it must spread rapidly and thoroughly on the film surface. In the process, it is believed that the liquid in the foamy film is displaced and the film thins to a point of mechanical instability (9). This project also looked at the effects of a synthetic defoamer on retention.

Methods of Fine Particle Retention

Floc Formation

The prime mechanism of fine particle retention involves free floc formation in a highly agitated filler/pulp slurry, followed by floc entrapment during slurry drainage and fiber mat formation (10). When using a high molecular weight retention aid, fine particle floc formation is mainly caused by the bridging mechanism. Bridging occurs when the loosely structured floc of the fine particles becomes attached to the long-chain molecule which can also become attached to the fibers. Floc size may range from 10um to 500um or more

in a low shear system (11). These flocs form very rapidly and are degraded by the turbulent shear that exists on the papermachine, and reform only partially when the shear is removed. The flocs which are not attached to fibers then can become entrapped in the multilayered fiber mat which forms during rapid drainage.

Mat Formation

Paper is a multilayered structure formed by rapid drainage of the slurry through an increasingly thicker mat of fibers building up on the forming fabric (7). A certain thickness of mat must be formed before substantial entrapment occurs. As the fiber mat builds, more fines are caught as a result of the denser network which provides more available points of entrapment. The retention is a strong function of basis weight, increasing with increasing basis weights.

PRESENTATION OF PROBLEM

Some deinking mills have experienced retention problems on their papermachines. These problems can come from any number of causes. One plausible cause for the reduced retention was thought to be residual amounts of surfactants that might be present in the stock system. It was thought that the surfactants could have been coming from the deinking pulp mill or from the defoamer used on the papermachine. The objective of this project was to determine if these types of surfactants could affect retention. The first half of the project used the Britt Jar (shown in Fig. 1) to determine the effects of the concentration of the surfactant, the effects of shear and the effects of the retention aids. The Britt Jar used differed some from the one illustrated. It did not have a three way valve connected to an air line. Instead it just a tube with a glass dropper connected at the end. The flow was controlled by pinching the tube. The pilot papermachine was used in the second half of the project to verify the results obtained with the Britt Jar.

EXPERIMENTAL

Materials

A mixture of hardwood and softwood was used for the fiber in this experiment. The bleached softwood was Dryden DCX and the bleached hardwood was E.B. Eddy. These were mixed in a 60% - 40% hardwood/softwood ratio for the Britt Jar experiments. Twenty percent precipitated (ppt.) calcium carbonate (CaCO_3) based on dry fiber was also added to the furnish. The carbonate was Pfizer PFICARB H ppt. CaCO_3 .

Two retention aid systems were used, the first was a high molecular weight cationic polymer. The polymer was RETEN 1232 supplied by Hercules. The second system was a high molecular weight anionic polymer and alum used for a cationic charge. This polymer was RETEN 1523-H also supplied by Hercules.

The surfactants used for the Britt Jar and for the pilot machine were supplied by Union Carbide. These surfactants were from the Tergitol series, named 15-S-7 and 15-S-12. These non-ionic surfactants are mixtures of 11-15 carbon, linear secondary alcohols reacted with ethylene oxide. The number following the names designates the degree of ethoxylation. For example the 15-S-7 had seven moles of ethylene oxide reacted per mole of alcohol. The following table summarizes the properties of these surfactants.

Surfactant Characteristics

	15-S-7	15-S-12
Cloud Point	98.6 F	194 F
Molec. Wght.	515 g/mol	738 g/mol
HLB Factor	12.4	14.7
CMC wt%	0.0039%	0.110%
Surface Ten.	28 D/cm	31 D/cm

Taken from Tergitol performance series pamphlet

These surfactants are used for washing deinking as well as other areas of industry. Hercules 831 defoaming surfactant was also used for this experiment in the pilot machine run. This defoamer was a paraffin oil based material.

The first three phases of the experiment were performed using the Britt Jar. The pilot papermachine was used for the last phase of the experiment.

Procedure

The 60/40 softwood/hardwood furnish was slushed using the Morden Slush Maker. The stock was then transferred to the Valley Beater and refined at 1.57% consistency for seventy minutes to a CSF of 300. The beating followed TAPPI Standard T 200 om89 "Laboratory Processing of Pulp (beater method)". 55 minutes into the beating cycle the calcium carbonate was added to the beater to ensure good mixing. The stock was diluted to 0.5% consistency before it was used in the Britt Jar.

The Britt Jar was used to determine the effects of concentration of the surfactant, the effect of shear in the jar, and the effect of the retention aids. 500 ml of stock was poured into the jar, the agitator was turned on. The desired amount of surfactant was added. Fifteen seconds later the retention aid was added another fifteen seconds later the valve was opened at the bottom of the jar. The first 15-20 ml from the jar was discarded and the next 100 ml was collected in a volumetric flask. The material collected was analyzed for solids.

The liquid collected from the Britt Jar, was filtered on a preweighed Whatman 40 quantitative filter paper. The paper was dried and weighed to determine the weight of material in the filtrate. The weight was then used as a comparison of the retention. The smaller amount of material in the filtrate the higher the retention and vice versa.

The last part of the experiment was to use the pilot machine to see if it would correlate with the Britt Jar. The furnish used on the pilot machine was a 50% - 50% softwood/hardwood blend. The same pulps were used on the machine as used in the Britt Jar. This time 30% calcium carbonate was added to the stock to give more fine particles, and to make and retention differences of fine particles more noticeable. The stock was refined to a CSF of 250ml using a disk refiner. The machine was set up to make fine particle retention as difficult as possible. To

do this a 30 lb sheet was made as fast as the machine could run which was 120 fpm. The cationic retention aid was used and was added on the inlet of the fan pump. The three surfactants were metered into the first mixing tank. First pass retentions were taken for each concentration of each surfactant. Also tensile tests were performed on the paper collected at the reel using TAPPI Standard T 494 "Tensile Breaking Properties of Paper and Paperboard (using constant rate of elongation apparatus)".

RESULTS AND DISCUSSION

Effects of Concentration

The first part of this experiment was to determine the effects of the concentration of the surfactant on retention using the Britt Jar. The surfactant was added at specific concentrations to the jar. After 15 seconds the cationic retention aid was added. The stirring speed of the jar was 500 rpm. The cationic polymer was added at 0.5 lbs/ton and the consistency in the jar was 0.5%.

