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EFFECT OF PRETREATMENT ON THE FILTRATION OF LOW TURBIDITY SECONDARY EFFLUENT

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and for minimizing the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Removal of residual suspended solids after biological treatment is one of the proven procedures for upgrading wastewater treatment plant performance. This report details studies on filtration of secondary effluent after either conventional coagulation flocculation sedimentation or in-line coagulation.

Francis T. Mayo, Director
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ABSTRACT

A 17-month pilot plant study dealing with inert media filtration of an activated sludge plant effluent was conducted at Pomona, California, under the auspices of the U.S. Environmental Protection Agency and the Los Angeles County Sanitation Districts. The pilot plant consisted of two pressure filters operated at surface loading rates of 3.4 $l/sec/m^2$ (5 gpm/ft^2) and 6.8 $l/sec/m^2$ (10 gpm/ft^2). During the study, two types of filter media configurations were evaluated; namely, a specially designed dual-media filter and a Neptune Microfloc, Inc., mixed-media filter. Two types of filter pretreatment schemes were evaluated. The first scheme was a conventional chemical coagulation-sedimentation system and the second scheme was an in-line coagulation system. In both pretreatment schemes, alum and polymer were used.

The primary objectives of the study were to evaluate the relative effectiveness of the two types of pretreatment schemes on the performance of multimedia pressure filters in the removal of turbidity, suspended solids, and other associated pollutants from an activated sludge plant effluent.

The comparative evaluation of the dual-media and the mixed-media pressure filters showed that the turbidity removal performance was essentially the same in both types of filters. The headloss levels across the mixed-media filter, however, were consistently higher than those observed in the dual media filter.

The study demonstrated that for a low turbidity secondary effluent, an in-line coagulation pretreatment is feasible and results in significantly lower overall capital and operating costs than that of a conventional chemical coagulation-sedimentation pretreatment system. Moreover, it was observed from a limited filtration data that without chemical addition, the resulting filter effluent turbidity levels were comparable to those obtained in filters with an inline coagulation pretreatment system operated at optimum doses of alum and polymer. The lengths of filter run with an in-line coagulation pretreatment were consistently shorter than those observed without chemical addition or with a chemical coagulation-sedimentation pretreatment. It should be pointed out, however, that the effluent discharge requirements of California mandates the addition of chemical prior to filtration. This, therefore, precludes the operation of the filters without some semblance of chemical pretreatment.

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ACKNOWLEDGMENTS

This project was undertaken through a cooperative effort of the U.S. Environmental Protection Agency and the Los Angeles County Sanitation Districts. The pilot plant evaluation was conducted at the Sanitation Districts' Advanced Waste Treatment Research Facility in Pomona, California.

The untiring efforts and assistance of both the Laboratory and the pilot plant operating personnel of the Pomona Advanced Waste Treatment Research Facility are gratefully acknowledged.

SECTION 1

INTRODUCTION

In recent years there has been a growing interest in wastewater filtration largely because of the need to meet the increasingly more stringent effluent discharge standards. For instance, some effluent discharge standards now require limit not only on coliforms but also on viruses (1,2). It is generally recognized, however, that in order to achieve an effective bacterial and/or viral kill, the wastewater effluent stream must be essentially free of suspended matter prior to the terminal disinfection step. Therefore, some form of filtration must follow the secondary treatment process. Moreover, the filtration step is usually preceded by a suitable pretreatment in order to bring about more effective suspended solids removal.

Although there are a number of filtration processes possible, the inert media filtration process was evaluated in the current study. In the course of the pilot plant study, two types of inert media filter configurations were evaluated; namely, a specially designed dual-media filter and a mixed-media filter specified by Neptune-Microfloc, Inc. Two types of filter pretreatment schemes were evaluated. The first scheme (Scheme A) was a conventional chemical coagulation-sedimentation system and the second scheme (Scheme B for non-nitrified effluent feedwater and Scheme C for nitrified effluent feedwater) was the direct chemical injection of polymer or alum and polymer. The latter pretreatment scheme is referred to in this report as in-line coagulation. In addition, some runs with plain filtration were conducted.

The data presented in this report cover the results of seventeen months of pilot plant study. The pilot plant study, which was a joint undertaking by the Los Angeles County Sanitation Districts and the Environmental Protection Agency, was conducted at the Districts' Advanced Waste Treatment Research Facility in Pomona, California.

