WATER POLLUTION CONTROL RESEARCH SERIES • 17050 EJB 11/70

FULL-SCALE RAW WASTEWATER FLOCCULATION WITH POLYMERS

U.S. ENVIRONMENTAL PROTECTION AGENCY

WATER POLLUTION CONTROL RESEARCH SERIES

The Water Pollution Control Research Reports describe the results and progress in the control and abatement of pollution in our Nation's waters. They provide a central source of information on the research, development, and demonstration activities in the Environmental Protection Agency, through inhouse research and grants and contracts with Federal, State, and local agencies, research institutions, and industrial organizations.

Inquiries pertaining to Water Pollution Control Research Reports should be directed to the Chief, Publications Branch (Water), Research Information Division, R&M, Environmental Protection Agency, Washington, D. C. 20460.

FULL-SCALE RAW WASTEWATER FLOCCULATION WITH POLYMERS

by

Paul V. Freese
Edward Hicks

Department of Sanitary Engineering
District of Columbia
Washington, D.C. 20004

for the

Office of Research and Monitoring
ENVIRONMENTAL PROTECTION AGENCY

Program #17050 EJB
Grant #WPRD 53-01-67

November, 1970

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 60 cents

EPA Review Notice

ABSTRACT

A21-M (90% anionic A21, 10% cationic C31) at an average dose of 0.74 mg/1 increased the removal of suspended solids from 50% to 63% and BOD removal from 36% to 45% from the raw wastewater and recycled thickener overflow in the primary settlers. With recycle of the plant's elutriate into the primary settlers, 1.14 mg/1 of A21-M increased the solids removal from 43% without polymer treatment to 64%. Cationic Reten 210 at a dose of 0.089 mg/1 did not improve the sedimentation of solids or BOD removal from the raw wastewater or recycled thickener overflow. With the recycle of solids in the elutriate into the primary basins, a dose of 0.124 mg/1 of Reten 210 increased the solids removal from 43% to 51%. Addition of an average of 0.294 mg/1 of anionic ST 269 with 2.54 mg/1 of clay builder did not improve primary sedimentation of the wastewater or recycled thickener overflow. During the last half of the elutriate recycle test and with reduced ST 269 doses of 0.197 mg/1, the primary sedimentation of solids increased from 38% without polymer treatment to 54%, and indicated a probable polymer overdose in the earlier portions of the ST 269 test.

Without elutriate recycle, improved primary sedimentation with effective flocculation (A21-M treatment) decreased the waste activated sludge production by 25%, increased the accumulated BOD removal through secondary treatment from 73.6 to 78.3%, but did not increase the accumulated solids removal. The polymers did not improve solids capture in elutriation, and, with recycle of the elutriate to the primary basins, the solids in the elutriate accumulated in the plant's solids handling system. As in previous operations without polymer treatment, the accumulating solids would have prevented continuous recycle of the elutriate. Thus, without an independent solution to the problem of pollutants in the plant's elutriate, polymer treatment in the primaries was not practical for reducing the pollutants discharged from the District of Columbia Water Pollution Control Plant.

This report was submitted in fulfillment of Grant No. WPRD 53-01-67, Program No. 17050 EJB, between the Federal Water Quality Administration and the District of Columbia, Department of Sanitary Engineering.

Key words:

raw wastewater flocculation
polymer treatment
primary sedimentation

TABLE OF CONTENTS

List of Figures

List of Tables

RECOMMENDATIONS

Polymer treatment in the primary basins should not be adopted for the District of Columbia plant because of problems in the recycling of solids lost in elutriation and of hydraulic overload in the plant's secondary settlers.

Polymer treatment should be re-evalutated at a small scale by observing overall effects on the performance of a plant without a problem with elutriate recycle.

Polymer treatment in the primary basins should be evaluated in a plant which is overloaded with respect to pollutants but is not overloaded hydraulically.

INTRODUCTION

High molecular-weight organic polyelectrolytes (polymers) have been used successfully to flocculate raw wastewater and to increase the removal of pollutants from the wastewater during primary sedimentation[1]. At present, however, a satisfactory method for predicting the effectiveness of a particular polymer for flocculating solids in a specific wastewater is not available. In general, laboratory and full-scale experimental studies are required to evaluate the effectiveness of the flocculation and to determine the optimum doses of the polymer.

Often the laboratory investigations conducted under controlled environments are promising, but results are difficult to reproduce in normal plant operation. Thus, a full-scale study of raw wastewater flocculation with high molecular-weight organic polymers was conducted at the District of Columbia Water Pollution Control Plant (figure 1).

The District of Columbia Plant is a 240 mgd modified activated sludge plant comprised of primary settling, two hour aeration, and final clarification. The aeration tanks operate with 400-600 mg/l of mixed liquor suspended solids and employ approximately 0.6 cubic feet of air per gallon of wastewater. The sludge treatment system includes thickening, digestion, elutriation, chemical conditioning, and vacuum filtration. The overflows from the thickening processes are recycled to the plant influent. Recycle of the elutriate, produced by washing the digested sludge, has in the past overloaded the Plant's solids handling system and prevented satisfactory operation. Thus, the elutriate was normally discharged directly into the Potomac River and contributed significantly to the total load of pollutants discharged from the plant into the River.

The research objectives of the "Raw Wastewater Flocculation Study" in the District of Columbia Water Pollution Control Plant were to:

(1) determine and optimize the improvement in solids capture produced by polymer flocculation of solids in the primary settlers,

(2) determine the effects of the polymer and of any increased solids capture in the primary settlers on the operational efficiency of all other processes in the plant,

(3) reduce the solids and BOD load to the aerators and permit recycle of the elutriate to the plant influent,

(4) evaluate various polymers.

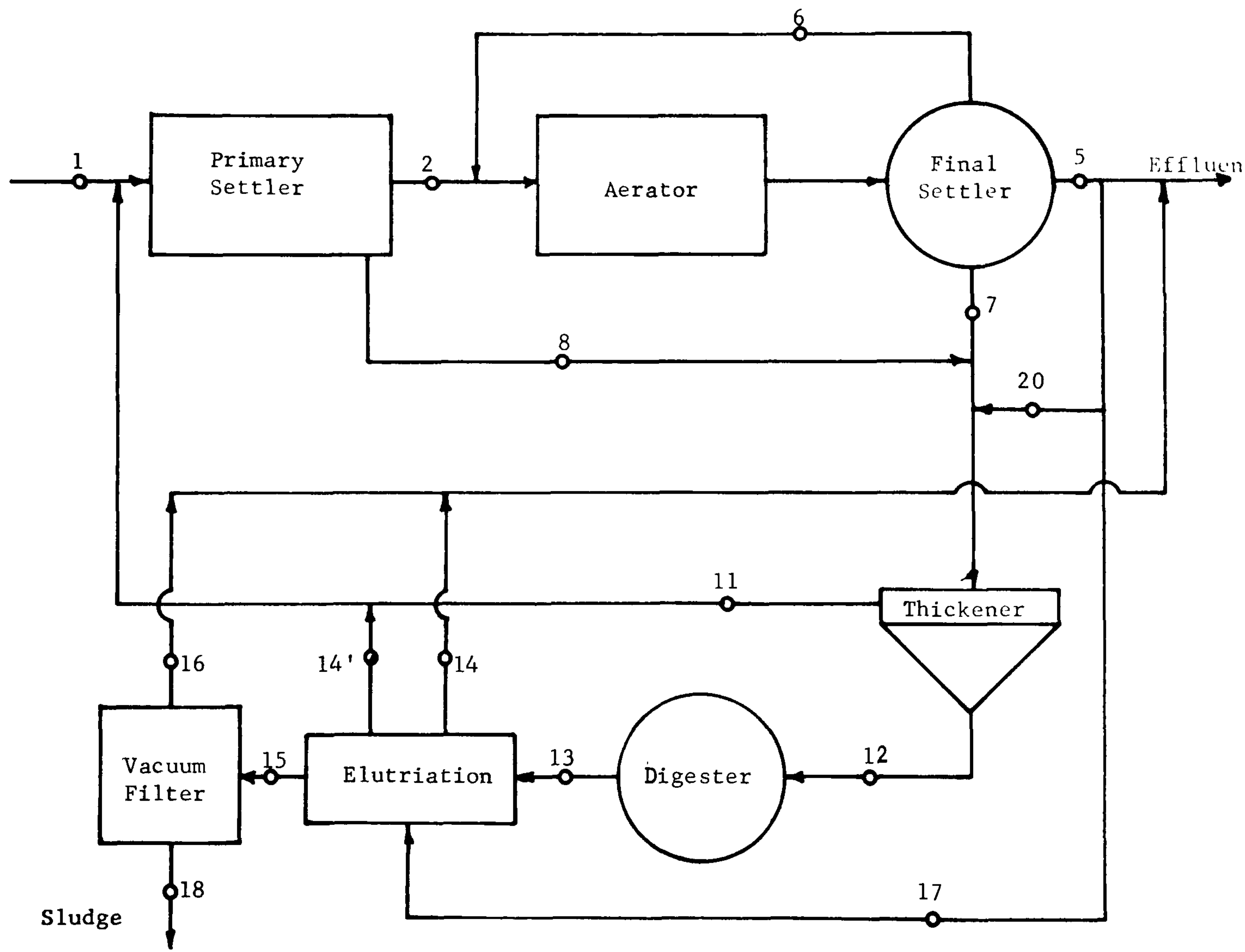

Figure 1: Schematic Flow Diagram of the District of Columbia Water Pollution Control Plant Showing the Locations of the Sampling Stations

PLAN OF OPERATION

General

Since the plant hydraulics does not permit dual train operation, of the primary tanks the general procedure for evaluating the polymers on the full scale plant consisted of:

(1) determining plant "baseline" data before addition of polymer,

(2) adding polymer to the inlet flows to the primary settlers for a period of about 30 days with the plant operating normally (i.e. elutriate and filtrate discharge to the river) to acclimate the plant to the polymer,

(3) continuing polymer addition for a period of about 50 days with elutriate and filtrate recycled to the plant influent,

(4) redetermining the "baseline" data between polymers to remove the preceding polymer and to indicate seasonal variations.

The baseline periods, periods of polymer addition for plant acclimation, periods of polymer addition with elutriate recycle for each of the various polymers, and the corresponding overflow rates in the plant's settlers during these periods are summarized in Table 1. The average overflow rates of 1626 to 1839 gallons per day per square foot in the primary settlers and 972 to 1273 gallons per day per square foot in the final settlers were higher than usually recommended by the Ten State Standards[3] and thus stressed the sedimentation processes. The final period (XI) was operated as a "baseline" in which the elutriate was recycled to the plant influent without polymer treatment. In addition, a summary of the plant operation on suspended solids for the year preceding the polymer study was prepared. Several periods were also divided into sub-periods a and b to reveal time related changes in plant performance.

Polymer Selection, Preparation, and Dosing

Laboratory evaluations of the polyelectrolytes were performed to measure their effectiveness in the District of Columbia wastewater and to select the polymers for full-scale testing. All polymers and polymer systems were evaluated using the manufacturers' suggested methods of solution preparation, mixing, and addition to the wastewater. Varying concentrations were used on raw wastewater alone, raw wastewater with 5% thickener overflow, and

TABLE 1

PERIOD	DATE	AVG FLOW Q1 mgd	POLYMER mg/1	ADDITIVE mg/1	ELUTRIATE RECYCLE	OVERFLOW RATES gpd/ft^2 Primary Avg	Primary Max	Secondary Avg	Secondary Max
	4/66-3/67	217							
A21-M									
I	4/3-4/30/67	224.1	0.0	---	No	1626	1777	984	1122
II	5/1-6/5	235.7	0.743	---	No	1684	1942	1095	1262
III	6/7-7/20	241.7	1.137	---	Yes	1799	1957	1169	1272
IIIa	6/7-6/30	237.2	1.125	---	Yes	----	----	----	----
IIIb	7/1-7/20	247.2	1.151	---	Yes	----	----	----	----
Reten 210									
IV	7/21-9/26	244.1	0.0	---	No	1822	2096	1173	1322
V	9/27-10/29	219.2	0.089	---	No	1644	1816	1018	1146
VI	10/30-12/16	217.7	0.124	---	Yes	1628	2092	972	1246
VIa	10/30-11/24	207.7	0.137	---	Yes	----	----	----	----
VIb	11/25-12/16	229.5	0.110	---	Yes	----	----	----	----
ST 269 + CA-25									
VII	12/17/67-1/28/68	225.6	0.0	0.0	No	1648	1975	983	1177
VIII	2/5-3/5	212.4	0.284	2.94	No	1569	1784	1023	1159
IX	3/7-4/24	239.7	0.239	2.64	Yes	1783	2209	1273	1579
IXa	3/7-4/2	243.7	0.270	3.11	Yes	----	----	----	----
IXb	4/3-4/24	234.8	0.197	2.05	Yes	----	----	----	----
No Polymer									
X	5/1-5/27	229.4	---	---	No	1666	1948	1141	1303
XI	5/28-7/16	254.0	---	---	Yes	1839	2213	1110	1320
XIa	5/28-6/21	252.6	---	---	Yes	----	----	----	----
XIb	6/22-7/16	255.4	---	---	Yes	----	----	----	----

raw wastewater with 5% thickener overflow and 1% elutriation overflow. The percentages of the added materials were selected to correspond to average plant conditions.

