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Rotary Precoat Filtration Of Sludge From Acid Mine Drainage Neutralization

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Rotary Precoat Filtration
Of Sludge From
Acid Mine Drainage Neutralization

by

Johns-Manville Products Corporation
Research & Engineering Center
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for the

Commonwealth of Pennsylvania
Coal Research Board

and

Water Quality Office
Environmental Protection Agency

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ABSTRACT

Rotary vacuum precoat filtration was investigated as a means for dewatering sludge produced by the neutralization of mine drainage at four locations in Pennsylvania during 1969 and 1970.

The process used at these sites consisted of neutralization, aeration, sedimentation, and filtration. The alkalies investigated were limestone, limestone with hydrated lime, calcined magnesite, partially and fully calcined dolomite, and hydrated lime. Filter aids tested included HYFLO ® SUPER-CEL ®, CELITE ® 501, CELITE 503, and CELITE 545. Work at the first three locations indicated that limestone and hydrated lime were the preferred alkalies and that CELITE 501 was the preferred filter aid.

A more extensive program was conducted at the fourth site. A 27 run factorial experiment was conducted investigating the effect of flow rate, limestone feed level, aeration level, and sludge recirculation on equipment operation and on process cost. The significant variables affecting process cost were found to be sludge solids content, the filtration rate, and sludge recirculation. A detailed economic analysis of the process is included in the report.

This report was submitted in fulfillment of Project No. 14010 DII under the sponsorship of the Water Quality Office, Environmental Protection Agency and the Commonwealth of Pennsylvania Coal Research Board.

Key Words: Mine Drainage, Neutralization, Lime, Limestone, Sludge, Rotary Precoat Filtration, Dewater, Economics, Pennsylvania.

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SECTION I

CONCLUSIONS

1. The sedimentation and filtration unit processes were found to be the major factors contributing to treatment costs for systems using chemical neutralization followed by solids concentration and dewatering via rotary vacuum precoat filtration.

2. The optimum economic system design for a given chemical process can be found by optimizing the individual unit processes with the exception of the sedimentation and filtration processes. Due to the interaction between these processes, they should be considered as a single unit process in optimizing the design of the system.

3. The use of polyelectrolytes appeared to offer an economic means of increasing sludge concentration, thereby reducing the sludge volume and the respective filtration costs.

4. The presence of unreacted limestone appeared to enhance the settleability and filterability of the sludge.

5. Chemical neutralization with a combination of limestone and lime offers a definite cost advantage over lime alone and operational advantages over limestone alone.

6. Production of a fine limestone slurry by attrition of rock in a wet mill on-site appeared to be the most economical method for feeding limestone.

7. Optimum conditions for operation of the rotary vacuum precoat filter are a drum speed of one revolution per minute, 30 per cent submergence, a CELITE 501 precoat, and a knife advance of 0.001 inches per drum revolution.

SECTION II

RECOMMENDATIONS

The tests were inconclusive in determining the optimum chemical addition levels for treatment of mine drainage with limestone and lime in a combined process. There was also a degree of uncertainty in the optimization calculations for design of the sedimentation and filtration equipment. It is recommended that a designed experimental program to evaluate relationships between limestone dosage, lime dosage, sludge settling rates as a function of solids concentration, and filtration rates as a function of solids concentration be undertaken to confirm and expand on the relationships developed under this program. This could be accomplished on a bench-scale using batch operations. The data could be analyzed using the computerized design and cost estimating techniques developed under this program to optimize the important variables in the limestone-lime neutralization process.

SECTION III

INTRODUCTION

The discharge of acidic waters containing high concentrations of ferrous iron has resulted in a serious pollution problem in numerous streams and other waterways in Appalachia. The polluted conditions of these discharges from both active and inactive coal mining operations is caused by the oxidation of sulfur-bearing minerals, primarily the pyrites associated with most coal seams, in the presence of water to produce sulfuric acid. The acid subsequently dissolves minerals with which it comes in contact resulting in a highly mineralized acidic discharge. The acid present can be disastrous to living matter in the streams as evidenced by the massive fish kills in recent years. The Environmental Protection Agency and the Commonwealth of Pennsylvania, as part of their programs to investigate techniques of mine drainage pollution abatement, have jointly sponsored a project undertaken by Johns-Manville Products Corporation to develop and optimize chemical techniques in conjunction with sludge dewatering via rotary vacuum precoat filtration for the treatment of coal mine drainage.

The treatment of this type of waste involves four unit operations: Neutralization, aeration, sedimentation, and sludge dewatering or concentration. The neutralization step is accomplished via addition of one or more chemical alkalies to the discharge water in an agitated vessel. Aeration is used to promote the oxidation of ferrous iron to the more readily precipitated ferric state. Sedimentation removes the precipitated iron from the discharge resulting in two streams, an overflow of quality acceptable for discharge to waterways and a concentrated underflow. The underflow is then further concentrated by dewatering on a rotary vacuum precoat filter so that the solids may be disposed of in an acceptable manner such as by use in land fill operations.

Chemical alkalies are used to neutralize the sulfuric acid present in the discharges as well as the acidity resulting from the hydrolysis reactions of ferrous and ferric iron. Since both of the hydrolysis reactions are equilibrium reactions, it is essential to neutralize the generated acidity to promote the continued formation of the iron hydroxides. It has been reported[1] that ferric hydroxide will form at a pH of around 5.5 whereas ferrous hydroxide does not form until a pH of 9.5 to 10 is reached. The range of acceptable pH for discharge in Pennsylvania is 6 to 9. Aeration is therefore utilized to oxidize the ferrous iron to ferric resulting in precipitation of the iron at a lower pH so that the standards for iron (less than 7 mg/l) and pH can be met.

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[1] These references refer to the bibliography.

One of the most common methods for removal of solids from liquid streams is sedimentation. Unfortunately, sedimentation equipment often performs unsatisfactorily due to failure to consider all of the fundamental factors involved in designing the system. Poor design gives rise to the problem of solids escaping with the effluent. In the cylindrical clarifier/thickener utilized during the test work, the major difficulties encountered were with uniform flow distribution and upflow velocities exceeding the settling rate of the solids. When the latter condition exists, the solids are carried over with the overflow.

The rotary vacuum precoat filter (Figures 1 and 2) is a modification of the rotary vacuum filter that combines the feature of almost continuous operation while eliminating the primary maintenance difficulty of a plugged filter septum. In operation, a thick precoat of filter aid, two to four inches thick, is applied from clean liquid to the surface of the filter drum. Once the precoat is in place, the precoating liquid is displaced from the filter bowl by the sludge to be filtered. The drum is continuously rotated with from 30 to 50 per cent of the surface submerged in the sludge. As the drum rotates, three phases of operation are performed during each revolution. These are solids deposition, solids dewatering, and solids removal. The solids are deposited by straining action as the liquid is drawn through the precoat into the vacuum system. As the drum rotates out of the sludge, air is drawn through the solids and the precoat dislodging the water from the deposited solids. A knife controlled by an automatic advance mechanism removes the solids along with a small amount of the precoat on each revolution of the drum, thus exposing a clean surface for filtration. This type of filter can handle extremely difficult filtration problems because of the features of continuous solids removal and exposure of a fresh surface of the precoat on each revolution of the drum.

Pilot Plant System

The pilot plant treatment system was fabricated from the following equipment:

1. The U.S. Bureau of Mines' 4-foot diameter by 24-foot long tube mill[2] which was used to produce a fine limestone slurry from one-half inch to two inch rock. This mill is shown in Figure 3.

2. The Pennsylvania Department of Environmental Resources' Operation Yellowboy Trailer. This trailer contains a variable capacity feed pump, a 50-gallon flash mixer with agitator and screw feeder, a 1200-gallon agitated aerator tank with a 17-cfm blower-sprayer unit, a 1000-gallon thickener, and a variable speed sludge recycle/discharge pump.

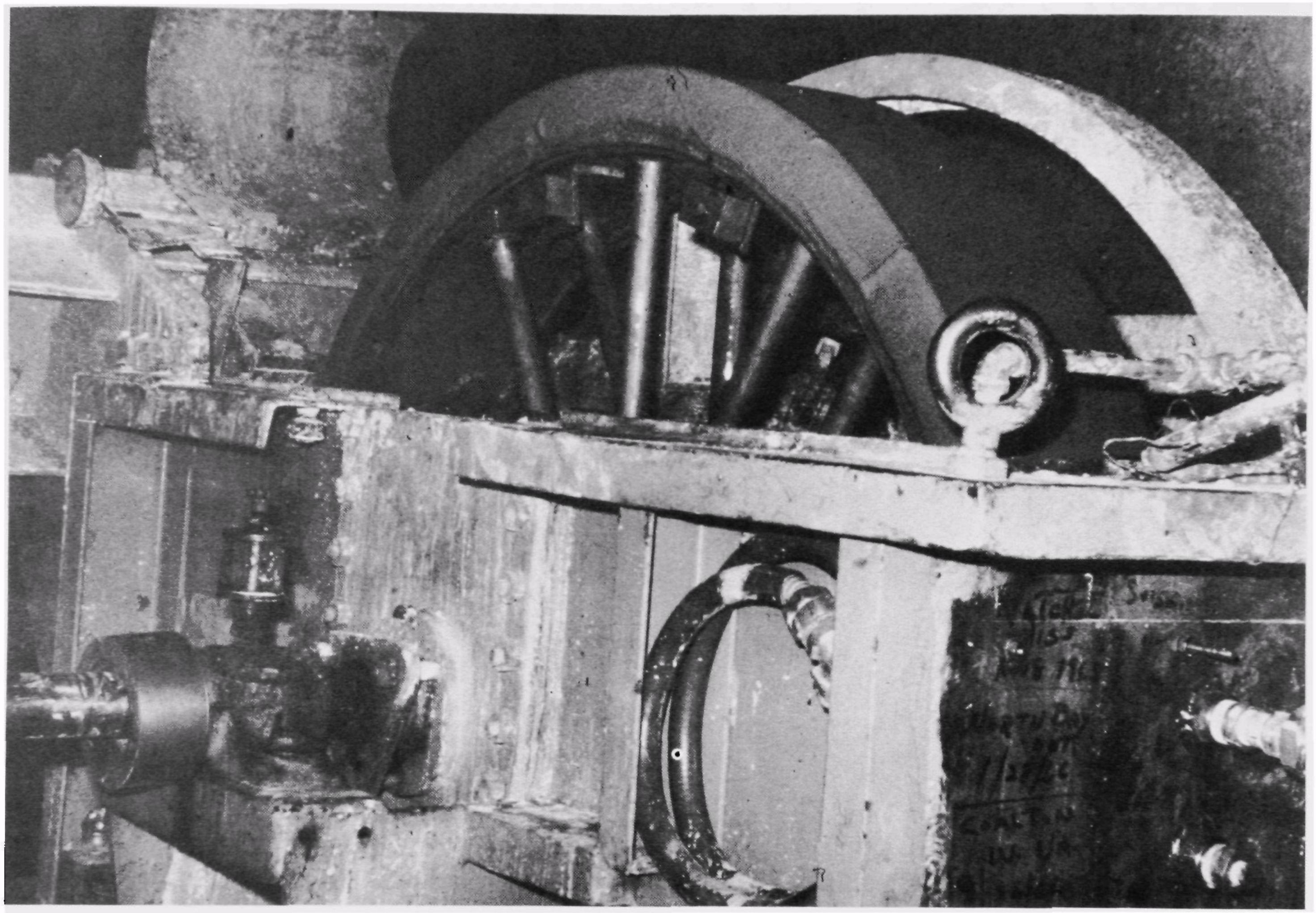

FIGURE 1 — ROTARY PRECOAT FILTER

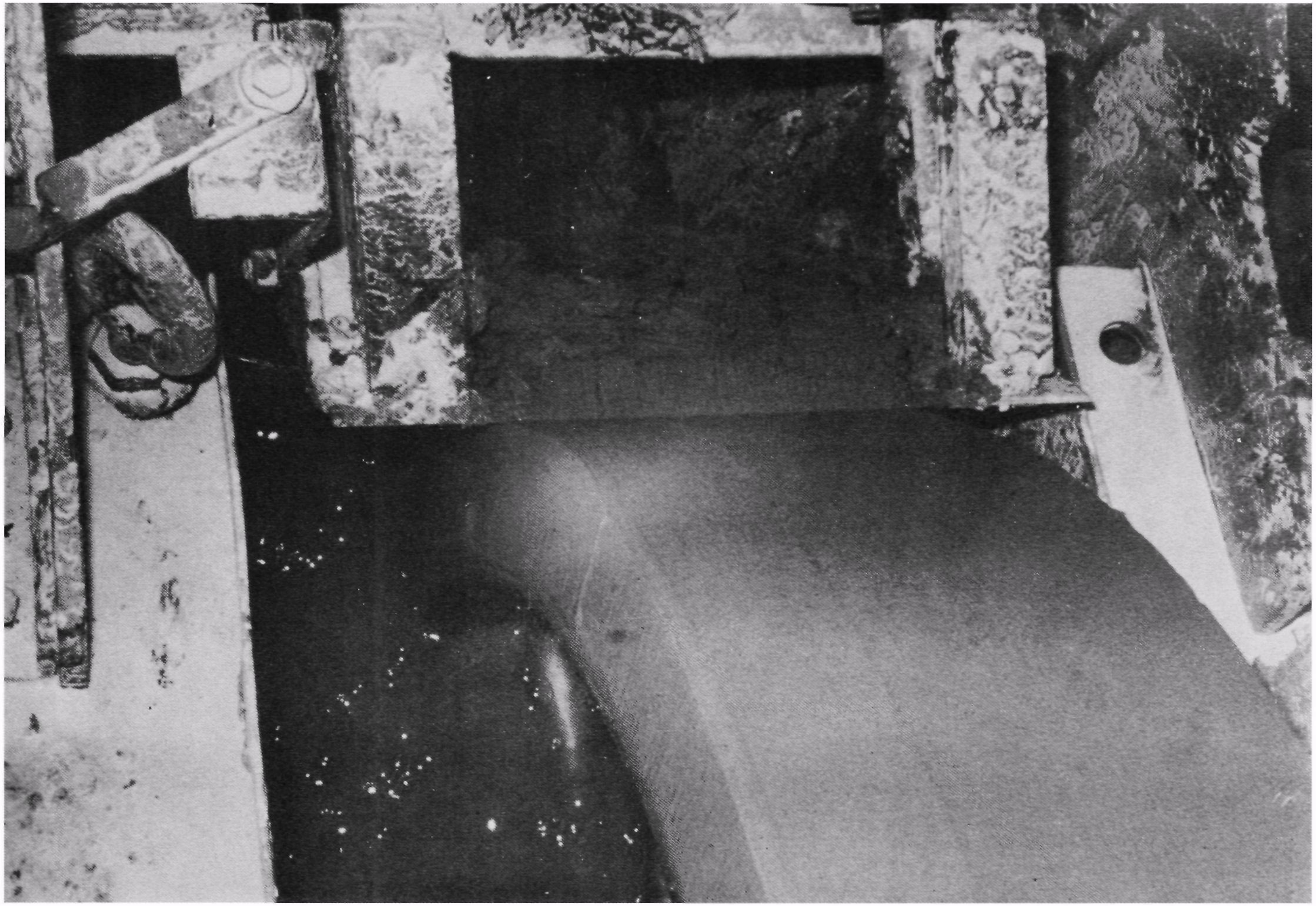

FIGURE 2 — ROTARY PRECOAT FILTER - CUTTING

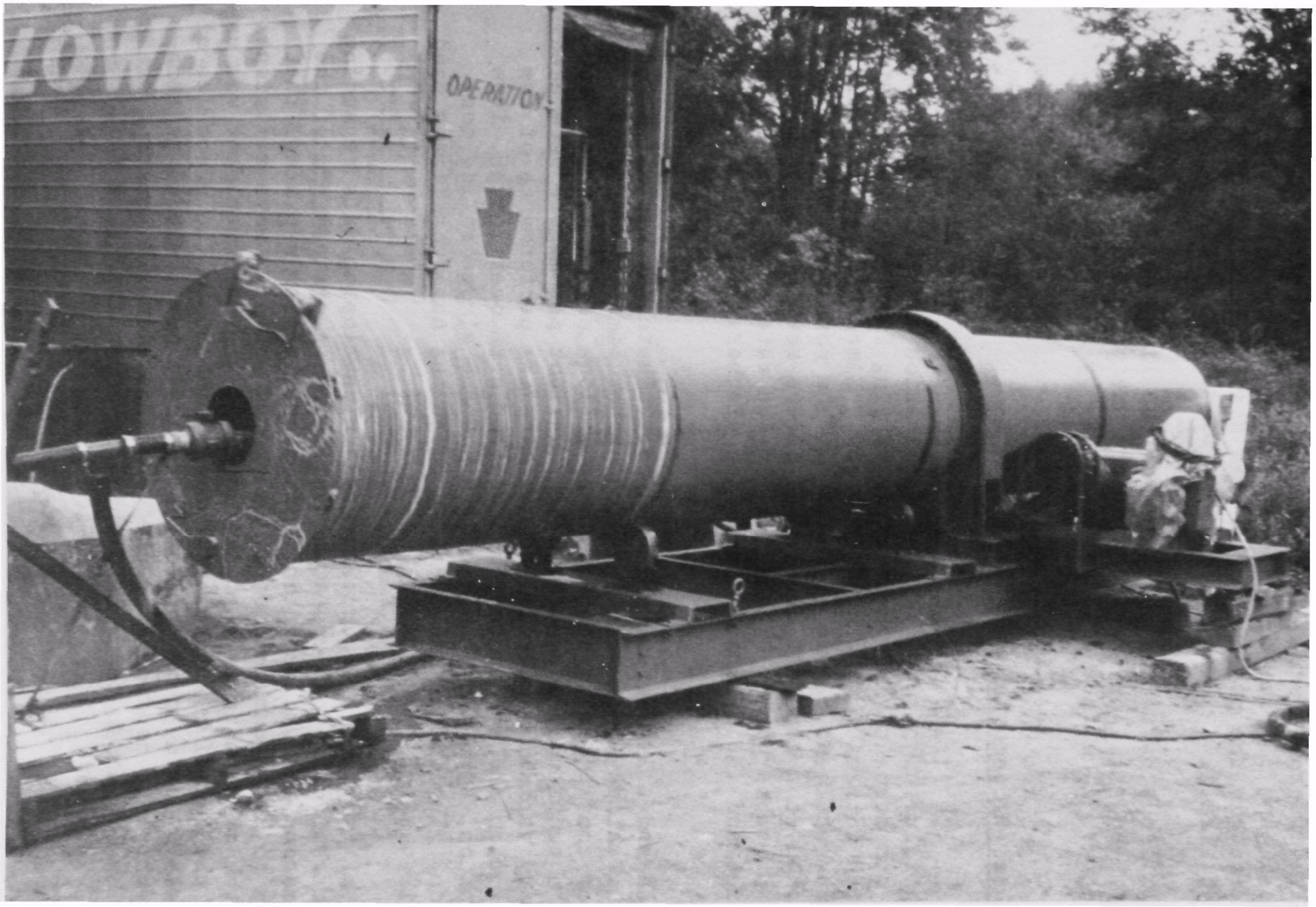

FIGURE 3 – TUBE MILL

3. Johns-Manville's 6-inch face by 36-inch diameter rotary vacuum precoat filter with a variable speed drum drive, variable speed knife advance and 30 and 50 per cent submergence ports in the filter bowl.

A flow diagram of this system as set up at the first three sites is presented in Figure 4. In an attempt to increase the limestone efficiency, a slightly different setup was used at the fourth site. This is presented in Figure 5. The theory behind this was to allow the limestone time to react in the presence of a high acidity before adding the additional alkali.

All alkali feeds, with the exception of the limestone slurry, were made using dry feeders. The limestone slurry was produced by attrition of limestone rock in a tube mill as described by E. A. Mihok et al.[2]

Experimental Procedures

The work at the first site was limited to production of sludge for use in making filtration runs. The neutralization and sedimentation equipment was operated at throughput rates varying from 10 to 30 gallons per minute with intermittent sludge draw off. Limestone addition was adjusted so that the effluent pH was at least 7. The rotary vacuum precoat filter was operated at a constant drum speed of one revolution per minute with 50 per cent submergence. The knife advance rate and filter aid grade were varied and the filtration rate and discharge cake solids content measured.

The second and third sites were used to evaluate the use of different chemical alkalies in combination with either limestone or lime. Constant flow conditions consisting of 20 gallons per minute raw flow rate and a continuous sludge draw of 2 gallons per minute were used. The primary variables measured to evaluate the performance of the neutralization and sedimentation equipment were overflow pH, iron concentration, turbidity, and acidity and the sludge solids concentration. The filter was operated under the same conditions used at the first site.

The work at the last site concentrated on developing data regarding the effects of different operating variables on performance of the neutralization and sedimentation unit processes for a process that attempted to use a combination of limestone and lime more efficiently than at the other sites. A statistically designed experiment was used to study the relative effects of these variables on the economics of the process. During this portion of the test work, sludge filterability tests were conducted on the Johns-Manville 0.1 square foot rotary vacuum precoat test leaf, which is shown in Figure 6.