The Britt Jar was run with no additives and the filtrate was measured. The polymer was then run alone and the filtrate was measured. Then the surfactants were added at the following concentrations: (wt. % based on mass of water)

0.00003%	0.00006%	0.00012%
0.00025%	0.00050%	0.00100%

The concentration of the surfactant was doubled for each trial. The results of the weights of the filtrate are shown in Table 1. As the concentration of the surfactant increased there was no significant effect on the weight of filtrate coming out the jar. Fig. 2 is a linear graph of this data. The first point on the graph is much higher than the others. This error was probably in error due to some

type of human error in measuring the filtrate weight. The average of the next five points was calculated and is drawn in on Fig. 2. The average of the standard deviations was also calculated. A plus and minus standard deviation was also drawn on the graph. One can see that all of the five points lie between the standard deviations. Therefore there was no significant effect on retention.

Effects of Shear

The second and third part of the experiment was to study the effects of shear and retention aid on the role of surfactant on retention of fine particles. The shear in the Britt Jar is controlled by the rotational speed of the impeller. The shear was increased in the jar to study the interaction between shear and retention.

The 15-S-7 surfactant was again used in this trial. The cationic polymer was added to the jar at 1.0 lb/ton. The surfactant was added at two levels 0.001% and 0.01%. The trial was also run with no surfactants of cationic polymer in the jar and the filtrate was analyzed. This is labeled blank in Table 2. Then 1 lb/ton of cationic polymer was added and the filtrated was analyzed for comparison with the runs with the surfactant addition. One can see the weight of the filtrate increased when the shear increased as expected. Also as expected there was no significant effect at 500 rpm. Looking at the 700 rpm data one can see that

the filtrate weights went down. If retention were affected by the surfactant these weights would have gone up. The most probable reason of the drop in weights was the stock started to foam in the jar at the higher shear rate. The foam then prevented the fine particles from passing through the wire mesh, and hence the weights went down. Fig. 3 shows a graphical analysis of this data. Again, as expected, the weights of filtrate increased as the shear increased, but there was no effect of shear on the retention when the surfactant was added. Therefore one can conclude that the shear and retention did not interact in this experiment.

Effects of Retention Aids

The last part of the Britt Jar experiment was to determine if the retention aid was interacting to effect the retention. Two retention aid systems were used. A high molecular weight cationic polymer used alone was the first system. The second system incorporated a high molecular weight anionic polymer and alum added as a source of cationic charge. Retention aids were necessary for this experiment because without them too much of the fine particles passed through the Britt Jar and no comparison could be made when subsequent surfactants were added.

The first part of the experiment used the cationic system. The 15-S-7 surfactant was again used for this trial

and the shear rate was 500 rpm. The surfactant was added at 0.001% to make sure there was no foaming present in the jar. The cationic polymer was added at three different addition rates: 0.5, 0.8, and 1.0 lb/ton. A blank was run with polymer only and the filtrate weight was analyzed for comparison with subsequent runs in which the surfactant was added. Table 3 shows the data collected from these runs. One can see that there was no significant difference between the blank runs and the ones in which polymers were added. Fig. 4 graphically shows these results. If the surfactant adversely affected the retention the surfactant bars on the graph would have been significantly higher than with polymer alone. One can see that there was no significant difference between these results.

The anionic polymer system was then used as a comparison. The Britt Jar was set up identically as before during the cationic polymer trial. The anionic polymer was again added at 0.5, 0.8 and 1.0 lb/ton. Also 20 lb/ton of alum was added before the polymer as a cationic charge to favor adsorption of the polymer onto the fiber surfaces. The results from this trial are shown in table 3 also. The only significant difference noticed was at the 0.5 lb/ton addition rate. A significantly higher amount of fine particles was found at this level. This can also be seen in Fig. 5. The surfactant bar is much higher than the polymer only bar, but at the other two polymer addition rates there

were as no significant differences.

Machine Trial

The last part of this study was to run a trial on the pilot machine to determine if the effects seen in the Britt Jar would also be observed on a paper machine. In this part of the experiment both of the Tergitol surfactants were used along with the defoamer. The addition concentrations of these surfactants is shown in table 4. These are weight percents based on total flow going to the headbox at a production rate of 160 lb/hr at 0.05% consistency.

The first trial on the machine used the 15-S-7 surfactant. Subsequent trials used the 15-S-12 and the Hercules Defoamer surfactants. They were added in the first mix tank which is located just after the basis wt. control valve. The cationic retention aid was added at 1.5 lb/ton at inlet of the fan pump. A higher level of retention aid than used in the Britt Jar, was necessary to obtain high enough retention values on the machine in order to see any differences that might appear due to the surfactant.

The first pass retention was monitored throughout all the trials at each of the concentrations. Samples were taken from the headbox and the first wire pit. 500 ml was filtered and the first pass retentions was calculated. These results are shown in table 5 following this discussion. The table lists the headbox and white water

solids, their respective averages and the standard deviations. A percent retention was then calculated using the averages and is listed in the last column. Figure 6 shows these results graphically. According to the graph the retention did not change significantly. The only differences were about 1.5 percentage points. Comparing the standard deviation of the filtrate weights and the headbox weights proved that the retention differences were not significant (Appendix I).

After the machine trial samples were taken from the reel for tensile tests. The results of these tests are shown in table 6. Ten tests were made at each concentration as shown. The outliers were tested with the Q-test to determine if they could be thrown out. The data listed with an asterisk after it was not used in calculating the average or the standard deviation. A student t-test was also run on this data and it showed that the average tensile readings were significantly different (Appendix II).

Tensile readings were taken as a method to determine if there were small amounts of filler loss that were not detected using the first pass retention method. Because the sheet was so heavily filled the sheet strength was very low. If the sheet lost some of the filler the strength would increase. Fig. 7 shows these tensile results graphically. These results were used for comparison purposes between the different concentrations.