In selecting a laboratory procedure for the evaluation of the polymers, the hydraulic conditions in the District of Columbia Plant suggested the selection of a rapid mixing (100 rpm) period of one minute, four minutes for flocculation, and ninety minutes for settling. However, in preliminary tests, settling times from two to sixty minutes under dynamic mixing conditions (5-10 rmp) in a conventional jar test apparatus indicated that a five minute dynamic settling time was necessary to maximize the differential laboratory settling rate between the polymer treated samples and an untreated control. Longer settling times in the small laboratory apparatus showed decreasing differences in solids removal with and without polymer and prevented effective laboratory evaluation.

The final laboratory procedure used was:

1. Each polymer was prepared in accordance with the manufacturer's directions. Usually a 1% stock solution was prepared and was stable for at least a 2-week period. From the stock solution a suitable working solution of 0.1, 0.05, or 0.01% was prepared each day.

2. Liter samples of fresh raw wastewater were arranged in a jar test apparatus with one sample as a control. Rapid mixing (100 rpm) of the samples was initiated before polymer addition. Polymers were added at various concentrations. After polymer addition, the system was rapidly mixed for one minute.

3. Mixing was then slowed to a flocculation speed of 30 rpm and flocculated for four minutes.

4. After flocculation, the mixing was slowed to 5-10 rpm for a dynamic settling period, and settled for five minutes. Samples were then removed with a large tip syringe for analysis of suspended solids and TOC. Pertinent observations such as size and type of floc, and of their settling characteristics were recorded.

The three polymers selected from the laboratory studies for the full-scale tests were Dow Chemical Company's A21-M, Hercules Inc.'s Reten 210, and Calgon Inc.'s ST 269 with coagulant aid No. 25. A21-M and ST 269, both basically anionic polymers, were effective in the laboratory in increasing the rate of sedimentation of the solids in the raw wastewater. Reten 210, a cationic polymer, was effective on the solids in the elutriate.

Each manufacturer was responsible for furnishing full-scale equipment to feed his own polymer. The manufacturer, in cooperation with the District, selected the feed points and the dosages. Brief descriptions of each polymer and dosing system are:

Polymer A21-M

Polymer A21-M consists of a pre-mixed combination of PURIFLOC A-21 and PURIFLOC C-31 in an approximate 10:1 weight ratio of A-21 to C-31. PURIFLOC A-21 is a granular anionic sodium polystyrene sulfonate with molecular weight greater than five million. PURIFLOC C-31 is a liquid cationic polyamine with a molecular weight greater than 30,000.

The polymer mixture was prepared as a stock solution of 1.5% concentration based on total content of A-21 and C-31. The stock solution of combined polymers was mixed in equipment specially designed by Dow. The 1.5% concentrate was then pumped to an eductor and further diluted with about 70 GPM of service water. After studying several dosing points, the dosing location finally selected was at the Plant's grit chamber elevators.

Polymer Reten 210

Reten 210 is a powdered, strongly-cationic, high-molecular weight, synthetic polymer. It was prepared as a 0.5% solution using an automated feeder-mixing system developed for the trial by Hercules. The 0.5% solution was further diluted with from 5 to 10 parts of dilution water prior to introduction into the wastewater. The point of application was varied several times during the course of the trial. Multiple individual dosing locations at the inlet to each primary basin were finally selected.

Polymer ST 269 and Coagulant Aid No. 25

Sludge Conditioner ST 269 is an anionic hydrolyzed polyacrylamide with a molecular weight in excess of two million. Coagulant Aid No. 25 is a clay-base inorganic material of the montmorillonite class. In the test, the chemicals were fed from two dry feeders into mixing tanks, and were added as pre-mixed and separate solutions. The pre-mixed or separate solutions were introduced to the effluent leaving the grit chamber.

Analytical and Sampling Program

The analytical program established to compare the plant's operation before and during polymer addition (table 2) employed procedures from Standard Methods[4] except for TOC (total organic carbon) and total phosphate analyses. The TOC analysis included

TABLE 2

ANALYTICAL PROGRAM

Sample Location		Analyses
Station 1	Raw Wastewater	
Station 2	Primary Effluent	
Station 5, 17, 20	Secondary Effluent	SS, BOD, TOC, P, NH_3, TKN, TS, TVS
Station 11	Thickener Overflow	
Station 14, 14	Elutriate	
Station 16	Filtrate	
Station 7	Waste Secondary	
Station 8	Raw Primary Sludge	
Station 12	Thickened Sludge	TS, TVS, TOC, P, TKN
Station 13	Digested Sludge	
Station 15	Elutriated Sludge	
Station 18	Filtercake	Tons wet cake, % moisture

Notes

1. Sample stations are shown on figure 1.
2. All samples are 24-hour composites proportioned to flow.

Key:

BOD	5-day Biochemical Oxygen Demand, mg/l
NH_3	Ammonia Nitrogen, mg/l as N
P	Total Phosphorus as PO_4, mg/l
SS	Suspended Solids mg/l
TKN	Total Kjeldahl Nitrogen, mg/l
TOC	Total Organic Carbon, mg/l
TS	Total Solids, mg 1
TVS	Total Volatile Solids, mg/l

acidification, blending, and nitrogen stripping before organic carbon determination with a Beckman Carbonaceous Analyzer[5]. The total phosphate method[2] used the digestion of the sample with sulfuric acid-potassium persulfate before phosphate analysis.

The various sampling points in the plant are indicated in Figure 1. Initially, twenty-four hour samples of the raw wastewater (point 1), primary effluent (point 2), and secondary effluent (point 5) were automatically proportioned to flow and composited by the plant's Chicago Pump Automatic Samplers. All other twenty-four hour composite samples were collected manually, usually at 30 minute intervals, and were manually composited pro-rated to flow.

Material balances were computed around the primary settlers (table 3) for suspended solids, total organic carbon (TOC), total phosphate, and total Kejdhal nitrogen (TKN) to verify flow measurement, analytical, and sampling techniques. BOD balances could not be computed since the BOD of the underflow (primary sludge) was not measurable. The computations on the first two months of data (periods I and II) revealed negative unbalances of approximately 35% for suspended solids and 20% for TOC. The computations for total phosphates and TKN, which in the District of Columbia raw wastewater were mainly soluble components, produced satisfactory balances within 9%. Subsequent review of the previous year's suspending solids analyses also revealed the same unbalance and indicated more solids leaving the settlers than entering. Discussions with District of Columbia plant personnel concerning gas production and solids handling confirmed that more solids were entering the plant than were being measured.

Laboratory grab samples, composited manually over twenty-four hours on raw wastewater, revealed raw wastewater suspended solids nearly double that in the samples from the automatic sampler. In contrast, laboratory grab samples on the primary and secondary effluents (point 2 and 5) showed that the automatic samples at these points were operating satisfactorily. Thus, a flow proportioned grab sampling schedule on the raw wastewater was added to the overall analytical program to eliminate the incorrect automatic sampling of the raw wastewater.

With the grab sample schedule on the raw wastewater, material balances on suspended solids and TOC based on the grab samples of the raw wastewater were usually within 10% for any period and averaged 1.9% and 6.5% respectively for the entire test period. Material balances for the phosphates and TKN average 0.6% and 6.0% respectively. These balances support the flow measurement, analytical, and sampling techniques. For the first two months of the test (periods I and II) and for all plant data before the test, the amounts of suspended solids, TOC, total phosphate, and TKN in

TABLE 3

PRIMARY SETTLER MATERIAL BALANCE

PERIOD	% DIFFERENCE SS	TOC	PO_4	TKN
4/66-3/67	-39.9[2]			
A21-M				
I	-33.5[2]	-19.9[2]	0.7[2]	-2.3[2]
II	-38.5[2]	-29.4[2]	-8.4[2]	0.8[2]
III	-41.3[2]	-17.0[2]	-2.4[2]	3.7[2]
	2.0	2.9	4.7	5.2
Reten 210				
IV	-4.9	4.7	4.1	
V	-0.7	-6.8	-2.7	
VI	2.7	7.0	-7.0	
St 269 + CA-25				
VII	0	12.6	0.4	
VIII	13.2	9.7		
IX	-7.1	2.8		
No Polymer				
X	-7.1	8.0		
XI	-10.3	14.7		

1. $\% \text{ Difference} = \dfrac{\text{Input} - \text{Output}}{\text{Input}} (100)$

2. Automatic Samples

the raw wastewater were calculated by material balance from the recycle, underflow, and overflow measurements on the primary settlers.

Since the BOD of the underflow (primary sludge) could not be determined satisfactorily, the amounts of BOD in the raw wastewater could not be calculated and the BOD content for periods I and II had to be estimated by multiplying the BOD concentration obtained from the automatic raw wastewater sampler by 1.22, which was the average ratio of BOD in the grab samples to the BOD in corresponding automatic samples from 9 months of data. The results from the periods III-XI are based completely upon measured values.

PRIMARY SETTLER PERFORMANCE

The performance of the plant's primary settlers in removing pollutants, especially suspended solids, from the raw wastewater and the recycled streams entering the settlers is the most important factor in evaluating polymer induced flocculation and settling. In the polymer tests, the recycled streams included thickener overflow alone, and thickener overflow and elutriate. Thus, the performance of the settler was best characterized by the percent removal of a pollutant based upon the total amount of the pollutant in the influent to the settlers (raw wastewater and recycle). The conventional removal efficiencies based upon the amount of pollutant in the raw wastewater and the amounts of the pollutants in the primary effluent are presented in the tabulated results (tables 4-8).

Before discussing polymer treatment, the baseline settler performance with and without elutriate recycled must be reviewed. For the year preceding the polymer study, the primary settlers removed an average of 47.8% of the suspended solids based upon the total influent (thickener overflow solids and raw solids) to the settlers. During the baseline periods (I, IV, VII, and X) without elutriate recycle, the solids removals by the settlers varied between 46.7% and 52.4% of the solids in the total influent (table 4). The average removals of BOD by the primary settlers from the total influent during the same baseline operations (periods I, IV, VII, and X) varied from 23.9% to 36.0%; the average removals of TOC, from 39.4% to 45.5%; the average removals of total phosphorus, from 7.7% to 11.3%; and the average removal of TKN for period I (TKN measurements were discontinued at the end of period III), 11.5% (tables 5, 6, 7, and 8).

In the baseline elutriate recycle without polymers (period XI), the recycled elutriate added digested solids to the recycled solids and increased the solids loading on the settlers to an average of 299 tons per day compared to the normal 202-233 tons per day for baseline operation without elutriate recycle. During the addition of the digested solids, the 43.2% removal of the total influent solids in primary settlers represented a decrease of approximately 18% in the 52.4% removal of the preceding baseline without elutriate recycle (period X). The solids in the recycled elutriate caused the solids in the primary effluent to increase from the normal 102-116 tons per day without elutriate recycle to an average of 169.9 tons per day.