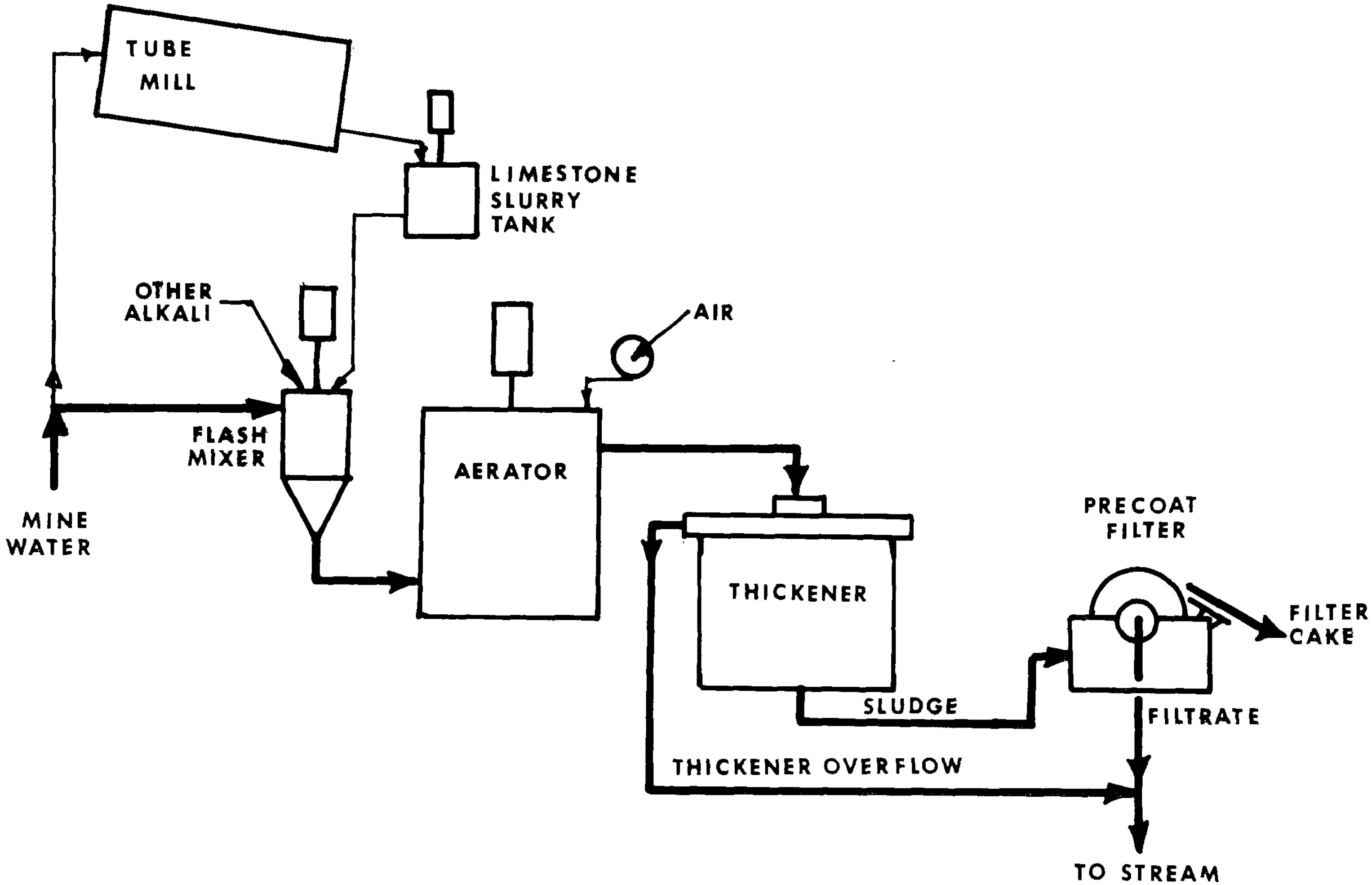

FIGURE 4 - ORIGINAL SYSTEM

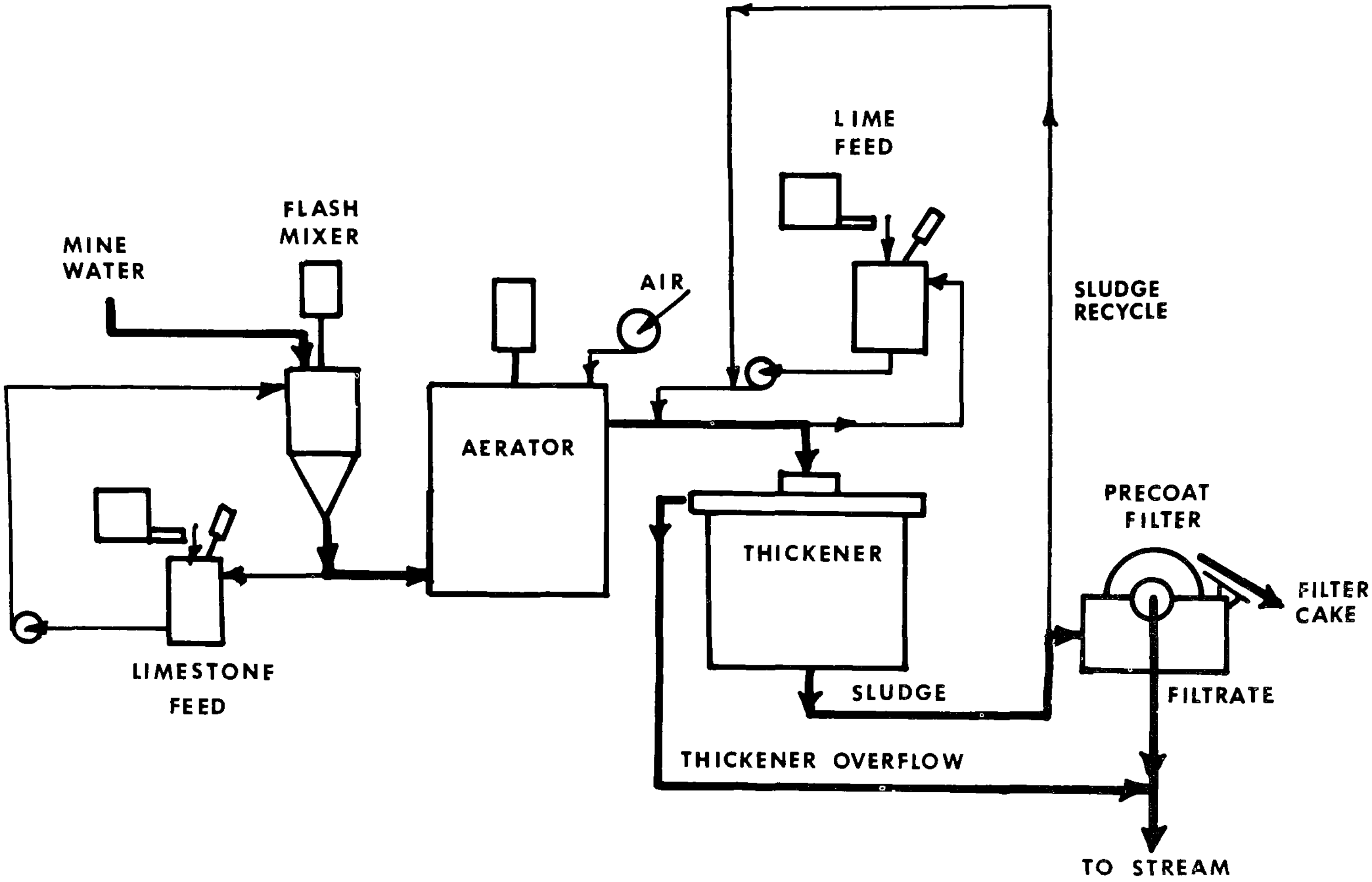

FIGURE 5 - PROCTOR 2 SYSTEM

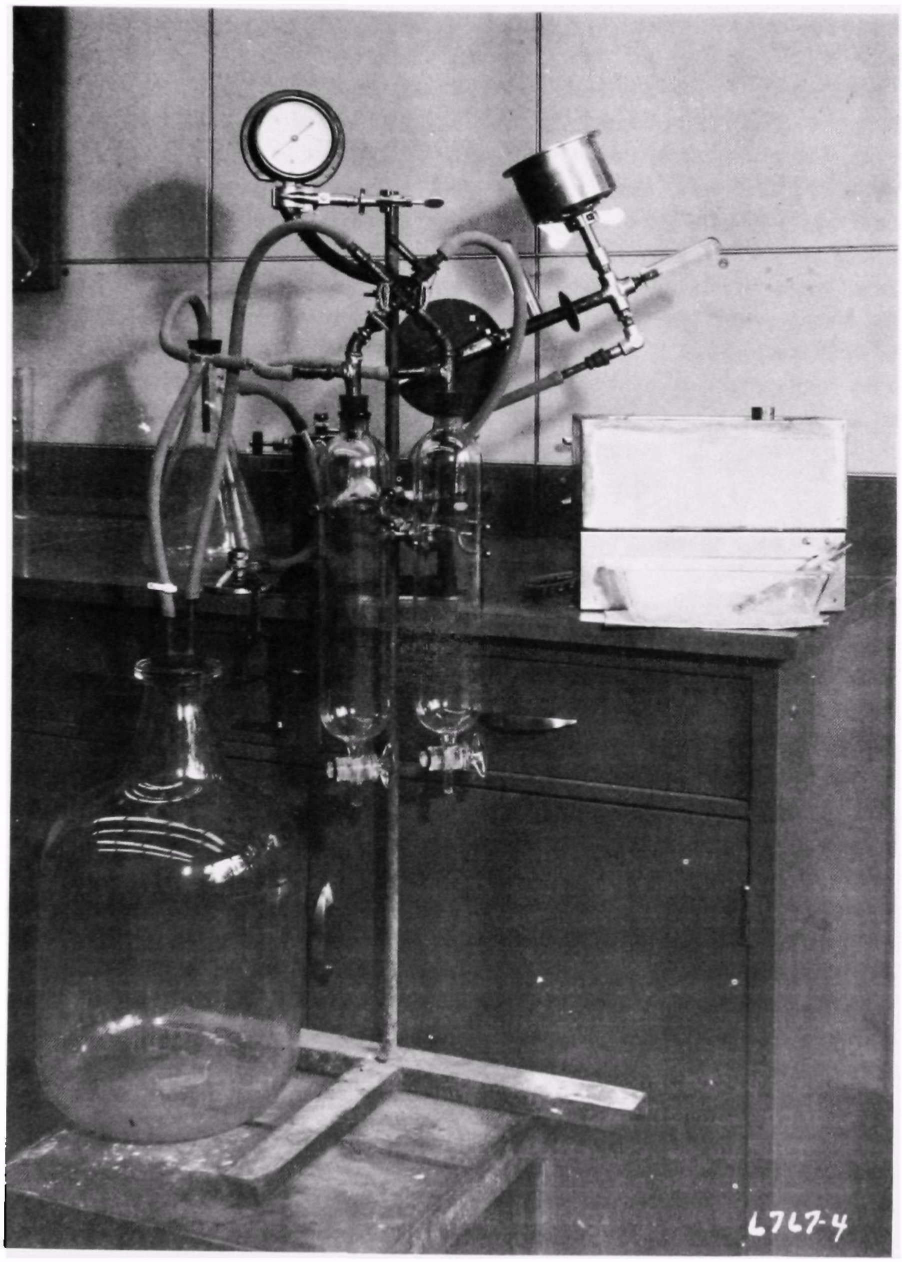

FIGURE 6 - PRECOAT TEST LEAF

The filtration work at this last site was expanded to evaluate the effects of varying drum speed at both 30 and 50 per cent submergences. CELITE 501 was used for precoating and the knife advance rate was varied at all conditions.

Detailed analysis of the results obtained at each of the sites are presented in Appendixes A through D. Appendix E describes the results of economic analysis that were made for the different processes.

SECTION IV

DISCUSSION

The use of limestone in neutralization of the acidity in mine water appears to offer advantages to the economics of treatment. The benefits are derived from the lower cost of limestone as compared with lime and the better settling and filtration characteristics of solids containing unreacted limestone. There are also some disadvantages that may actually result in higher costs. These must be taken into consideration when designing a treatment system using limestone. Limestone is an extremely inefficient neutralizer. Tests indicate that only about 35 per cent of the limestone is actually reactive in neutralizing mine water. There has been work done[3] that has shown that the efficiency of limestone is dependent on particle size, calcium and magnesium content, and surface area. The above efficiency was based on a slurry with a volume average diameter of 6 microns. Use of a commercially available pulverized limestone with a volume average diameter of 46 microns gave an efficiency of 25 per cent. The use of finer limestone is therefore desirable based on operating criteria. However, the costs of reducing the particle size can result in a material costing more than lime. The use of on-site production of a fine limestone slurry from rock in some sort of wet mill appears to be the most economical method of supply.

The use of an additional alkali with limestone such as lime or magnesite to produce higher final effluent pH's also appeared to improve the settleability characteristics of the solids without adversely affecting the filtration characteristics. The main objective of the preliminary work had been to replace a portion of the excess limestone with the additional alkali. Since the costs did not appear to be overly increased, further optimization of the ratio of limestone and other alkali resulting in better economics was a possibility. Typical estimated operating costs are given in Table I. A statistically designed experiment was utilized to attempt to define the effects of various operating variables on the economics of a limestone and lime process. Unfortunately, the effects of either limestone or lime dosages were found to be insignificant for the system studied because of the high costs of the filter installation and operation. The results of these tests are further described in Appendix D. The indication of the significant part played by filtration in the economics of the treatment system places considerably importance on optimizing this unit process.

CELITE 501 was the best suited filter aid grade based on tests run at three of the four sites. A typical comparison is given in Table II. No comparative tests were conducted at the fourth site. The optimum knife advance in all cases was in the range of 0.0010 to 0.0015 inches

TABLE I

Typical Operating Costs
for a 1.5 MGD Plant

Neutralization	Cost per 100 lb Acidity
Lime	\$8.00
Limestone-Lime	\$5.30-\$6.50+
Limestone	\$5.00-\$5.20*

+Depends on ratio used. Lower figure is based on process used at Proctor 2.

*Quality of effluents is questionable.

TABLE II

Typical Flow Rates
for Various Filter Aids

Filter Aid Grade	Knife Advance mil/min	Flow Rate gsfm
HYFLO	1.3	0.58
CELITE 501	1.3	0.60
CELITE 503	1.3	0.55
CELITE 545	1.3	0.55

per drum revolution. In comparing the differences between operation at 50 and 30 per cent submergences, it must be considered that a 20 per cent savings on equipment cost will be realized with the 30 per cent submergence unit. In addition, the cost to maintain the seals on a 50 per cent submergence unit will represent a significant cost factor. For these reasons, most filter manufacturers do not recommend the use of a 50 per cent submergence unit. The economics of lower capital cost and higher filter aid requirements appear to be offsetting. Consequently, the use of a 30 per cent submergence unit with a knife advance of 0.001 inches per revolution and a CELITE 501 precoat appears to offer the best performance.

The factors that would govern the size of the filter unit should also be considered. The data obtained at the last site indicated a somewhat inverse linear relationship between filtration rate and solids concentration of the sludge. For a given feed concentration, the higher solids concentrations are associated with lower sludge volumes. An optimization calculation indicated that a solids concentration of 1.1 per cent resulted in the least cost. However, as indicated in Appendixes D and E, when the cost of a thickener to produce the desired sludge concentration is also considered, the optimum concentration becomes considerably reduced. This thus places that major responsibility for the bulk of the economics of treatment on both the sedimentation and dewatering processes. Optimization of one cannot be attempted without considering the effects on the other. Some techniques that could be useful in reducing the costs of treatment would be the use of polyelectrolytes to aid in the thickening of the sludge. A run conducted at the last site using a polyelectrolyte significantly increased the sludge solids concentration. The filterability of the sludge did not contradict the characteristics that would be expected if no polyelectrolyte were used. The use of a multiple step clarification and thickening process may also offer an economic solution.

The type of neutralization process utilized may also have an effect on these costs. The difference in flow rates obtained at the first three sites as opposed to the last site may have been the result of the presence of large amounts of unreacted limestone in the sludge. Further data would be needed to verify this conclusion.

SECTION V

ACKNOWLEDGMENTS

The work summarized in this report was jointly sponsored by the Coal Research Board, Commonwealth of Pennsylvania and the Water Quality Office, Environmental Protection Agency. The guidance and assistance of Dr. David Maneval of the Pennsylvania Department of Environmental Resources and Mr. Ronald Hill of the Water Quality Office, Environmental Protection Agency is acknowledged with sincere thanks.

The assistance of the following groups from the Johns-Manville Research & Engineering Center is gratefully acknowledged: The Celite Filtration Section for operation of the pilot plant, the Analytical Chemistry Section for sample analysis, and the Physics Section for assistance in statistical design and data evaluation. Acknowledgment is also given with sincere thanks to the Reading Anthracite Company, the Rushton Mining Company, and Pennsylvania State University for furnishing test sites and to Dr. Lovell of the Pennsylvania State University for his assistance.

SECTION VI

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APPENDIX A

DARK WATER DISCHARGE MINE, ST. CLAIR, PENNSYLVANIA

Site Description

The raw water was obtained from the natural overflow discharge of the Dark Water Discharge Mine in St. Clair, Pennsylvania operated by the Reading Anthracite Company. The discharge was a low iron water with all iron present in the ferrous state. A typical analysis of this discharge is given in Table III. The test program was conducted during May and June 1969.

Test Program Description

The pilot plant system is described in the main body of this report. Due to the low sludge volumes produced by neutralization of the feed water, the sedimentation equipment was operated primarily to produce enough sludge to allow operation of the pilot filter unit. A limestone slurry, produced by passing a stream of water through a tube mill as described by E. A. Mihok et al[2] was used for neutralization. The tube mill initially contained 7000 pounds of 98.6 per cent calcium carbonate limestone purchased from the Appalachian Stone Division of the Martin-Marietta Corporation. The tube mill was periodically replenished by addition of unregulated amounts of the rock.

The average flow rate through the system was 25 gallons per minute, alhtough runs were made ranging from 10 to 30 gallons per minute. The limestone slurry feed rate averaged 1.2 gallons per minute averaging 48.4 grams of calcium carbonate per gallon of slurry.

The sludge was withdrawn from the thickener intermittently and stored. The rotary vacuum precoat filter was operated only when there was sufficient sludge stored to allow a meaningful run.

Discussion

The limestone neutralization process was performed using a dosage of 488.5 mg/l. No attempts were made to optimize this dosage. Using the free mineral acidity analysis of 108 mg/l, this represents a usage efficiency of 22.2 per cent. This resulted in an overflow with a pH in the range of 6.9 to 7.5. A sample of the limestone slurry was analyzed for particle size distribution by the Coulter Counter method. The results are presented in Table IV.

The aerator was operated to provide two basic operations. The first was removal of carbon dioxide generated by the neutralization reaction.

TABLE III

Typical Raw Water Analysis
St. Clair, Pennsylvania

pH	5.7
Total Acidity	8 mg/l (as $CaCO_3$)
Free Mineral Acidity	108 mg/l (as $CaCO_3$)
Total Iron	25 mg/l
Ferrous Iron	25 mg/l
Sulfates	620 mg/l
Calcium	250 mg/l (as $CaCO_3$)
Magnesium	400 mg/l (as $CaCO_3$)

TABLE IV

The following table is a Coulter Counter analysis of the limestone slurry coming from the rotary neutralizer and being fed to the flash mixer.

Average Particle Volume	Average Particle Diam.	Weight Distribution Difference %	Weight Distribution Less Than %	Number Distribution Difference %	Number Distribution Less Than %
22511.60	34.58	0.0	100.00	0.0	100.00
11255.80	27.44	2.49	97.51	0.0	100.00
5627.90	21.78	0.0	97.51	0.0	100.00
2813.95	17.29	1.87	95.64	0.01	99.99
1406.98	13.72	3.11	92.53	0.02	99.97
703.49	10.89	5.76	86.77	0.09	99.88
351.74	8.65	7.16	79.61	0.22	99.65
175.87	6.86	10.55	69.06	0.66	98.99
87.94	5.45	12.80	56.27	1.61	97.38
43.97	4.32	13.93	42.34	3.50	93.88
21.98	3.43	12.99	29.35	6.53	87.35
10.99	2.72	10.79	18.56	10.84	76.51
5.50	2.16	10.78	7.78	21.67	54.84
2.75	1.72	4.57	3.20	18.38	36.46
1.37	1.36	2.20	1.00	17.72	18.74
0.69	1.10	0.69	0.31	11.16	7.58
0.34	0.87	0.24	0.07	7.58	0.0

Volume average diameter is 5.79 microns. Area average diameter is 3.72 microns. Length average diameter is 2.66 microns.

The carbon dioxide would otherwise have the effect of buffering the solution thus inhibiting the iron precipitation reaction and reducing the efficiency of limestone usage. The second function was to oxidize iron from the ferrous to the ferric state. Analyses showed that almost total oxidation occurred. This result would be expected because only 2.36 grams per minute of ferrous iron was being fed. The "Operation Yellowboy"(8) report stated that the aerator was deisnged to provide at 17 cfm sufficient oxygen to oxidize 121 grams per minute (assuming 100 per cent efficiency) of ferrous iron to the ferric state.

The aeration and sedimentation equipment was operated at throughput rates ranging from 10 to 30 gallons per minute. The effect of varying the flow rate in the aerator was primarily a change in detention time.

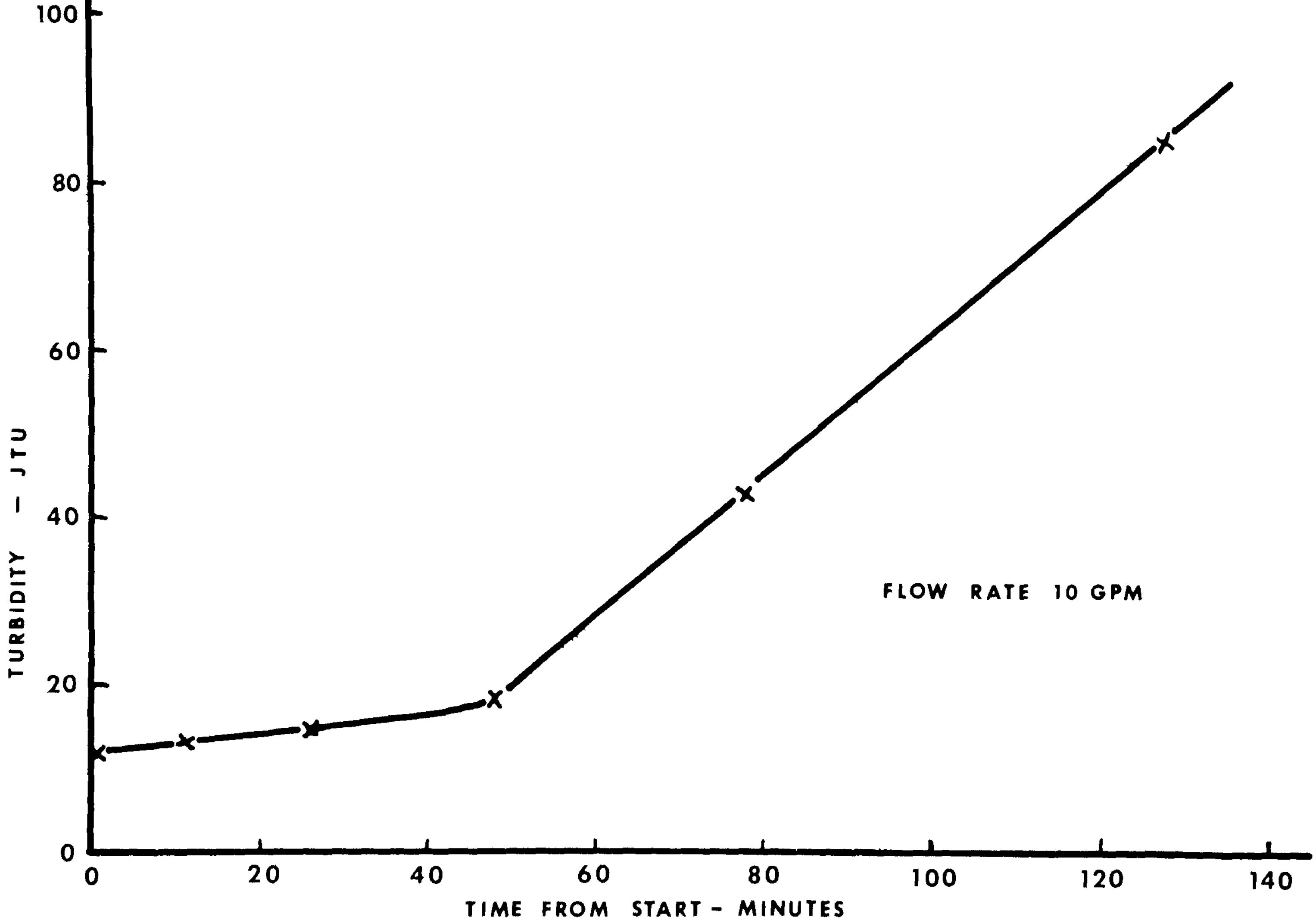
The effect of flow rate on operation of the thickener is very significant. Since the thickener was operated with only intermittent sludge draws, a change in the raw flow rate was a direct change in the overflow rate, assuming an even distribution of upward flow in the annular clarification region of the thickener. Thus, the upflow velocity range during these tests would ideally have been 3.17 feet per hour at 10 gallons per minute to 9.52 feet per hour at 30 gallons per minute. For efficient clarification, the settling rates would therefore have to exceed these upflow velocities. The settling rates could not be measured by the standard settling tests using 1 liter graduated cylinders because of the extremely low volumes of sludge produced. The average solids concentration in the thickener influent was on the order of 330 mg/l.

The only qualitative analysis of the thickener function that could be obtained was by examining the operation of this unit. The overflow clarity was found to deteriorate with time at the 10 gallon per minute flow rate (Figure 7). This would indicate that as the sludge blanket built up towards the level of the feed distributor, a greater portion of the solids were carried into the clarification zone and out with the overflow. Thus, it can be concluded that the settling rate of the solids was less than 3.17 feet per hour.

Some attempts were made to improve the efficiency of operation of the thickener by increasing the settling rate of the solids. Calcined magnesite was known to produce a faster settling iron floc.(7) Addition of a concentrated slurry to the distribution zone of the thickener was unsuccessful. Recycling of sludge to the distribution zone, thus effectively increasing the solids concentration of the feed, was also unsuccessful. The use of polyelectrolytes to promote formation of a denser and therefore faster settling floc was also attempted. Jar tests using Catfloc (Calgon) and Magna Floc 985 N (American Cyanamid) showed some improvement. Again, however, qualitative settling tests could not be run due to low sludge volumes. A run at a feed rate of 25 gallons per

FIGURE 7

OVERFLOW TURBIDITY AS A FUNCTION OF TIME



minute (overflow velocity of 7.93 feet per hour) using Purifloc 601 (Dow) was also unsuccessful. Since the primary purpose of operation at this point had become to produce sufficient sludge for operation of the filter unit, no qualitative analysis of the effects of these methods was attempted.

Rotary vacuum precoat filtration did an excellent job in dewatering the sludges produced. Figure 8 shows the relationship between knife advance, sludge solids concentration and filtrate flow rate for CELITE 501. The sludge solids concentration does not appear to have a significant effect based on this data. The optimum knife advance appears to be somewhere between 0.001 and 0.002 inches per drum revolution. Filtrate clarities on the order of 5 JTU and iron concentrations less than 1 mg/l were obtained. Figures 9 and 10 present the knife advance/filtrate flow rate relationship for filter aid grades CELITE 545 and 503. The CELITE 545 gave approximately the same filtrate flow rate as CELITE 501 and would therefore be ruled out on the basis of economics. CELITE 503 gave lower filtrate rates and was therefore ruled out. CELITE 501 was thus the optimum filter aid grade used at this site. The cake discharge averaged 64 per cent dry solids.

Conclusions

The operation of a standard neutralization, aeration, sedimentation, and sludge dewatering system on a source water of this nature caused considerable problems in operation. Due to the extremely low volume of sludge produced, the controlling design factor for the sedimentation unit would be the overflow velocity. This would result in a unit capable of handling a solids volume much larger than actually present.

An economic alternative to the above process could be a two-step process involving chemical pretreatment followed by filtration of the entire stream using standard diatomite pressure or vacuum filters. The techniques for this process have been well developed by Johns-Manville for use on potable and industrial feed waters. An iron concentration similar to the St. Clair water has been encountered by Johns-Manville in work done at the DuPont Plant in Deepwater, New Jersey. The cake discharge using this process could be either wet or dry.