One can see that as the surfactant concentration increased the tensile strength also increased. This indicates that small amounts of filler and fine particles were lost through the wire. One must however keep in mind that these are very small differences which were not even noticed in the first pass retention data. Also one would know that the system was contaminated with these surfactants before retention was adversely affected because they started to foam on the machine. At the second highest concentration there was a significant amount of foam on the machine, and by the time the trial was finished there was about two feet of foam in the wire pit. Therefore foaming on the machine was more of a problem than any retention loss.

The Hercules defoamer did not affect the tensile as much as the other surfactants. As shown in fig 7 the tensile strength went up as some filler was lost, but at the higher dosages the tensile readings also decreased. The strength initially went up as some fines and filler were lost, but as more defoamer was added the surface tension of the water probably went down which affected the sheet strength. Therefore the theory that this defoamer would adversely affect the retention of the papermachine was not seen in this experiment.

CONCLUSIONS

The objective of this thesis was to determine if small amounts of surfactants in the stock would significantly effect the retention on the papermachine. Primary results using the Britt Jar showed that even fairly high addition rates the surfactant did not effect the retention. Subsequent results verified that the shear in the jar, and the retention aids were not masking or interfering with the retention results found in the first experiment. Finally the a pilot machine run was used to see if the results obtained with the Britt Jar would also be confirmed on a papermachine. The results from the papermachine were in good correlation with those obtained with the Britt Jar.

Therefore one can conclude that these non-ionic surfactants did not effect the retention on the papermachine. This disproves previous theories that small amounts of surfactants would effect the retention. Before one would see any retention loss there would be substantial foaming on the papermachine.

A recommendation for further work would be to investigate why at 0.5 lb/ton anionic addition rate there was a significant retention difference.

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Table 1 Effects of Concentration

Settings:

Stirring speed - 500 rpm
Reten 1232 Cationic Polymer @ 0.5#/ton
Consistency in jar - 0.5%

Trials:

Blank - 0.0822g Std: .0021
Polymer Only - 0.0483g Std: .0019

Surfactant Conc.	Weight of Filtrate (g)	Standard Deviation
0.00003%	0.0557	.0009
0.00006%	0.0486	.0013
0.00012%	0.0487	.0021
0.00025%	0.0487	.0019
0.00050%	0.0498	.0006
0.00100%	0.0480	.0021

Table 2 Effect of Shear

Settings

Surfactant: 15-S-7

Polymer: RETEN 1232 Cationic
Added at 1.0lb/ton

Results

	500 RPM	700 RPM
Blank	0.0822g	0.1233g
1 #/t Polymer	0.0252g	0.0441g
15-S-7 @ .001%	0.0289	0.0370
15-S-7 @ .01%	0.0247	0.0154

Std of weights: 0.0030g

Table 3
Effect of Retention Aids

Cationic @ 500 RPM

Addition Rate	Surfactant Run (0.001%)	Blank Run
0.5 lb/ton	0.0461g	0.0483g
0.8 lb/ton	0.0323g	0.0357g
1.0 lb/ton	0.0289g	0.0253g

Std: 0.0020g

Anionic @ 500 RPM

Addition Rate	Surfactant Run (0.001%)	Blank Run
0.5 lb/ton	0.0540g	0.0460g
0.8 lb/ton	0.0297g	0.0274g
1.0 lb/ton	0.0213g	0.0232g

Std: 0.0020g

Table 4
Surfactant Addition Rates

15-S-7

Concentration

A 0.0005%

B 0.0010%

C 0.0020%

D 0.0040%

15-S-12

Concentration

A 0.0013%

B 0.0028%

C 0.0055%

D 0.0110%

Hercules 831 Defoamer

Concentration

A 0.0002%

B 0.0004%

C 0.0008%

D 0.0016%

E 0.0032%

Table 5: Machine Retention Data

15-S-7

	Headbox Solids (g)	Average Std. Dev.	Wht Wtr Solids (g)	Average Std. Dev.	Reten %
0.0005%					
Sample 1	2.10	2.110	0.23	0.230	89.0995260
Sample 2	2.12	0.010	0.21	0.016	
Sample 3	----		0.25		
0.0010%					
Sample 1	2.50	2.393	0.26	0.263	88.9972144
Sample 2	2.30	0.032	0.26	0.005	
Sample 3	2.38		0.27		
0.0020%					
Sample 1	2.20	2.215	0.26	0.263	88.1113619
Sample 2	2.23	0.015	0.28	0.012	
Sample 3	----		0.25		
0.0040%					
Sample 1	2.76	2.733	0.25	0.273	90
Sample 2	2.42	0.246	0.30	0.021	
Sample 3	3.02		0.27		

15-S-12

	Headbox Solids (g)	Average Std. Dev.	Wht Wtr Solids (g)	Average Std. Dev.	Reten %
0.0013%					
Sample 1	2.89	3.007	0.28	0.290	90.3547671
Sample 2	3.32	0.224	0.3	0.008	
Sample 3	2.81		0.29		
0.0026%					
Sample 1	2.16	2.300	0.29	0.287	87.5362318
Sample 2	2.44	0.140	0.27	0.012	
Sample 3	----		0.3		
0.0055%					
Sample 1	2.2	2.233	0.31	0.293	86.8656716
Sample 2	2.3	0.047	0.29	0.012	
Sample 3	2.2		0.28		
0.0110%					
Sample 1	2.23	2.320	0.28	0.270	88.3620689
Sample 2	2.41	0.090	0.26	0.010	
Sample 3	----		----		

Table 5: Continued

	H-Defoam Headbox Solids (g)	Average Std. Dev.	Wht Wtr Solids (g)	Average Std. Dev.	Reten %
=====					
0.0002%					
Sample 1	2.23	2.263	0.27	0.267	88.2179675
Sample 2	2.27	0.025	0.27	0.005	
Sample 3	2.29		0.26		
0.0004%					
Sample 1	2.34	2.260	0.27	0.257	88.6430678
Sample 2	2.3	0.086	0.25	0.009	
Sample 3	2.14		0.25		
0.0008%					
Sample 1	1.97	2.013	0.23	0.247	87.7483443
Sample 2	1.97	0.061	0.25	0.012	
Sample 3	2.1		0.26		
0.0016%					
Sample 1	2.22	2.197	0.25	0.260	88.1638846
Sample 2	2.15	0.033	0.27	0.010	
Sample 3	2.22		----		
0.0032%					
Sample 1	2.01	2.070	0.2	0.205	90.0966183
Sample 2	2.13	0.049	0.21	0.005	
Sample 3	2.07		----		