The primary objective of the study was to evaluate the relative effectiveness of two different pretreatment schemes; namely, in-line coagulation and chemical coagulation-sedimentation on the performance of multi-media pressure filters in the removal of turbidity, suspended solids, and other associated pollutants from an activated sludge plant effluent. In this study, turbidity removal and headloss were used as the principal parameters for evaluating the filter performance.

SECTION 2

CONCLUSIONS

1. For low-turbidity secondary effluent, such as that obtained in Pomona, an in-line coagulation pretreatment is feasible and results in significantly lower overall capital and operating costs than that of a conventional chemical coagulation-sedimentation pretreatment system. With an in-line coagulation pretreatment, however, it is very important to provide the necessary instrumentation to automatically adjust the chemical dosage in response to the diurnal flow variations as the filter performance was very sensitive to alum dose.

2. From limited filtration data, it was observed that without chemical addition, filter performance was essentially the same at filtration rates of 3.4 $l/sec/m^2$ (5 gpm/ft^2) and 6.8 $l/sec/m^2$ (10 gpm/ft^2). Moreover, the observed filter effluent turbidity levels were comparable to those obtained in filters with an in-line coagulation pretreatment system using the optimum dose of alum and polymer.

3. With both in-line coagulation and chemical coagulation-sedimentation pretreatments, the headloss levels through the filters were higher at higher concentration of polymer filter aid. This observation suggests that while the use of polymer filter aid is desirable in enhancing the attachment of solids on the media surface thereby precluding premature solids breakthrough, higher levels of polymers could cause rapid headloss buildup across the filter.

4. Of the two filter backwash auxiliaries evaluated, surface wash and air scour, the latter proved to be more effective in cleaning the filter bed.

5. The results of the comparative evaluation of the dual-media and mixed-media filters showed that the turbidity removal performance was essentially the same in both types of inert media filters. The headloss levels through the mixed-media filters, however, were consistently higher than those observed in the dual-media filter.

6. During the long-term filter evaluation, the chemical coagulation system (Scheme A) was operated at an alum dose of 150 mg/l and an anionic polymer dose of 0.2 mg/l. At this dosage in the pretreatment system, the average removal efficiency through the filter was 90.6 percent for suspected solids and 83.3 percent for turbidity. This corresponds to an average filter effluent suspended solids and turbidity of 1.3 mg/l and 0.7 FTU, respectively.

Total phosphate was reduced about 89 percent, resulting in a filter effluent with total phosphate concentration of 0.9 mg/l. Total COD and color were reduced 48 percent and 38 percent, respectively.

7. The optimum chemical dosage in the in-line coagulation pretreatment system (Schemes B and C) was 5.5 mg/l alum and 0.06 mg/l anionic polymer. At this dosage, the filter removed 80 percent of the suspended solids and turbidity, resulting in a filter effluent with an average suspended solids of 2.7 mg/l and turbidity of 1.2 FTU.

8. The estimated total treatment cost for a 37,850 cu m/day (10 mgd) dual-media filtration system is 4.02¢/cu m (15.07¢/1000 gallons) with coagulation-sedimentation pretreatment and 2.19¢/cu m (8.2¢/1000 gallons) with an in-line coagulation pretreatment. Therefore, from economic and operation point of view, filtration with an in-line coagulation pretreatment system is the choice particularly for secondary effluents with low but objectionable concentrations of colloidal and suspended materials.

SECTION 3

RECOMMENDATIONS

1. In the filtration of secondary effluents with low but objectionable concentrations of colloidal and suspended particles, in-line coagulation pretreatment should be considered thereby permitting an appreciable reduction in operating costs. While this pretreatment process is expected to permit the filters to achieve the desired effluent quality objective, it is imperative to have the necessary instrumentation to provide feedback control of the required chemicals.

2. Batch coagulation tests (laboratory jar tests) may be used for the preliminary screening of chemicals for filter pretreatment, especially in the filtration of secondary effluents with relatively high levels of suspended solids. For secondary effluents with low levels of suspended solids, however, optimum chemical dosage is rather difficult to obtain by jar tests. Consequently, the final selection of the type and dosage of the pretreatment chemicals should be obtained from pilot filtration experiments.