FIGURE 8

KNIFE ADVANCE CURVE

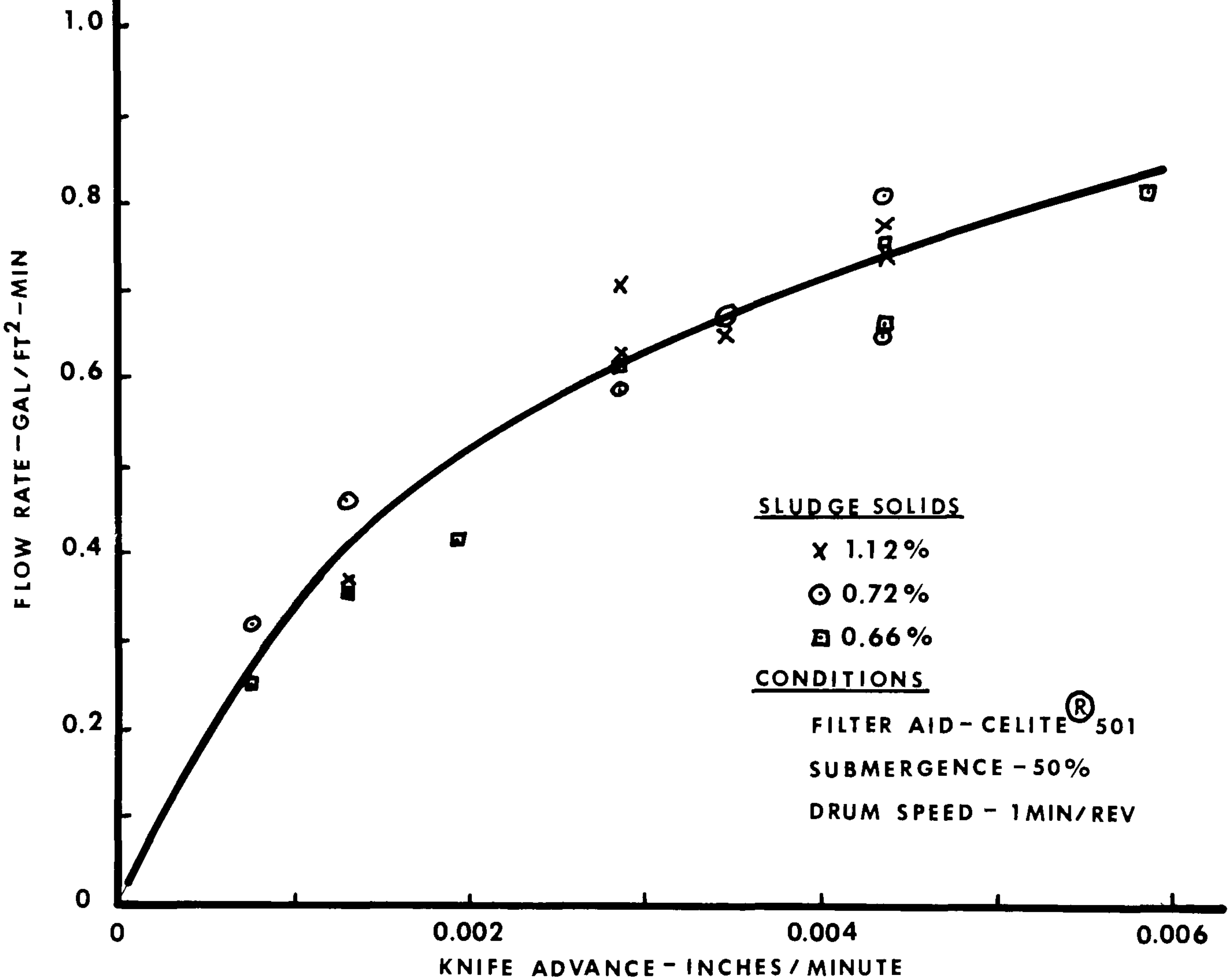


FIGURE 9

KNIFE ADVANCE CURVE

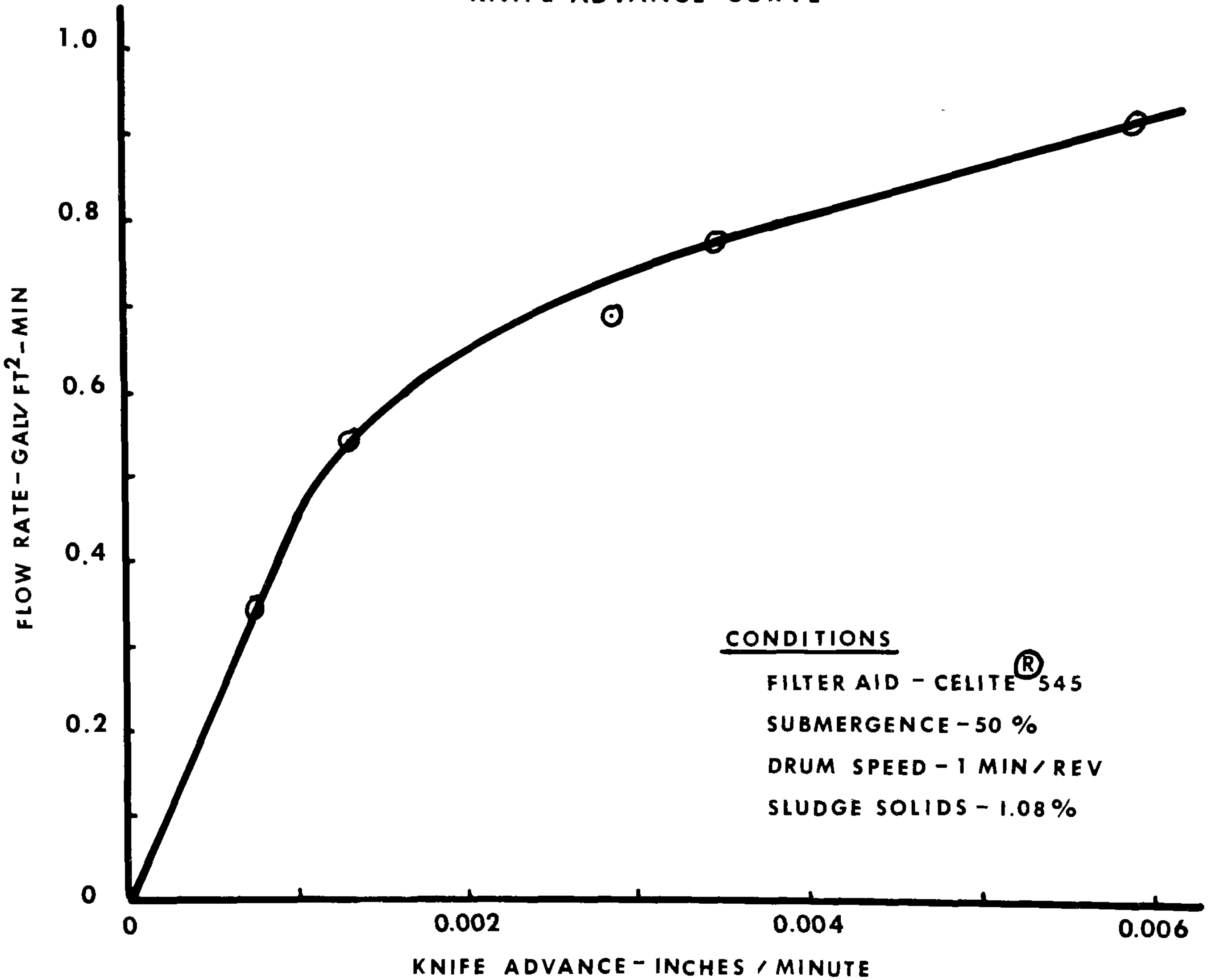
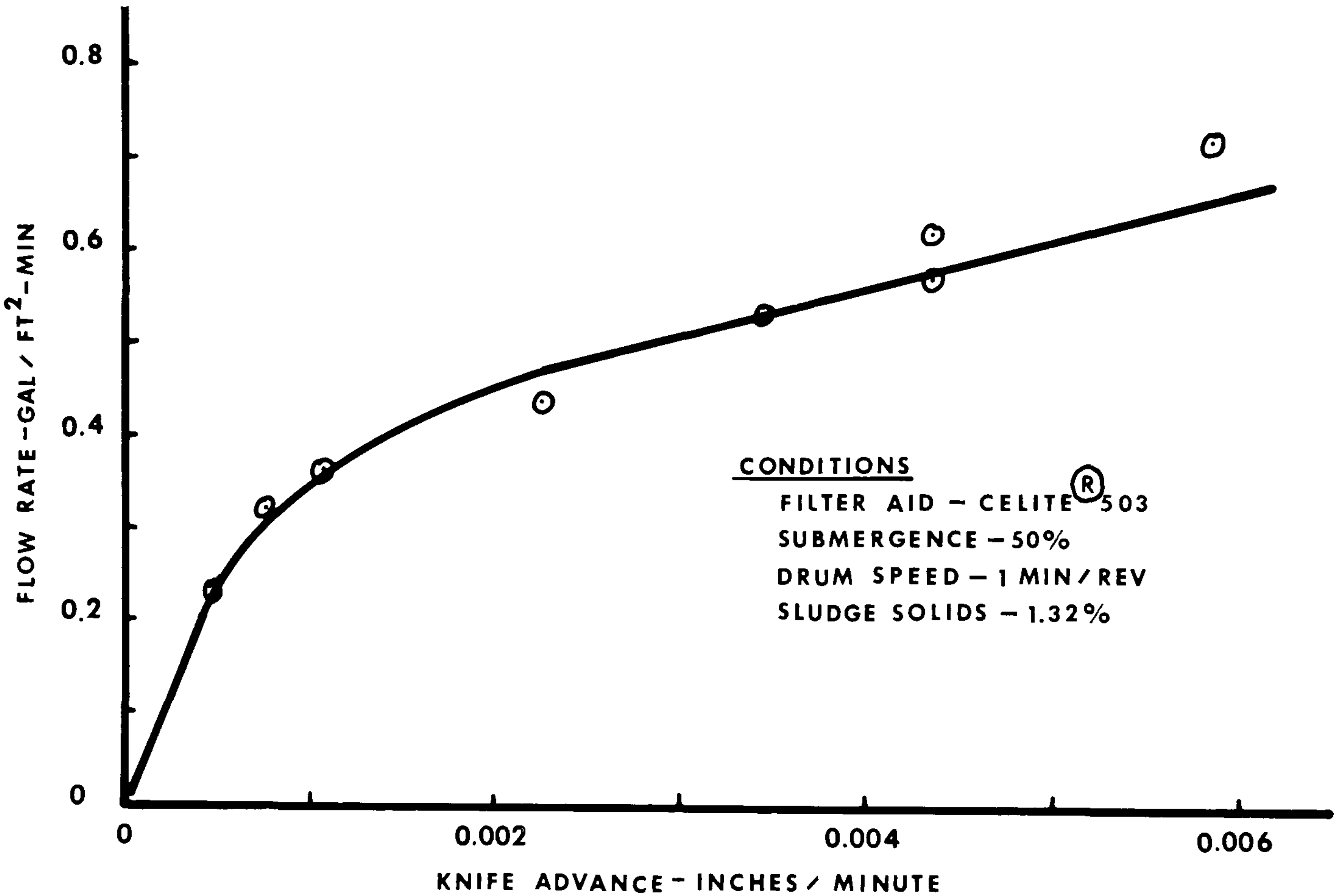


FIGURE 10
KNIFE ADVANCE CURVE



APPENDIX B

RUSHTON MINING COMPANY, OSCEOLA MILLS, PENNSYLVANIA

Site Description

The raw water was obtained from the holding pond receiving mine discharge at the Rushton Mining Company mine located at Osceola Mills, Pennsylvania. The flow to the pond was intermittent, the pumps being controlled by level probes in the mine. An average analysis of the mine water is presented in Table V. The test work at this site was performed in July and August 1969.

Test Program Description

Tests were conducted to evaluate various techniques of chemical neutralization from both the operational and economic viewpoints. In all, four combinations of alkalies were used in the neutralization step. These included limestone with magnesite, limestone with lime, lime with magnesite, and limestone alone. With the exception of the limestone, chemicals were fed by dry feeders. The limestone was fed as a slurry produced by attrition of limestone rock in a tube mill.(2)

Four filter aid grades (HYFLO SUPER-CEL, CELITE 501, CELITE 503 and CELITE 545) were evaluated while using the limestone with magnesite neutralization. The grade with the best balance of flow rate per unit area and usage was used in evaluating the other neutralization processes.

Discussion

The tests run for the purpose of evaluating the four filter aid grades are summarized in Table VI. At the optimum knife advance of 0.0013 inches per revolution, CELITE 501 exhibited the highest flow rate. It was therefore chosen for use in the subsequent tests.

The initial tests involved a comparison of the three chemical neutralization techniques utilizing a combination of two chemical alkalies. The purpose of the dual chemical feeds was to utilize limestone (lime in the case of the lime-magnesite combination) as the primary neutralizing agent with the additional alkali provided as a sort of polishing step. The limestone feed rate was controlled by the pH of the feed to the flash mixer. A pH of 6 was the goal. All chemical feeds were made prior to the aerator. The additional alkali was added to produce an effluent with pH between 7.5 and 8.5. No attempts were made to optimize the additions of the two alkalies. The results of these tests are summarized in Table VII, and the filtration data is presented in Figures 11 to 14. Since all tests were run under constant flow conditions, a 20 gallon per minute feed and

TABLE V

Typical Raw Water Analysis
Osceola Mills, Pennsylvania

pH	3.3
Ferrous Iron	45 mg/l
Total Iron	159 mg/l
Calcium	410 mg/l (as $CaCO_3$)
Magnesium	270 mg/l (as $CaCO_3$)
Silica	31 mg/l
Sulfates	2665 mg/l
Free Mineral Acidity	356 mg/l (as $CaCO_3$)
Total Acidity	367 mg/l (as $CaCO_3$)
Total Solids	1420 mg/l

TABLE VI

Filter Aid Comparisons

Filter Aid	HYFLO	501	503	545
Filtrate				
pH	7.8	8.9	8.9	8.3
Total Iron, mg/l	0.3	1.4	0.2	4.0
Turbidity, JTU	2.8	2.1	1.5	3.7
Cake				
Per Cent Solids	35.4	42.3	48.8	---
Optimum Knife Advance, mils/min	1.30	1.30	1.30	1.30
Flow Rate, gsfm	0.575	0.600	0.550	0.550

TABLE VII

Data From Preliminary Test Runs
Filter Aid - CELITE 501

	Limestone Magnesite	Limestone Lime	Lime Magnesite
Clarifier Overflow			
pH	8.5	7.6	7.5
Total Iron, mg/l	5.1	2.9	4.7
Calcium, mg/l	621	856	686
Total Hardness, mg/l	1073	1030	988
Suspended Solids, mg/l	51	32	53
Total Solids, mg/l	1700	1450	-----
Clarifier Underflow Suspended Solids, mg/l	5921	7089	1644
Filtrate			
pH	8.9	7.8	7.6
Total Iron, mg/l	1.4	0.1	0.2
Turbidity, JTU	2.1	1.6	2.1
Filter Cake Per Cent Solids	42.3	29.6	24.8

FIGURE 11
KNIFE ADVANCE CURVE
LIME & MAGNESITE WITH AERATION

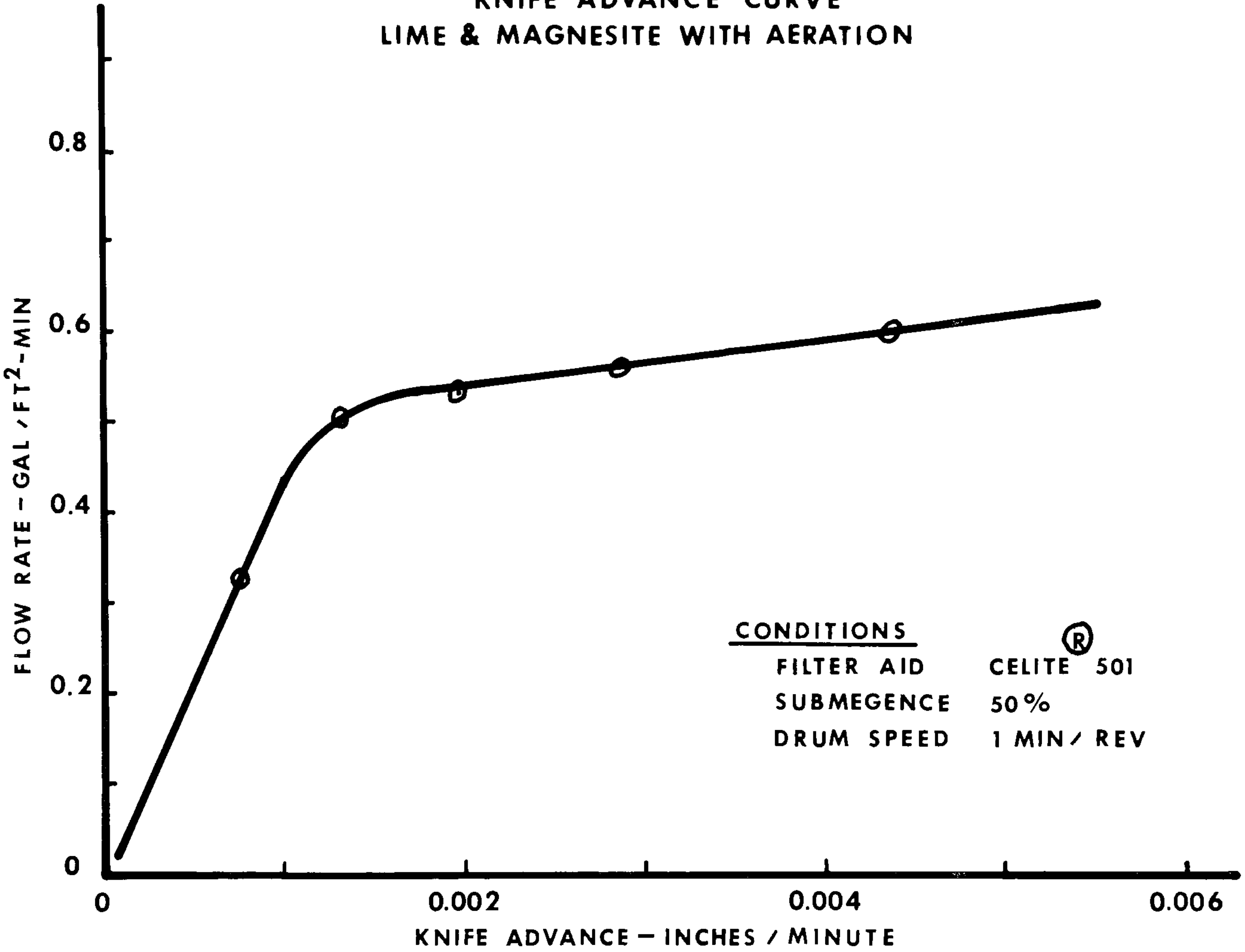


FIGURE 12
KNIFE ADVANCE CURVE
LIME & MAGNESITE WITHOUT AERATION

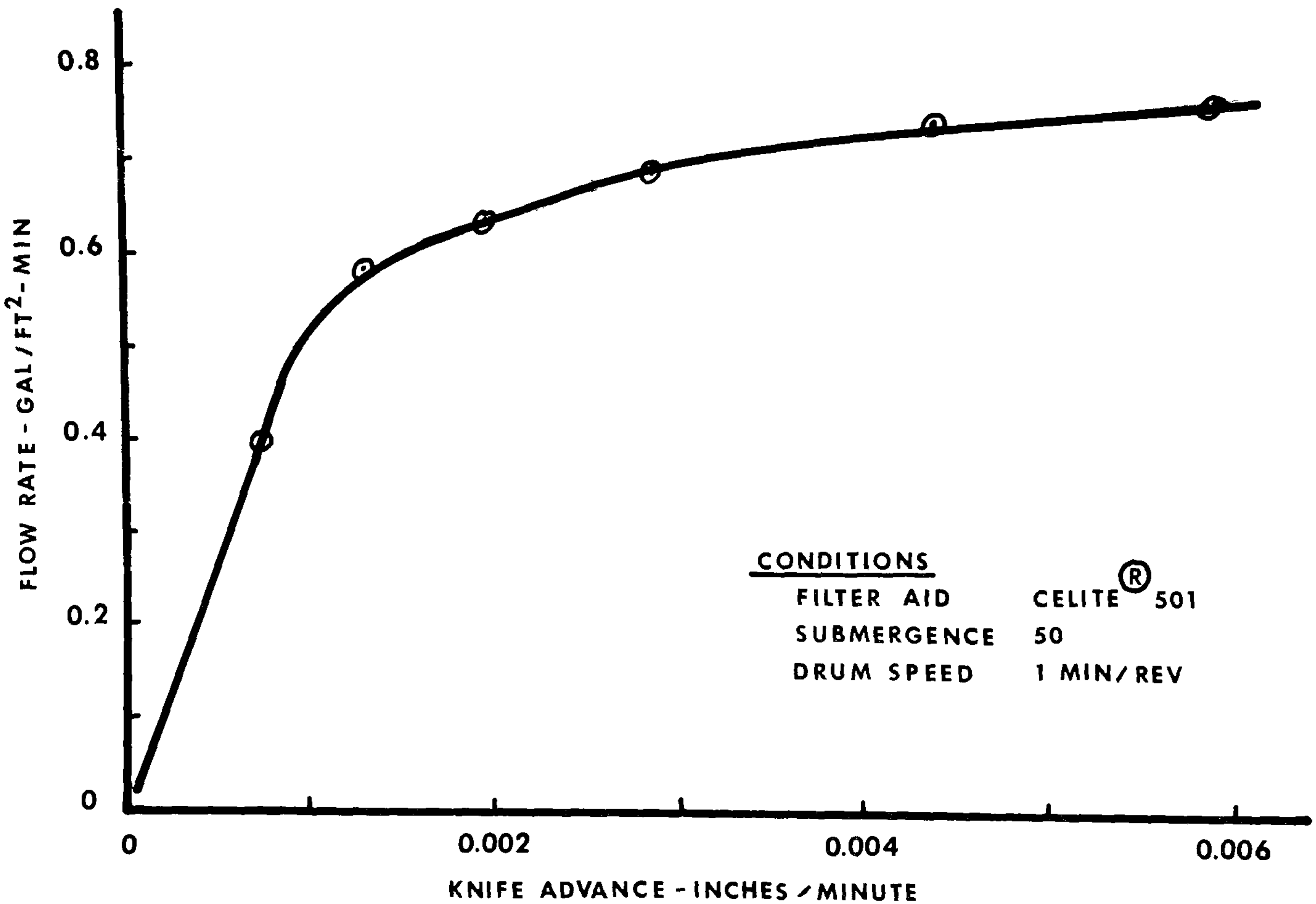


FIGURE 13
KNIFE ADVANCE CURVE
LIMESTONE & MAGNESITE

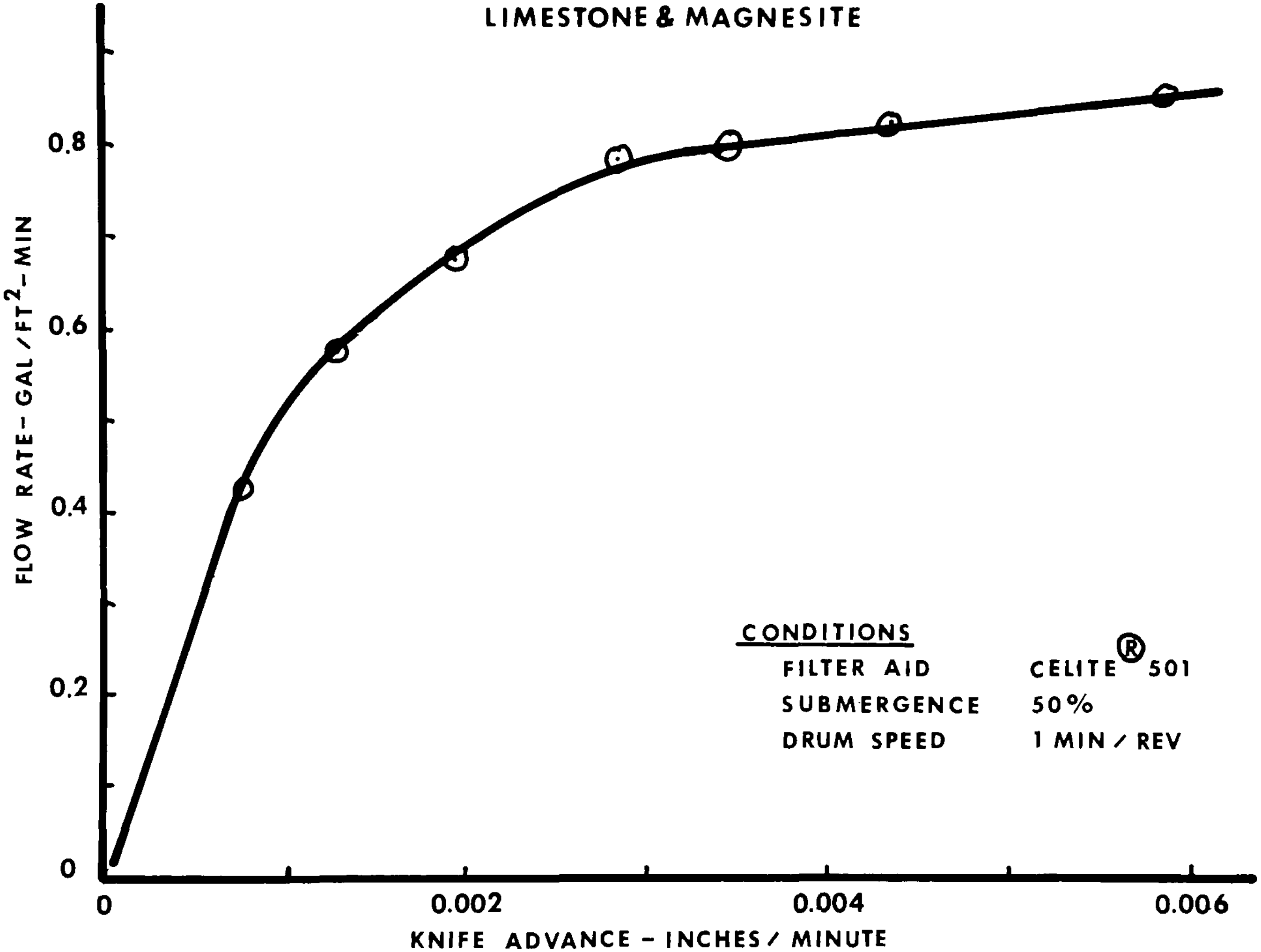
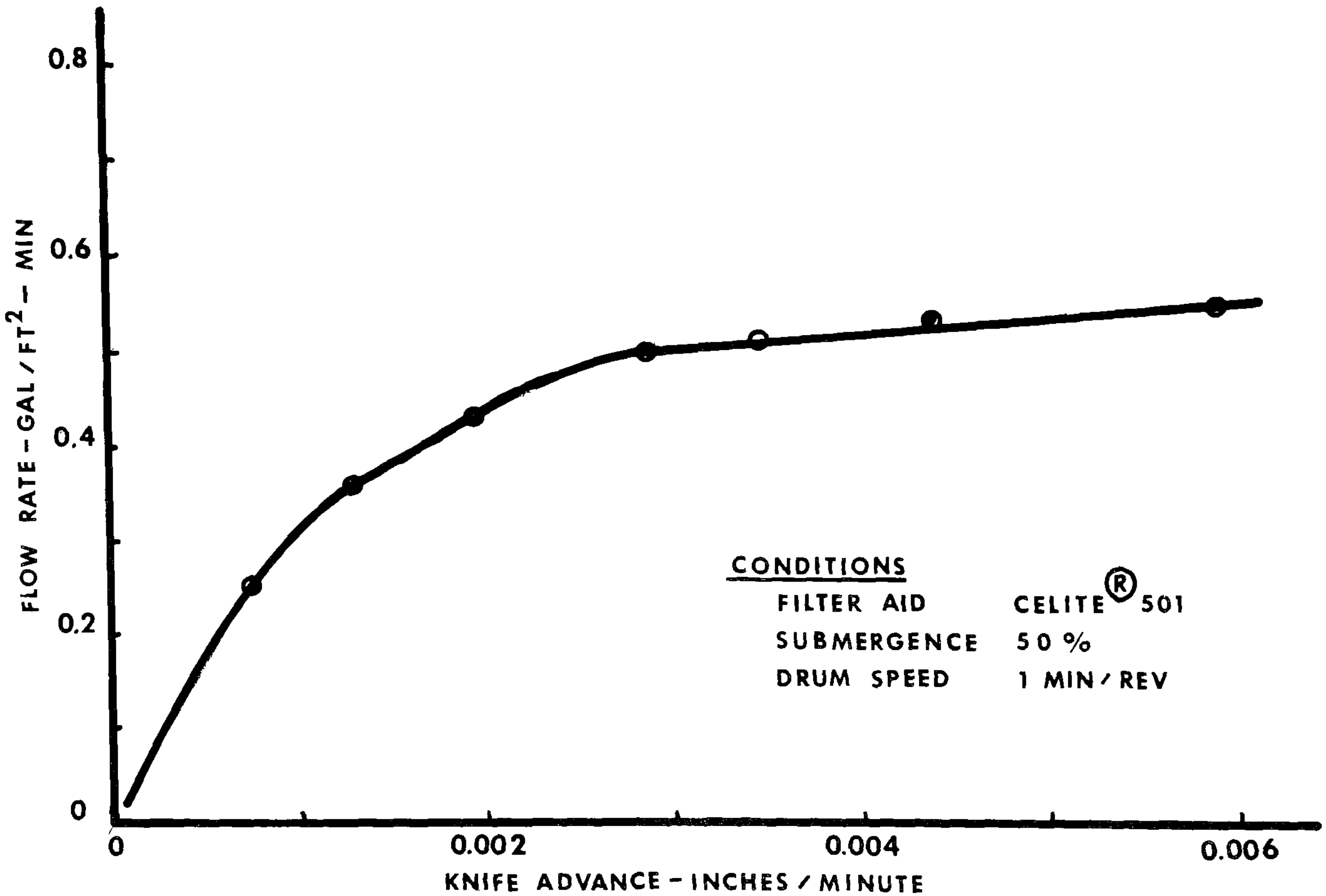


FIGURE 14
KNIFE ADVANCE CURVE
LIMESTONE & LIME



a continuous 2 gallon per minute sludge draw, the 18 gallon per minute overflow rate (ideal upflow velocity of 5.7 feet per hour) did not appear excessive for any of the three techniques. Based on the analysis of the overflow and underflow suspended solids concentrations, the limestone-lime combination resulted in the best settling sludge while lime-magnesite produced the worst settling characteristics. The limestone-magnesite combination, however, produced the sludge with the best filtration characteristics, giving the highest filtrate flow rate and per cent solids in the discharged cake. Based on the high capital and operating costs of the filter station, the limestone-magnesite combination was selected for comparison with limestone only neutralization during round-the-clock operation of the system.

The data obtained during round-the-clock operation of the system is summarized in Table VIII and Figures 15 and 16. The use of straight limestone neutralization appeared to give marginal results in operation of the thickener at the 18 gallon per minute overflow rate. It would therefore be desirable to design for a lower overflow rate in process scale-up. The limestone-magnesite would appear to be a better choice based on overflow quality, higher filtrate flow rate, and higher filter cake solids content. The high cost of magnesite may be, however, an offsetting factor. Economic analysis is presented in a separate part of the report. In the straight limestone technique, a usage efficiency of 34 per cent was obtained.

The use of aeration at this site did not appear to be as beneficial as at other sites. Due to the low ratio of ferrous iron to total iron in the raw water, the oxidation of ferrous to ferric iron is of minor importance as this reaction had occurred primarily in the holding pond prior to being fed to the experimental system. The use of aeration to strip carbon dioxide generated by the limestone reaction was probably of some benefit. The use of air in the aerator also served to increase the degree of agitation present in this vessel. Operationally, this increased agitation appeared to do more harm than good. It appeared that excessive floc breakdown resulted which, in turn, produced a poorer settling sludge in the thickener feed. Examination of Figures 11 and 12 would indicate that the filterability of the resultant concentrated sludge may also be affected.

Conclusions

At a site where significant oxidation of ferrous to ferric iron occurs prior to the neutralization step, the use of additional aeration seems to produce mostly an increase in the degree of agitation in the aeration vessel which was detrimental. The aeration required to remove carbon dioxide generated by the reaction with limestone is probably considerably less than was used during these tests.