Contol

	Headbox Solids (g)	Average Std. Dev.	Wht Wtr Solids (g)	Average Std. Dev.	Reten %
=====					
Sample 1	2.02	2.015	0.22	0.220	89.0818858
Sample 2	2.01	0.005	0.22	0.000	
Sample 3	----		0.22		

Table 6: Tensile Data

	Control	15-S-7 A	15-S-7 B	15-S-7 C	15-S-7 D
	=====	=====	=====	=====	=====
	2.25*	2.62	2.25	2.09*	2.45
	2.90	2.66	2.44	2.38	2.45
	2.90	2.72	2.69	2.67	2.68
	2.91	2.80	3.00	3.45	3.39
	3.02	2.82	3.20	3.51	3.60
	3.08	2.86	3.20	3.67	3.71
	3.09	3.00	3.21	3.79	3.85
	3.25	3.14	3.21	4.00	3.90
	3.31	3.20	3.31	4.01	3.95
	3.51	3.40	3.40	4.44*	4.01
Average	3.11	2.92	2.99	3.44	3.40
Std	0.20	0.24	0.37	0.56	0.60
Breaking length (km)	2.50	2.35	2.40	2.77	2.73
	15-S-12 A	15-S-12 B	15-S-12 C	15-S-12 D	
	=====	=====	=====	=====	
	1.85*	3.01	2.29*	3.35	
	2.08*	3.38	3.10	3.75	
	2.80	3.42	3.38	3.79	
	3.05	3.51	3.42	3.81	
	3.20	3.78	3.62	3.82	
	3.20	3.90	3.72	3.89	
	3.34	4.05	3.74	4.00	
	3.35	4.05	3.78	4.12	
	3.41	4.10	3.89	4.22	
	3.50	4.21	3.95	4.48	
Average	3.23	3.74	3.62	3.92	
Std	0.21	0.37	0.26	0.29	
Breaking length (km)	2.60	3.00	2.91	3.15	
	Herc A	Herc B	Herc C	Herc D	Herc E
	=====	=====	=====	=====	=====
	1.2*	3.32	2.89	3.08	2.60
	2.74	3.35	3.00	3.09	2.62
	2.82	3.49	3.02	3.20	2.80
	3.22	3.50	3.10	3.25	2.88
	3.29	3.52	3.10	3.38	2.90
	3.35	3.56	3.11	3.50	3.00
	3.41	3.62	3.11	3.58	3.20
	3.42	3.80	3.15	3.59	3.35
	3.58	3.82	3.41	3.75	3.38
	3.75	3.85	3.49	3.82	3.45
Average	3.29	3.58	3.14	3.42	3.02
Std	0.31	0.18	0.17	0.25	0.30
Breaking length (km)	2.64	2.88	2.52	2.74	2.43