3. Additional work on plain filtration should be conducted.

SECTION 4

EXPERIMENTAL PROGRAM

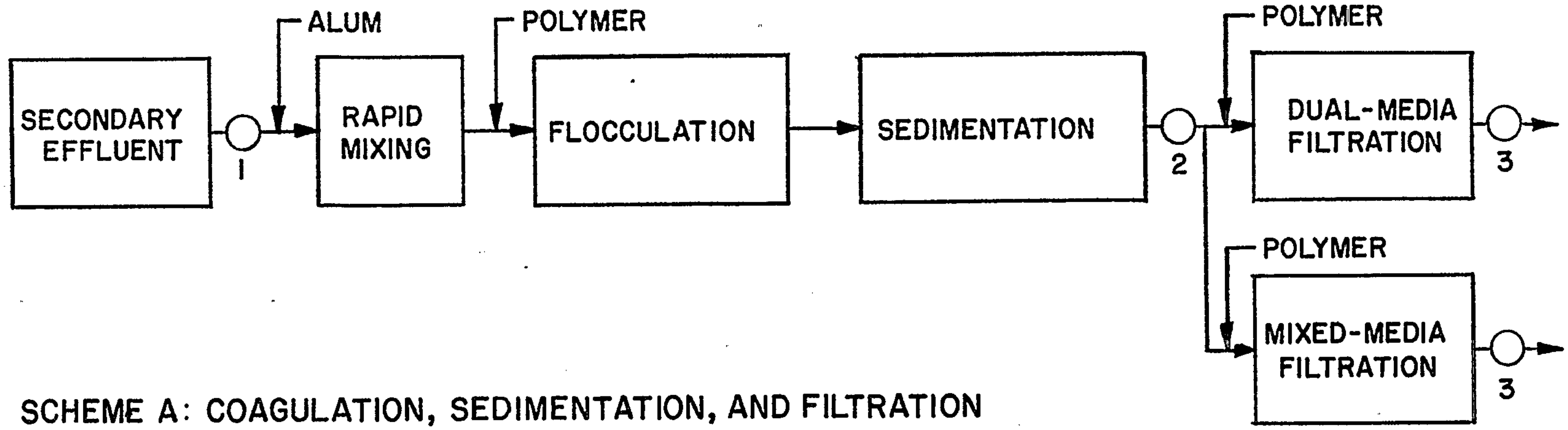
PILOT PLANT DESCRIPTION AND OPERATION

Filter Pretreatment Schemes

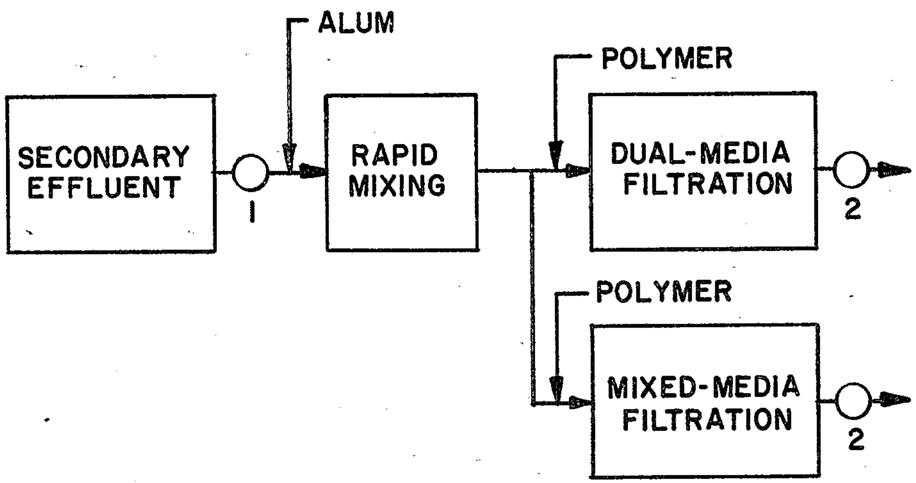
In Figure 1 are presented the schematic flow diagrams of the two types of pretreatment schemes evaluated. The first type, shown as Scheme A, is a conventional chemical coagulation-sedimentation system. The system consisted of a rapid mixing unit 0.76 m square (2.5 ft square) with 1.07 m (3.5 ft) liquid depth followed by a three-compartment flocculation unit 1.37 m (4.5 ft) wide and 4.11 m (13.5 ft) long with 1.67 m (5.5 ft) liquid depth. The flocculation unit was equipped with three variable speed paddle-type flocculators. The secondary effluent was pumped at a constant rate of 3.47 l/sec (55 gpm) to the rapid mixing chamber where alum was added. After 3 minutes of rapid mixing at 140 rpm, the coagulated secondary effluent flowed into the flocculation unit where slow stirring for about 45 minutes was provided. An anionic polymer (Calgon WT-3000) at an average dosage of 0.2 mg/l was added as a coagulant aid to the first compartment of the flocculation unit.