TABLE VIII

Data From 24-Hour Runs

	Limestone-Magnesite	Limestone
Raw Sample Average		
pH	3.1	
Ferrous Iron, mg/l	48	
Total Iron, mg/l	165	
Calcium, mg/l	440	
Total Hardness, mg/l	784	
Clarifier Overflow		
pH	8.0	7.0
Total Iron, mg/l	6.0	7.0
Calcium, mg/l	703	848
Total Hardness, mg/l	1180	1098
Sludge		
% Solids	0.5	0.3
Filtrate		
pH	8.1	7.3
Total Iron, mg/l	0.3	0.2
Calcium, mg/l	598	744
Total Hardness, mg/l	1069	1100
Filter Cake		
% Solids	45	32

FIGURE 15
FLOW RATE - 24 HOUR RUN
LIMESTONE & MAGNESITE

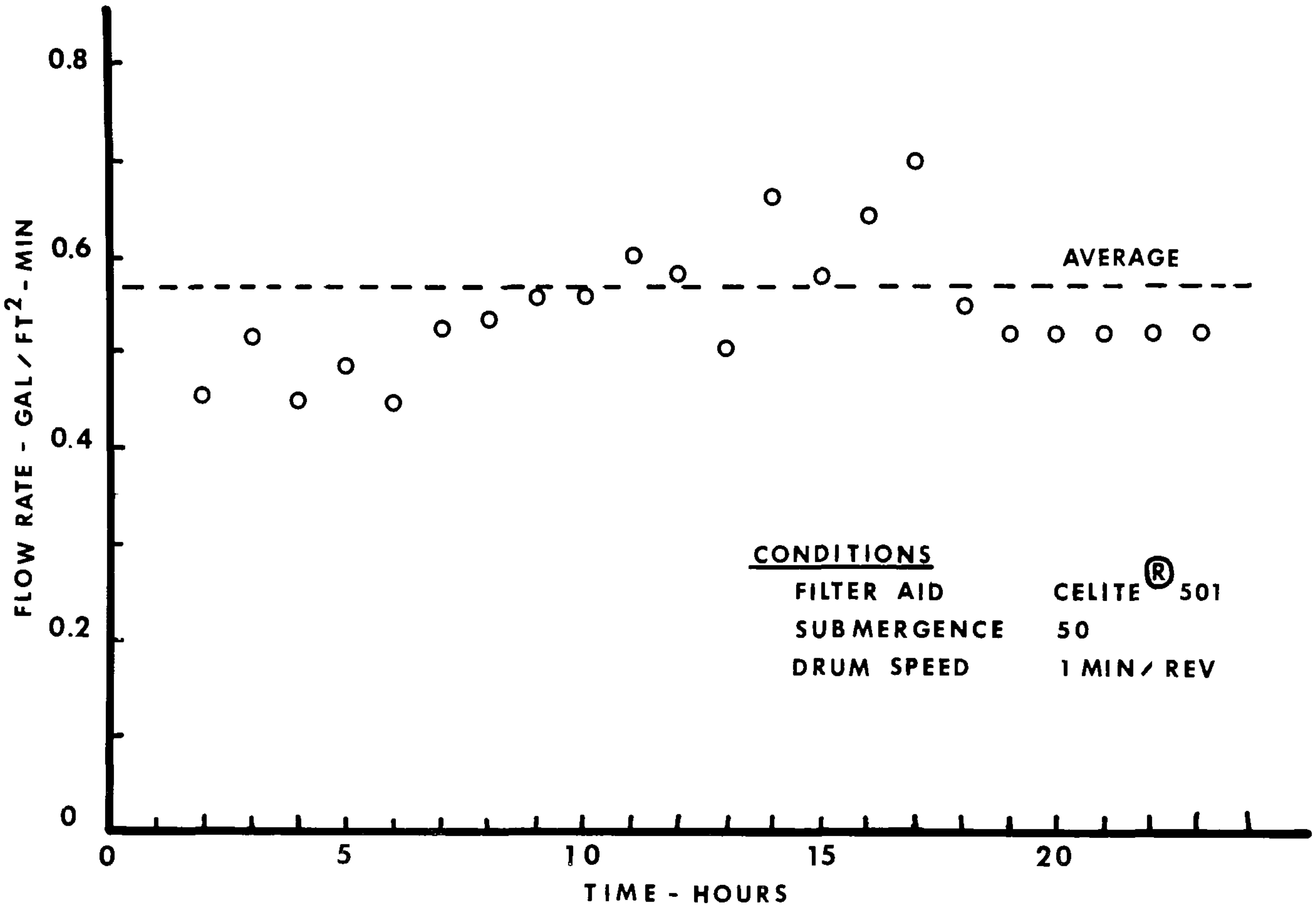
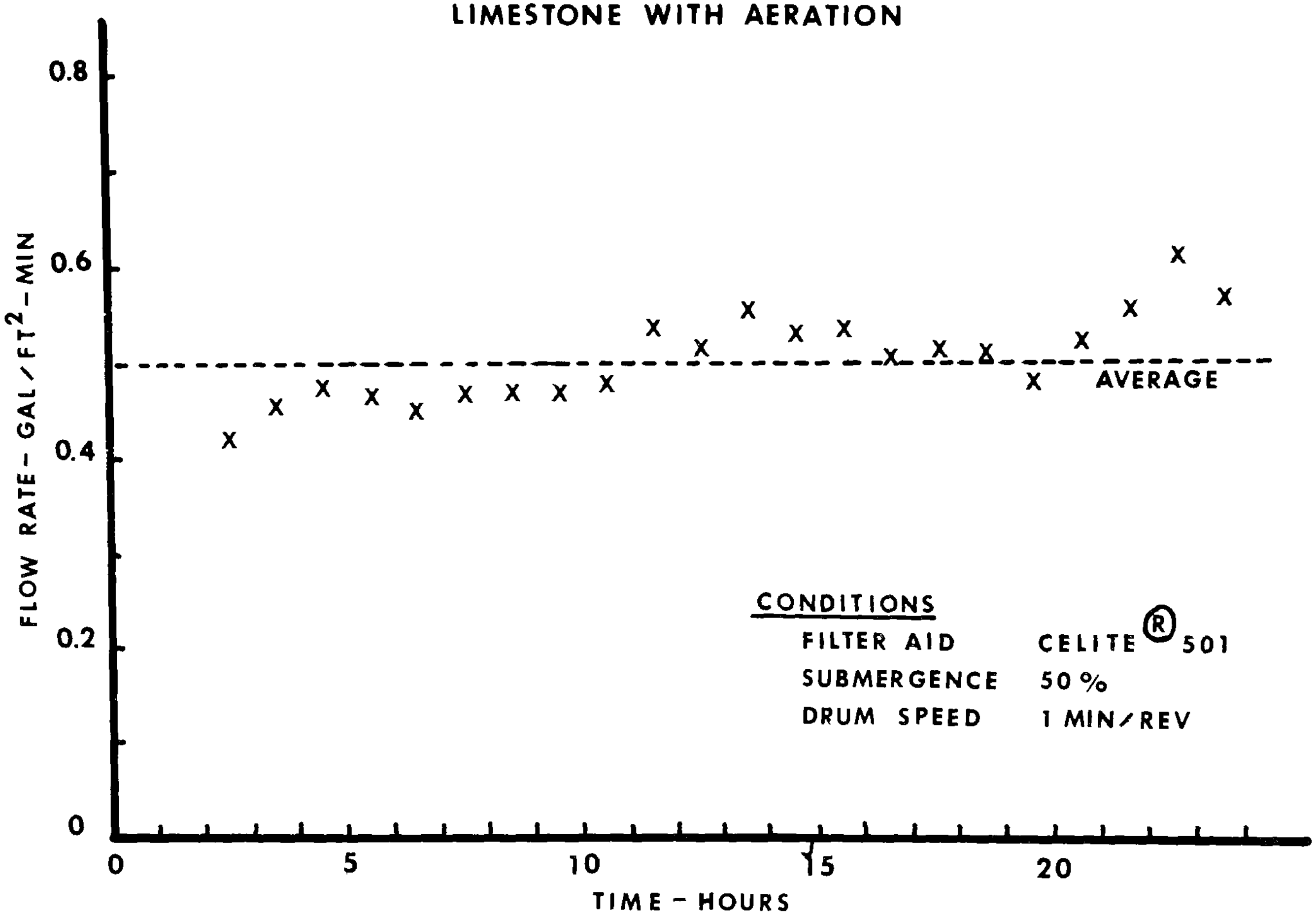


FIGURE 16
FLOW RATE - 24 HOUR RUN
LIMESTONE WITH AERATION



The use of a second alkali in combination with limestone appears to be beneficial from two standpoints. The final pH obtainable can be increased, thereby insuring complete precipitation of all iron present. In addition, precipitated flocs appear to have faster settling rates.

APPENDIX C

BENNETT BRANCH, HOLLYWOOD, PENNSYLVANIA

Site Description

The raw water was obtained from Bennett Branch adjacent to the pumping station feeding the experimental treatment facility operated by the Pennsylvania State University. A typical analysis of this waterway is given in Table IX. The work at this site was performed in September 1969.

Test Program Description

The system was operated at a throughput of 20 gallons per minute using seven different techniques for neutralization. The techniques consisted of various combinations of chemical alkalies as follows:

1. Limestone slurry with magnesite
2. Limestone slurry with lime
3. Limestone rock dust with magnesite
4. Limestone rock dust with fully calcined dolomite
5. Limestone slurry with partially calcined dolomite
6. Limestone slurry
7. Limestone rock dust

The test work performed at this site was limited because of a deadline for removal of the equipment to avoid interferring with the shakedown of the treatment facility equipment. The tests were run using a CELITE 501 precoat on the rotary vacuum precoat filter. One duplicate run using a CELITE 545 precoat was also made.

All chemicals were fed by means of a dry feeder with the exception of the limestone slurry. The limestone slurry was produced by attrition of limestone rock in a tube mill.[2]

Discussion

Sludge flow rates were controlled as well as possible in the range of 2-4 gallons per minute. It was the intention during these tests to

TABLE IX

Typical Raw Water Analysis
Bennett Branch
Hollywood, Pennsylvania

pH	3.3	
Ferrous Iron	58	mg/l
Total Iron	67	mg/l
Calcium	185	mg/l (as $CaCO_3$)
Magnesium	70	mg/l (as $CaCO_3$)
Silica	30	mg/l
Sulfates	1480	mg/l
Free Mineral Acidity	311	mg/l (as $CaCO_3$)
Total Acidity	337	mg/l (as $CaCO_3$)
Total Solids	1060	mg/l

maintain steady flow rate conditions. Under these conditions, the overflow rate was in the range of 16-18 gallons per minute (ideal upflow velocity of 5.1 to 5.7 feet per hour). Analysis of the data presented in Table X shows that only the limestone slurry, limestone rock dust, and limestone with partially calcined dolomite techniques failed to produce a satisfactory thickener overflow under these conditions. Due to inaccuracies in the analytical method used in the field to determine iron above 6 mg/l, the actual iron concentration could have been between 7 mg/l and 35 mg/l for any of these runs. In any case, the high iron concentration was due to excessive carryover of precipitated iron floc.

The results of the filtration tests for the seven techniques are presented in Figures 17 to 21. The limestone slurry with partially calcined dolomite appeared to give the best filtration characteristics. The only combination, however, that did not produce filtration characteristics fairly close to that of the limestone-partially calcined dolomite run was the limestone rock dust with fully calcined dolomite. The overflow pH during this run was a clear indication that an excessive dosage of the fully calcined dolomite was being used. What effect optimizing this dosage would have on the filterability characteristics is not known.

The comparison of the filtration tests for the runs using limestone slurry and limestone rock dust is given in Figure 21. There is no distinct difference, although, referring to Table X, the limestone slurry sludge was dewatered to a higher per cent solids in the cake. In neutralization, however, the limestone slurry was found to be more efficiently utilized, 36.4 per cent as opposed to 26.6 per cent. The primary reason for this would be the difference in particle size distributions. An earlier particle size analysis of the limestone slurry (Table IV) showed it to have a mean particle size approximately one-tenth of the limestone rock dust (Table XI).

Conclusions

The use of either technique involving limestone alone or the limestone-partially calcined dolomite combination would require a larger thickener area than the other techniques. The similarity in filtration characteristics would thus suggest that one of the techniques which produced a satisfactory overflow would be economically desirable from capital costs considerations.

The comparison between the limestone slurry produced by the rotary neutralizer and the commerically available rock dust indicates that the finer particle sizes in the slurry are considerably more efficient. Economically, this says that the less expensive limestone rock would gain an even greater advantage over the dust. The aeration requirements when utilizing limestone dust could become a factor if a primarily ferric raw water is used. Some aeration is provided for when using rock by the very nature of the attrition process in the tube mill.[2]

TABLE X. Data From Preliminary Test Runs

Sample Source and Analysis	Limestone Magnesite	Limestone Lime	Limestone Dust Magnesite	Limestone Dust, Full Calc. Dol.	Limestone Part. Calc. Dol.	Limestone	Limestone Dust
Raw							
pH	3.4	3.4	3.3	3.5	3.4	3.1	3.1
Ferrous Iron, mg/l	60.9	59.8	58.6	60.8	54.7	55.8	55.8
Total Iron, mg/l	67.7	62.9	67.6	73.6	59.2	68.1	68.1
Calcium, mg/l	292	180	164	156	156	172	172
Total Hardness, mg/l	433	296	276	224	180	188	188
Free Mineral Acidity, mg/l	336	314	298	296	N.D.	N.D.	N.D.
Total Acidity, mg/l	352	318	330	346	N.D.	N.D.	N.D.
Sulfate, mg/l	1799	1384	1352	1386	N.D.	N.D.	N.D.
Silica, mg/l	31	32	30	28	N.D.	N.D.	N.D.
Total Solids, mg/l	1400	1000	900	1000	1000	N.D.	N.D.
Clarifier Overflow							
pH	7.9	7.9	8.1	12	7.5	N.D.	7.5
Total Iron, mg/l	4.0	5.0	1.5	1.5	7.5	7.0	7.0
Calcium, mg/l	617	528	208	1244	540	N.D.	N.D.
Total Hardness, mg/l	1017	544	580	1284	700	N.D.	N.D.
Sulfate, mg/l	1874	N.D.	1536	1338	N.D.	N.D.	N.D.
Silica, mg/l	5	7	4	N.D.	N.D.	N.D.	N.D.
Suspended Solids, mg/l	N.D.	28	23	N.D.	N.D.	N.D.	N.D.
Total Solids, mg/l	N.D.	900	1000	1100	1200	N.D.	N.D.
Sludge - Per Cent Solids	0.655	0.398	0.861	1.164	1.370	0.153	0.105
Filtrate							
pH	8.2	7.7	8.0	11.9	8.0	N.D.	N.D.
Total Iron, mg/l	0.1	0.1	0.1	0.1	0.2	0.1	0.4
Turbidity, JTU	2.1	2.3	3.7	4.2	3.5	N.D.	N.D.
Calcium, mg/l	444	472	216	1016	500	N.D.	N.D.
Total Hardness, mg/l	668	500	512	1032	620	N.D.	N.D.
Sulfates, mg/l	1838	1194	1446	1728	N.D.	N.D.	N.D.
Silica, mg/l	4.5	N.D.	2	2	N.D.	N.D.	N.D.
Total Solids, mg/l	550	N.D.	900	1100	800	N.D.	N.D.
Suspended Solids, mg/l	20	14	7	N.D.	N.D.	N.D.	N.D.
Cake - Per Cent Solids	37.0	30.7	43.3	27.6	44.7	49.9	38.2