Figure 1: Britt Jar Diagram

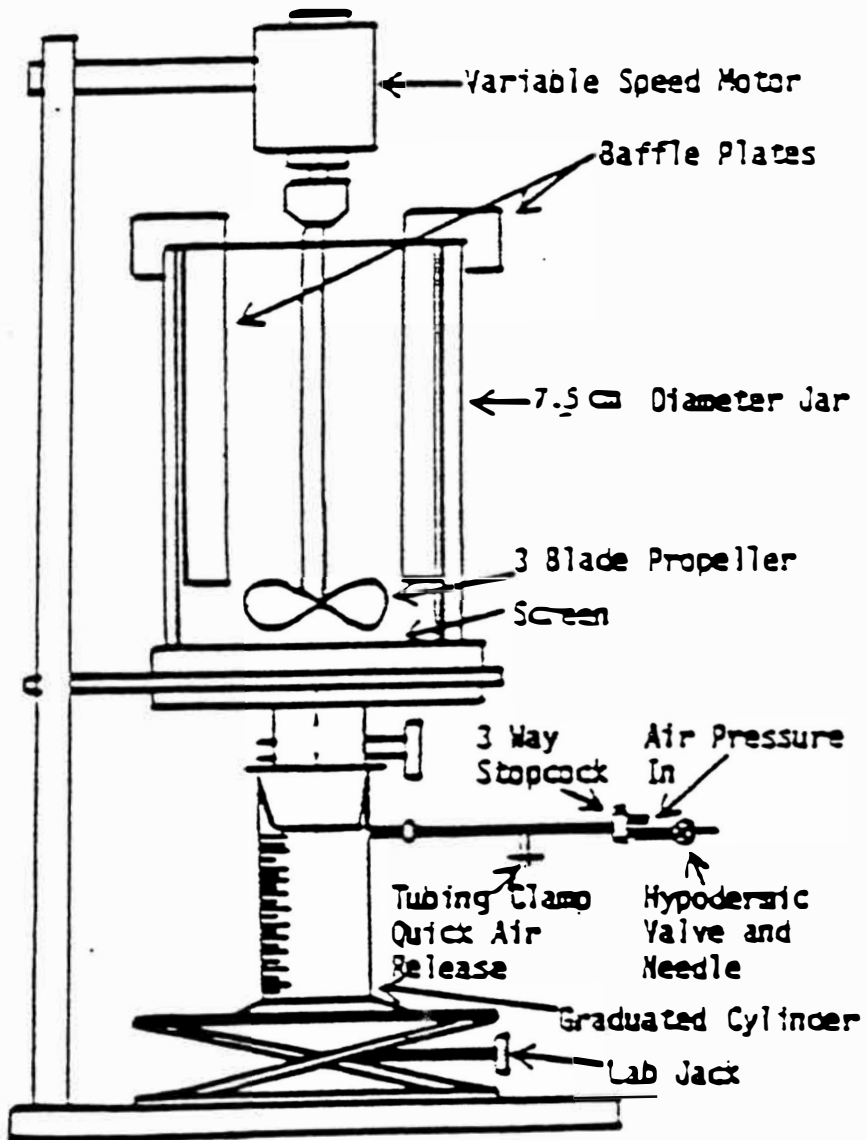


Figure 2:
Effect of Concentration

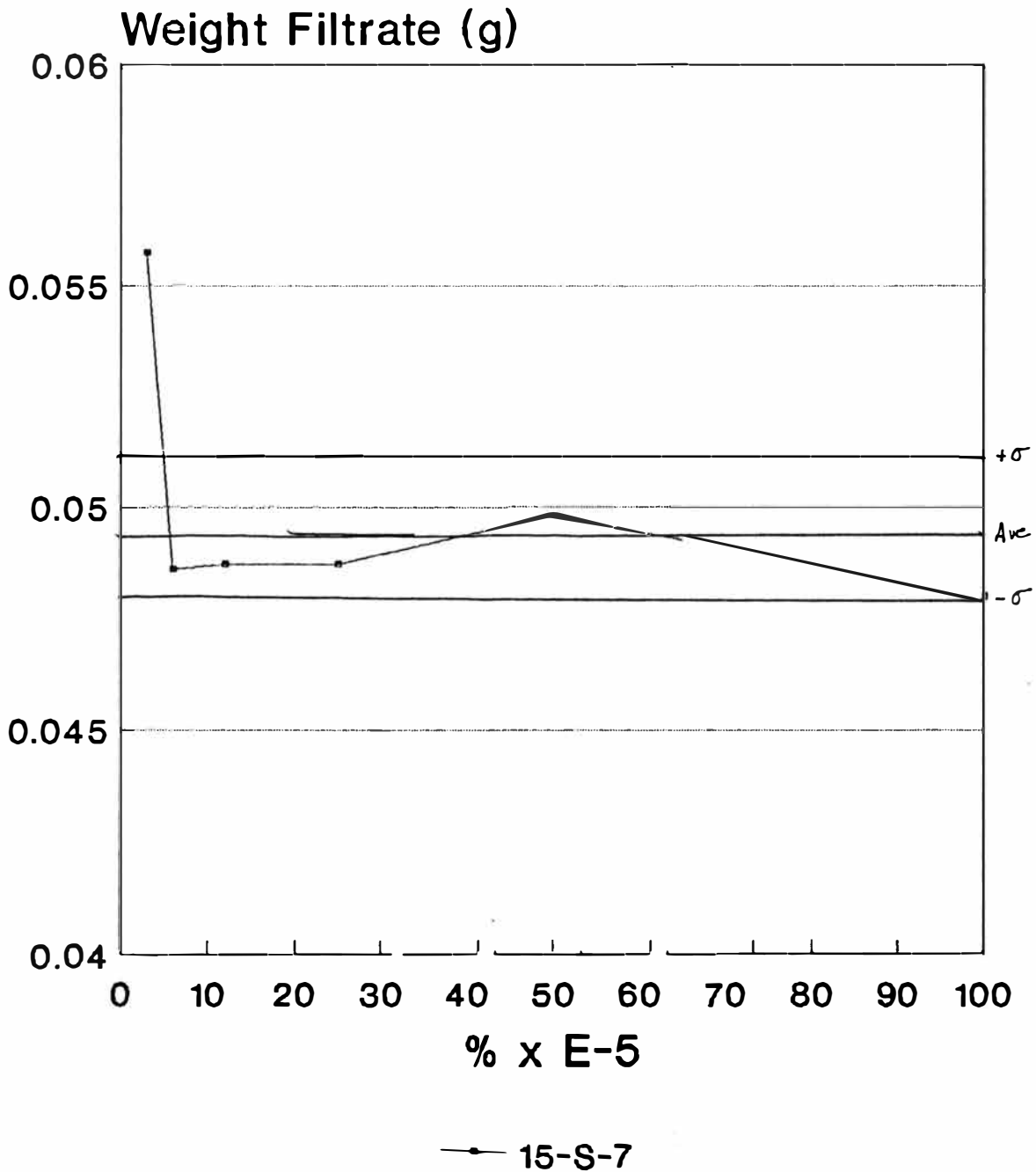


Figure 3:
Effect of Shear

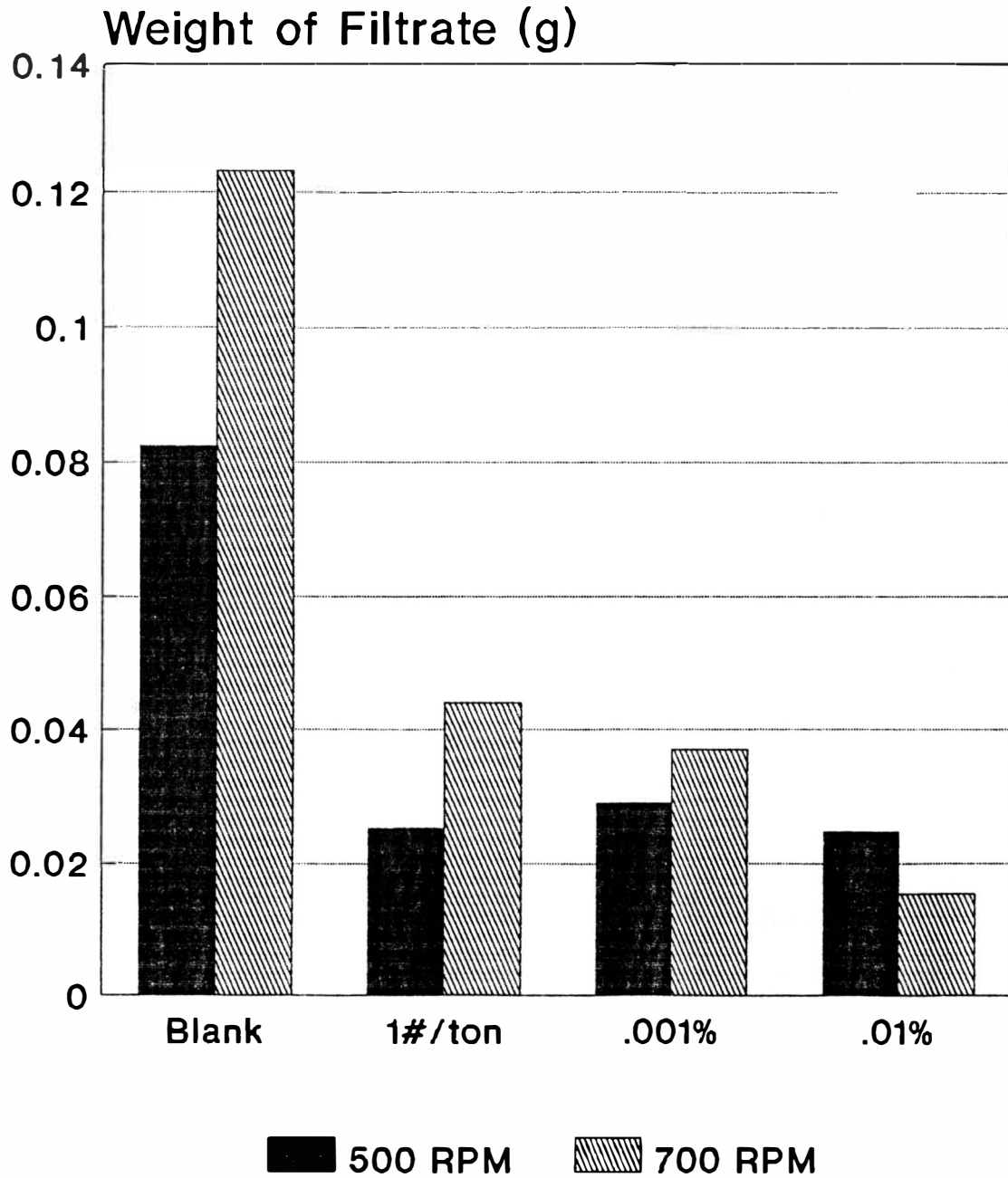


Figure 4:
Effect of Cationic Aid

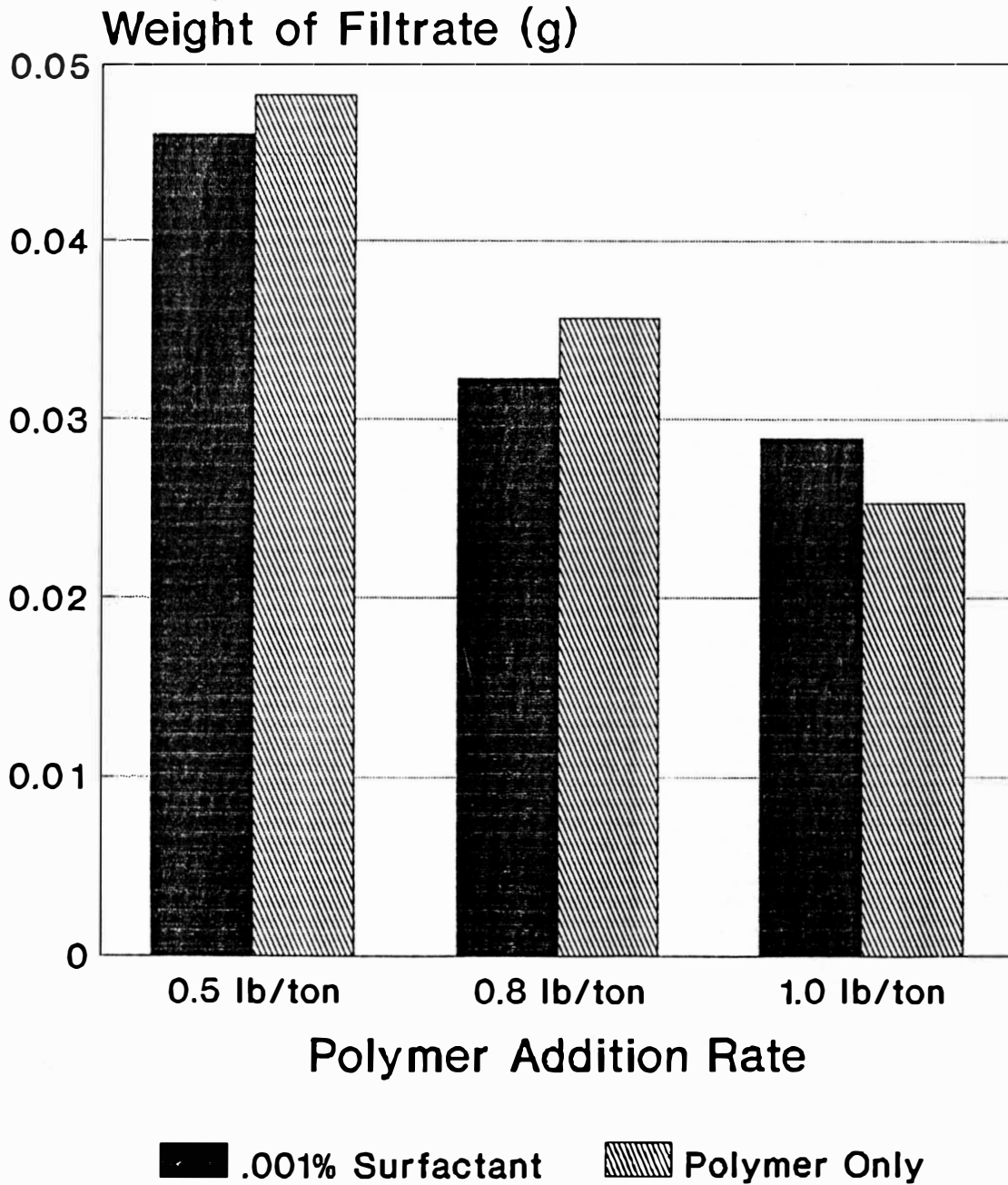


Figure 5:
Effect of Anionic Aid