Both the primary effluent quality and the solids removal percentages, as shown by sub-periods XIa and XIb in Table 4, progressively deteriorated as the elutriate recycle proceeded. For the last half of the recycle baseline (period XIb), the primary effluent contained an average of 184.3 tons per day of solids, and the settlers removed

TABLE 4 SUSPENDED SOLIDS AND PRIMARY SETTLING

PERIOD	POLYMER DOSE mg/1	SUSPENDED SOLIDS - TONS/DAY				% REMOVAL	
		RAW WASTE-WATER GRAB M_1	RECYCLE[1] M_{RE}	UNDERFLOW M_8	EFFLUENT M_2	TOTAL INPUT[2]	RAW WASTEWATER[3]
4/66-3/67	0	177.4[4]	25.8	97.2	106.0	47.8	40.2
A21-M							
I	0	177.8[4]	25.4	101.3	101.9	49.9	42.7
II	0.743	199.0[4]	23.1	140.2	81.9	63.1	58.8
III	1.137	214.3	74.1[5]	178.0	104.7	63.9	51.1
IIIa	1.125	214.5	63.5[5]	161.5	103.9	62.6	51.6
IIIb	1.151	213.8	86.3[5]	197.5	105.6	64.8	50.6
Reten 210							
IV	0	189.0	28.0	112.0	115.7	46.7	38.8
V	0.089	191.4	32.9	106.7	119.2	46.9	37.7
VI	0.124	178.9	87.1[5]	129.2	129.7	51.2	27.5
VIa	0.137	177.4	71.9[5]	124.2	120.4	51.7	32.1
VIb	0.110	179.7	106.3[5]	135.2	141.1	50.7	21.5
ST 269 + CA-25							
VII	---	186.0	40.2	118.0	108.6	52.0	41.6
VIII	0.294	179.4	39.6	89.6	100.4	54.2	44.0
IX	0.239	192.2	111.8[5]	168.3	157.2	48.3	18.2
IXa	0.27	189.1	89.3[5]	143.9	159.4	42.7	15.7
IXb	0.197	195.8	143.7[5]	197.2	154.6	54.5	21.0
No Polymer							
X	---	200.7	33.0	139.2	111.2	52.4	44.6
XI	---	200.4	98.9[5]	160.2	169.9	43.2	15.2
XIa	---	209.4	90.9[5]	160.5	155.1	48.4	25.9
XIb	---	191.2	107.1[5]	159.9	184.3	38.2	3.6

1. $M_{RE} = M_{11}$ or $M_{(11 + 14 + 16)}$

2. % Removal = $\frac{(M_1 + M_{RE} - M_2)}{(M_1 + M_{RE})} (100)$

3. % Removal = $\frac{(M_1 - M_2)}{(M_1)} (100)$

4. Calculated $M_1 = M_2 + M_8 - M_{RE}$

5. Elutriate Recycled

TABLE 5 BOD AND PRIMARY SETTLING

PERIOD	POLYMER DOSE mg/l	BOD - TONS/DAY				% REMOVAL	
		RAW WASTE-WATER GRAB M_1	RECYCLE[1] M_{RE}	UNDERFLOW M_8[6]	EFFLUENT M_2	TOTAL INPUT[2]	RAW WASTEWATER[3]
A21-M							
I	0	151.5[4]	23.3	---	112.0	36.0	26.1
II	0.743	153.3[4]	21.6	---	96.6	44.8	37.0
III	1.137	153.3	32.8[5]	---	110.4	40.6	28.0
IIIa	1.125	153.2	35.4[5]	---	108.9	42.3	28.9
IIIb	1.151	153.4	29.4[5]	---	112.0	38.7	27.0
Reten 210							
IV	0	148.7	20.6	---	128.9	23.9	13.3
V	0.089	150.5	27.3	---	131.6	26.0	12.6
VI	0.124	143.7	47.9[5]	---	129.2	32.6	10.1
VIa	0.137	148.2	47.9[5]	---	128.5	34.5	13.3
VIb	0.110	137.0	48.0[5]	---	129.4	30.1	5.6
ST 269 + CA-25							
VII	0	151.5	34.0	---	124.2	33.1	18.0
VIII	0.294	149.9	31.1	---	120.6	33.4	19.5
IX	0.239	184.9	52.3[5]	---	138.2	41.8	25.3
IXa	0.270	153.8	49.8[5]	---	137.4	32.5	10.7
IXb	0.197	221.5	56.1[5]	---	139.0	49.9	37.2
No Polymer							
X	---	156.3	29.9	---	120.3	35.4	23.0
XI	---	149.8	42.9[5]	---	120.0	37.7	19.9
XIa	---	153.6	39.1[5]	---	121.7	36.9	20.8
XIb	---	145.8	47.1[5]	---	118.3	38.7	18.9

Footnotes:

1. $M_{RE} = M_{11}$ or $M_{(11 + 14 + 16)}$

2. % Removal = $\frac{(M_1 + M_{RE} - M_2)}{(M_1 + M_{RE})}$ (100)

3. % Removal = $\frac{(M_1 - M_2)}{(M_1)}$ (100)

4. Estimated Grab = 1.22 Auto M_1

5. Elutriate Recycled

6. BOD of Underflow not used.

TABLE 6 TOC AND PRIMARY SETTLING

PERIOD	POLYMER DOSE mg/1	TOC IN TONS/DAY						% REMOVAL	
		RAW WASTE-WATER GRAB M_1	RECYCLE[1] M_{RE}	UNDERFLOW M_8	EFFLUENT M_2	TOTAL INPUT[2]	RAW WASTE-WATER[3]		
A21-M									
I	0	94.7[4]	13.3	42.5	65.5	39.4	30.8		
II	0.743	105.3[4]	11.5	59.0	57.8	50.5	45.1		
III	1.137	85.7	29.2[5]	49.2	62.4	45.7	27.2		
IIIa	1.125	87.3	31.6[5]	57.8	66.5	44.0	23.8		
IIIb	1.151	83.7	26.4[5]	38.9	57.4	47.9	31.4		
Reten 210									
IV	0	88.9	23.5	40.4	66.7	40.7	25.0		
V	0.089	109.7	22.7	68.4	73.0	44.9	33.5		
VI	0.124	107.2	35.5[5]	54.0	78.7	44.9	26.6		
VIa	0.137	105.1	32.9	58.5	75.5	45.3	28.2		
VIb	0.110	109.3	38.6[5]	48.7	82.6	44.2	24.4		
St 269 + CA-25									
VII	0	98.4	21.1	39.2	65.2	45.5	33.7		
VIII	0.294	100.1	19.6	42.2	65.9	44.9	34.2		
IX	0.239	107.8	39.1[5]	52.8	90.0	38.7	16.5		
IXa	0.270	105.3	33.6[5]	44.0	88.8	36.1	15.7		
IXb	0.197	110.7	46.6[5]	63.5	91.5	41.9	17.3		
No Polymer									
X	---	108.4	18.4	42.6	74.0	41.6	31.7		
XI	---	107.0	32.3[5]	37.6	81.2	41.7	24.1		
XIa	---	113.6	30.6[5]	35.9	79.3	45.0	30.2		
XIb	---	99.9	34.2[5]	39.2	83.1	38.0	16.8		

Footnotes:

1. $M_{RE} = M_{11}$ or $M_{(11 + 14 + 16)}$

2. % Removal = $\frac{(M_1 + M_{RE} - M_2)}{(M_1 + M_{RE})}(100)$

3. % Removal = $\frac{(M_1 - M_2)}{(M_1)}(100)$

4. Calculated $M_1 = M_2 + M_8 - M_{RE}$

5. Elutruate Recycled

TABLE 7 TOTAL PHOSPHATES AND PRIMARY SETTLING

PERIOD	POLYMER DOSE mg/1	TOTAL PO_4 - TONS/DAY				% REMOVAL	
		RAW WASTE-WATER GRAB M_1	RECYCLE[1] M_{RE}	UNDERFLOW M_8	EFFLUENT M_2	TOTAL INPUT[2]	RAW WASTEWATER[3]
A21-M							
I	0	24.8[4]	3.5	2.4	25.9	8.5	-4.2
II	0.743	28.6[4]	3.2	5.3	26.5	16.7	+7.3
III	1.137	26.9	7.3[5]	4.5	28.1	17.9	-14.5
IIIa	1.125	26.5	7.5[5]	4.2	28.3	17.0	-15.5
IIIb	1.151	27.3	7.0[5]	4.9	27.8	19.0	-13.0
Reten 210							
IV	0	25.2	4.1	2.1	26.0	11.3	-3.2
V	0.089	25.7	3.9	2.8	27.6	6.8	-7.4
VI	0.124	25.0	7.8[5]	4.7	30.4	7.3	-21.6
VIa	0.137	25.2	7.1[5]	4.2	30.0	7.1	-19.0
VIb	0.110	24.5	8.8[5]	5.3	30.6	8.1	-24.9
ST 269 + CA-25							
VII	0	24.7	3.8	2.3	26.1	8.6	-5.7
VIII	0.294	26.3	4.5	---	27.9	9.3	-6.1
IX	0.239	27.2	9.7[5]	---	33.2	9.9	-22.1
IXa	0.270	26.8	8.0[5]	---	32.7	6.2	-22.0
IXb	0.197	27.6	12.0[5]	---	33.8	14.4	-22.5
No Polymer							
X	---	26.9	4.1	---	28.6	7.7	-6.3
XI	---	26.2	8.4[5]	---	31.8	8.1	-21.4
XIa	---	26.8	7.9[5]	---	31.0	10.5	-15.7
XIb	---	25.6	8.9[5]	---	32.5	5.7	-27.0

Footnotes:

1. $M_{RE} = M_{11}$ or $M_{(11 + 14 + 16)}$

2. % Removal = $\frac{(M_1 + M_{RE} - M_2)}{(M_1 + M_{RE})}(100)$

3. % Removal = $\frac{(M_1 - M_2)}{(M_1)}(100)$

4. Calculated $M_1 = M_2 + M_8 - M_{RE}$

5. Elutriate Recycled

TABLE 8 TOTAL NITROGEN AND PRIMARY SETTLING

PERIOD	POLYMER DOSE mg/1	TOTAL NITROGEN - TONS/DAY					% REMOVAL	
		RAW WASTE-WATER GRAB M_1	RECYCLE[1] M_{RE}	UNDERFLOW M_8	EFFLUENT M_2		TOTAL INPUT[2]	RAW WASTEWATER[3]
A21-M								
I	0	24.9[4]	3.8	3.3	25.4		11.5	-2.0
II	0.743	23.1[4]	3.3	4.3	22.1		16.3	+4.3
III	1.137	23.8	9.2[5]	5.3	25.7		22.0	-8.0
IIIa	1.125	23.3	9.6[5]	5.1	26.3		20.2	-12.9
IIIb	1.151	24.3	8.8[5]	5.5	25.1		24.3	-3.2

Footnotes:

1. $M_{RE} = M_{11}$ or $M_{(11 + 14 + 16)}$
2. % Removal = $\frac{(M_1 + M_{RE} - M_2)}{(M_1 + M_{RE})}(100)$
3. % Removal = $\frac{(M_1 - M_2)}{(M_1)}(100)$
4. Calculated $M_1 = M_2 + M_8 - M_{RE}$
5. Elutriate Recycled

only 38.2% of the total solids entering the settlers. In the past operation of the plant, this progressive deterioration in the removals of suspended solids by the primary settlers and the progressive increase in recycled solids when the elutriate was returned to the plant influent eventually forced the discharge of the elutriate into the river.

The amounts of BOD, TOC, and total phosphate in the elutriate compared to the amounts in the raw wastewater were lower relative to the same comparison for solids. Recycle of the elutriate without polymer addition did not significantly alter the settler removal efficiencies for these pollutants (periods X and XI; tables 5, 6, and 7), but did increase the amounts of these pollutants entering and leaving the primary settlers.

Since each polymer test was divided into two periods, polymer treatment with the elutriate discharged into the river and polymer treatment with the elutriate recycled to the plant, the effects of each polymer on the different solids in primary settlers for these two operating variations were considered separately. With the elutriate discharged into the river the addition of the first polymer, A21-M, at an average dose of 0.743 mg/l increased the average solids capture of the combined raw and thickener overflow solids from the preceding baseline removal (period I) of 49.9% by 26% to 63.1% removal of the solids in the total influent (table 4). The actual solids in the primary effluent correspondingly decreased during the A21-M treatment by approximately 20% from over 100 tons per day to 81.9 tons per day.