FIGURE 17
KNIFE ADVANCE CURVE
LIMESTONE & MAGNESITE

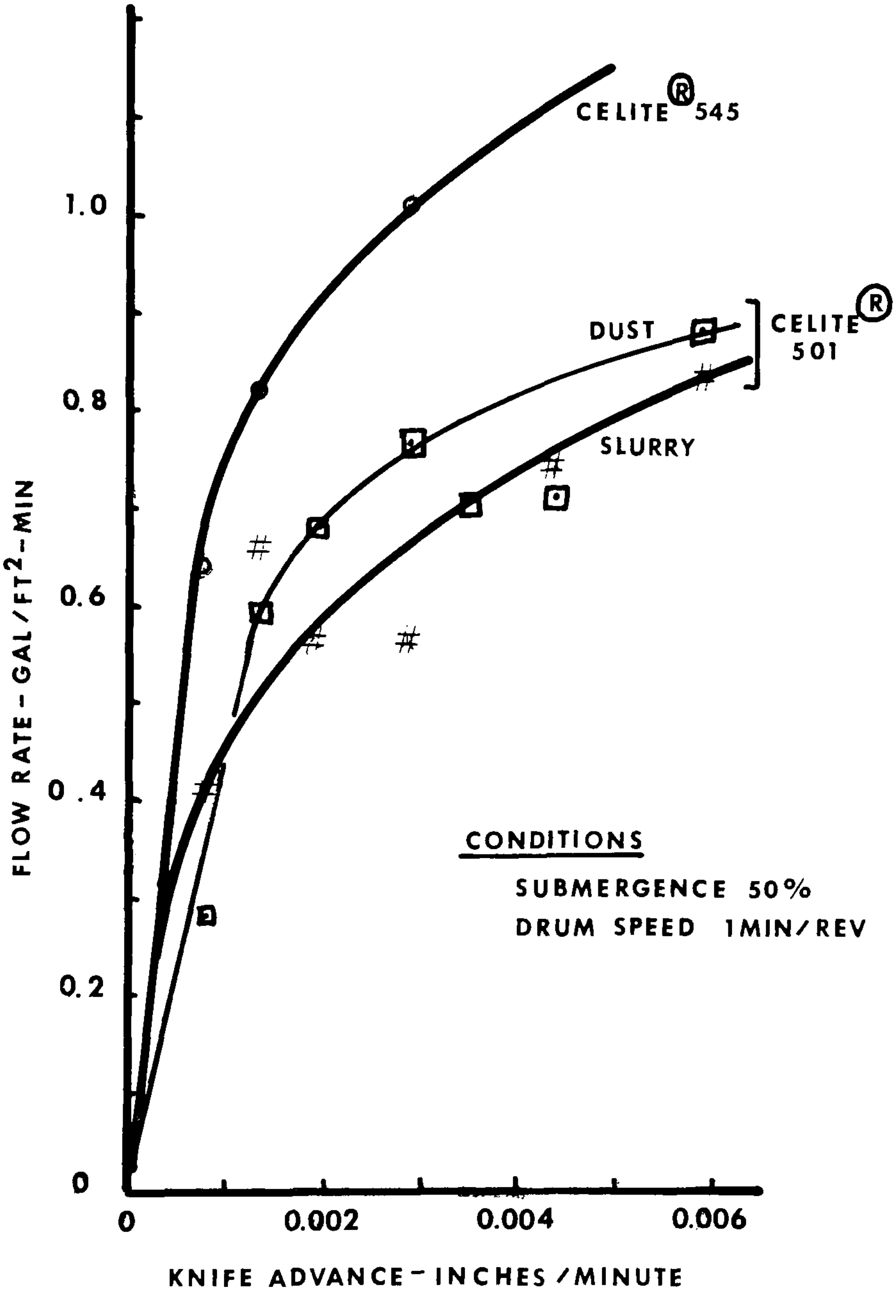


FIGURE 18
KNIFE ADVANCE CURVE
LIMESTONE SLURRY & LIME

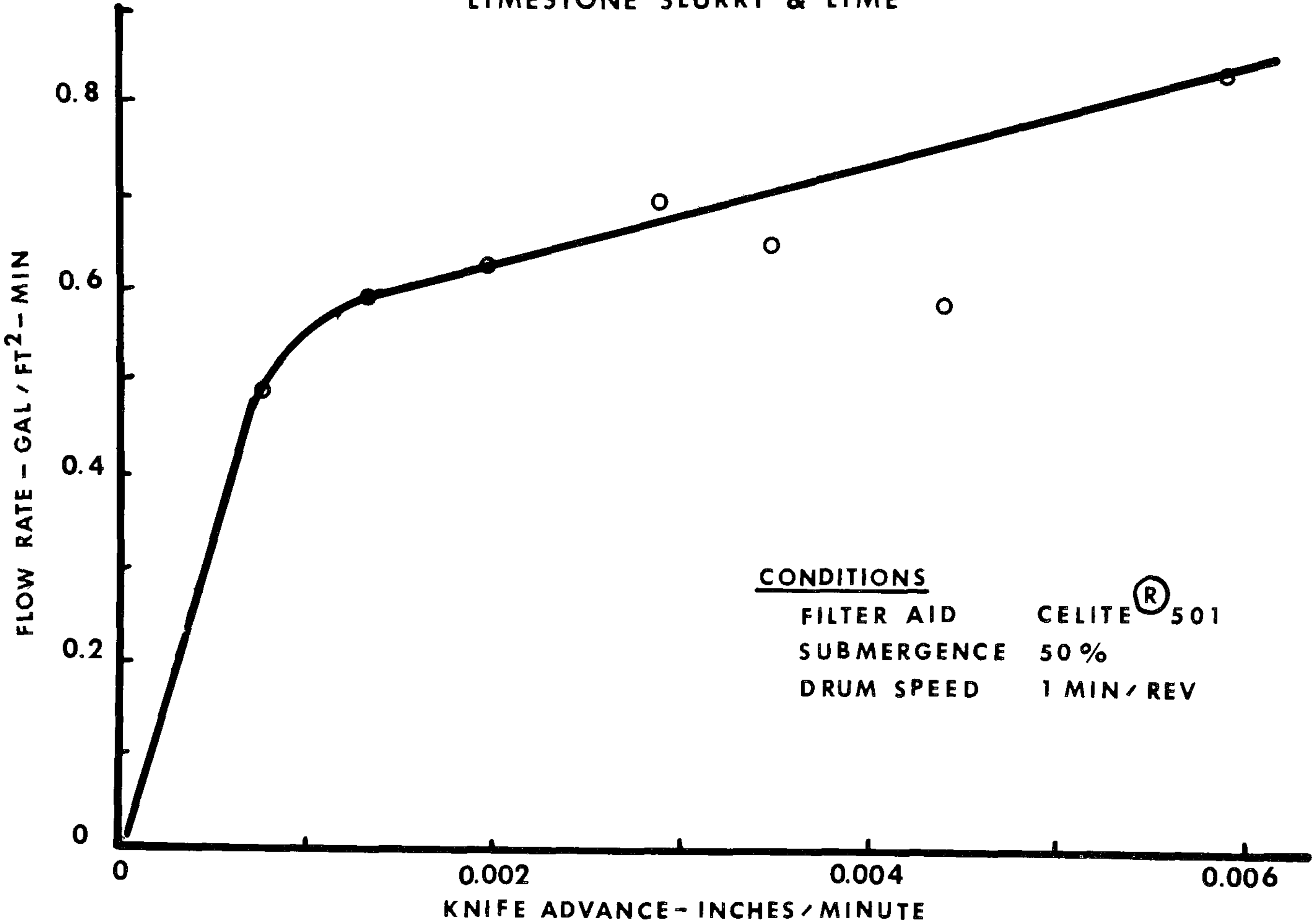


FIGURE 19
LIMESTONE DUST & FULLY CALCINED DOLOMITE

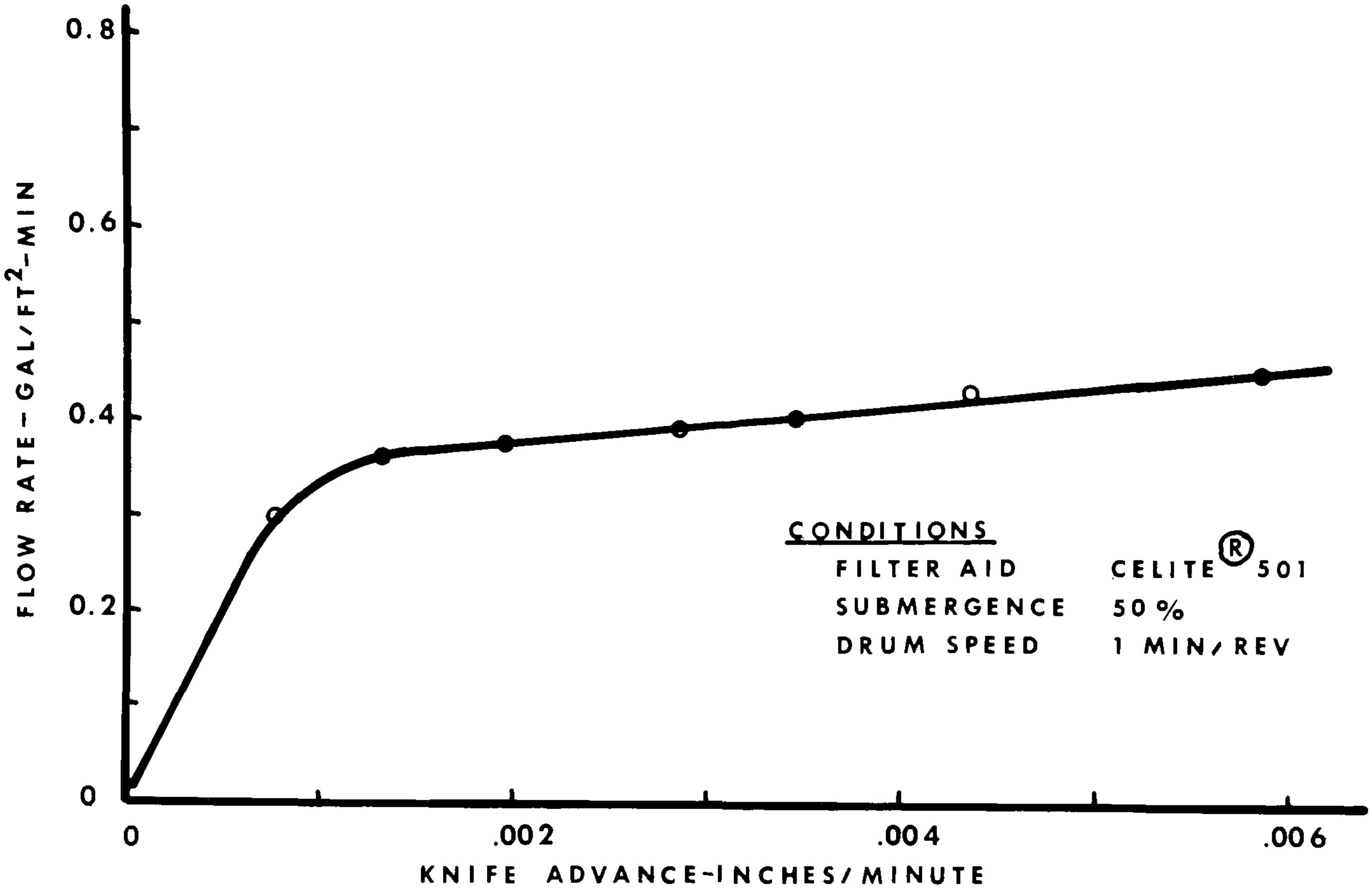


FIGURE 20
LIMESTONE SLURRY &
PARTIALLY CALCINED DOLOMITE

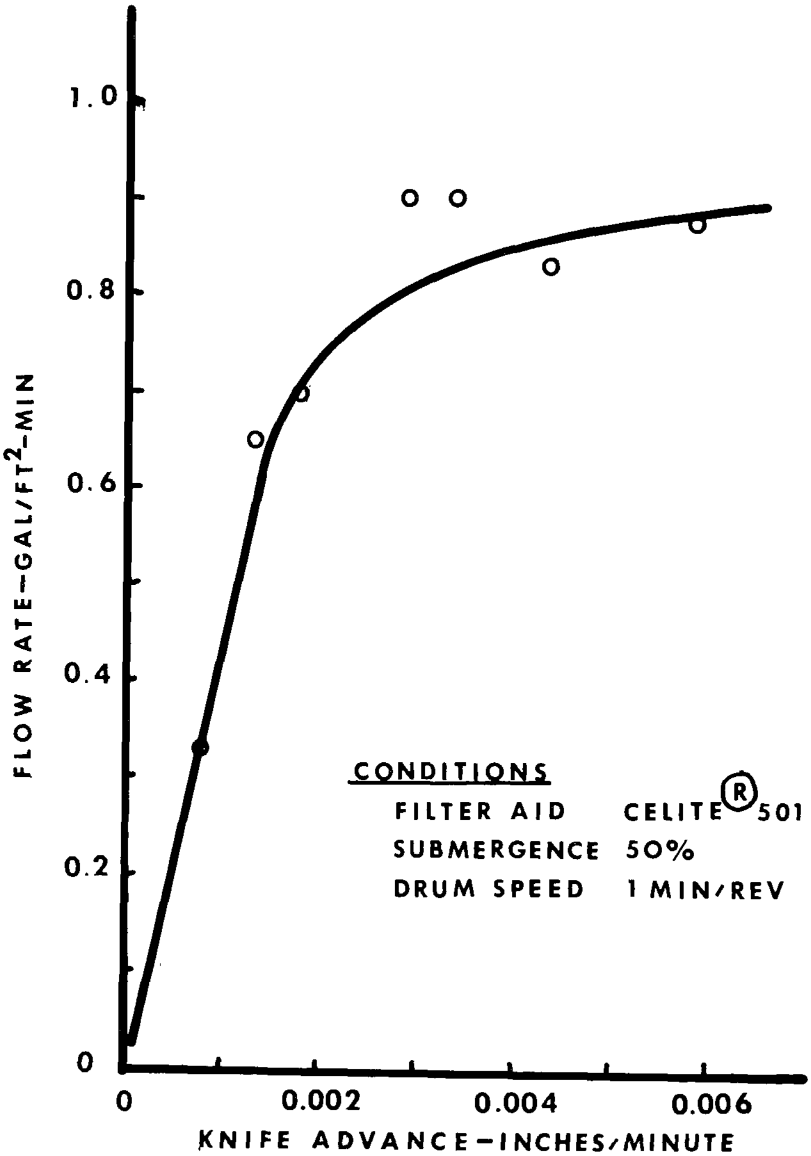


FIGURE 21
FILTRATION PERFOMANCE OF
LIMESTONE SLURRY & ROCK DUST

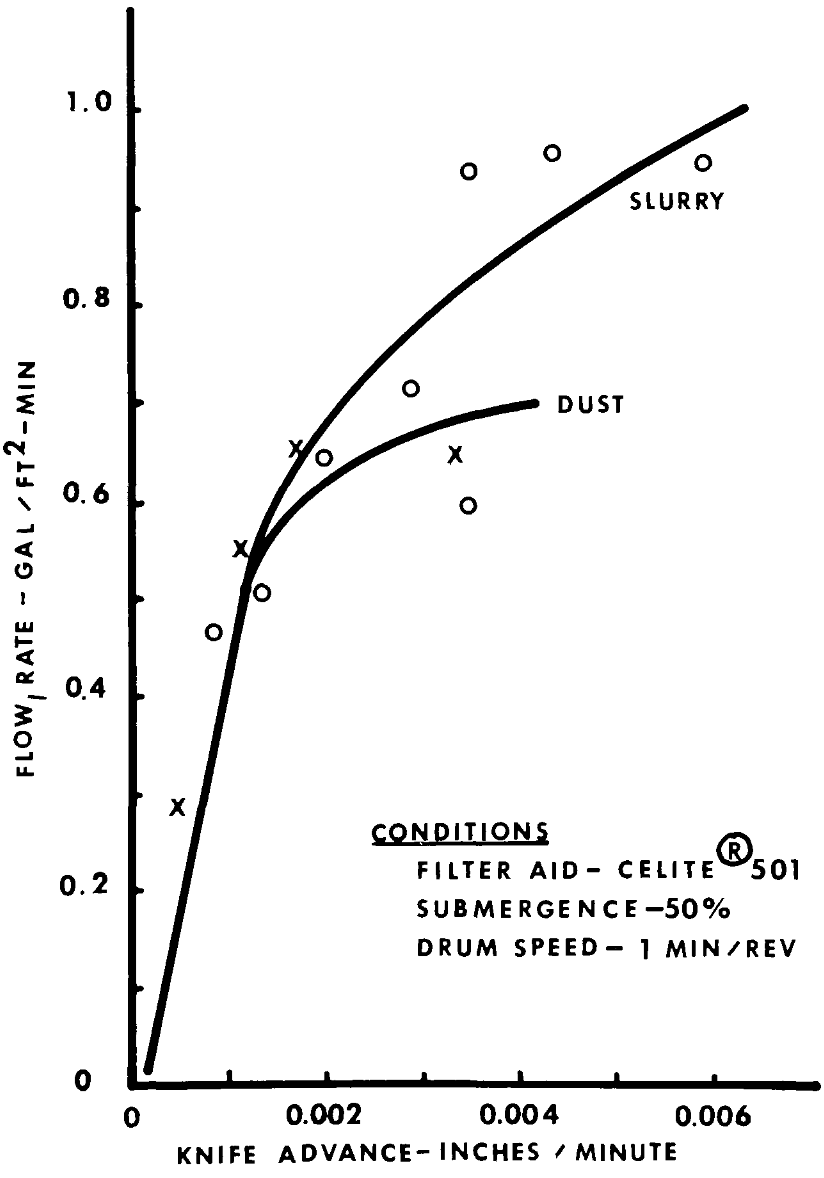


TABLE XI

The following table is a Coulter Counter analysis of the Warner #80 rock dust used on the Bennett Branch water at Hollywood, Pennsylvania.

Average Particle		Weight Distribution		Number Distribution	
Volume	Diam.	Difference %	Less Than %	Difference %	Less Than %
1028915	125.23	0.0	100.00	0.0	100.00
771686	112.31	5.97	94.03	0.01	99.99
385843	89.14	8.96	85.07	0.04	99.95
192922	70.75	13.44	71.63	0.11	99.84
96461	56.16	17.55	54.07	0.29	99.56
48230	44.57	4.11	49.97	0.13	99.42
24115	35.38	7.85	42.12	0.51	98.91
12058	28.08	9.07	33.05	1.18	97.73
6029	22.29	6.62	26.43	1.73	96.00
3014	17.69	7.33	19.11	3.82	92.18
1507	14.04	4.85	14.25	5.06	87.12
754	11.15	5.36	8.90	11.18	75.94
377	8.85	3.83	5.06	15.99	59.96
188	7.02	2.94	2.12	24.54	35.42
94	5.57	2.12	0.0	35.42	0.0

Volume average diameter is 45.92 microns. Area average diameter is 24.60 microns. Length average diameter is 13.06 microns.

APPENDIX D

PROCTOR 2, HOLLYWOOD, PENNSYLVANIA

Site Description

The raw water was obtained from the pump well of the Proctor 2 pumping station feeding the Hollywood, Pennsylvania experimental mine drainage treatment facility. The water was very high in both iron and acidity compared to the other three sites. An average analysis is presented in Table XII.

Experimental Program Description

The test work at this site concentrated on developing data on a process utilizing a limestone with lime neutralization different from the processes used at any of the other sites. It had been shown(4) that the efficiency of limestone utilization decreased drastically above a pH of 6. It was felt that better economics might result if the limestone addition was limited to a level where a higher utilization efficiency would be realized and using lime to complete the neutralization.

The test program was broken down into four phases:

1. Jar tests to determine limestone dosage range that would include the optimum dosage based on efficiency.

2. A statistically designed experimental program to investigate the effects on plant cost of several controlled and uncontrolled variables that would effect operating efficiency of the various unit processes.

3. A detailed study of the effects of various operating variables on the operation of the rotary vacuum precoat filter used for sludge dewatering. The variables studied were submergence, drum speed, and knife advance rate.

4. Operation on a round-the-clock basis to confirm the previously collected data.

Discussion

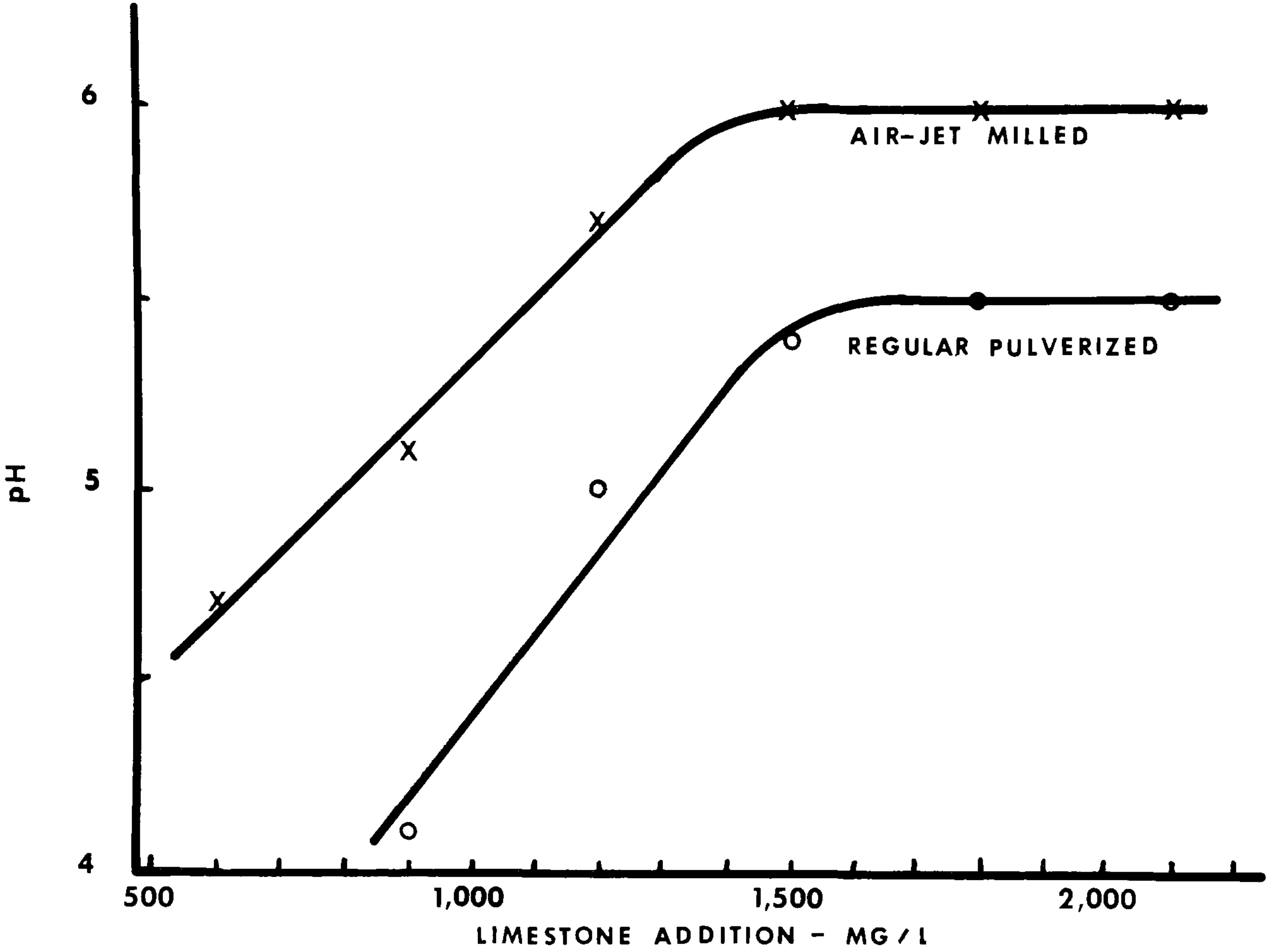
A plot of pH versus limestone dosage for both pulverized limestone and air-jet milled pulverized limestone is presented in Figure 22. The

TABLE XII

Average Raw Water Analysis
Proctor #2
Hollywood, Pennsylvania

pH	3.0
Total Iron	653 mg/l
Ferrous Iron	445 mg/l
Total Acidity	1560 mg/l (as $CaCO_3$)
Free Mineral Acidity	1740 mg/l (as $CaCO_3$)
Calcium	233 mg/l (as $CaCO_3$)
Magnesium	168 mg/l (as $CaCO_3$)
Total Solids	4110 mg/l

FIGURE 22
pH VS LIMESTONE ADDITIONS



procedure for these tests was to add measured aliquots of a standard limestone slurry to 500 milliliter samples of the raw water and continuously agitate for one-half hour before measuring the pH. Aliquots of the supernatant collected after a one-half hour settling period were analyzed for free mineral acidity. These results are presented in Figure 23. From these tests, standard dosages of 1500 mg/l for the air-jet milled pulverized limestone and 1800 mg/l for the pulverized limestone were selected. Particle size analysis for these two materials were made by use of Coulter Counter techniques. The results for the pulverized limestone were presented in Table XI. The results for the air-jet milled pulverized limestone are presented in Table XIII. The results would indicate the higher efficiencies are associated with lower average particle size.

The setup of the designed experiment is presented in Table XIV and a diagram of the system in Figure 5. The standard limestone dosage referred to is the 1800 mg/l dosage determined above. For purposes of the experiment, the limestone dosage was varied higher and lower by 25 per cent of the standard dosage. During these runs, the lime dosage was adjusted to attempt to obtain an acceptable iron analysis on a filtered sample of the clarifier feed. Due to the high ferrous iron content of the raw water and insufficient aeration capacity in the pilot plant, the resulting pH in the clarifier overflow was necessarily in the range of pH 9.0 to 10.0. Use of sufficient aeration would probably result in acceptable iron concentrations below pH 8.0. The data that was recorded or calcualted for use in the statistical analysis were:

Level number

Raw flow rate - gallons per minute

Air flow rate - cubic feet per minute

Per cent sludge recirculation

Limestone dosage - pounds per gallon

Sludge volume as per cent of raw flow

Filtration rate - gallons per hour per square foot

Overflow velocity - feet per hour

Settling velocity - feet per hour

Solids loading - pounds per hour per square foot

Unit Relative Cost

Sludge solids concentration - per cent

FIGURE 23
FFMA VS LIMESTONE ADDITION

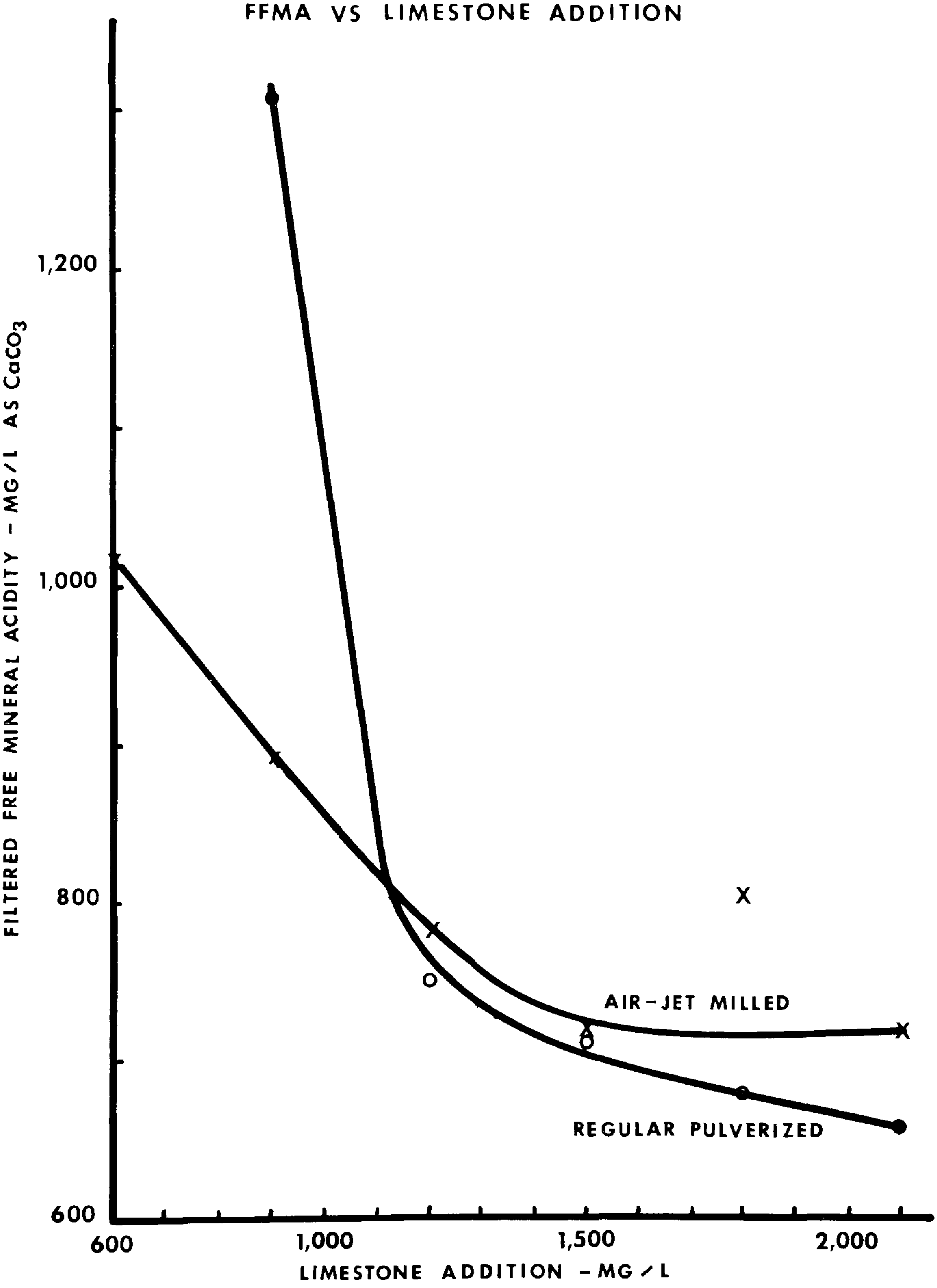


TABLE XIII

Coulter Counter Analysis
of Air-jet Milled Pulverized Limestone

Average Particle		Weight Distribution		Number Distribution	
Volume	Diam.	Differential %	% Less than	Differential %	% Less than
231997	76.22	0.00	100.00	0.00	100.00
173998	68.36	11.99	88.00	0.00	99.99
86999	54.25	3.99	84.00	0.00	99.98
43499	43.06	3.99	80.00	0.01	99.97
21750	34.18	6.49	73.50	0.03	99.94
10875	27.13	10.74	62.75	0.11	99.83
5437	21.53	7.62	55.13	0.15	99.67
2719	17.09	9.12	46.00	0.37	99.30
1359	13.56	6.62	39.37	0.54	98.75
680	10.76	7.59	31.78	1.24	97.51
340	8.54	5.73	26.04	1.88	95.63
170	6.78	5.24	20.80	3.44	92.18
85	5.38	5.59	15.20	7.34	84.84
42	4.27	5.70	9.49	14.98	69.85
21	3.39	5.68	3.81	29.82	40.03
11	2.69	3.81	0.00	40.03	0.00

Volume average diameter is 23.83 microns. Area average diameter is 10.07 microns. Length average diameter is 5.23 microns.

TABLE XIV

Statistically Designed Experimental Program

	Raw Feed Rate gpm	Aeration Rate cfm	Sludge Recirculation %	Limestone Feed
	5	0	0	-25%
Levels	10	10	20	Standard
	15	17	50	+25%
Run				
1	5	0	0	-25
2	10	17	20	+25
3	15	10	50	Standard
4	5	0	50	Standard
5	10	17	0	-25
6	15	10	20	+25
7	5	0	20	+25
8	10	17	50	Standard
9	15	10	0	-25
10	5	10	0	+25
11	10	0	20	Standard
12	15	17	50	-25
13	5	10	50	-25
14	10	0	0	+25
15	15	17	20	Standard
16	5	10	20	Standard
17	10	0	50	-25
18	15	17	0	+25
19	5	17	0	Standard
20	10	10	20	-25
21	15	0	50	+25
22	5	17	50	+25
23	10	10	0	Standard
24	15	0	20	-25
25	5	17	20	-25
26	10	10	50	+25
27	15	0	0	Standard

The first four items after level number were the controlled variables in the experiment. The sludge volume was calculated from the flow rate required to obtain a balance of filterable solids in and out of the thickener. The filtration rate was measured during filterability tests using the Johns-Manville 0.1 square foot rotary vacuum precoat test leaf. Overflow velocity was calculated from the overflow rate and the cross-sectional area of the clarification zone in the thickener. Settling velocity was calculated from the relationship

$$R = \frac{Q(F - D)}{PA}$$

where R = settling rate - feet per hour

Q = solids feed rate - pounds per hour

F = feed concentration - pounds liquid/pound solids

D = sludge concentration - pounds liquid/pound solids

P = density of solution - pounds per cubic foot

A = cross-sectional area - square feet.

Solids loading was calculated based on the feed solids concentration, the overflow rate, and the cross-sectional area of the clarification zone. To calculate the Unit Relative Cost, the cost of equipment that would vary with different conditions was estimated. This included the blowers required, the thickener, and the filter unit. These costs were amortized on the basis of 20 year life with straight-line depreciation. Cost of capital was neglected. A unit cost computed from the amortization and the chemical costs were calculated. The lowest cost was used as the basis, and the costs at other conditions computed as a factor relative to it.

The statistical analysis of the data proudced the following equation relating process variables to Unit Relative Cost (URC):

$$\begin{aligned} URC = {} & 1.667 + 0.02298 \times (\text{per cent sludge}) \\ & - 5.319 \times (\text{filtration rate, gal./ft}^2 - \text{min}) \\ & + 6.492 \times 10^{-5} \times (\text{per cent recirculation})^2 \end{aligned}$$

Eighty per cent of the total observed variation in the URC was accounted for by this expression. Higher URC was associated with higher volumes of sludge, higher recirculation rates, and lower filtration rates. The data were examined to determine what relationships might exist among them. The results were:

1. Sludge solids concentration and filtration rate were inversely related.

2. Sludge solids concentration and raw flow rate were inversely related.

3. Raw flow was related with overflow velocity.

4. Raw flow was related with settling velocity.

5. Raw flow was related very closely with solids loading.

6. Sludge volume was related inversely with sludge solids concentration.

7. Sludge volume was related inversely with settling velocity.

8. Overflow velocity was related with settling velocity.

9. Overflow velocity was related with solids loading.

10. Settling velocity was related with solids loading.

The analytical data from each of the runs is presented in Tables XV.1 to XV.27. The iron reported in the clarifier feed stream was determined by analysis of a filtered sample to represent the unprecipitated iron at this point in the process. The chemical usage efficiency for the limestone was calculated as the acidity reduction in the aerator over the dosage. The chemical usage efficiency for lime was similarly computed based on acidity reduction between aerator overflow and clarifier overflow. Due to the problem of supply of air-jet milled pulverized limestone, pulverized limestone was used during the twenty-seven levels of the designed experiment. Two additional runs were made using the air-jet milled material. The analysis of these runs is presented in Tables XVI.1 and XVI.2. A run was made using lime only and the results are presented in Table XVII. One run at the high flow rate was made using the standard limestone dosage with lime and one milligram per liter of ATLASEP 1A1, a weakly anionic polyelectrolyte. The results are presented in Table XVIII.