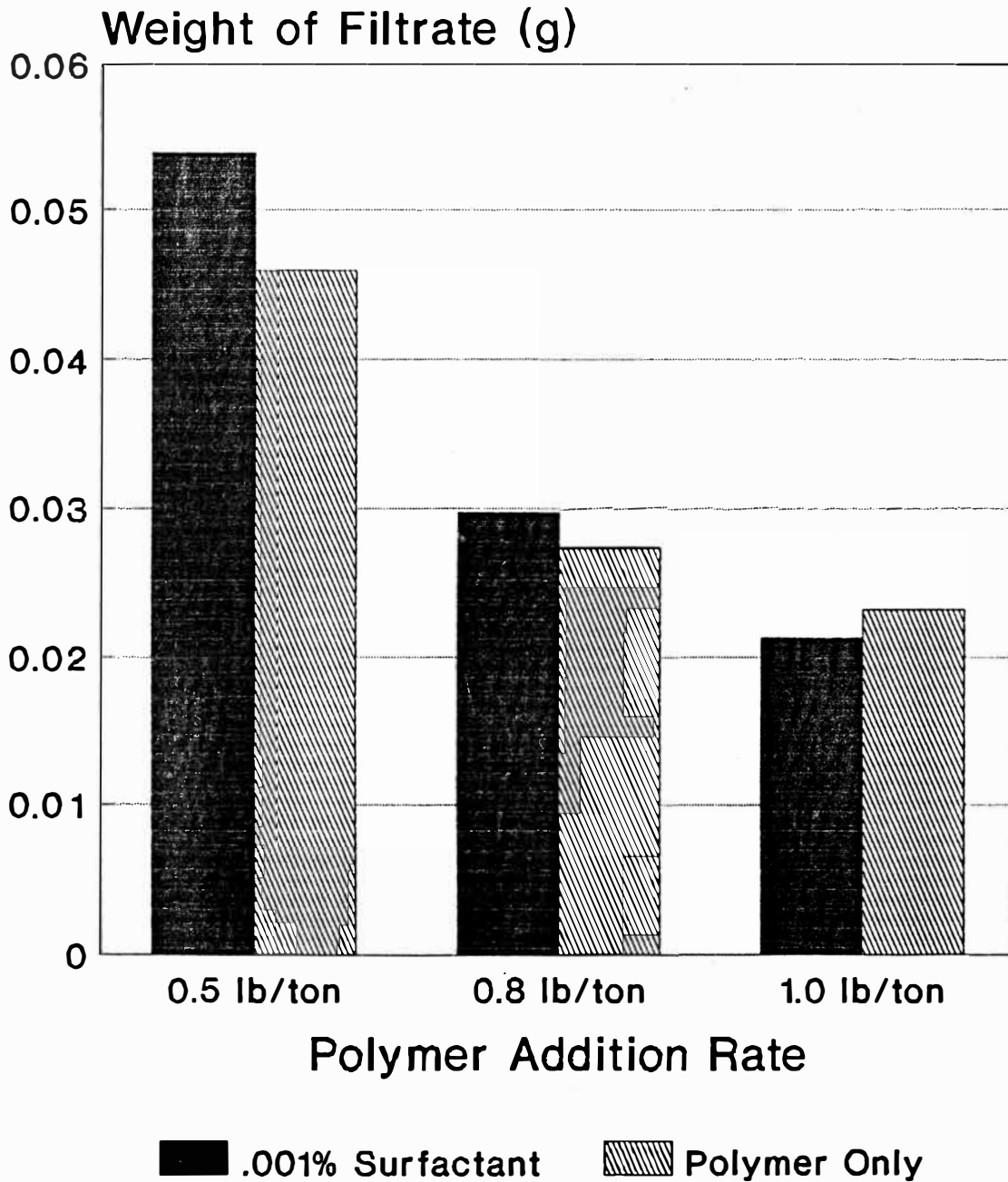


Figure 6: Retention vs. Surfactant Concentration

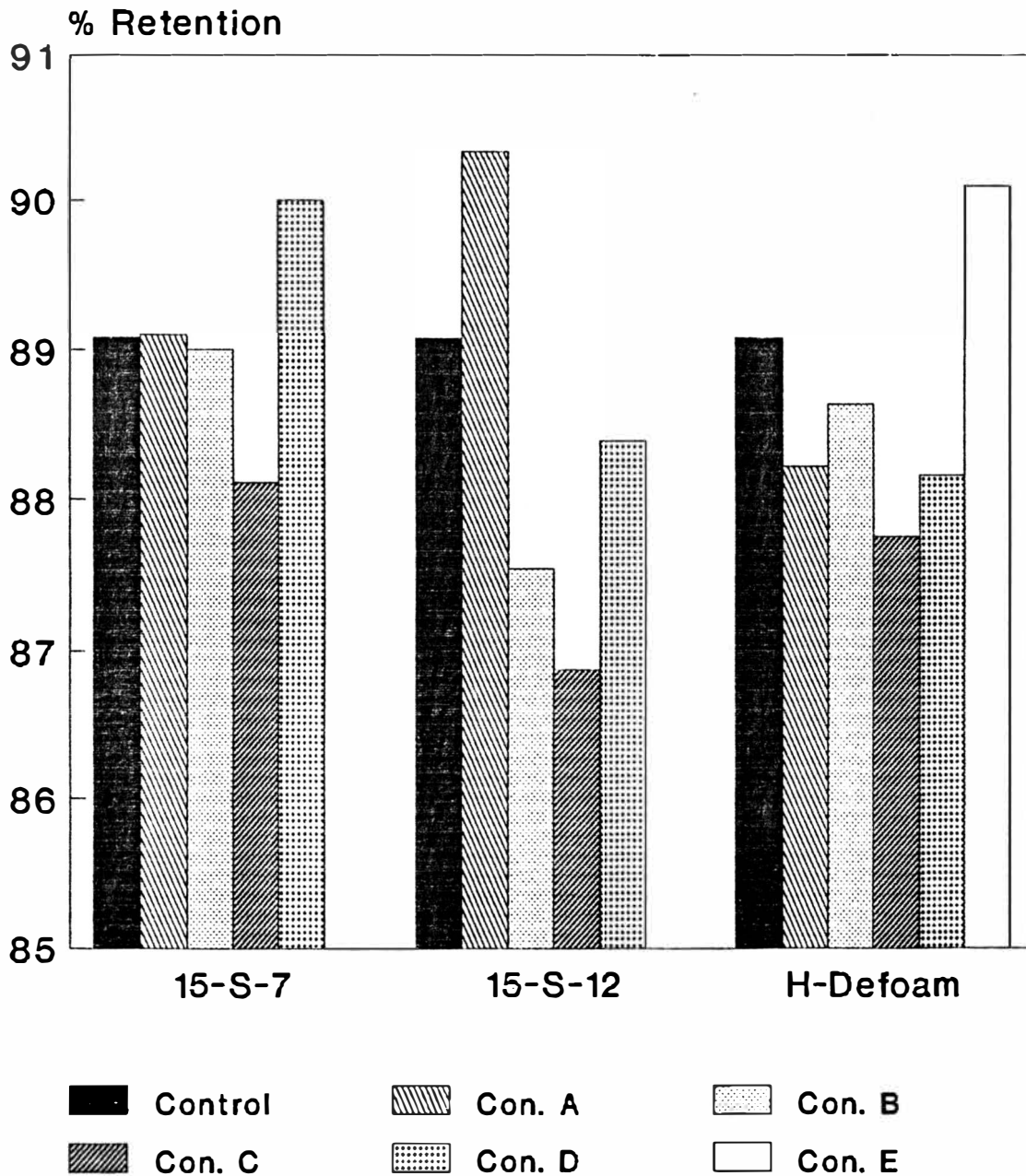
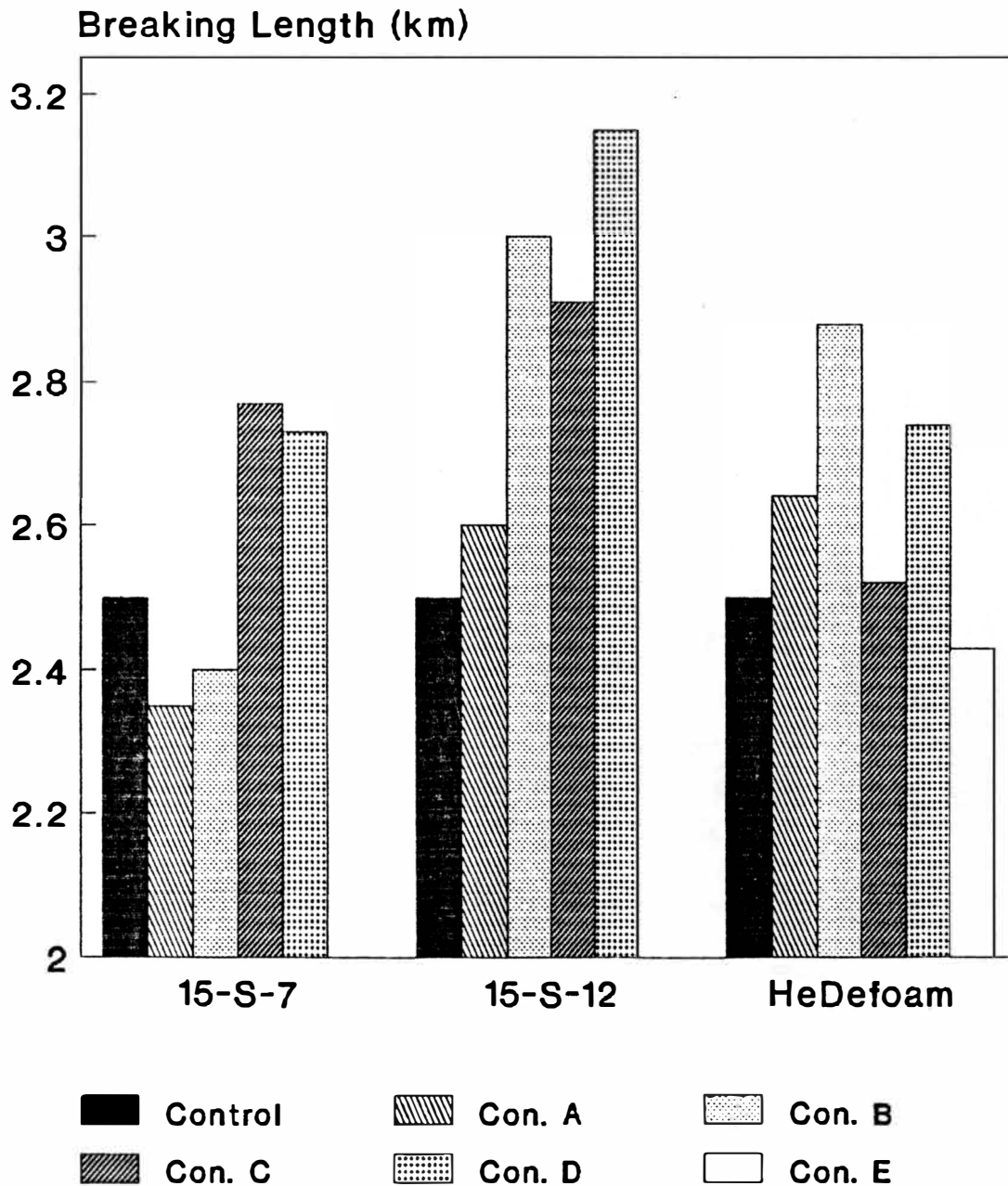


Figure 7: Breaking Length Vs. Surfactant Concentration



APPENDIX I
RETENTION CALCULATION

15-S-7:

$$\frac{2.110 \pm 0.10g - 0.230 \pm 0.16g}{2.110 \pm 0.10g} \times 100 = 89.09\% \pm 6.34$$

0.0005% 89.09 ± 6.34

0.0010% 88.99 ± 3.44

0.0020% 88.11 ± 4.21

0.0040% 90.00 ± 3.28

15-S-12

0.0013% 90.35 ± 7.2

0.0026% 87.53 ± 6.5

0.0026% 86.86 ± 4.2

0.0110% 88.36 ± 4.4

Defoamer

0.0002% 88.22 ± 1.8

0.0004% 88.64 ± 4.6

0.0008% 87.74 ± 5.2

0.0016% 88.16 ± 3.6

0.0032% 90.10 ± 3.0

Control 89.08 ± 0.5

APPENDIX II
STUDENT T-TEST
EXAMPLE CALCULATION

\bar{x} = Control

\bar{y} = 15-S-7 Concentration 0.0005%

$$\bar{x} - \bar{y} \pm z \sqrt{(\alpha/2) \left(Sx^2/n + S\bar{y}^2/n \right)}$$
$$3.11 - 2.92 \pm 2.28 \sqrt{0.20^2/10 + 0.24^2/10}$$
$$.19 \pm .23$$

The range encompasses zero, therefore the averages are statistically different.