For the same periods, the average BOD removal efficiency with A21-M addition increased by 24% from a baseline of 36% to 44.8% removal, and the average BOD in the primary effluent decreased by 14% from 112 tons per day to 96.6 tons per day (table 5). Similarly the TOC removal efficiency increased by 28% from a baseline 39.4% to 50.5% (table 6). The total phosphate removal efficiency increased from a baseline 8.5% to 16.7% (table 7); and the total nitrogen removal, from 11.5% to 16.3% (table 8).

The average overflow rate in the primary settlers (table 1) during the baseline (period I) was 3.5% lower than during A21-M treatment (period II). This small increase in overflow rate during polymer treatment should, if any effect occurred, decrease the settler performance when compared to baseline. The above primary settler performance, during A21-M treatment with the elutriate discharged into the river, not only exceeded the settler performance during the preceding baseline, but was also markedly superior to all baseline performances. Thus A21-M was an efficient flocculant of the raw solids and the solids in the thickener overflow.

After approximately 30 days of A21-M treatment, the elutriate was recycled to the influent of the primary settlers. The digested solids in the elutriate increased the solids in the recycle streams from about 25 tons per day to an average of 74 tons per day. The average solids loading (period III) to the primary settlers of 288 tons per day represented a 42% increase in solids compared to the preceding baseline (period I), and was similar to the 299 tons per day of solids in the influent to the primary settlers during elutriate recycle without polymer treatment. The 63.9% capture of solids, however, with similar solids loading represented a 48% improvement over the 43.2% capture during elutriate recycle without polymer treatment (period XI). The removal percentage was essentially the same as that achieved during A21-M treatment without elutriate recycle (period II).

The solids in the elutriate entering the primary settlers increased the average required dose of A21-M from 0.743 mg/l without elutriate recycle to 1.137 mg/l. The additional loading to the settlers also increased the solids in the primary effluent to 104.7 tons per day compared to the 81.9 tons per day for A21-M treatment without elutriate recycle. The primary effluent with 104.7 tons per day of solids had approximately the same solids content as the primary effluent without elutriate recycle and without polymer treatment, and contained 65.2 fewer tons of solids than the effluent during the baseline elutriate recycle. While the solids in the primary effluent did not increase as elutriate recycle continued, the amount of solids in the recycle stream to the settlers gradually increased. This increase in solids in the recycle stream represented an unstable plant operation.

Recycle of the elutriate in period III reduced the removal efficiencies of BOD and TOC (tables 5 and 6) compared to A21-M treatment without elutriate recycle, but maintained or improved the removal efficiencies and the primary effluent quality compared to the baseline (period I). The total phosphorus and TKN removals in the settlers (tables 7 and 8) actually increased with elutriate recycle and A21-M treatment to 18 and 22% respectively. Thus, A21-M was an effective flocculant to all solids entering the plant's primary settlers and either maintained or improved the primary effluent quality for all pollutants during the entire A21-M test.

In the Reten 210 test without elutriate recycle (period V), the solids capture of 46.9% (table 4) with an average dose of 0.089 mg/l of Reten 210 remained unchanged compared to the 46.7% capture of the preceding baseline. The average removals of BOD and TOC slightly exceeded the removals of the preceding baseline (tables 5 and 6), but the increases were marginal as they did not exceed the average removals occurring in the most efficient baseline period. The removals of phosphates (table 7; period V) actually decreased compared to the baseline removal (period IV).

The overflow rate (table 1) in the primary settlers during Reten 210 addition (period V) was approximately 10% lower than the baseline (period IV). When compared to the baseline, this lower overflow rate during polymer treatment should have improved settler performance during polymer treatment. However, for operation without elutriate recycle, Reten 210 did not improve the capture of the raw and thickener recycle solids in the primary settlers, and did not improve the overall performance of the settlers.

With the recycle of the elutriate, the solids removal of 51.2% during an average Reten 210 dose of .124 mg/l represented a 19% improvement over the 43.4% removal for baseline elutriate recycle, but the solids in the primary effluent increased from 120.4 tons per day for the first half of elutriate recycle test (period VIa) to 141.1 tons per day for the second half (period VIb). Thus, although the solids capture increased and the solids in the primary effluent were less than those of the baseline elutriate recycle (period XI), Reten 210 did not prevent a gradual increase in the solids content of the primary effluent. In addition, the removals of BOD, TOC, and total phosphorus during elutriate recycle with Reten 210 addition (tables 5, 6, and 7; period VI) were not significantly different from those during elutriate recycle without polymer treatment. Hence, although Reten 210 produced some improvement in solids capture during elutriate recycle, the polymer, as applied, was not generally an effective flocculant in the District of Columbia primary settlers and with recycle of the elutriate did not prevent gradual deterioration in the primary effluent.

In the ST 269 test, an average of 0.294 mg/l of ST 269 and 2.94 mg/l of clay builder did not produce significant changes in the primary settler performance with the elutriate discharged into the river. The average overflow rate (table 1) in the primary settlers during ST 269 addition (period VIII) was 4.8% lower than the preceding baseline (period VII) and should have slightly improved settler performance. The solids capture (table 4) marginally increased from 52.0% to 54.2%; BOD, TOC, and total phosphate removals (tables 5, 6, and 7) remained essentially unchanged at 33%, 45%, and 9%, respectively.

The recycle of the elutriate immediately increased the solids in the primary effluent from an approximately 100 tons per day to 157 tons per day. In fact, in the first portion of elutriate recycle with ST 269 addition (period IX), the solids capture of 42.7% was less than that during the elutriate recycle baseline (period XI). However, in spite of a solids loading which increased from 278.4 tons per day in period IXa to 339.5 tons per day in period IXb, the overall solids capture increased during the last half of the test (period IXb) to 54.5% and indicated a significant reversal in polymer performance. The 54.5% overall solids capture at the highest solids loading rate encountered with or without polymers in the entire Study represented 44% improvement over the 38.2% capture for the corresponding elutriate recycle without polymer addition (period XIb). Indeed, the solids in the primary effluent actually decreased in period IXb compared to period IXa even though the solids entering the settlers increased.

The pin point floc produced by ST 269 was difficult to capture in the settlers, especially early in the test. The reduction in the average polymer dose from 0.270 mg/l of ST 269 and 3.11 mg/l of clay to 0.197 mg/l of ST 269 and 2.05 mg/l of clay along with the increased solids loading apparently improved the solids capture in the settlers, and indicated initial improper dosing with ST 269.

Similarly, ST 269 with its clay builder did not initially produce improvements in removals of BOD, TOC, or total phosphate (table 5, 6, and 7) during the first half of elutriate recycle (period IXa). The removals actually decreased compared to those of the elutriate recycle baseline (period XIa). In the last half of elutriate recycle (period IXb), however, the average overall BOD removal (table 5) increased to 49.9%; the overall total phosphate removal (table 7) increased to 14.4%. Both removals sharply exceeded those of the elutriate recycle baseline. In the same period (IXb), the overall TOC removals of 41.9% (table 6) slightly exceeded that of the elutriate recycle baseline (period XIb).

The very high removals of BOD occurred with an unusually high BOD content of 221.5 tons per day in the raw wastewater compared to the normal 150-180 tons per day. The phosphate content in the recycle to the primary settlers was also unusually high averaging 12.0 tons per day compared to 8-9 tons per day normally occurring during elutriate recycle. Thus the wastewater and plant operation during period IXb was not typical of the District of Columbia Plant, and its uncertainty in the test prevented clear evaluation of ST 269 in the primary settlers.

PRODUCTION OF PRIMARY AND WASTE ACTIVATED SLUDGE

The primary sludge and the secondary sludge in the District of Columbia Plant are combined, thickened, digested, elutriated, and finally dewatered by vacuum filtration. The ratio of the amounts of primary to waste activated sludge in the combined sludges must increase sharply with efficient polymer flocculation because the ratio reflects changes in the relative amounts of primary and waste activated sludge.

For baseline operation (periods I, IV, VII, and X), the average ratios of primary to waste activated sludge (table 9) varied between 1.48 and 1.91. During elutriate recycle without polymer addition (period XI), the ratio averaged 1.43 and indicated that significant portions of the digested solids recycled in the elutriate were recaptured in the plant's final settlers rather than in the primary settlers. In fact, during elutriate recycle without polymer addition, the primary sludge (table 9) actually increased by only 21 tons per day over that of the preceding baseline (period X), while the waste activated sludge increased by 39 tons per day.

In the A21-M test, the ratio of primary to waste activated sludge increased to 2.74 without elutriate recycle (period II) and to 2.88 with elutriate recycle (period III). During polymer treatment without elutriate recycle, the waste activated sludge production with A21-M treatment decreased by 25% from a baseline average of 68.5 tons per day to only 51.1 tons per day. Even with the digested solids and BOD recycled in the elutriate, the waste activated sludge averaged only 61.7 tons per day for A21-M treatment.

The waste activated sludge production in the last half of the elutriate recycle (period IIIb) averaged only 55.8 tons per day compared to a baseline of 117.9 tons per day in period XIb. The ratio of primary to waste activated sludge in the period IIIb increased to 3.54, compared to the baseline 1.36 even with the increasing amounts of digested solids in the elutriate recycled to the primary settlers. These results clearly confirmed the improved performance of the primary settlers during A21-M treatment.

In the Reten 210 test, the ratio of primary to waste activated sludge (table 9) of 1.55 without elutriate recycle (period V) and 1.38 with elutriate recycle (period VI) were slightly lower than the corresponding baseline ratios, and thus confirmed the lack of improvement in the performance of the primary settlers during Reten 210 treatment.

TABLE 9 RATIO OF PRIMARY TO SECONDARY SLUDGE

PERIOD	TOTAL SOLIDS (TONS/DAY)			RATIO
	Primary	Secondary	Combined	Primary / Secondary
4/66-3/67	97.2	84.1	181.3	1.16
A21-M				
I	101.3	68.5	169.8	1.48
II	140.2	51.1	191.3	2.74
III	178.0	61.7	239.7	2.88
IIIa	161.5	65.3	226.8	2.47
IIIb	197.5	55.8	253.3	3.54
Reten 210				
IV	112.0	60.8	172.8	1.84
V	106.7	69.0	175.7	1.55
VI	129.2	93.9	223.1	1.38
VIa	124.2	81.8	206.0	1.52
VIb	135.2	108.9	244.1	1.24
ST 269 + CA-25				
VII	118.0	78.1	196.1	1.51
VIII	89.6	69.9	159.5	1.28
IX	168.3	141.5	309.8	1.19
IXa	143.9	160.0	303.9	0.90
IXb	197.2	119.0	316.2	1.66
No Polymer				
X	139.2	72.8	212.0	1.91
XI	160.2	111.9	272.1	1.43
XIa	160.5	105.2	265.7	1.53
XIb	159.9	117.9	277.8	1.36

In the ST 269 test, during the period of polymer addition without elutriate recycle (period VIII) the average overflow rate in the primary settlers decreased 4.8% and in the secondary settlers increased 4.4% from the baseline period VII; the suspended solids concentration in the primary influent during this period increased less than 1% from the baseline. However, contrary to these favorable conditions for improved primary performance relative to secondary, the ratio of primary to waste activated sludge decreased from 1.51 to 1.28. This decrease in ratio indicated that the 0.294 mg/l dosage of polymer had actually dispersed the solids while in the primary settlers. Indeed, the change from a very low ratio of 0.90 during the first half of the elutriate recycle (period IXa) to a ratio 1.66 in last half (period IXb) and the decrease in production of waste activated sludge from 160 to 119 tons per day in the same intervals occurred with increasing amounts of recycled digested solids and with decreased polymer dosage. This sudden increase in ratio of primary to waste activated sludge strongly supported the suspected polymer overdoses during the initial portions of ST 269 test.

PRIMARY-SECONDARY PLANT PERFORMANCE

In the District of Columbia Plant, the plant pollutant removal efficiencies and the pollutants discharged into the river varied not only with the pollutants in the secondary effluent, but also with those in the elutriate when it was discharged directly into the river. In addition, the pollutants in the elutriate fluctuated widely and independently of primary and secondary treatment.