The effects of reducing the particle size distribution by air-jet milling operationally appeared to offer significant advantages. Comparing the first run using air-jet milled material with the level 14 run, approximately 55 per cent less air-jet milled limestone gave about the same neutralization results, indicating a considerably greater efficiency from the air-jet milled material. Better settling characteristics due partially to a lower solids loading were obtained with the finer material as indicated by the improved quality overflow

TABLE XV.1

Level No. 1

<u>Designed Conditions</u>: Raw Flow - 5 gal./min
Aeration - 0 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.1	10.0	10.2		6.2
Total Iron	637.0	436.0	1.0	6.0		0.0
Ferrous Iron	413.0	385.0	1.0			
Total Acidity	1670.0			0.0		20.0
Free Mineral Acidity	1700.0	770.0				
Calcium	190.0			1600.0		1590.0
Magnesium	170.0			0.0		0.0
Filterable Solids		900.0	3963.0		10208.0	
Total Solids	3720.0			3200.0		3000.0
Total Alkalinity				36.0		4.0
Phenol Alkalinity				22.0		0.0
Solids Balance (as lb/hr)			9.9		6.1	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.8	3.0
Clarifier Underflow, gal./min	1.2	1.9
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.29	0.23

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1320.0	1272.0
Efficiency, per cent	70.4	60.5

TABLE XV.2

Level No. 2

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 17 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	6.1	9.8	10.3		6.6
Total Iron	564.0	452.0	0.0	2.0		1.0
Ferrous Iron	419.0	385.0	0.0			
Total Acidity	1440.0			0.0		5.0
Free Mineral Acidity	1690.0	710.0				
Calcium	230.0			1440.0		1540.0
Magnesium	160.0			120.0		0.0
Filterable Solids		1680.0	3300.0		6250.0	
Total Solids	3840.0			3120.0		2920.0
Total Alkalinity				48.0		10.0
Phenol Alkalinity				32.0		0.0
Solids Balance (as lb/hr)			15.2		12.5	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	6.0	5.1
Clarifier Underflow, gal./min	4.0	4.8
Sludge Recycle, gal./min	0.9	0.9
Clarifier Solids Loading, lb/sq ft-hr	0.39	0.33

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2304	1296
Efficiency, per cent	42.5	54.7

TABLE XV.3

Level No. 3

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 10 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	6.0	6.5	6.8		6.8
Total Iron	590.0	430.0	0.0	11.0		1.0
Ferrous Iron	446.0	279.0	0.0			
Total Acidity	1350.0	890.0		70.0		20.0
Free Mineral Acidity	1350.0					
Calcium	250.0			1340.0		1550.0
Magnesium	220.0			230.0		0.0
Filterable Solids		1440.0	3240.0		8440.0	
Total Solids	0.0			0.0		0.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			20.2		14.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	11.5	10.2
Clarifier Underflow, gal./min	3.5	4.7
Sludge Recycle, gal./min	1.6	1.6
Clarifier Solids Loading, lb/sq ft-hr	0.73	0.65

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1728	1112
Efficiency, per cent	26.6	80.0

TABLE XV.4

Level No. 4

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 0 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	5.6	8.2	9.4		7.0
Total Iron	626.0	420.0	1.0	5.0		1.0
Ferrous Iron	480.0	409.0	0.0			
Total Acidity	1450.0	640.0		0.0		30.0
Free Mineral Acidity	1450.0					
Calcium	290.0			1580.0		1560.0
Magnesium	210.0			0.0		0.0
Filterable Solids		1296.0	4348.0		6976.0	
Total Solids	4120.0			3280.0		3160.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			9.7		6.6	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.1	2.2
Clarifier Underflow, gal./min	1.9	2.7
Sludge Recycle, gal./min	0.9	0.9
Clarifier Solids Loading, lb/sq ft-hr	0.26	0.19

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1775	1152
Efficiency, per cent	45.6	55.5

TABLE XV.5

Level No. 5

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 17 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.7	5.5	10.6	9.7		7.9
Total Iron	660.0	503.0	1.0	22.0		1.0
Ferrous Iron	444.0	430.0	0.0			
Total Acidity	1500.0	730.0		0.0		30.0
Free Mineral Acidity	1650.0					
Calcium	290.0			1630.0		1630.0
Magnesium	210.0			0.0		0.0
Filterable Solids		1644.0	3400.0		5788.0	
Total Solids	3800.0			3480.0		3200.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			17.0		10.4	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	6.4	4.1
Clarifier Underflow, gal./min	3.6	5.8
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.43	0.27

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1380	1104
Efficiency, per cent	55.7	66.1

TABLE XV.6

Level No. 6

<u>Designed Conditions</u>: Raw Flow - 15 gal./min
Aeration - 10 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.1	6.4	8.6	9.0		8.5
Total Iron	675.0	460.0	1.0	9.0		1.0
Ferrous Iron	441.0	408.0	0.0			
Total Acidity	1450.0	820.0		0.0		10.0
Free Mineral Acidity	1600.0					
Calcium	270.0			1560.0		1620.0
Magnesium	210.0			70.0		60.0
Filterable Solids		1672.0	3348.0		7992.0	
Total Solids	3800.0			3400.0		3360.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			21.9		24.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	8.8	9.5
Clarifier Underflow, gal./min	6.2	5.4
Sludge Recycle, gal./min	1.4	1.4
Clarifier Solids Loading, lb/sq ft-hr	0.58	0.63

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2256	984
Efficiency, per cent	27.9	83.3

TABLE XV.7

Level No. 7

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 0 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	5.7	9.6	8.3		8.5
Total Iron	697.0	468.0	1.0	12.0		1.0
Ferrous Iron	440.0	403.0	0.0			
Total Acidity	1490.0	830.0		0.0		40.0
Free Mineral Acidity	1670.0					
Calcium	280.0			1590.0		1690.0
Magnesium	310.0			270.0		0.0
Filterable Solids		1360.0	5252.0		12832.0	
Total Solids	3800.0			3360.0		3600.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			11.6		12.2	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.1	3.1
Clarifier Underflow, gal./min	1.9	1.8
Sludge Recycle, gal./min	0.4	0.4
Clarifier Solids Loading, lb/sq ft-hr	0.32	0.33

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1752	960
Efficiency, per cent	37.6	86.4

TABLE XV.8

Level No. 8

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 10 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	6.0	9.3	9.9		8.6
Total Iron	627.0	452.0	0.0	5.0		0.0
Ferrous Iron	427.0	407.0	0.0			
Total Acidity	1490.0	850.0		0.0		20.0
Free Mineral Acidity	1650.0					
Calcium	270.0			1650.0		1630.0
Magnesium	250.0			10.0		10.0
Filterable Solids		1980.0	5976.0		7390.0	
Total Solids	3020.0			2920.0		3280.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			28.5		14.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	6.0	2.2
Clarifier Underflow, gal./min	4.0	7.7
Sludge Recycle, gal./min	2.0	2.0
Clarifier Solids Loading, lb/sq ft-hr	0.70	0.26

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1775	899
Efficiency, per cent	36.0	94.4

TABLE XV.9

Level No. 9

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 10 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	4.9	9.9	9.4		8.3
Total Iron	575.0	445.0	1.0	12.0		0.0
Ferrous Iron	424.0	421.0	0.0			
Total Acidity	1490.0	820.0		0.0		0.0
Free Mineral Acidity	1680.0					
Calcium	280.0			1610.0		1690.0
Magnesium	220.0			80.0		10.0
Filterable Solids		1328.0	3896.0		5696.0	
Total Solids	3800.0			3360.0		3360.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			29.3		17.1	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	9.0	4.7
Clarifier Underflow, gal./min	6.0	10.2
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.69	0.36

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1232	936
Efficiency, per cent	54.3	87.6

TABLE XV.10

Level No. 10

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 10 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	6.2	9.4	9.5		9.1
Total Iron	536.0	417.0	0.0	4.0		0.0
Ferrous Iron	430.0	362.0	0.0			
Total Acidity	1510.0	810.0		20.0		30.0
Free Mineral Acidity	1680.0					
Calcium	290.0			1580.0		1620.0
Magnesium	180.0			60.0		0.0
Filterable Solids		1520.0	3832.0		9476.0	
Total Solids	3840.0			3320.0		3160.0
Total Alkalinity				0.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			9.6		8.1	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.3	2.9
Clarifier Underflow, gal./min	1.7	2.0
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.25	0.22

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2064	696
Efficiency, per cent	33.9	100.0

TABLE XV.11

Level No. 11

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 0 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	5.5	8.9	7.8		7.6
Total Iron	675.0	385.0	1.0	10.0		0.0
Ferrous Iron	374.0	348.0	0.0			
Total Acidity	1420.0	520.0		0.0		0.0
Free Mineral Acidity	1690.0					
Calcium	300.0			1600.0		1680.0
Magnesium	150.0			50.0		80.0
Filterable Solids		2000.0	4470.0		6000.0	
Total Solids	3880.0			3360.0		3400.0
Total Alkalinity				99.0		0.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			21.8		12.0	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	6.0	2.7
Clarifier Underflow, gal./min	4.0	7.2
Sludge Recycle, gal./min	0.8	0.8
Clarifier Solids Loading, lb/sq ft-hr	0.53	0.24

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1704	815
Efficiency, per cent	52.8	63.7

TABLE XV.12

Level No. 12

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 17 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	4.9	10.8	8.5		7.8
Total Iron	619.0	402.0	1.0	2.0		1.0
Ferrous Iron	374.0	357.0	0.0			
Total Acidity	1430.0	640.0		0.0		40.0
Free Mineral Acidity	1420.0					
Calcium	260.0			1560.0		1670.0
Magnesium	160.0			40.0		20.0
Filterable Solids		2240.0	3480.0		5410.0	
Total Solids	3920.0			4560.0		3680.0
Total Alkalinity				24.0		10.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			23.2		16.3	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	9.0	6.4
Clarifier Underflow, gal./min	6.0	8.5
Sludge Recycle, gal./min	3.0	3.0
Clarifier Solids Loading, lb/sq ft-hr	0.61	0.44

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1328	1000
Efficiency, per cent	59.4	64.0

TABLE XV.13

Level No. 13

<u>Designed Conditions</u>: Raw Flow - 5 gal./min
Aeration - 10 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/1)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.6	10.9	10.1		7.5
Total Iron	564.0	0.0	1.0	1.0		0.0
Ferrous Iron	385.0	357.0	0.0			
Total Acidity	1450.0	510.0		20.0		40.0
Free Mineral Acidity	1490.0					
Calcium	260.0			1540.0		1550.0
Magnesium	80.0			40.0		0.0
Filterable Solids		2800.0	5760.0		6800.0	
Total Solids	5000.0			3650.0		3000.0
Total Alkalinity				20.0		8.0
Phenol Alkalinity				8.0		0.0
Solids Balance (as lb/hr)			13.9		6.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.0	0.9
Clarifier Underflow, gal./min	2.0	4.0
Sludge Recycle, gal./min	1.0	1.0
Clarifier Solids Loading, lb/sq ft-hr	0.34	0.10

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/1	1320	744
Efficiency, per cent	71.2	68.5

TABLE XV.14

Level No. 14

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 0 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.5	8.0	7.6		7.7
Total Iron	705.0	447.0	8.0	10.0		0.0
Ferrous Iron	441.0	408.0	8.0			
Total Acidity	1680.0	640.0		0.0		0.0
Free Mineral Acidity	1890.0					
Calcium	220.0			1710.0		1690.0
Magnesium	80.0			150.0		200.0
Filterable Solids		1600.0	2960.0		5200.0	
Total Solids	4680.0			3640.0		3720.0
Total Alkalinity				88.0		64.0
Phenol Alkalinity				0.0		4.0
Solids Balance (as lb/hr)			14.8		14.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	4.3	4.2
Clarifier Underflow, gal./min	5.7	5.7
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.25	0.25

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2256	1008
Efficiency, per cent	46.0	63.4

TABLE XV.15

Level No. 15

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 17 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.2	7.5	7.9		7.2
Total Iron	610.0	513.0	12.0	3.0		1.0
Ferrous Iron	441.0	430.0	12.0			
Total Acidity	1700.0	720.0		10.0		10.0
Free Mineral Acidity	1840.0					
Calcium	280.0			1670.0		1670.0
Magnesium	110.0			160.0		200.0
Filterable Solids		1520.0	2360.0		4080.0	
Total Solids	4160.0			3600.0		3600.0
Total Alkalinity				28.0		30.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			16.3		22.5	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	4.0	6.9
Clarifier Underflow, gal./min	11.0	8.0
Sludge Recycle, gal./min	1.6	1.6
Clarifier Solids Loading, lb/sq ft-hr	0.18	0.32

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1800	808
Efficiency, per cent	54.4	89.1

TABLE XV.16

Level No. 16

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 10 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.8	10.1	7.3		8.4
Total Iron	580.0	486.0	0.0	7.0		0.0
Ferrous Iron	446.0	424.0	0.0			
Total Acidity	1730.0	710.0		20.0		20.0
Free Mineral Acidity	1910.0					
Calcium	200.0			1660.0		1800.0
Magnesium	140.0			120.0		100.0
Filterable Solids		1300.0	4120.0		7528.0	
Total Solids	4200.0			3560.0		3640.0
Total Alkalinity				26.0		24.0
Phenol Alkalinity				0.0		2.0
Solids Balance (as lb/hr)			9.5		6.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.2	2.4
Clarifier Underflow, gal./min	1.8	2.5
Sludge Recycle, gal./min	0.5	0.5
Clarifier Solids Loading, lb/sq ft-hr	0.26	0.20

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1799	528
Efficiency, per cent	56.6	100

TABLE XV.17

Level No. 17

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 0 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	4.8	7.6	7.3		7.1
Total Iron	591.0	530.0	0.0	18.0		9.0
Ferrous Iron	446.0	446.0	0.0			
Total Acidity	1640.0	820.0		0.0		0.0
Free Mineral Acidity	1820.0					
Calcium	250.0			1670.0		1720.0
Magnesium	90.0			210.0		160.0
Filterable Solids		1692.0	3240.0		3592.0	
Total Solids	4120.0			3640.0		3640.0
Total Alkalinity				94.0		99.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			15.6		12.9	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	2.8	1.2
Clarifier Underflow, gal./min	7.2	8.7
Sludge Recycle, gal./min	3.5	3.5
Clarifier Solids Loading, lb/sq ft-hr	0.17	0.08

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1356	899
Efficiency, per cent	60.4	91.1

TABLE XV.18

Level No. 18

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 17 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.2	9.9	8.2		8.4
Total Iron	591.0	525.0	0.0	18.0		0.0
Ferrous Iron	453.0	446.0	0.0			
Total Acidity	1660.0	750.0		30.0		10.0
Free Mineral Acidity	1860.0					
Calcium	250.0			1640.0		1730.0
Magnesium	120.0			190.0		160.0
Filterable Solids		2340.0	3100.0		3562.0	
Total Solids	4240.0			3640.0		3640.0
Total Alkalinity				44.0		32.0
Phenol Alkalinity				0.0		4.0
Solids Balance (as lb/hr)			23.3		16.1	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	6.0	1.9
Clarifier Underflow, gal./min	9.0	13.0
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.36	0.11

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2256	800
Efficiency, per cent	40.3	93.7

TABLE XV.19

Level No. 19

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 17 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.9	6.9	6.7		8.3
Total Iron	591.0	480.0	18.0	22.0		0.0
Ferrous Iron	458.0	419.0	0.0			
Total Acidity	1680.0	700.0		130.0		30.0
Free Mineral Acidity	1910.0					
Calcium	174.0			1630.0		1800.0
Magnesium	152.0			140.0		80.0
Filterable Solids		1764.0	3004.0		10832.0	
Total Solids	4120.0			3480.0		3640.0
Total Alkalinity				16.0		18.0
Phenol Alkalinity				0.0		2.0
Solids Balance (as lb/hr)			7.5		9.2	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.3	3.6
Clarifier Underflow, gal./min	1.7	1.3
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.19	0.21

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1799	528
Efficiency, per cent	54.4	100.0

TABLE XV.20

Level No. 20

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 10 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.2	7.6	9.4		8.6
Total Iron	616.0	531.0	120.0	5.0		0.0
Ferrous Iron	458.0	442.0	0.0			
Total Acidity	1650.0	750.0		10.0		30.0
Free Mineral Acidity	1970.0					
Calcium	220.0			1730.0		1780.0
Magnesium	120.0			80.0		50.0
Filterable Solids		1368.0	2780.0		4884.0	
Total Solids	4280.0			3440.0		3320.0
Total Alkalinity				42.0		20.0
Phenol Alkalinity				14.0		4.0
Solids Balance (as lb/hr)			12.4		13.2	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	4.6	4.8
Clarifier Underflow, gal./min	5.4	5.1
Sludge Recycle, gal./min	1.4	1.4
Clarifier Solids Loading, lb/sq ft-hr	0.25	0.26

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1356	744
Efficiency, per cent	66.3	100.0

TABLE XV.21

Level No. 21

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 0 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.2	5.6	6.7	6.7		6.8
Total Iron	745.0	690.0	178.0	28.0		30.0
Ferrous Iron	490.0	490.0	0.0			
Total Acidity	1580.0	450.0		0.0		0.0
Free Mineral Acidity	1840.0					
Calcium	180.0			1660.0		1726.0
Magnesium	180.0			140.0		294.0
Filterable Solids		1520.0	2732.0		5552.0	
Total Solids	4336.0			3932.0		3940.0
Total Alkalinity				90.0		56.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			16.7		16.7	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow - gal./min	9.0	8.9
Clarifier Underflow - gal./min	6.0	6.0
Sludge Recycle - gal./min	2.7	2.7
Clarifier Solids Loading - lb/sq ft-hr	0.48	0.48

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2200	832
Efficiency, per cent	51.3	54.0

TABLE XV.22

Level No. 22

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 17 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	5.7	9.2	8.3		8.3
Total Iron	692.0	812.0	0.0	2.0		0.0
Ferrous Iron	510.0	458.0	0.0			
Total Acidity	1550.0			70.0		70.0
Free Mineral Acidity	1850.0					
Calcium	180.0			1720.0		1800.0
Magnesium	160.0			100.0		170.0
Filterable Solids		2056.0	3900.0		7236.0	
Total Solids	4524.0			3593.0		3972.0
Total Alkalinity				12.0		14.0
Phenol Alkalinity				4.0		0.0
Solids Balance (as lb/hr)			8.1		7.2	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.0	2.7
Clarifier Underflow, gal./min	2.0	2.2
Sludge Recycle, gal./min	1.0	1.0
Clarifier Solids Loading, lb/sq ft-hr	0.23	0.21

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2280	648

TABLE XV.23

Level No. 23

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 10 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.4	9.1	7.6		7.4
Total Iron	683.0	855.0	1.0	12.0		1.0
Ferrous Iron	527.0	490.0	0.0			
Total Acidity	1590.0	250.0		50.0		40.0
Free Mineral Acidity	1870.0					
Calcium	190.0			1720.0		1820.0
Magnesium	120.0			130.0		110.0
Filterable Solids		1756.0	3208.0		8096.0	
Total Solids	4256.0			3576.0		3668.0
Total Alkalinity				12.0		10.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			16.1		24.7	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.9	6.0
Clarifier Underflow, gal./min	6.1	3.9
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.24	0.38

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1799	840
Efficiency, per cent	74.4	29.7

TABLE XV.24

Level No. 24

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 0 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	4.9	7.2	7.0		7.3
Total Iron	849.0	818.0	50.0	50.0		5.0
Ferrous Iron	505.0	504.0	0.0			
Total Acidity	1620.0	680.0		70.0		0.0
Free Mineral Acidity	1880.0					
Calcium	170.0			1580.0		2220.0
Magnesium	130.0			210.0		0.0
Filterable Solids		2988.0	2852.0		4092.0	
Total Solids	4372.0			3844.0		3768.0
Total Alkalinity				9.0		9.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			20.7		20.5	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gaL/min	5.0	4.8
Clarifier Underflow, gal./min	10.0	10.1
Sludge Recycle, gal./min	1.1	1.1
Clarifier Solids Loading, lb/sq ft-hr	0.28	0.27

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1360	1008
Efficiency, per cent	69.1	67.4

TABLE XV.25

Level No. 25

Designed Conditions: Raw Flow - 5 gal./min
Aeration - 17 cu ft/min
Recycle - 20 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	5.4	10.1	9.5		8.2
Total Iron	832.0	755.0	1.0	2.0		1.0
Ferrous Iron	504.0	625.0	0.0			
Total Acidity	1600.0	670.0		30.0		90.0
Free Mineral Acidity	1890.0					
Calcium	220.0			2270.0		2360.0
Magnesium	200.0			180.0		60.0
Filterable Solids		1704.0	3416.0		4912.0	
Total Solids	4492.0			3624.0		3360.0
Total Alkalinity				20.0		18.0
Phenol Alkalinity				6.0		0.0
Solids Balance (as lb/hr)			8.1		7.6	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	1.9	1.6
Clarifier Underflow, gal./min	3.1	3.3
Sludge Recycle, gal./min	0.6	0.6
Clarifier Solids Loading, lb/sq ft-hr	0.12	0.11

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1320	840
Efficiency, per cent	70.4	79.7

TABLE XV.26

Level No. 26

Designed Conditions: Raw Flow - 10 gal./min
Aeration - 10 cu ft/min
Recycle - 50 per cent
Limestone (Fraction of Standard) - 1.25

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.1	6.0	11.3	9.4		8.4
Total Iron	780.0	725.0	8.0	1.0		0.0
Ferrous Iron	513.0	500.0	0.0			
Total Acidity	1540.0	370.0		40.0		50.0
Free Mineral Acidity	1800.0					
Calcium	170.0			2300.0		2300.0
Magnesium	200.0			260.0		250.0
Filterable Solids		1328.0	4024.0		5356.0	
Total Solids	4300.0			3436.0		3486.0
Total Alkalinity				20.0		12.0
Phenol Alkalinity				8.0		1.0
Solids Balance (as lb/hr)			17.7		16.6	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	3.8	3.3
Clarifier Underflow, gal./min	6.2	6.6
Sludge Recycle, gal./min	3.6	3.6
Clarifier Solids Loading, lb/sq ft-hr	0.30	0.26

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	2256	971
Efficiency, per cent	51.8	38.0

TABLE XV.27

Level No. 27

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 0 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	5.2	7.2	7.4		7.0
Total Iron	830.0	717.0	55.0	55.0		10.0
Ferrous Iron	480.0	497.0	0.0			
Total Acidity	1600.0	420.0		30.0		0.0
Free Mineral Acidity	1830.0					
Calcium	250.0			2150.0		2440.0
Magnesium	190.0			320.0		350.0
Filterable Solids		912.0	3520.0		7088.0	
Total Solids	4196.0			3860.0		3920.0
Total Alkalinity				90.0		84.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			26.4		20.2	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	9.3	7.5
Clarifier Underflow, gal./min	5.7	7.4
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.64	0.52

Chemical Usage Efficiencies	Limestone	Lime
Feed, mg/l	1800	880
Efficiency, per cent	65.5	47.7

TABLE XVI.1

Air-jet Milled Pulverized Limestone

Designed Conditions: Raw Flow - 10 gal/min
Aeration - 0 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 0.75

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.1	5.6	7.6	8.9		7.6
Total Iron	620.0			4.0		1.0
Ferrous Iron	382.0					
Total Acidity	1700.0			0.0		0.0
Free Mineral Acidity	1700.0					
Calcium	208.0			1640.0		1520.0
Magnesium	252.0			0.0		40.0
Filterable Solids		952.0	1180.0		11240.0	
Total Solids	4000.0			3400.0		3200.0
Total Alkalinity				40.0		18.0
Phenol Alkalinity				2.0		0.0
Solids Balance (as lb/hr)			5.9		12.4	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal/min	7.8	8.9
Clarifier Underflow, gal/min	2.2	1.0
Sludge Recycle, gal/min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.18	0.20

Chemical Usage	Limestone	Lime
Feed, mg/l	1020	1188

TABLE XVI.2

Air-jet Milled Pulverized Limestone

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 0 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Raw	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	2.9	5.7	9.1	7.0		7.7
Total Iron	676.0	385.0	1.0	55.0		0.0
Ferrous Iron	408.0	374.0	0.0			
Total Acidity	1680.0			0.0		0.0
Free Mineral Acidity	1700.0					
Calcium	250.0			1600.0		1490.0
Magnesium	80.0			80.0		120.0
Filterable Solids		1340.0	3580.0		10000.0	
Total Solids	4400.0			3480.0		3360.0
Total Alkalinity				99.0		32.0
Phenol Alkalinity				0.0		0.0
Solids Balance (as lb/hr)			26.9		15.0	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	12.0	9.6
Clarifier Underflow, gal./min	3.0	5.3
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.85	0.68

Chemical Usage	Limestone	Lime
Feed, mg/l	1504	968

TABLE XVII

Lime Only

Designed Conditions: Raw Flow - 10 gal/min
Aeration - 0 cu ft
Recycle - 0 per cent

Chemical Analysis (as mg/l)	Raw	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	3.0	8.7	7.0		7.0
Total Iron	561.0	55.0	55.0		0.0
Ferrous Iron	392.0	0.0			
Total Acidity	1530.0		0.0		
Free Mineral Acidity	1890.0				
Calcium	130.0		1660.0		
Magnesium	300.0		0.0		
Filterable Solids		1960.0		2700.0	
Total Solids	4040.0		3750.0		
Total Alkalinity			14.0		
Phenol Alkalinity			0.0		
Solids Balance (as lb/hr)		9.8		6.8	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal/min	5.0	2.7
Clarifier Underflow, gal/min	5.0	7.2
Sludge Recycle, gal/min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.19	0.10

Chemical Usage	Limestone	Lime
Feed, mg/l	0.0	1512

TABLE XVIII

Polyelectrolyte Run

Designed Conditions: Raw Flow - 15 gal./min
Aeration - 17 cu ft/min
Recycle - 0 per cent
Limestone (Fraction of Standard) - 1.00

Chemical Analysis (as mg/l)	Aerator Overflow	Clarifier Feed	Clarifier Overflow	Clarifier Underflow	Filtrate
pH	5.1	8.9	8.0		6.6
Total Iron		55.0	15.0		5.0
Filterable Solids		2596.0		5284.0	
Solids Balance (as lb/hr)		19.5		15.9	

Flow Conditions	Operating	Equilibrium
Clarifier Overflow, gal./min	9.0	7.6
Clarifier Underflow, gal./min	6.0	7.3
Sludge Recycle, gal./min	0.0	0.0
Clarifier Solids Loading, lb/sq ft-hr	0.46	0.39

Chemical Usage	Limestone	Lime
Feed, mg/l	1800	768

and the denser sludge. Comparing the second run using air-jet milled material with level 27, approximately 15 per cent less air-jet milled limestone resulted in more neutralization as indicated by the aerator overflow pH. The solids loading was about the same, but again a denser sludge was obtained. The cost incurred in obtaining air-jet milled material and possibly the availability may, however, more than offset the benefits of lower usage requirements due to increased efficiency. The use of on-site wet grinding as provided in the tube mill described by E. A. Mihok et al and used at the three previous sites appears to offer a very promising alternative. The economics of this will be discussed in the appendix on economics of the various treatment processes.

The use of lime only in the neutralization step resulted in considerable increases in costs for a number of reasons. The solids produced, although lower in quantity than from the combined lime with limestone process, have considerably poorer settling characteristics offering problems in both clarification and thickening. The filtration rate of the sludge is also much lower than for an equally concentrated sludge from the combined lime with limestone process.

The use of the ATLASEP 1A1 polyelectrolyte resulted in a denser sludge that appeared to have about the same filterability as the other sludges produced during the designed experiment. As discussed later, this may be an extremely beneficial result.

The analysis of the data to select the best conditions for use in the last two phases of the program was made before the statistical analysis was done. The two levels with the lowest unit relative cost that were felt to be capable of producing a satisfactory effluent were selected. Most of the low unit relative cost levels were eliminated because excessive solids carryover in the overflow had occurred at those conditions. Levels 19 and 23 were selected as those levels that were felt could best produce the desired results.

The results of the filtration tests are presented in Figures 24 to 27. The 30 per cent submergence and one revolution per minute conditions were selected for further tests because of the consideration that about a 20 per cent reduction in cost of the filter unit as opposed to a 50 per cent submergence unit would result and the maintenance costs would be significantly lower. Based on these tests using level 23 conditions, a flow rate of 0.19 to 0.20 gallons per minute per square foot at a knife advance of 0.001 inches per revolution was expected. A CELITE 501 precoat was used for all tests.

The round-the-clock operation was made at level 23 conditions. The system was operated for approximately 33 hours during which time two precoats were applied to the filter. The first precoat had a usable thickness of about 0.6 inches. At an average knife advance of 0.0010

FIGURE 24
FILTRATION CHARACTERISTICS
LEVEL 19 SLUDGE

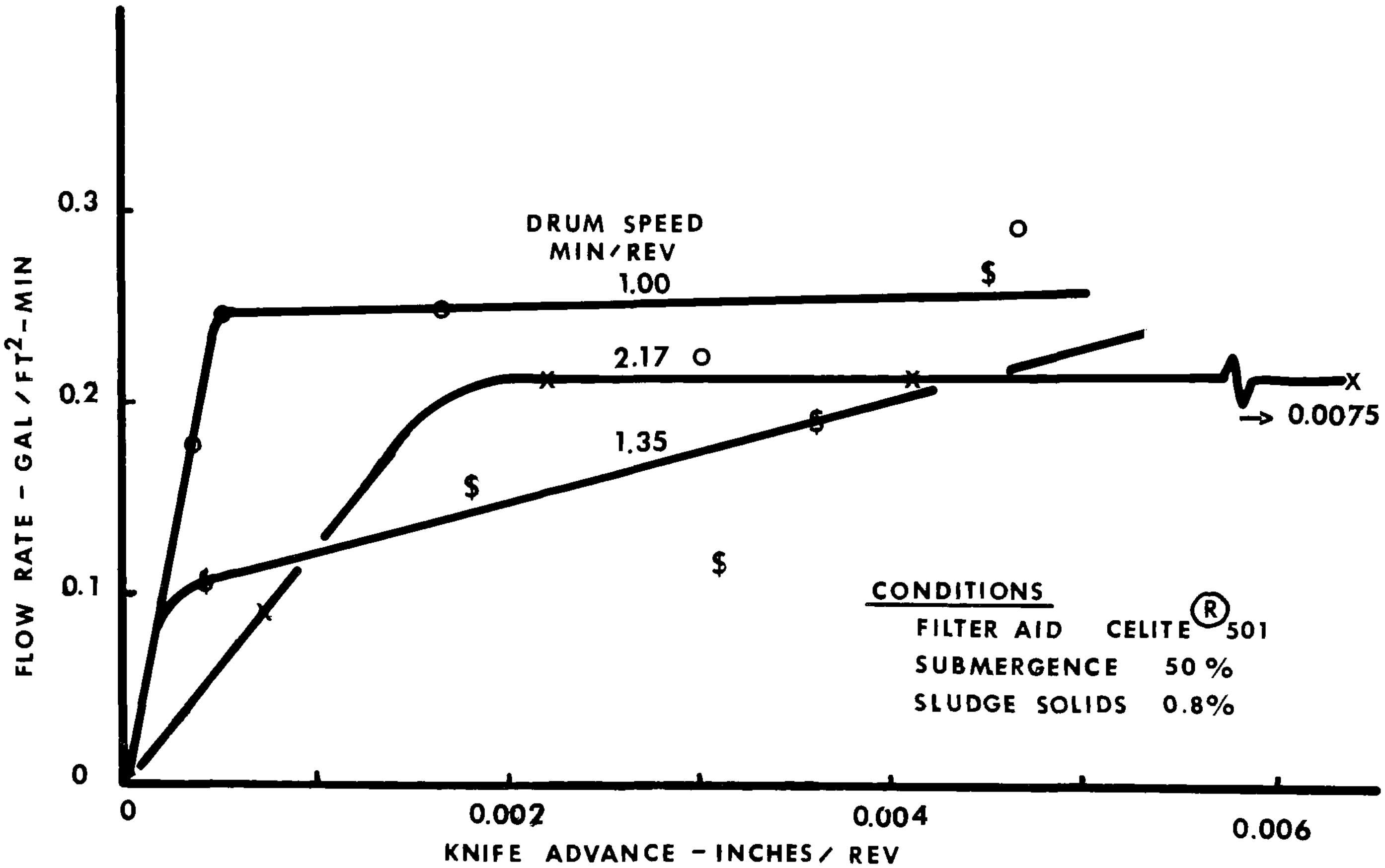


FIGURE 25
FILTRATION CHARACTERISTICS
LEVEL 19 SLUDGE

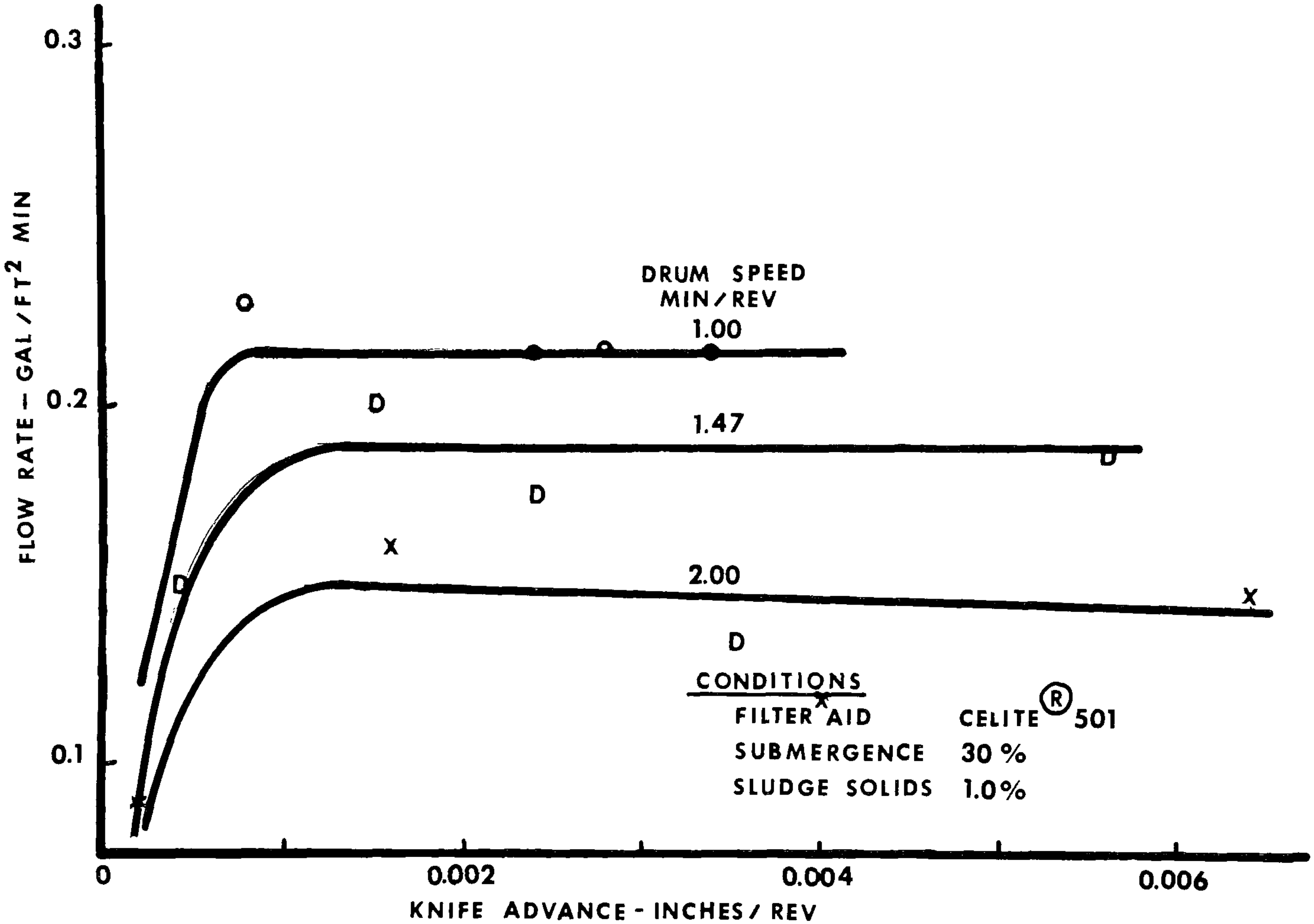


FIGURE 26
FILTRATION CHARACTERISTICS
LEVEL 23 SLUDGE

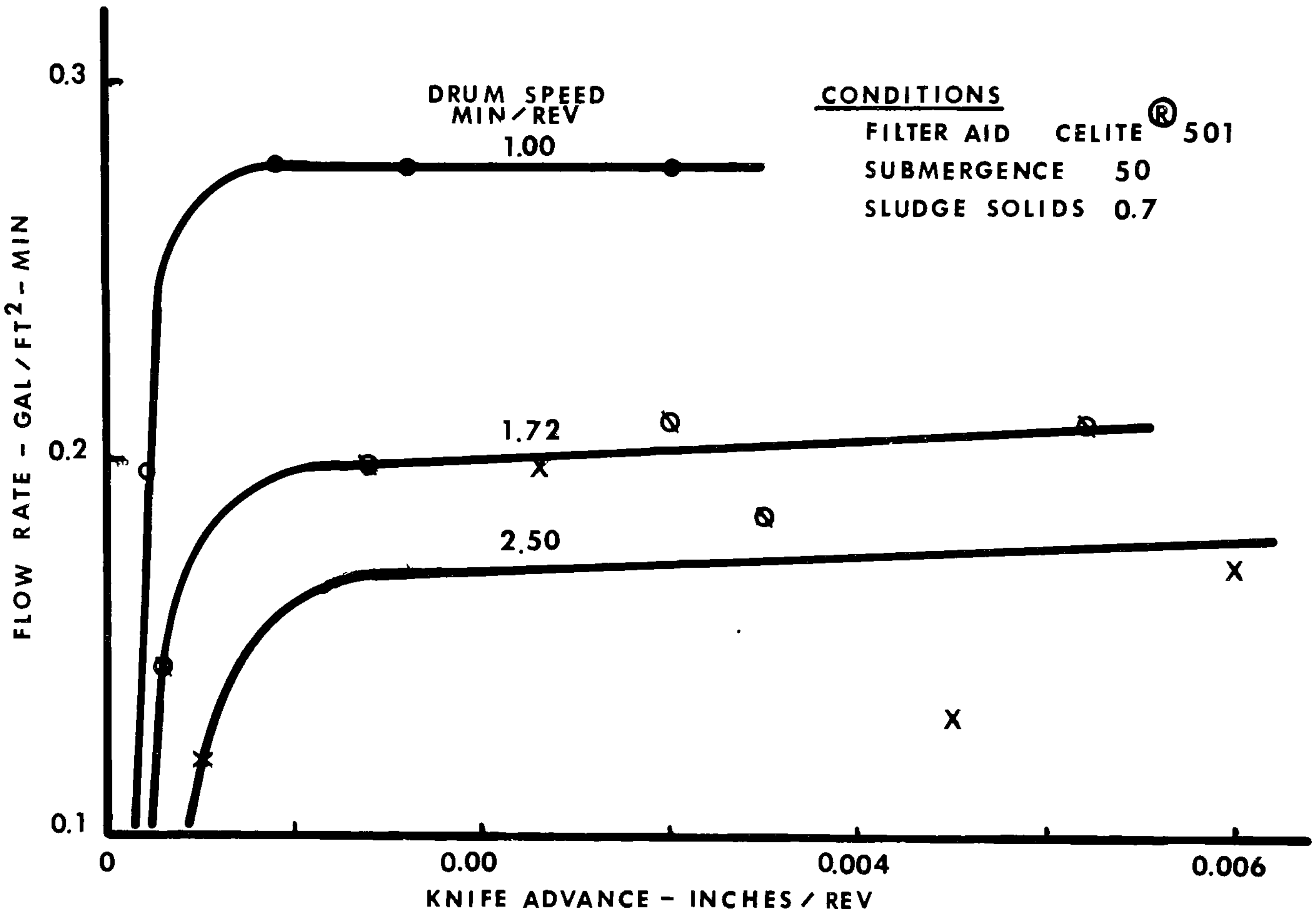
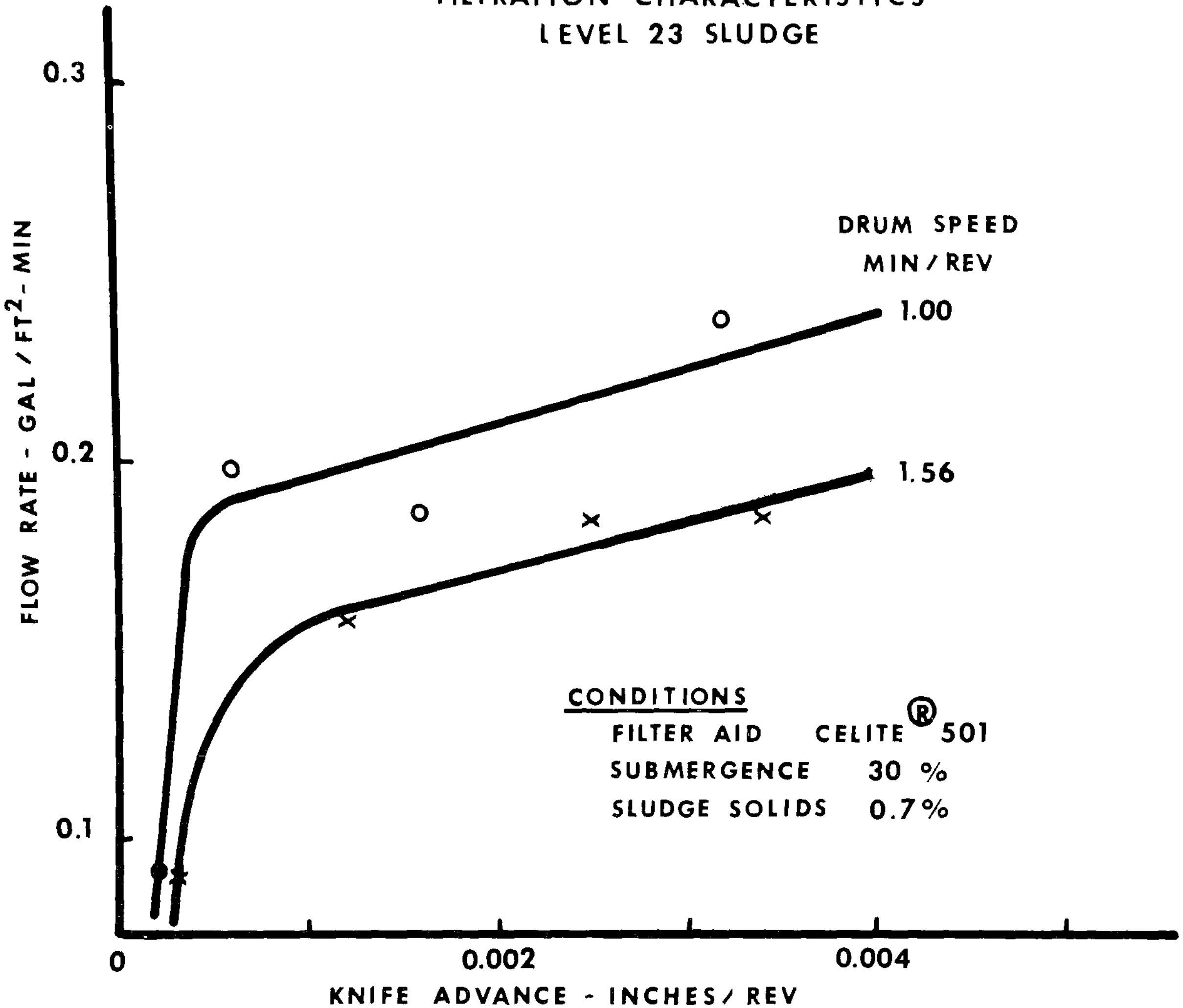


FIGURE 27
FILTRATION CHARACTERISTICS
LEVEL 23 SLUDGE



inches per revolution, an average flow rate of 0.195 gallons per minute per square foot was obtained. The second precoat had a usable thickness of 1.1 inches. The filter was initially operated with an average knife advance of 0.0011 inches per revolution and an average filtration rate of 0.165 gallons per minute per square foot was obtained. During this period, however, the cake appeared to be undergoing compression with the filtration rate steadily increasing from 0.13 to 0.20 gallons per minute per square foot. The knife advance was increased so that an average advance of 0.0017 inches per revolution was obtained. The optimum knife advance thus appears to be 0.001 inches per drum revolution. The average filtration rate during this period was 0.205 gallons per minute per square foot. No indication of precoat penetration and blinding was observed during either run.

The analysis of composite samples from the round-the-clock run are presented in Table IXX. A material balance based on these figures is found in Table XX. Difficulty was encountered with both feeding systems during the round-the-clock run. Measurements indicated that the limestone feed rate was 0.011 pounds per gallon rather than the 0.015 pounds per gallon level desired. In addition, difficulty was encountered in maintaining a pH between 8.5 and 9 in the thickener overflow that would insure sufficient precipitation of the ferrous iron.

The relationship indicated by the statistical analysis between sludge solids and filtration rate was used in making optimization calculations for the process based on level 23 conditions. A plot of the filtration rate versus the sludge solids concentration is presented in Figure 28. A linear regression was made on the data to obtain an equation describing the filtrate rate as a function of the sludge solids concentration. Using this relationship and a material balance around the sedimentation unit, the cost for a rotary vacuum precoat filter unit at various sludge solids concentrations was calculated. The results are presented in Figure 29. In addition, settling tests had been run for various concentrations of the solids obtained during the round-the-clock operation that was analyzed to give a log-log relationship between settling rate and solids concentration. Using the methods described by R. I. Dick[6] and the above relationship, the cost of a thickener to produce the various sludge solids concentrations was calculated. The results are presented in Figure 30. For concentrations above 6000 mg/l, the cost of the thickener was calculated from values extrapolated beyond the range of the original data. In costing the filter unit, the values above 12,000 mg/l were based on extrapolated flow rates. Combining the above two calculations, an optimization curve for the combined sedimentation-sludge dewatering process was obtained. This is presented in Figure 31.

A series of tests planned to confirm the extrapolated values in the above calcualtions had to be canceled because of a drastic change in the quality of the Proctor 2 water at the time they were scheduled. The quality change may have been the result of dilution of the water in the mine caused by heavy rains.

TABLE IXX

24 Hour Run Composite Sample Analysis

	Raw	Aerator Overflow	Clarifier Feed	Sludge	Filtrate	Clarifier Overflow
Fluids						
pH	2.6	4.85	8.30	8.40	7.20	7.65
Total Solids, mg/l	3891	4327	5194	8677	3454	3237
Free Mineral Acidity, mg/l (as $CaCO_3$)	1668	668	0	0	2	2
Total Acidity, mg/l (as $CaCO_3$)	1560	460	1	0	8	4
Sulfate, mg/l (as SO_4)	2230	2180	2150	2190	2150	2530
Chloride, mg/l (as Cl)	2.7	5.4	5.6	4.4	2.4	2.7
Iron, mg/l (as Fe)	470	495	480	1270	1	10.5
Calcium, mg/l (as $CaCO_3$)	432	1493	2686	3464	2033	1908
Magnesium, mg/l (as $CaCO_3$)	334	346	402	803	289	289
Aluminum, mg/l (as Al)	171	158	154	336	7	3
Silica, mg/l (as SiO_2)	75	72	7	280	22	81

Filter Cake	0.001 in./min cut	0.0017 in./min cut
Moisture, %	79.7	78.5
Carbonates (as % CO_2 - dry basis)	4.6	4.3
Silica (as % SiO_2 - dry basis)	18.1	26.4
Iron (as % Fe_2O_3 - dry basis)	32.8	27.2
Calcium (as % $CaCO_3$ - dry basis)	14.8	14.3

TABLE XX

Material Balances

Flows: Raw - 10 gpm
Sludge Draw - 4 gpm
Overflow - 6 gpm

Quantities (lb/hr)	Raw	Aerator Overflow	Clarifier Feed	Sludge	Clarifier Overflow
Total Solids	19.5	21.7	26	17.36	9.72
Free Mineral Acidity	8.4	3.3	0	0	0.006
Total Acidity	7.8	2.3	0.005	0	0.012
Sulfate	9.3	9.1	9.0	3.68	5.1
Chloride	0.01	0.3	0.03	0.008	0.006
Iron	3.4	3.5	3.4	3.64	0.048
Calcium	2.2	7.5	13.4	6.9	6.0
Magnesium	1.7	1.7	2.0	1.6	0.84
Aluminum	1.6	1.5	1.4	1.28	0.018
Silica	0.4	0.4	0.004	0.56	0.24

Material Balance at Clarifier (lb/hr)	Feed	Overflow	Underflow	Total Out	Difference
Total Solids	26	9.72	17.36	27.08	+1.08
Free Mineral Acidity	0	0.006	0	0.006	+0.006
Total Acidity	0.005	0.012	0	0.012	+0.007
Sulfate	9.0	5.1	3.68	8.78	-0.22
Chloride	0.03	0.006	0.008	0.014	-0.016
Iron	3.4	0.05	3.64	3.69	+0.29
Calcium	13.4	6.0	6.9	12.9	-0.5
Magnesium	2.0	0.84	1.6	2.44	+0.44
Alum	1.4	0.018	1.28	1.30	-0.1
Silica	0.04	0.24	0.56	0.70	+0.66

Material Balance at Filter (lb/hr)	Sludge	Filtrate	Cake	Difference
Iron	0.96	Trace	0.90	-0.06
Calcium	1.82	1.04	0.41	-0.37