Suspended solids in the elutriate especially were a significant portion of the solids entering the river. As examples, for the year preceding the polymer study, the solids discharged into the river (table 10) averaged 55.9 tons per day of which 27.1 tons per day or 48.5% of the total was in the elutriate. In the baseline periods (I, IV, VII, and X), the solids in the elutriate varied from 11.4 to 31.2 tons per day and averaged 39.7% of the solids discharged into the river. The overall solids removals for the same periods with the solids in the elutriate included in the calculation varied from 65.6 to 75.9%. In contrast, the solids removal efficiencies for primary-secondary treatment, excluding the effect of the elutriate, exhibited only a 2% variation from 80.3 to 82.3% for the four baseline periods, and thus revealed the marked variability produced in overall plant solids removal efficiency by the solids in the elutriate. In fact, if the elutriate could have been continuously recycled without loss of primary-secondary treatment efficiency, the 80% efficiency in primary-secondary treatment would have represented an 8 to 24% improvement in overall plant solids removal during the baseline periods.

The elutriate did not produce as marked variability in the plant removals of BOD, TOC, total phosphorus and TKN. The overall BOD removal efficiencies (table 11) for the baseline with the elutriate included in the calculation varied from 68.1 to 69.7%; TOC removals (table 12), from 48.4 to 63.3%; and the total phosphorus removals (table 13), from 4.4 to 8.9%. The overall TKN removal (table 14) for the first baseline (period I) was 6.4%. Plant BOD removal efficiencies based only upon the amounts of BOD in the secondary effluent varied from 73.6 to 75.4%; TOC removal efficiencies, from 64 to 70.5%; and total phosphorus removal efficiencies, from 12.3 to 19.0%. Plant TKN removal efficiency based upon the secondary effluent was 20.9% for the first baseline. Nevertheless, the amounts of BOD, TOC and total phosphorus in the elutriate during the four baseline periods average 17, 24.2, and 11.4% respectively, of their totals entering the river. Thus, elimination of the discharge of the elutriate by recycling it to the plant influent without decreases in secondary effluent quality, would have represented significant improvements in removal of all pollutants.

TABLE 10 PLANT SUSPENDED SOLIDS REMOVAL

PERIOD	POLYMER DOSE mg/1	AVERAGE SUSPENDED SOLIDS IN TONS/DAY				% REMOVAL	
		RAW WASTE-WATER GRAB M_1	SECONDARY[1] M_{5*}	ELUTRIATE M_{14}	DISCHARGE[2] M_R	SECONDARY[3]	OVERALL[4]
4/66-3/67	0	177.4[5]	28.8	27.1	55.9	83.8	68.5
A21-M							
I	0	177.8[5]	31.4	11.4	42.8	82.3	75.9
II	0.743	199.0[5]	32.4	13.8	46.3	83.7	76.7
III	1.137	214.3	37.7	52.4[6]	37.7	82.5	82.5
IIIa	1.125	214.5	40.7	50.0[6]	40.7	81.0	81.0
IIIb	1.151	213.8	34.2	55.6[6]	34.2	84.0	84.0
Reten 210							
IV	0	189.0	37.2	28.7	66.1	80.3	65.0
V	0.089	191.4	42.8	26.1	69.3	77.6	63.8
VI	0.124	178.9	42.9	39.3[6]	42.9	76.0	76.0
VIa	0.137	177.4	44.4	26.2[6]	44.4	75.0	75.0
VIb	0.110	179.7	40.7	56.0[6]	40.7	77.4	77.4
ST 269 + CA-25							
VII	0	186.0	33.2	25.3	58.6	82.2	68.5
VIII	0.294	179.4	38.1	19.7	57.9	78.8	67.7
IX	0.239	192.2	39.9	62.2[6]	39.9	79.2	79.2
IXa	0.270	189.1	40.1	41.2[6]	40.1	78.8	78.8
IXb	0.197	195.8	39.6	92.6[6]	39.6	79.8	79.8
No Polymer							
X	---	200.7	37.8	31.2	69.1	81.2	65.6
XI	---	200.4	44.8	52.7[6]	44.8	77.6	77.6
XIa	---	209.4	46.5	46.6[6]	46.5	77.8	77.8
XIb	---	191.2	43.1	59.1[6]	43.1	77.5	77.5

Footnotes:

1. $M_{5*} = M_5 - M_{17} - M_{20}$ (Figure 1)
2. $M_R = M_{5*} + M_{14} + M_{16}$ (no elutriate recycle)
3. % Removal $= \frac{M_1 - M_{5*}}{M_1}(100)$
4. % Removal $= \frac{M_1 - M_R}{M_1}(100)$
5. Calculated M_1 (Table 4)
6. Elutriate Recycled

TABLE 11 PLANT BOD REMOVAL

PERIOD	POLYMER DOSE mg/l	AVERAGE BOD IN TONS/DAY				% REMOVAL	
		RAW WASTE-WATER GRAB M_1	SECONDARY[1] M_{5*}	ELUTRIATE M_{14}	DISCHARGE[2] M_R	SECONDARY[3]	OVERALL[4]
A21-M							
I	0	151.5[5]	40.1	5.7	45.8	73.6	69.7
II	0.743	153.3[5]	33.2	6.6	39.8	78.3	74.0
III	1.137	153.3	35.9	11.3[6]	35.9	76.6	76.6
IIIa	1.125	153.2	36.9	12.1[6]	36.9	75.9	75.9
IIIb	1.151	153.4	34.7	10.1[6]	34.7	77.4	77.4
Reten 210							
IV	0	148.7	38.7	7.4	46.2	74.0	68.9
V	0.089	150.5	48.7	12.1	61.0	67.6	59.5
VI	0.124	143.7	44.7	10.9[6]	44.7	68.9	68.9
VIa	0.137	148.2	44.5	9.3[6]	44.5	70.0	70.0
VIb	0.110	137.0	44.7	12.9[6]	44.7	67.4	67.4
ST 269 + CA-25							
VII	0	151.5	37.2	10.5	47.8	75.4	68.1
VIII	0.294	149.9	44.7	6.8	51.5	70.2	65.6
IX	0.239	184.9	48.9	13.2[6]	48.9	73.6	73.6
IXa	0.270	153.8	48.6	8.8[6]	48.6	68.4	68.4
IXb	0.197	221.5	49.3	19.5[6]	49.3	77.7	77.7
No Polymer							
X	---	156.3	39.6	8.4	48.1	74.7	69.2
XI	---	149.8	41.7	12.9[6]	41.7	72.2	72.2
XIa	---	153.6	44.3	10.6[6]	44.3	71.2	71.2
XIb	---	145.8	39.1	15.5[6]	39.1	73.2	73.2

Footnotes:

1. $M_{5*} = M_5 - M_{17} - M_{20}$
2. $M_R = M_{5*} + M_{14} + M_{16}$ (No elutriate recycle)
3. % Removal $= \frac{M_1 - M_{5*}}{M_1}(100)$
4. % Removal $= \frac{M_1 - M_R}{M_1}(100)$
5. Estimated Grab M_1 = 1.22 Auto M_1
6. Elutriate Recycled

TABLE 12 PLANT TOC REMOVAL

PERIOD	POLYMER DOSE mg/1	AVERAGE TOC IN TONS/DAY: RAW WASTE-WATER GRAB M_1	AVERAGE TOC IN TONS/DAY: SECONDARY[1] M_{5*}	AVERAGE TOC IN TONS/DAY: ELUTRIATE M_{14}	AVERAGE TOC IN TONS/DAY: DISCHARGE[2] M_R	% REMOVAL: SECONDARY[3]	% REMOVAL: OVERALL[4]
A21-M							
I	0	94.7[5]	29.2	5.5	34.7	69.2	63.3
II	0.743	105.3[5]	29.6	6.5	36.1	71.9	65.7
III	1.137	85.7	32.4	14.3[6]	32.4	62.2	62.2
IIIa	1.125	87.3	33.1	15.0[6]	33.1	62.3	62.3
IIIb	1.151	83.7	31.5	13.4[6]	31.5	62.2	62.2
Reten 210							
IV	0	88.9	32.0	13.8	45.9	64.0	48.4
V	0.089	109.7	34.6	8.6	43.3	68.5	60.5
VI	0.124	107.2	35.9	14.9	35.9	66.5	66.5
VIa	0.137	105.1	35.7	13.2	35.7	66.0	66.0
VIb	0.110	109.3	36.0	17.0	36.0	67.1	67.1
ST 269 + CA-25							
VII	0	98.4	29.2	9.1	38.3	70.3	61.1
VIII	0.294	100.1	32.1	11.3	43.4	67.9	56.6
IX	0.239	107.8	38.8	17.3[6]	38.8	64.0	64.0
IXa	0.270	105.3	39.0	12.8[6]	39.0	63.0	63.0
IXb	0.197	110.7	38.5	23.7[6]	38.5	65.2	65.2
No Polymer							
X	---	108.4	32.0	12.1	44.1	70.5	59.3
XI	---	107.0	41.7	14.3[6]	41.7	61.0	61.0
XIa	---	113.6	49.9	12.2[6]	49.9	56.1	56.1
XIb	---	99.9	33.6	16.7[6]	33.6	66.4	66.4

Footnotes:

1. $M_{5*} = M_5 - M_{17} - M_{20}$

2. $M_R = M_{5*} + M_{14} + M_{16}$ (No elutriate recycle)
   $M_R = M_{5*}$ (Elutriate recycled)

3. % Removal = $\frac{M_1 - M_{5*}}{M_1}(100)$

4. % Removal = $\frac{M_1 - M_R}{M_1}(100)$

5. Calculated M_1 (Table 6)

6. Elutriate Recycled

TABLE 13 PLANT PHOSPHORUS REMOVAL

PERIOD	POLYMER DOSE mg/1	AVERAGE PHOSPHORUS AS PO_4 TONS/DAY				% REMOVAL	
		RAW WASTE WATER GRAB M_1	SECONDARY[1] M_{5*}	ELUTRIATE M_{14}	DISCHARGE[2] M_R	SECONDARY[3]	OVERALL[4]
A21-M							
I	0	24.8[5]	21.3	1.9	23.3	12.3	6.0
II	0.743	28.6[5]	22.1	1.5	23.6	22.7	17.5
III	1.137	26.9	22.2	3.6[6]	22.2	17.4	17.4
IIIa	1.125	26.5	23.0	3.8[6]	23.0	13.2	13.2
IIIb	1.151	27.3	21.3	3.4[6]	21.3	22.1	22.1
Reten 210							
IV	0	25.2	20.7	3.3	24.1	17.9	4.4
V	0.089	25.7	21.9	2.6	24.6	14.8	4.3
VI	0.124	25.0	22.3	3.1[6]	22.3	10.8	10.8
VIa	0.137	25.2	22.4	2.4[6]	22.4	11.1	11.1
VIb	0.110	24.5	22.1	4.1[6]	22.1	9.8	9.8
ST 269 + CA-25							
VII	0	24.7	20.0	2.5	22.5	19.0	8.9
VIII	0.294	26.3	22.5	2.0	24.5	14.4	6.8
IX	0.239	27.2	23.9	4.5[6]	23.9	12.1	12.1
IXa	0.270	26.8	23.4	3.2[6]	23.4	12.7	12.7
IXb	0.197	27.6	24.6	6.3[6]	24.6	10.9	10.9
No Polymer							
X	---	26.9	21.3	3.1	24.5	17.1	8.9
XI	---	26.2	21.8	4.1[6]	21.8	16.8	16.8
XIa	---	26.8	22.2	3.7[6]	22.2	17.2	17.2
XIb	---	25.6	21.5	4.6[6]	21.5	16.0	16.0

Footnotes:

1. $M_{5*} = M_5 - M_{17} - M_{20}$
2. $M_R = M_{5*} + M_{14} + M_{16}$ (No elutriate recycle)
   $M_R = M_{5*}$ (Elutriate Recycle)
3. % Removal = $\frac{M_1 - M_{5*}}{M_1}$ (100)
4. % Removal = $\frac{M_1 - M_R}{M_1}$ (100)
5. Calculated M_1 (Table 1)
6. Elutriate Recycled

TABLE 14 PLANT NITROGEN REMOVAL

PERIOD	POLYMER DOSE mg/l	AVERAGE NITROGEN REMOVAL (TKN) AS N, TONS/DAY: RAW WASTE WATER GRAB M_1	SECONDARY[1] M_{5*}	ELUTRIATE M_{14}	DISCHARGE[2] M_R	% REMOVAL: SECONDARY[3]	OVERALL[4]
A21-M							
I	0	24.9[5]	19.7	3.7	23.3	20.9	6.4
II	0.743	23.1[5]	18.1	3.4	21.5	21.6	6.9
III	1.137	23.8	21.3	5.6[6]	21.3	10.4	10.4
IIIa	1.125	23.3	21.4	5.9[6]	21.4	3.7	3.7
IIIb	1.151	24.3	21.2	5.2[6]	21.2	12.9	12.9

Footnotes:

1. $M_{5*} = M_{(5 - 20 - 17)}$
2. $M_R = M_{5*} + M_{14} + M_{16}$ (No elutriate recycle)
   $M_R = M_{5*}$ (Elutriate recycled)
3. % Removal $= \frac{M_1 - M_{5*}}{M_1}(100)$
4. % Removal $= \frac{M_1 - M_R}{M_1}(100)$
5. Calculated M_1 (Table 6)
6. Elutriate Recycled

In the 50 day elutriate recycle baseline (period XI), recycle of the elutriate without polymer treatment, in general, produced improvements compared to the baseline (period X) in the overall plant removals for all pollutants (tables 10-13). The most important improvement occurred in the overall solids removal efficiency (table 10) which increased from 65.6 to 77.6% and represented a 35% reduction in the solids entering the river.

The additional loading from the recycled elutriate, however, produced for all pollutants a small but consistent decrease in the plant removal efficiencies based upon the secondary effluent. As examples, the solids removals for primary-secondary treatment decreased from the baseline efficiencies (periods I, IV, VII) of 80.3-82.3% without elutriate recycle to 77.6% with elutriate recycle, and the BOD removals, from the efficiencies of 73.6-75.4% without elutriate recycle to 72.2% with elutriate recycle. In the overall plant operation, useful polymer treatment should improve the plant removal efficiencies of the particulates (solids and BOD) based upon the secondary effluent when the elutriate is discharged into the river, and at least prevent the observed consistent decrease in the same efficiencies when the elutriate is recycled to the plant influent.

In the A21-M test with the elutriate discharged into the river (period II), the plant removal efficiencies based upon the secondary effuent of 83.7% for suspended solids (table 10), 71.9% for TOC (table 12), and 21.6% for TKN (table 14), remained essentially unchanged from the preceding baseline removals of 82.3, 69.2, and 20.9% respectively. The amounts of these three pollutants entering the river in the secondary effluent either remained unchanged or increased slightly with increased plant loading. The BOD removal (table 11), however, increased from 73.6% to 78.3% and the phosphorus (table 13) from 12.3% to 22.7%. The BOD in the secondary effluent actually decreased by 13%. Thus, in the 30 day test without elutriate recycle, the A21-M treatment, which reduced the loadings to the aerators by 20% for solids and by 14% for BOD, produced corresponding improvements in the primary-secondary efficiencies for BOD removal but not for solids removal. However, with the available plant aeration controls, the air used in aeration at the lower BOD and solids loading during A21-M treatment was not less than the preceding baseline.

With the recycle of the elutriate (period III), the plant removal efficiencies of 82.5% for solids and 76.6% for BOD represented an increase of approximately 6% over the efficiencies (76.6% and 72.2% respectively, for solids and BOD) of the elutriate recycle without polymer addition (period XI). This modest increase in overall efficiencies would reduce the solids entering the river by 22% and the BOD by 17% if applied to the baseline (period XI). In contrast, the TOC and phosphorus removal efficiencies during elutriate recycle with and without A21-M addition were essentially identical. With a 20% lower plant loading, the TOC discharged into the river in the elutriate recycle trial with the A21-M treatment was 22% lower than that in the elutriate recycle without A21-M; with the same plant loading, with and without polymer treatment, the phosphorus entering the river was unchanged.

The solids removal efficiency of 84% and the BOD removal efficiency of 77.4% in the last half of the elutriate recycle with A21-M treatment (period IIIb) represented the best performance of the plant during the entire study. This performance, however, occurred with ferric chloride addition in elutriation, and thus could not be attributed solely to the polymer. With only an 80 day trial, the A21-M treatment could not be fully assessed, but it prevented decreases in the important primary-secondary removal efficiencies for suspended solids and BOD which occurred when the elutriate was recycled without polymer treatment.

In the Reten 210 treatment with the elutriate discharged into the river (period V), the primary-secondary removal efficiencies based upon the secondary effluent of 77.6% for suspended solids (table 10), 67.6% for BOD (table 11), and 14.8% for total phosphorus (table 13) were from 2 to 17% lower than the corresponding baseline efficiency (period IV). The TOC removal (table 12) of 68.5% represented a 7% increase over the 64% efficiency of the baseline. The 64% baseline efficiency, however, was unusually low as the other three baseline efficiencies varied between 69.2 and 70.5%. The amount of TOC in the secondary effluent during the baseline was actually lower than that during the Reten 210 trial. Clearly, Reten 210 treatment with the elutriate discharged into the river did not produce improvements in the primary-secondary system.

When the elutriate was recycled (period VI), the removal efficiencies of 76.0% for suspended solids (table 10), 68.9% for BOD (table 11), and 10.8% for total phosphorus (table 13) were lower than similar efficiencies during elutriate recycle without polymer treatment (period XI). The TOC removal efficiency (table 12) of 66.5%, however, was 9% higher than that of the elutriate recycle baseline. Even with the increase in TOC removal efficiency, the decrease in the removal efficiencies for solids, BOD and total phosphorus indicated that Reten 210 during elutriate recycle did not improve the primary-secondary treatment system.

In the ST 269 test, the primary-secondary removal efficiencies (period VIII) of 78.8% for suspended solids (table 10), 70.2% for BOD (table 11), and 67.9% for TOC (table 12) were 3 to 7% lower than the corresponding baseline efficiencies (period VII). The total phosphorus removal efficiency (table 13) of 14.4% was also lower than that of the baseline. With the elutriate recycle (period IX), the removal efficiencies of 79.2% for solids and 73.6% for BOD were only 2% higher than those of the baseline elutriate recycle (period XI). The TOC removal of 64% was 5% higher than that of the baseline while the phosphorus removal of 12.1% was 28% lower. In general, ST 269 treatment, as applied, did not produce significant or consistent changes in the performance of the primary-secondary system during either the periods with the elutriate discharged into the river or recycled to the plant influent.

SOLIDS HANDLING

In normal operation, the plant's digested sludge could not be directly dewatered by vacuum filtration, and required elutriation to reduce the alkalinity and the fine solids in the sludge before dewatering by chemical conditioning and vacuum filtration. The digested solids during elutriation did not separate efficiently from the washwater and the overflow (elutriate) returning to the plant influent repeatedly recycled more than 50% of these solids back into the primary settlers and subsequently into the solids handling system.

In 1962 the plant's increasing solids loading finally overloaded the solids handling and disposal system, produced unstable plant operation, and forced the direct discharge of the elutriate into the Potomac River. Thus, the effects of the polymers on the various sludge handling processes, especially elutriation and vacuum filtration, were an important factor in the evaluation of the polymers.

The most important variable in solids handling was the amount of solids within the various sludge handling processes. In normal operation without elutriate recycle or polymer treatment, the combined primary and secondary solids (table 9) for the four baseline periods varied from 170 tons per day for period I to 212 tons per day for period X.

For the 30 days of polymer treatment without elutriate recycle, the total amount of solids fed to the solids handling system did not change significantly from the baselines. Even with the increased capture of solids in the primary settlers during A21-M treatment, the increased primary solids were off set by decreases in the waste activated sludge, and the combined sludges averaged approximately 190 tons per day (table 9) compared to the 170 tons of the preceding baseline (period I). Since the plant solids loading increased by 21 tons per day from the baseline to the period with A21-M addition, the increase of 20 tons per day in combined sludges was not significant. Thus, the solids in the handling system with the plant's elutriate discharged into the river were not increased by polymer treatment.

With the elutriate recycle, the amount of solids in the thickened sludge, in the digested sludge to elutriation, and in the elutriate began increasing (figure 2-5), with or without polymer treatment. The solids content in these streams generally increased as the period of the elutriate recycle continued. The larger amounts of solids in the elutriate in the second half of each polymer test with elutriate recycle (table 10; periods IIb, VIb, and IXb) indicated unstable increasing amounts of solids in the solids handling system. In general, similar increases in the last half of each elutriate recycle test also occurred for the BOD, TOC, total phosphate, and TKN (tables 11, 12, 13, 14).