FIGURE 28

EFFECT OF SLUDGE SOLIDS ON FILTRATION RATE

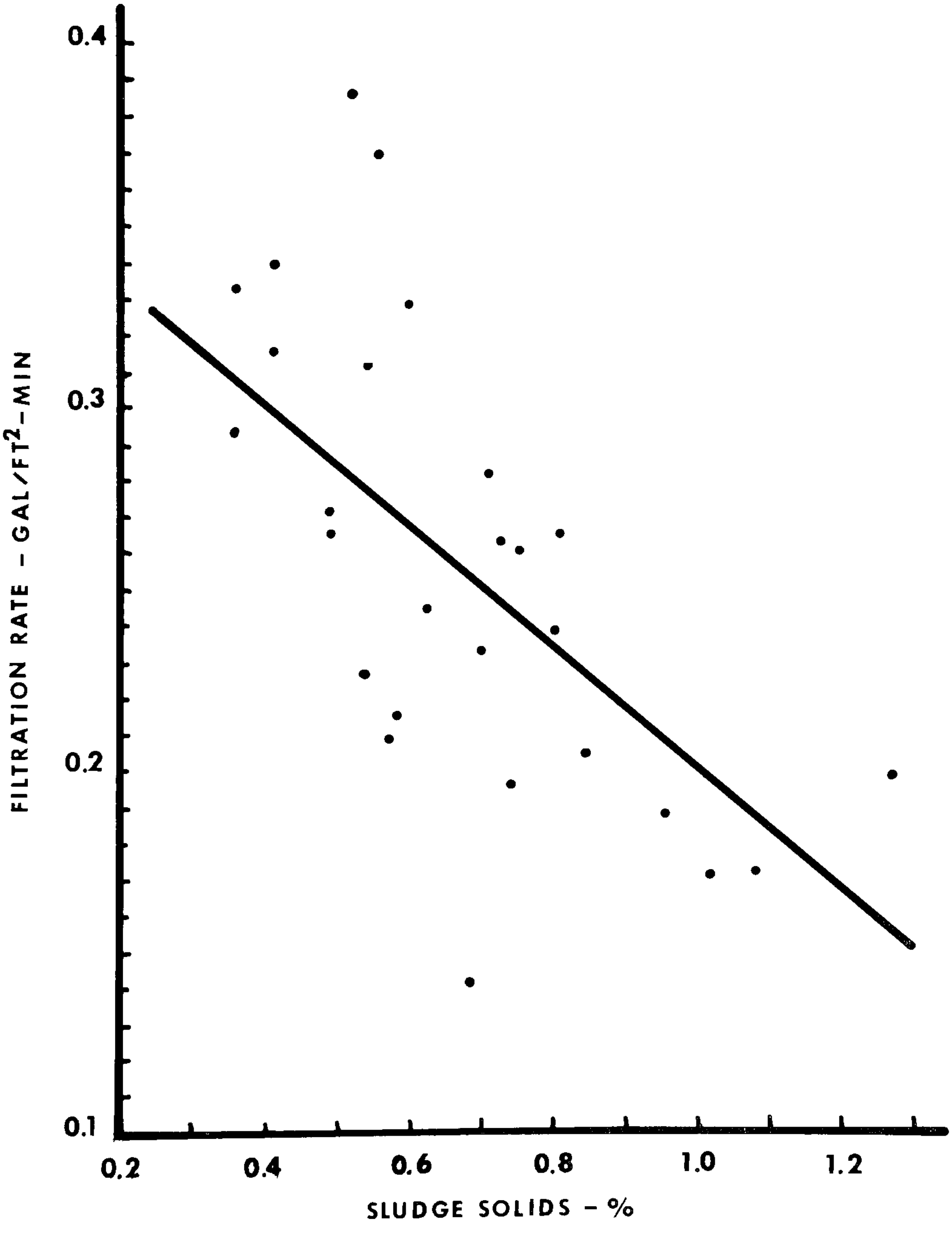


FIGURE 29

EFFECT OF SLUDGE SOLIDS
ON FILTER STATION COST

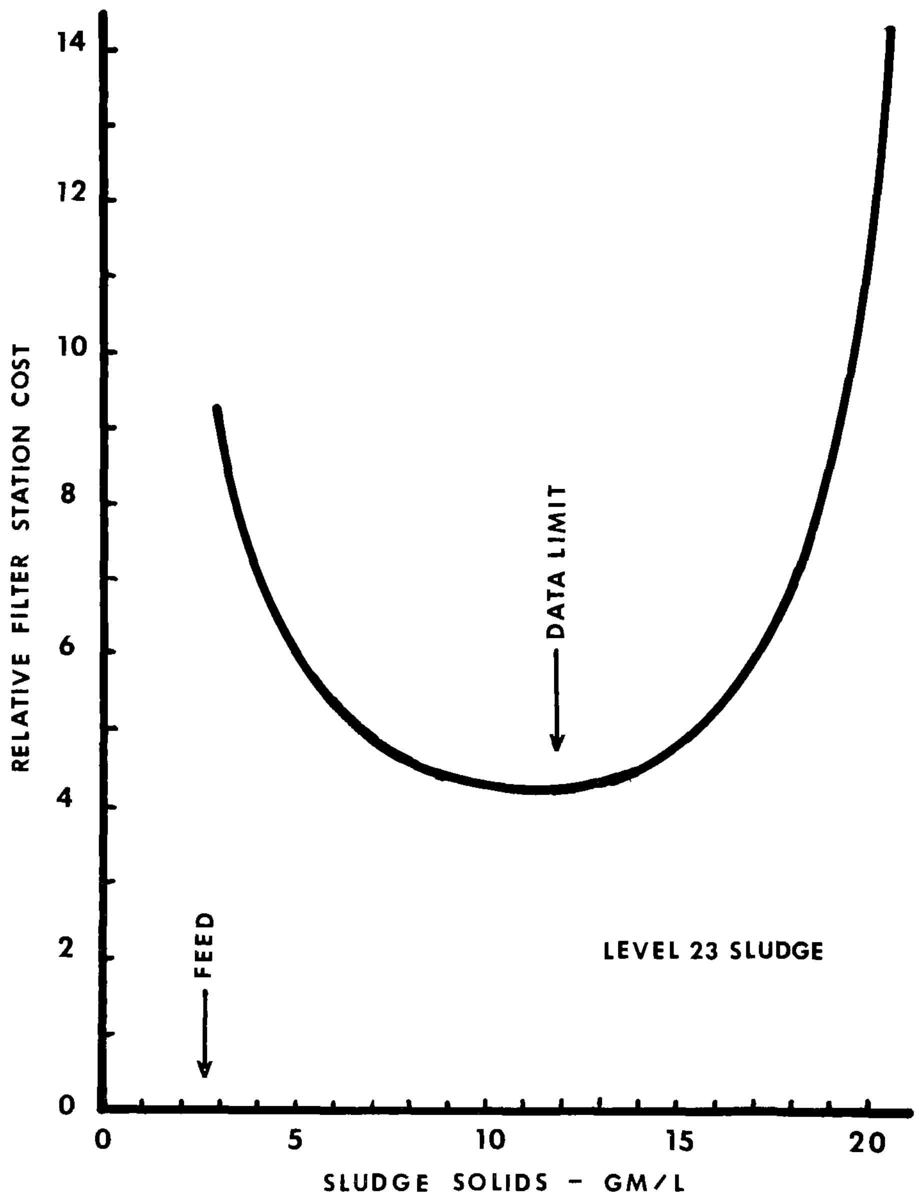


FIGURE 30

THICKENER AREA REQUIREMENT
LEVEL 23 SLUDGE

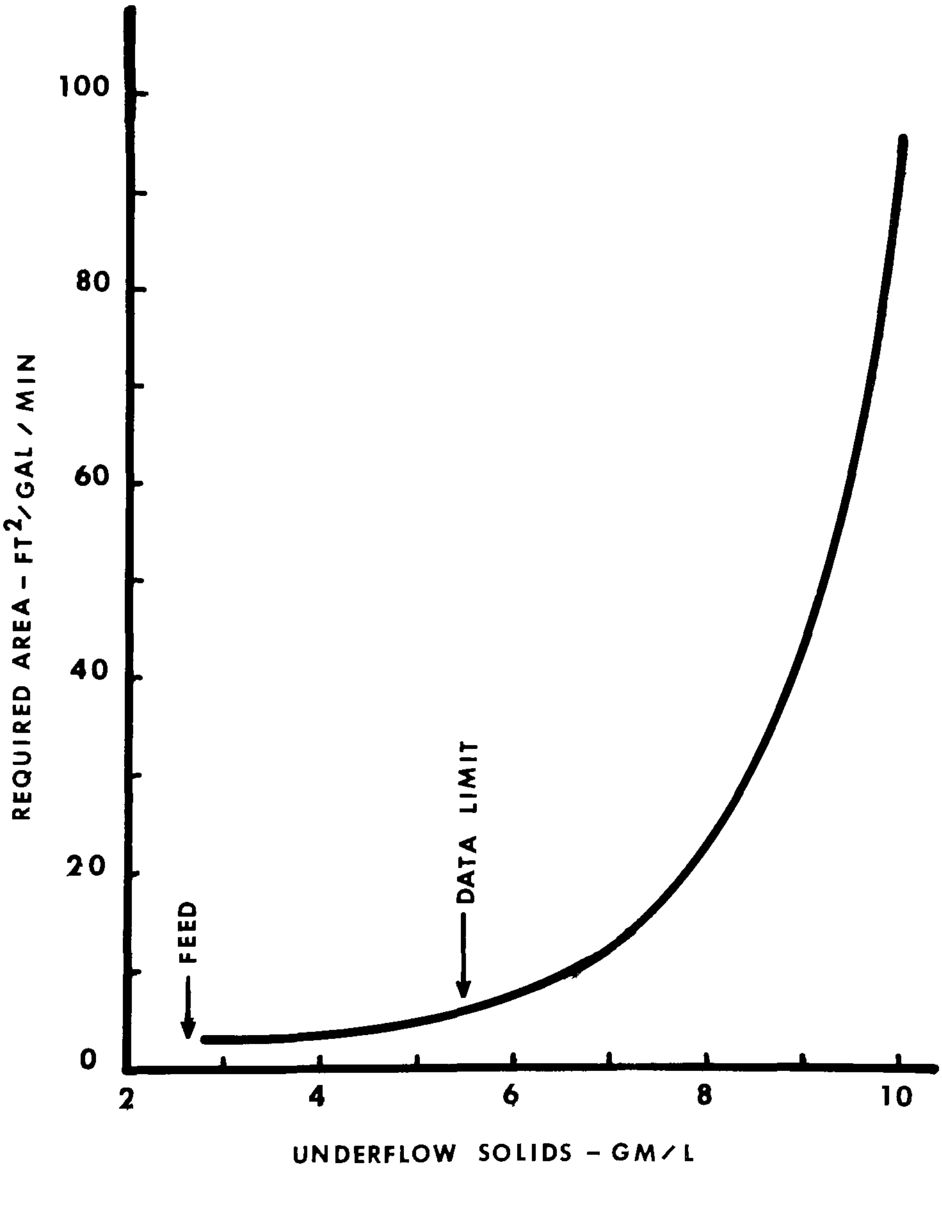
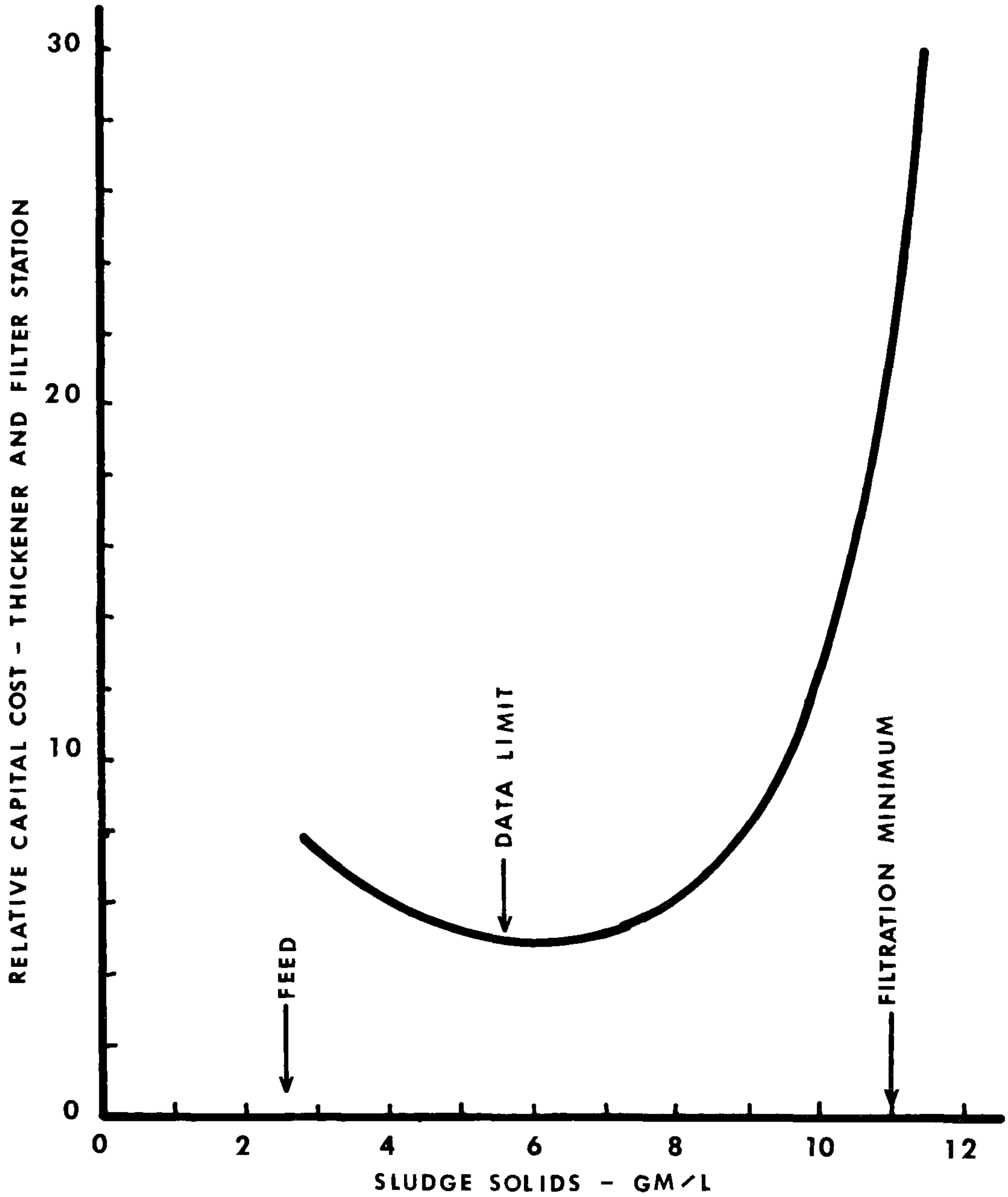


FIGURE 31

EFFECT OF SLUDGE SOLIDS
ON THICKENER & FILTER STATION COST



Conclusions

Based on the results of the statistical test program, the sedimentation and sludge dewatering steps were judged to have the greatest effect on the costs of the treatment system. The greater the volume of the sludge, the lower the sludge solids concentration, and the higher the filtration rate. Optimization calculations were made that indicated that the optimum sludge concentration was 1.1 per cent for operation of the filter alone. Including the cost of the thickener unit required, the optimum was reduced to 0.6 per cent solids. There is some degree of uncertainty in these numbers because of the previous described extrapolations. The use of a polyelectrolyte such as ATLASEP 1A1 to improve the settling characteristics would appear to offer a method for further optimizing the sedimentation-sludge dewatering process.

APPENDIX E

ECONOMIC ANALYSIS

Purpose

The purpose of the economic analysis made on data from the different sites was to provide a basis for comparing the various methods utilized in neutralization of the mine water. Since some methods of neutralization were used at some sites and not at others, it would have been desirable to have a common denominator to enable a rough estimation of costs of a particular process at another site. Unfortunately, insufficient data was generated at the first site to even allow an estimate of the costs for a treatment facility. At the last site, the main objective focused more on optimization of the entire process, which makes a comparison with the other sites meaningless since no optimization was attempted there. This therefore limits the number of conclusions that can be drawn.

Basis

The cost estimates were based on the system given in Figure 5. The cost estimates were made by the use of computer programs, copies of which are available from the authors upon request. The estimating procedure for the last site contained an optimization procedure similar to that described in Appendix D. Costs were computed from values found in the literature and updated to 1970 economics by use of the Marshall and Stevens Equipment Cost Index. Amortization was computed as per the technique specified by the Office of Saline Water, Department of the Interior.[5] A 20-year equipment life was assumed. The amortization was thus calculated as 8.7 per cent of the total capital cost per annum.

Economics for Tests Run at Constant Flow Conditions

The Rushton Mining Company and Bennett Branch sites fit in this category. It must be realized that the costs were computed based on the actual operating conditions of the tests. Some degree of optimization might therefore be possible that would further differentiate among the methods used.

The estimated capital and operating costs for the methods used at the Rushton Mining Company site are presented in Tables XXI and XXII respectively. All limestone additions at this site were slurries formed by wet attrition of limestone rock in a tube mill. The operating costs indicate that the limestone with lime process is slightly more expensive when compared with the other methods.

TABLE XXI

Estimated Capital Costs for a 1.5 MGD Plant Using Various Methods of Chemical Neutralization

Source: Rushton Mining Company, Osceola Mills, Pennsylvania

Note: All limestone feeds are as slurry produced in tube mill.

	Neutralization			
Item	Limestone	Limestone-Lime	Limestone-Magnesite	Lime-Magnesite
Raw Feed Pump	$ 5,300	$ 5,300	$ 5,300	$ 5,300
Limestone Tube Mill	59,300	44,800	43,700	
Limestone Reactor	13,000	13,000	13,000	
Aeration Pond	1,000	1,000	1,000	1,000
Aeration Equipment	3,400	3,400	3,400	3,400
Chemical Storage Bin(s)		1,900	300	1,300
Chemical Feeder(s)		5,800	3,000	7,800
Chemical Reactor(s)		13,000	13,000	26,000
Thickener	32,400	32,400	32,400	32,400
Sludge Pump	1,700	1,700	1,700	1,700
Rotary Vacuum Precoat Filter	68,700	95,500	58,300	59,300
Sludge Disposal	6,900	9,500	5,800	5,900
Control Building	20,000	20,000	20,000	20,000
Instrumentation	10,600	12,400	10,100	8,200
TOTAL EQUIPMENT	$222,300	$259,900	$211,000	$172,300
Installation and Piping	$111,000	$129,500	$105,500	$ 86,200
Contingencies and Engineering	$ 33,300	$ 38,900	$ 31,700	$ 25,900
TOTAL CAPITAL COST	$366,600	$428,300	$348,200	$284,400

TABLE XXII

Estimated Operating Costs for a 1.5 MGD Plant
Using Various Methods of Chemical Neutralization

Source: Rushton Mining Company, Osceola Mills, Pennsylvania

Note: All limestone feeds are as slurry produced in tube mill.

	Neutralization			
	Limestone	Limestone-Lime	Limestone-Magnesite	Lime-Magnesite
Amortization	$32,000	$ 37,300	$30,300	$24,800
Labor (366 man-hours @ $2.50)	1,000	1,000	1,000	1,000
Power (1.3 cents/kw-hr)	26,700	25,000	21,900	10,800
Chemicals				
Limestone	6,800	4,300	4,100	
Other Alkali(es)		21,500	12,000	31,000
Filter Aid	9,100	12,300	7,700	7,900
Subtotal	$75,600	$101,400	$77,000	$75,500
Maintenance	$ 7,600	$ 10,200	$ 7,600	$ 7,500
TOTAL ANNUAL OPERATING COST	$83,200	$111,600	$84,600	$83,000
Cost per thousand gallons treated	$ 0.15	$ 0.20	$ 0.15	$ 0.15
Cost per 100 pounds acidity treated	$ 4.95	$ 6.65	$ 5.04	$ 4.94

The estimated capital and operating costs for the methods used at the Bennett Branch site are presented In Table XXIII and XXIV respectively. The operating costs here show more variability than the Rushton data. The most interesting comparison is between the use of pulverized limestone and a limstone slurry formed by attrition of limestone rock. As discussed elsewhere in the report, the difference in particle size distributions causes a significant difference in the neutralization efficiencies of the two products. It is interesting to note that the higher equipment and power costs to produce the finer limestone slurry is more than offset by the cost differential for the raw materials which is further amplified by the difference in efficiencies. The on-site production of finer particles thus appears to be economical.

The only consistent trend exhibited by the data is that limestone alone provides the least expensive treatment. Referring to Appendixes A through C, it will, however, be noted that limestone alone presented difficulty in obtaining satisfactory effluents under the conditions of the tests. Differentiation between the various methods used on the basis of economics is difficult because of the variability exhibited at the different sites. Further work at optimizing the chemical dosages is required before a meaningful economic comparison can be made.

Economics for Tests Run on Proctor 2, Hollywood, Pennsylvania

The optimization calculations made for this site were concerned with finding the sludge solids concentration which minimized the combined capital cost of the thickener and the filter. The estimated capital costs at the optimum sludge concentration and the estimated operating costs for various size plants ranging from 0.5 to 5.0 million gallons per day are presented in Tables XXV and XXVI respectively. A graphical presentation of the effect of plant size on operating cost per thousand gallons is given in Figure 32. Based on the data, the operating costs appear to stabilize for plant sizes above 2.5 million gallons per day.

The absence of the limestone dosage as a significant effect on the Unit Relative Cost as reported in Appendix D was somewhat of a surprise. It had been hoped that the test program would give some indication of the optimum limestone dosage based on economics. From the results of the tests, it was obvious that additional work covering a wider range of limestone dosages would be required. Also, since the optimum sludge concentration was most often out of the range of the original data on settling rates, additional work is needed to confirm the relationships developed for the higher concentration ranges.

Tables XXVII and XXVIII present estimated costs for a 1.5 million gallon per day using lime neutralization. The plant was based on the sludge settling tests run at the last site. Design was based on obtaining the sludge solids concentration obtained during one run at that site, and therefore represents an unoptimized figure. It is easy to see, however, that this technique is considerably more expensive.

TABLE XXIII

Estimated Capital Costs for a 1.5 MGD Plant
Using Various Methods of Chemical Neutralization

Source: Bennett Branch, Hollywood, Pennsylvania

	Neutralization					
Item	Limestone Dust	Limestone Slurry	Limestone Slurry-Lime	Limestone Dust-Magnesite	Limestone Dust Fully Calc. Dolomite	Limestone Slurry Part. Calc. Dolomite
Raw Feed Pump	$ 5,300	$ 5,300	$ 5,300	$ 5,300	$ 5,300	$ 5,300
Limestone Tube Mill		54,000	54,000			55,800
Limestone Reactor		13,000	13,000			13,000
Aeration Pond	1,000	1,000	1,000	1,000	1,000	1,000
Aeration Equipment	3,400	3,400	3,400	3,400	3,400	3,400
Chemical Storage Bin(s)	2,800		1,000	6,900	5,300	2,500
Chemical Feeder(s)	8,700		4,600	16,700	17,200	8,400
Chemical Reactor(s)	13,000		13,000	26,000	26,000	13,000
Thickener	32,400	32,400	32,400	32,400	32,400	32,400
Sludge Pump	1,700	1,700	1,700	1,700	1,700	1,700
Rotary Precoat Filter	68,700	68,700	62,500	68,700	98,200	68,700
Sludge Disposal	6,900	6,900	6,200	6,900	9,800	6,900
Control Building	20,000	20,000	20,000	20,000	20,000	20,000
Instrumentation	8,900	10,300	10,900	9,500	11,000	11,600
TOTAL EQUIPMENT COST	$172,800	$216,700	$229,000	$198,500	$231,300	$243,700
Installation and Piping	$ 86,400	$108,400	$114,600	$ 99,300	$115,800	$122,000
Contingencies and Engineering	$ 25,900	$ 32,500	$ 34,400	$ 29,800	$ 34,700	$ 36,600
TOTAL CAPITAL COST	$285,100	$357,600	$378,000	$327,600	$381,800	$402,300

TABLE XXIV

Estimated Operating Costs for a 1.5 MGD Plant
Using Various Methods of Chemical Neutralization

Source: Bennett Branch, Hollywood, Pennsylvania

	Neutralization					
	Limestone Dust	Limestone Slurry	Limestone Slurry-Lime	Limestone Dust-Magnesite	Limestone Dust-Fully Calc. Dolomite	Limestone Slurry-Part. Calc. Dolomite
Amortization	$ 24,800	$ 31,200	$ 32,900	$ 28,500	$ 33,200	$ 35,000
Labor (366 man-hours @ $2.50)	1,000	1,000	1,000	1,000	1,000	1,000
Power (1.3 cents/kw-hr)	11,600	25,300	24,800	11,650	13,800	25,800
Chemicals						
Limestone	47,800	5,800	5,800	75,900	47,800	6,200
Other Alkali			10,700	123,500	69,000	67,500
Filter Aid	9,100	9,100	8,300	9,100	13,000	9,100
Subtotal	$ 94,300	$ 72,400	$ 83,500	$249,600	$177,800	$144,600
Maintenance	$ 9,400	$ 7,200	$ 8,400	$ 25,000	$ 17,800	$ 14,400
TOTAL ANNUAL OPERATING COST	$103,700	$ 79,600	$ 91,900	$274,600	$195,600	$159,000
Cost per thousand gallons treated	$0.19	$0.15	$0.17	$0.50	$0.36	$0.29
Cost per 100 pounds acidity treated	$6.74	$5.17	$5.96	$17.84	$12.70	$10.31

TABLE XXV

Estimated Capital Costs for Various Size Plants
Using Increased Efficiency Limestone-Lime Process

Source: Proctor No. 2, Hollywood, Pennsylvania

	Plant Size ÷ MGD				
Item	0.5	1.0	1.5	2.5	5.0
Raw Feed Pump	$ 3,100	$ 4,400	$ 5,300	$ 6,900	$ 9,700
Limestone Storage Bin	1,500	2,800	4,100	6,500	12,100
Limestone Feeder	7,000	8,800	10,100	11,900	15,000
Limestone Reactor	7,700	10,700	13,000	16,600	23,200
Aeration Pond	600	1,300	1,900	3,200	6,500
Helixors and Blowers	4,500	6,100	7,400	11,000	20,200
Lime Storage Bin	1,600	3,100	4,400	7,000	13,000
Lime Feeder	5,400	6,800	7,800	9,300	11,600
Lime Reactor	7,700	10,700	13,000	16,600	23,200
Thickener	57,200	95,300	152,600	187,100	197,900
Sludge Pump	2,100	2,900	3,400	4,100	6,200
Rotary Precoat Filter	209,000	418,000	586,900	934,700	1,956,200
Sludge Disposal	20,900	41,800	58,700	93,500	195,600
Control Building	20,000	20,000	20,000	20,000	20,000
Instrumentation	17,500	31,600	44,500	66,400	125,500
TOTAL EQUIPMENT	$365,800	$ 664,300	$ 933,100	$1,394,800	$2,635,900
Installation and Piping	$182,900	$ 332,200	$ 466,600	$ 697,400	$1,318,000
Contingencies and Engineering	$ 54,900	$ 99,600	$ 140,000	$ 209,200	$ 395,400
TOTAL CAPITAL COST	$603,600	$1,096,100	$1,539,700	$2,301,400	$4,349,300
Calculated Optimum Sludge Concentration, mg/l	7,000	7,000	8,000	9,000	8,000

TABLE XXVI

Estimated Operating Costs for Various Size Plants
Using Increased Efficiency Limestone-Lime Process

Source: Proctor No. 2, Hollywood, Pennsylvania

	Plant Size - MGD				
	0.5	1.0	1.5	2.5	5.0
Amortization	$ 52,500	$ 95,400	$133,900	$200,200	$ 378,400
Labor (366 man-hours @ $2.50)	1,000	1,000	1,000	1,000	1,000
Power (1.3 cents/kw-hr)	18,900	35,500	50,000	78,600	153,900
Chemicals					
Limestone	21,900	43,800	65,700	109,500	219,000
Lime	17,900	35,800	53,600	89,400	178,900
Filter Aid	27,700	55,500	77,900	124,000	259,600
Subtotal	$139,900	$267,000	$382,100	$602,700	$1,190,800
Maintenance (10% of above)	$ 14,000	$ 26,700	$ 38,200	$ 60,300	$ 119,100
TOTAL ANNUAL OPERATING COST	$153,900	$293,700	$420,300	$663,000	$1,309,900
Cost per thousand gallons treated	$0.84	$0.80	$0.77	$0.73	$0.72
Cost per 100 pounds acidity treated	$5.81	$5.54	$5.28	$5.00	$4.95

FIGURE 32
EFFECT OF PLANT SIZE ON OPERATING COST

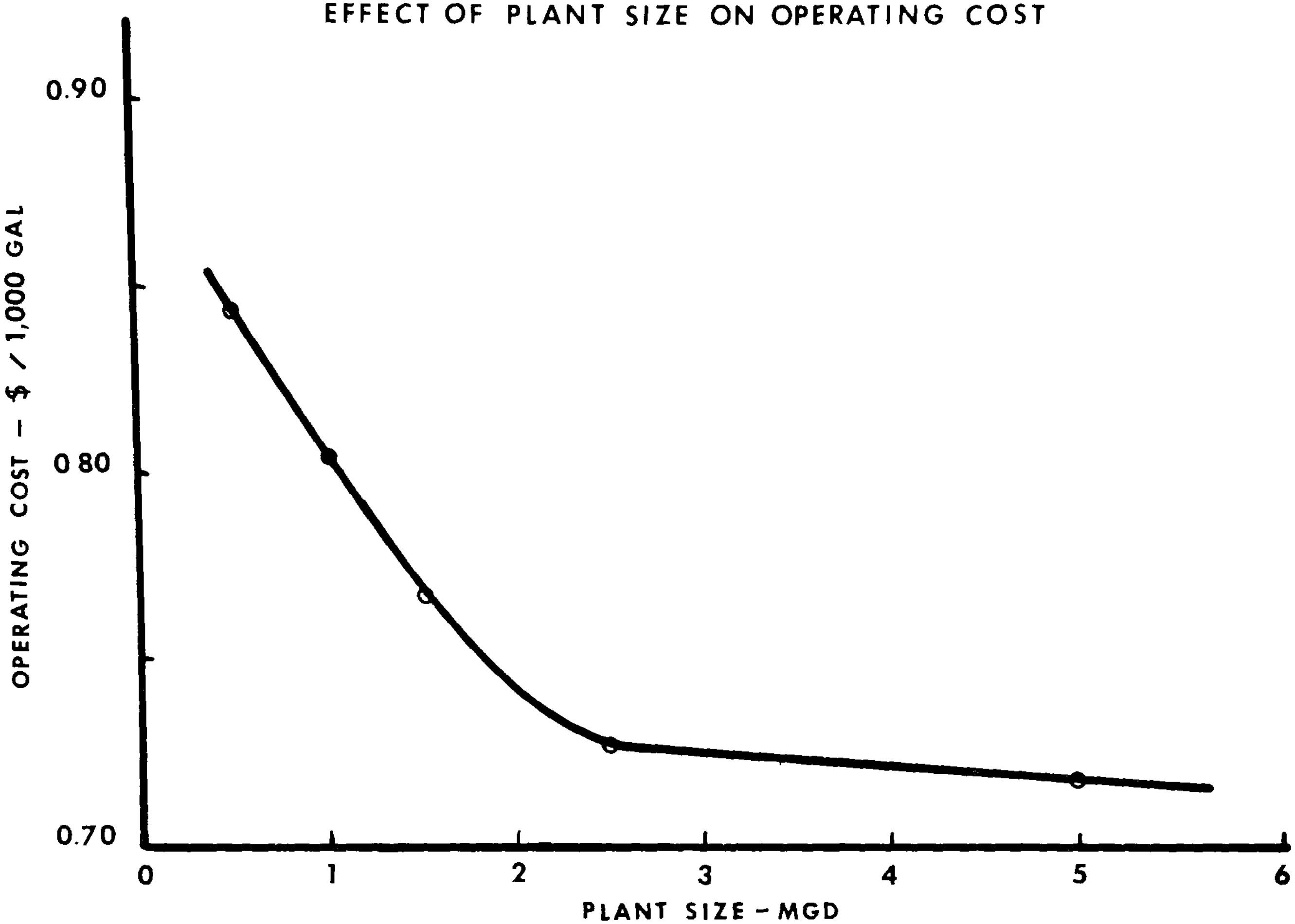


TABLE XXVII

Estimated Capital Costs for a 1.5 MGD Treatment Plant
Using Lime Neutralization

Source: Proctor No. 2, Hollywood, Pennsylvania

Item	
Raw Feed Pump	$ 5,300
Lime Storage Bin	8,800
Lime Feeder	10,100
Lime Reactor	13,000
Aeration Pond	1,900
Helixors and Blowers	7,400
Thickener	218,000
Sludge Pump	4,500
Rotary Precoat Filter	1,109,000
Sludge Disposal	110,900
Control Building	20,000
Instrumentation	75,500
TOTAL EQUIPMENT COST	$1,585,000
Installation and Piping	$ 792,500
Contingencies and Engineering	$ 237,800
TOTAL CAPITAL COST	$2,615,300

TABLE XXVIII

Estimated Operating Costs for a 1.5 MGD Treatment Plant
Using Lime Neutralization

<u>Source</u>: Proctor No. 2, Hollywood, Pennsylvania

Amortization	$228,000
Labor (366 man-hours @ $2.50)	1,000
Power (1.3 cents/kw-hr)	88,000
Chemicals	
Lime	115,000
Filter Aid	147,000
Subtotal	$579,000
Maintenance	$ 58,000
TOTAL ANNUAL OPERATING COST	$637,000
Cost per thousand gallons treated	$ 1.16
Cost per 100 pounds acidity treated	$ 8.02

BIBLIOGRAPHIC: Johns-Manville Research & Engineering Center.
Rotary Precoat Filtration of Sludge from Acid Mine Drainage Neutralization, Final Report WQO, EPA Grant No. 14010 DII, December 1970.

ABSTRACT

Rotary vacuum precoat filtration was investigated as a means for dewatering sludge produced by the neutralization of mine drainage at four locations in Pennsylvania during 1969 and 1970.

The process used at these sites consisted of neutralization, aeration, sedimentation, and filtration. The alkalies investigated

ACCESSION NO.

KEY WORDS:

Mine Drainage
Neutralization
Lime
Limestone
Sludge
Rotary Precoat Filtration
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Pennsylvania

were limestone, limestone with hydrated lime, calcined magnesite, partially and fully calcined dolomite, and hydrated lime. Filter aids tested included HYFLO SUPER-CEL, CELITE 501, CELITE 503, and CELITE 545. Work at the first three locations indicated that limestone and hydrated lime were the preferred alkalies and that CELITE 501 was the preferred filter aid.

A more extensive program was conducted at the fourth site. A 27 run factorial experiment was conducted investigating the effect of flow rate, limestone feed level, aeration level, and sludge recirculation on equipment operation and on process cost. The significant variables affecting process cost were found to be sludge solids content, the filtration rate, and sludge recirculation. A detailed economic analysis of the process is included in the report.

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1 Accession Number	2 Subject Field & Group	
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5 *Organization*

Johns-Manville Products Corporation, Research and Engineering Center, Manville, New Jersey 08835

6 *Title*

Rotary Precoat Filtration of Sludge from Acid Mine Drainage Neutralization

10 *Author(s)*

T. S. Brown

16 *Project Designation*

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21 *Note*

22 *Citation*

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Mine Drainage*, Acid Mine Drainage,* Neutralization,* Lime,* Limestone,* Sludge,* Filtration,* Econpmics, Dewatering

25 *Identifiers (Starred First)*

Vacuum Filter,* Rotary Precoat Filtration,* Pennsylvania

27 *Abstract*

Rotary vacuum precoat filtration was investigated as a means for dewatering sludge produced by the neutralization of mine drainage at four locations in Pennsylvania during 1969 and 1970.

The process used at these sites consisted of neutralization, aeration, sedimentation, and filtration. The alkalies investigated were limestone, limestone with hydrated lime, calcined magnesite, partially and fully calcined dolomite, and hydrated lime. Filter aids tested included HYFLO SUPER-CEL, CELITE 501, CELITE 503, and CELITE 545. Work at the first three locations indicated that limestone and hydrated lime were the preferred alkalies and that CELITE 501 was the preferred filter aid.

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