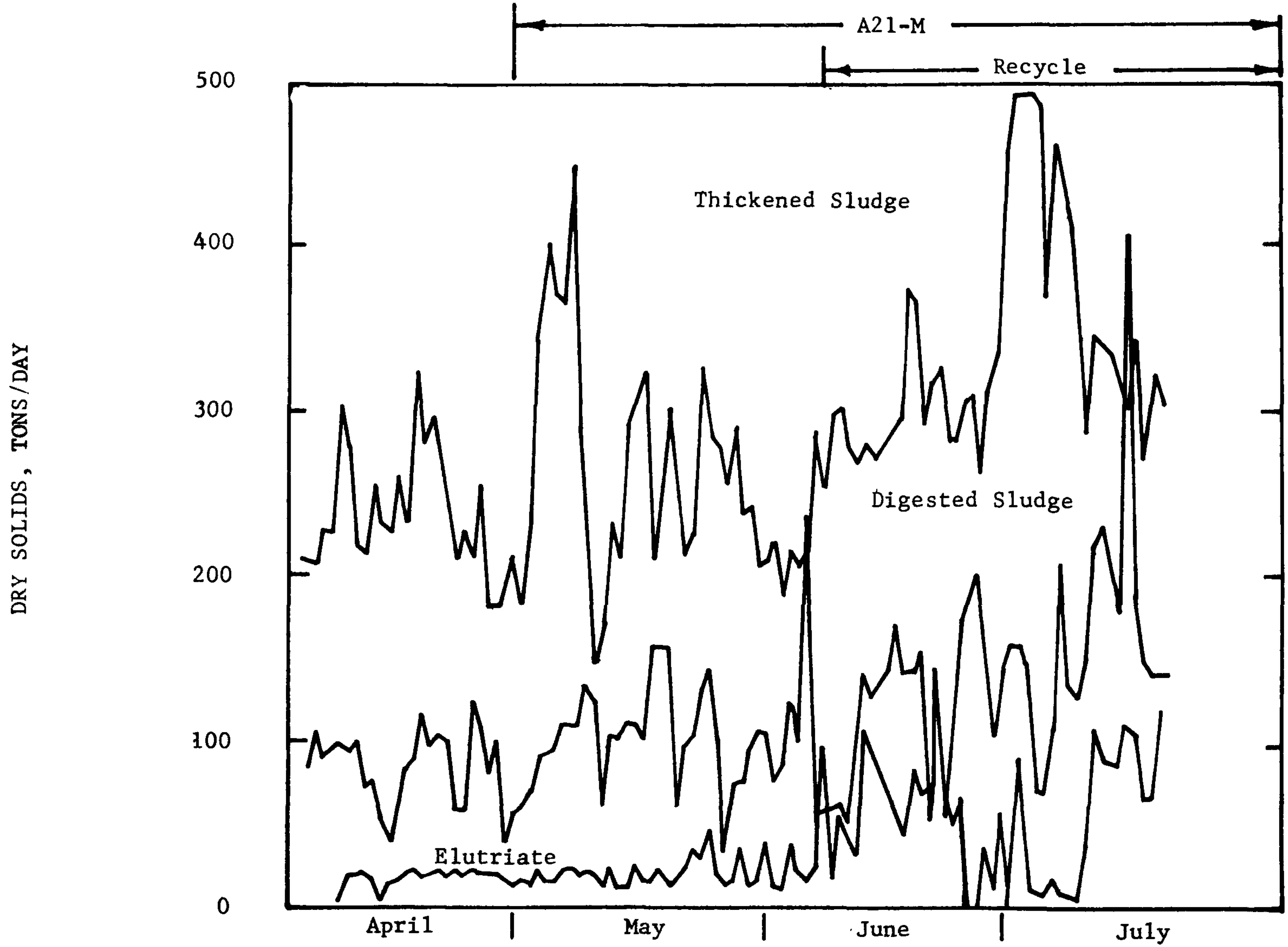

Figure 2: Quantity of Sludge Produced Using A21-M

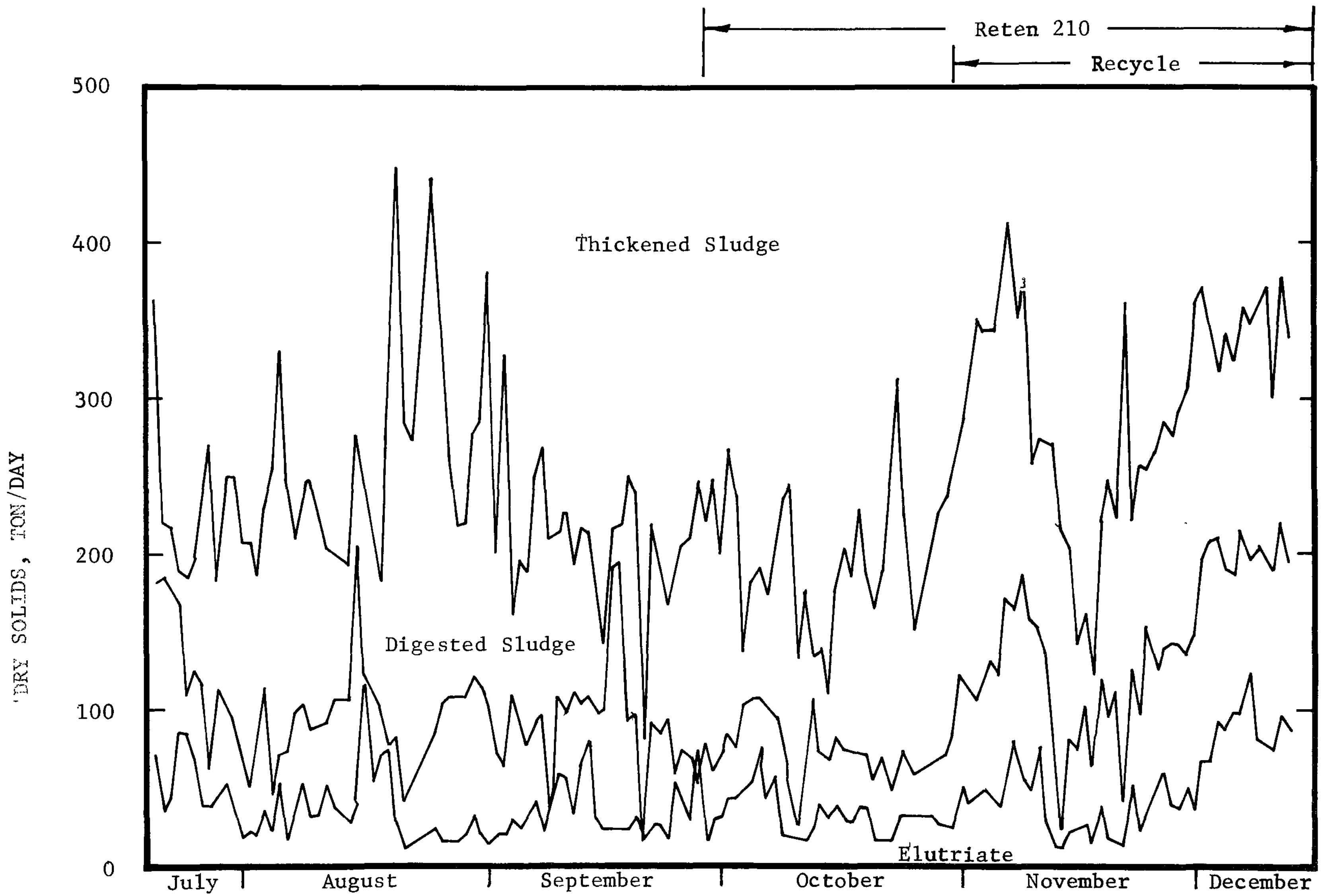

Figure 3: **Quantity** of Sludge Produced Using Reten 210

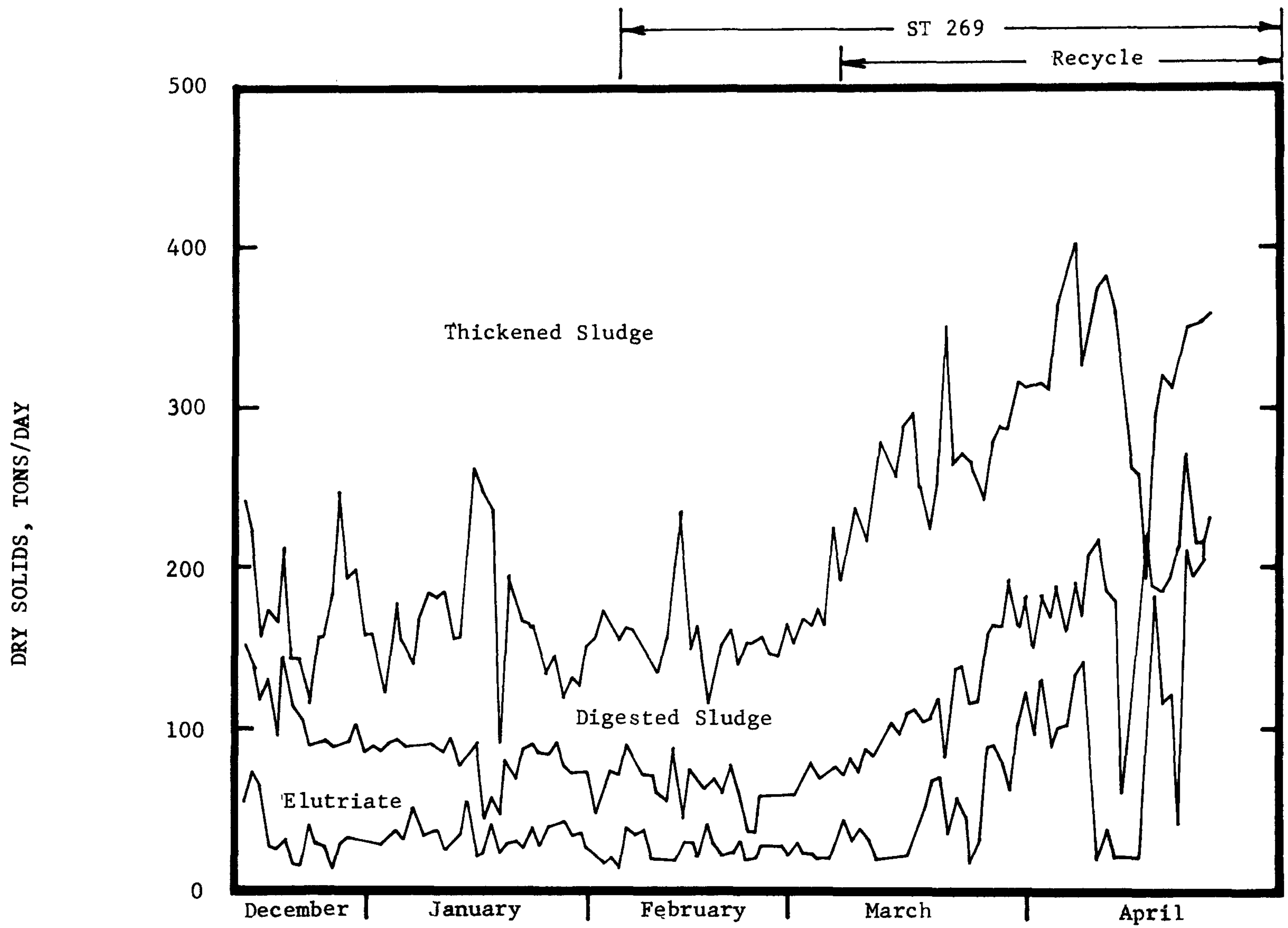

Figure 4: Quantity of Sludge Produced Using ST 269

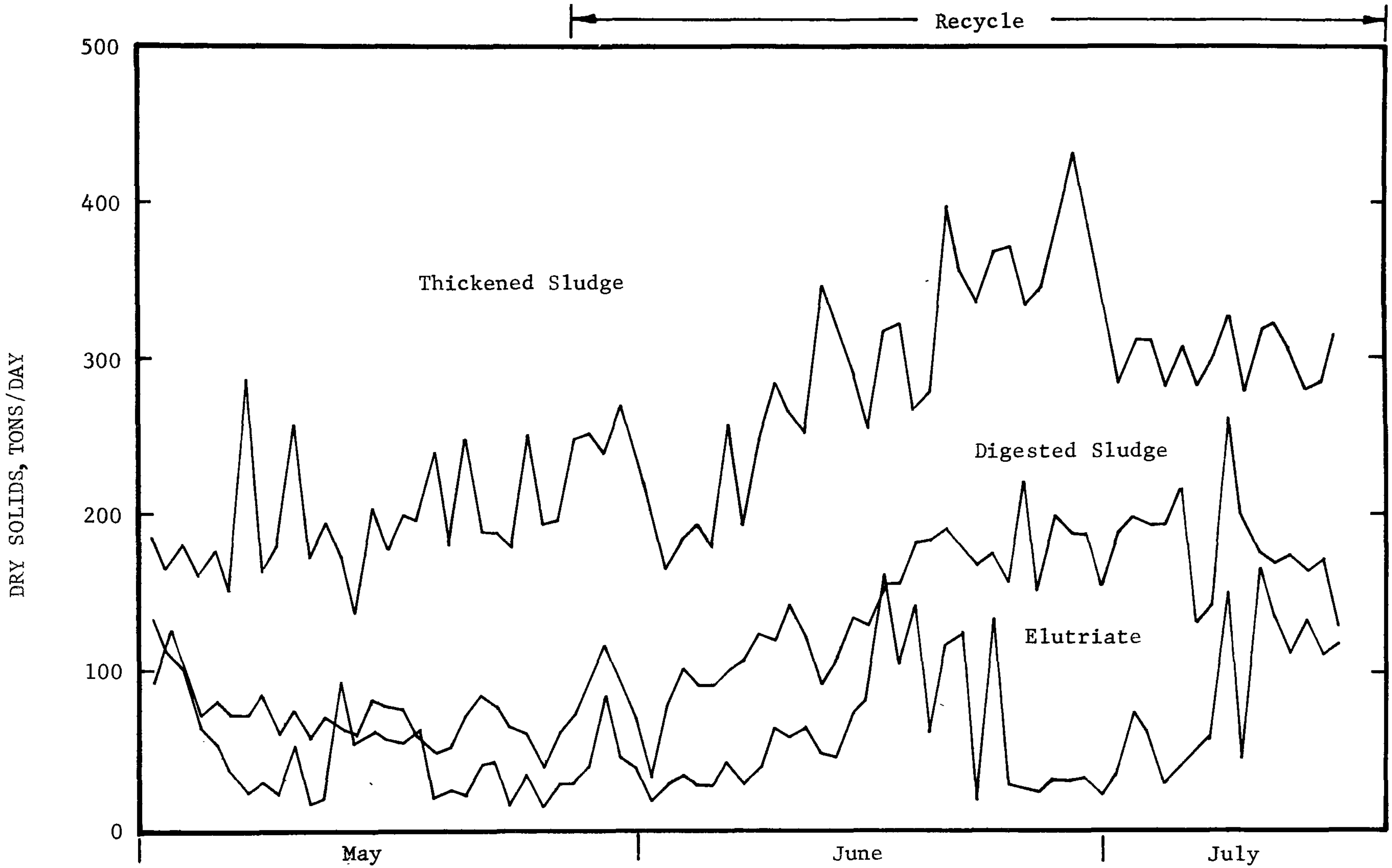

Figure 5: Quantity of Sludge Produced Using No Polymer

Although most of the solids in the recycled elutriate were recaptured either in the primary settlers or in the secondary settlers, and returned into the sludge handling system, the increased amounts of digested solids did not settle in elutriation. The production of dewatered sludge (filter cake) by the vacuum filters did not increase regardless of the polymer used in the primary settlers (table 15). Under the operating conditions in the plant, the accumulating solids in the sludge handling system would have eventually exceeded the system's capacity, and as in the past, forced discharge of the elutriate directly into the Potomac River. For A21-M treatment, attempts to increase filter cake production by increasing feed rates to elutriation during elutriate recycle were unsuccessful. The increased solids loading in elutriation increased the solids in the elutriate but not the filterability and production of the elutriated sludge.

For A21-M with its efficient capture of solids in the primary settlers, the accumulation of solids in the plant became immediately evident. Thus, $FeCl_3$ was added at a rate equivalent to 12.8 pounds per million gallons of raw wastewater to elutriation to increase production of dewatered sludge. Although in the short 80 days test with A21-M equilibrim in the solids handling system was not completely achieved, the filter cake production averaged 69 tons per day with peaks over 80 tons per day for $FeCl_3$ treatment compared to the normal 40-50 tons per day (table 15). The $FeCl_3$ treatment in elutriation removed excess solids and eventually should have stabilized solids handling system.

During elutriate recycle, solids gradually accumulated within the plant's solids handling system especially in the digesters, regardless of polymer treatment. After discontinuing all polymer addition, the solids capture in elutriation and the filterability of the accumulated solids improved. With the increased filterability, the solids production increased to 82.5 tons per day without elutriate recycle (period X). With the elutriate recycled (period XI), the plant's solids production increased from the normal 30-50 tons per day for elutriate recycle with polymer treatment to an average of 103.2 tons per day (table 15). The cause for these high filter yields during these two periods was not determined, and the high yields have not been repeated. These filter yields, however, were not possible during the polymer treatment. Thus it should be emphasized that polymer treatment alone did not stablize solids handling nor permit continuous elutriate recycle, and that chemical treatment such as $FeCl_3$ addition was necessary to remove solids accumulating within the plant during elutriate recycle.

TABLE 15 PLANT SOLIDS PRODUCTION

PERIOD	POLYMER DOSE mg/1	POLYMER USED lbs/day	$FeCl_3$ lbs/day	FILTERED SOLIDS Tons/day
4/66-3/67	---	---	---	44.8
A21-M				
I				58.0
II	0.74	1460	---	51.1
III[3]	1.137	2280	---	55.1
IIIa[3]	1.25	2240	2040[1]	49.6
7/1-7/16[3]	1.21	2460	3140[2]	69.0
IIIb[3]	1.15	2362	---	61.7
Reten 210				
IV	---	---	---	49.7
V	0.089	162.1	---	32.4
VI[3]	0.124	225.0	---	40.7
VIa[3]	0.137	236.5	---	42.4
VIb[3]	0.110	211.4	---	38.7
ST 269 + CA-25				
VII	---	---	---	36.0
VIII	0.294	520.8	---	30.9
IX[3]	0.239	477.8	---	32.4
IXa[3]	0.270	548.8	---	36.4
IXb	0.197	385.8	---	27.6
No Polymer				
X	---	---	---	82.9
XI[3]	---	---	---	103.2
XIa[3]	---	---	---	95.1
XIb[3]	---	---	---	111.3

1. Average lbs/day for 8 days (6/14-6/21) in elutriation
2. Average lbs/day for 16 days (7/1-7/16) in elutriation
3. Elutriate Recycled

CHEMICAL COSTS

The costs for each polymer employed in the trials are summarized in Table 16. If $FeCl_3$, added in elutriation, was included at \$0.05 per pound for a dose rate equivalent to 12.8 pounds per million gallons of raw wastewater, the chemical costs increased by \$0.64 per million gallons. Thus for A21-M treatment with ferric chloride in elutriation the combined chemical cost with the elutriate recycled (period III) was \$9.53 per million gallons.

Since polymer treatment of the raw wastewater did not produce satisfactory performance of the elutriation process, chemical treatment (either $FeCl_3$ or polymers) in elutriation must be applied independently of raw wastewater flocculation, and the costs of the chemical treatment in elutriation appropriately should be separated from those for raw wastewater flocculation. If chemical treatment is successfully (90% capture of solids) employed in elutriation, however, the solids in the elutriate would not significantly increase the solids loading in the primary settlers. Thus the chemical requirements and costs of raw wastewater flocculation alone, assuming an independent solution to the elutriate problem, would be closer to the dosages and costs in the polymer trials with the elutriate discharged into the river (periods II, V, and VIII).

Since Reten 210 and ST 269, as applied, did not produce significant overall plant improvement during their trials with the elutriate discharged into the river, the costs of these polymers can not be related to pollutant removals. In the A21-M test (period II), the chemical cost for the 17% reduction in the BOD in the secondary effluent was approximately \$5.90 per million gallons. Since with the aeration controls in the District of Columbia Plant the reduced BOD and solids loadings to the aerators during the A21-M test did not produce observable decreases in plant air requirements, the cost of the polymers were not offset by reduced plant operating costs. Further studies with the elutriate problem independently solved are needed before complete costs for the raw wastewater flocculation can be obtained for the District of Columbia wastewater.

TABLE 16 CHEMICAL COSTS

PERIOD	POLYMER DOSE lb/mg	ADDITIVE lb/mg	POLYMER	COST $/mg ADDITIVE	TOTAL
	A-21	C-31			
II	5.76	.44	5.76	.14	5.90
III	8.66	.82	8.66	.25	8.91
	Reten 210				
V	0.742	---	1.08	---	1.08
VI	1.035	---	1.50	---	1.50
	ST-269	CA-25			
VIII	2.45	24.5	3.55	2.02	5.57
IX	2.08	22.0	3.02	1.82	4.84

A-21 $1.00 per lb. C-31 $0.31 per lb.
Reten 210 $1.45 per lb.
ST-269 $1.45 per lb. CA-25 $0.0825 per lb.
All cost FOB manufacturer

CONCLUSIONS

Flocculation of solids in the raw wastewater and in the recycled thickener overflow by A21-M (anionic A21 modified with cationic C31) improved the efficiency of primary sedimentation by approximately 26% from a normal 50% solids removal to 63%. With the recycle of the solids in the elutriate to the influent of the primary settlers, the A21-M treatment increased the sedimentation efficiency by 48% from the 43% removal during elutriate recycle without polymer treatment to 63%.

Cationic Reten 210, at the doses employed, did not improve primary sedimentation of the solids in the raw wastewater and the recycled thickener overflow. With the recycle of the solids in the elutriate to the primary basins, Reten 210 increased the primary sedimentation efficiency by 19% from the 43% removal without polymer treatment to 51%.

Anionic ST 269 with its clay builder did not substantially improve primary sedimentation of the solids in the raw wastewater and the recycled thickener. During the last half of the elutriate recycle and with reduced ST 269 doses, the primary sedimentation efficiency increased by 43% from the 38% removal without polymer treatment to 54%. This reversal in treatment performance indicated a probable overdose of ST 269 in the beginning of the ST 269 test.

Before elutriate recycle, the improved primary sedimentation with A21-M reduced the solids entering aeration by 20% and the BOD by 14%, and decreased the amounts of waste activated sludge by 25%. The benefits of the improved primary sedimentation, however, did not produce completely parallel improvements in the secondary effluent, and with the available aeration controls did not reduce the plant air requirements. The high average rise rates of 1,000 to 1,300 gallons per day per square foot of clarification area washed solids out of the final settlers relatively independently of the solids and BOD load to the aeration tanks. Thus with the elutriate discharged into the river, the average removals through secondary treatment of solids, TOC, and TKN remained unchanged with or without polymer improved primary sedimentation. The decreased BOD load to aeration during A21-M treatment, however, increased the average BOD removals through secondary treatment from 73.6% to 78.3%, and represented a 13% decrease in BOD in secondary effluent.

With the recycle of the elutriate, none of the three polymers added in the primary basins increased the capture of the digested solids in elutriation. As with elutriate recycle without polymer treatment, the unsettled solids in the elutriate gradually accumulated during elutriate recycle in the plant's solids handling system. Although the addition of $FeCl_3$ in elutriation during the last portion of the A21-M test increased the solids capture of the digested solids and may have eventually stablized the plant, polymer addition in the primaries, including A21-M, did not prevent the accumulation of solids in the solids handling system. As in the past, these accumulating solids would have forced the discharge of the elutriate into the Potomac River.

In summary, while an appropriately applied polymer significantly improved primary sedimentation in the District of Columbia Plant, the improved primary sedimentation did not reduce solids discharge in the secondary effluent, only modestly decreased (13%) BOD discharge, and did not permit recycle of the elutriate to the plant influent. Since the test of each polymer was not long enough to achieve plant equilibrium, it is still undetermined whether efficient polymer flocculation of solids in primary sedimentation at the District may produce overall plant improvement if independent chemical treatment in elutriation is first developed to eliminate accumulation of solids in the elutriate.

REFERENCES

1. City of Cleveland, Ohio, "The Use of Organic Polyelectrolyte for Operational Improvement of Waste Treatment Processes." FWPCA Grant No. WPRD 102-01-68, May 1969.

2. Gales, M. E., Julian, E. C., and Kroner, R.C., "Methods for Quantitative Determination of Total Phosphorus in Water", JAWWA 58, 1363 (1966).

3. Recommended Standards for Sewage Works, Adopted by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers, May 10, 1960.

4. Standard Methods for the Examination of Water and Wastewater, 12 ed., APHA, AWWA, and WPCF, New York (1965).

5. Van Hall, C. E. Safranco, J., Stenger, V.A., "Rapid Combustion Method for Determination of Organic Substances in Aqueous Solutions", Analytical Chemistry, 35, 315 (1963).

☆ U. S. GOVERNMENT PRINTING OFFICE :1972—484-486/245

1 Accession Number	2 Subject Field & Group	
W	05D	**SELECTED WATER RESOURCES ABSTRACTS** INPUT TRANSACTION FORM

5 Organization

District of Columbia
Department of Sanitary Engineering
Washington, D.C.

6 Title

"FULL SCALE RAW WASTEWATER FLOCCULATION WITH POLYMERS"

10 Author(s)

Freese, Paul V.
Hicks, Edward
Bishop, Dolloff F.
Griggs, Samuel H.

16 Project Designation

17050 EJB

21 Note

22 Citation

23 Descriptors (Starred First)

*Flocculation
*Sedimentation
*Sludge Disposal
*Secondary Treatment
Wastewater Treatment
Filtration
Biochemical Oxygen Demand

25 Identifiers (Starred First)

*Raw Wastewater Flocculation
*Anionic Polymer
*Cationic Polymer
*Suspended Solids
Elutriation

27 Abstract

Three polymers, Dow's anionic A-21 modified with cationic C-31, Hercules' cationic Reten 210, and Calgon's anionic ST 269 with a clay builder, were added to the District of Columbia's raw wastewater in 240 MGD tests of raw wastewater flocculation. The objectives of polymer flocculation of the raw wastewater were to increase solid capture in the primary tanks, reduce the BOD load to aeration, and permit recycle of the elutriate to the plant's influent.

A-21 increased the amounts of raw and thickener overflow solids captured within the primary basins by 25%. With recycle of the solids in the elutriate, the amount of captured solids increased by 50%, compared to elutriate recycled without polymer treatment. ST 269 did not increase the capture of the raw and thickener overflow solids. Later, with reduced ST 269 dosage and recycled elutriate, the solids captured increased by 40% compared to the elutriate recycle without polymer treatment. Reten 210 increased amounts of the captured solids (by 19%) only when the elutriate solids were recycled.

Polymer treatment of raw wastewater did not improve the solids capture in elutriation or permit continuous elutriate recycle.

The best polymer treatment in the primary basins increased the plant BOD removal from 74% to 78%. (Bishop-FWQA)

Abstractor	Institution
Dolloff F. Bishop	Federal Water Quality Administration

SEND, WITH COPY OF DOCUMENT, TO: WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

★ GPO: 1970-389-930