The flocculated secondary effluent flowed into a rectangular clarifier where it was settled for about 92 minutes. At the flow rate of 3.47 l/sec (55 gpm), the clarifier overflow rate and weir rate were 44 cu m/day/m^2 (1080 gpd/ft^2) and 1.91 l/sec/m (9.2 gpm/ft), respectively. The clarified effluent discharged into a 1.9 cu m (500 gallon) surge tank from which 3.16 l/sec (50 gpm) was pumped to the inert media pressure filters. The excess clarified effluent flow was diverted to waste. The chemical sludge was withdrawn intermittently from the clarifier sludge hopper by means of a timer-controlled sludge pump.

The second type of filter pretreatment is shown as Scheme B or C in Figure 1. Scheme B used feedwater from a conventional activated sludge plant while Scheme C used feedwater from a two-stage nitrification system. Schemes A and B used the same type of feedwater. For both Schemes B and C, a cylindrical mixing tank 0.61 m (2 ft) diameter and 1.22 m (4 ft) high was installed ahead of the filters. The mixing tank was provided with a variable-speed propeller mixer. Alum was injected into the secondary effluent line feeding the mixing tank. After 1.5 minutes rapid mixing the alum-coagulated secondary effluent was pumped to the filters. An anionic polymer filter aid (either Calgon WT-3000 or WT-2700) was injected into the influent line of each



SCHEME A: COAGULATION, SEDIMENTATION, AND FILTRATION



SCHEME B or C : IN-LINE COAGULATION AND FILTRATION

○ SAMPLING POINT

Figure I : Schematic flow diagrams for filter pretreatment schemes filter. This second pretreatment scheme was selected to determine the possibility of replacing the conventional coagulation-sedimentation system with a much simpler in-line coagulation system, which if successful, could provide some savings both in capital investment and in operating costs.

Filtration System

The pilot plant filtration study was carried out using two identical 76.2 cm (30 in.) diameter pressure filters shown in detail in Figures 2 and 3. Each filter was provided with an automatic control panel with the capability to perform four separate operating sequences; namely, filtration, surface wash, air scour, and water backwash. The duration of each operating step was field-adjustable in the range of 0 to 30 hours for filtration and 0 to 30 minutes each for surface wash, air scour, and water backwash. The backwash sequence was triggered either by a predetermined headloss level or duration of filter run. During the entire period of filter evaluation, the filters were operated in such a way as to automatically backwash every 24 to 30 hours of filter run or whenever a 1.41 Kg/cm^2 (20 psi) pressure drop was attained. Two filter bed cleaning procedures were evaluated. In the first two months of the study, the surface wash-waster backwash procedure was used. The backwash sequence consisted of a surface wash at the rate of 1.7 $l/sec/m^2$ (2.5 gpm/ft^2) for 3 minutes followed by a water backwash of 13.6 $l/sec/m^2$ (20 gpm/ft^2) for five minutes. From the second through the fourth month of the study, both surface wash and air-assisted backwash procedures were evaluated. Thereafter, the air scour-water backwash procedure was used. In the air-assisted backwash, the filter backwash sequence consisted of an air scour at the rate of 20.3 $l/sec/m^2$ (4 $scfm/ft^2$) for three minutes followed by a water backwash of 13.6 $l/sec/m^2$ (20 gpm/ft^2 for 5 minutes.

In the course of the filter run, the influent and effluent turbidities were continuously monitored using in-line turbidimeters (Hach Model 1720 Low Range Turbidimeter) each equipped with a Rustrak recorder.

In Figure 2 is shown the pressure filter detail with dual-media configuration. The filter media consisted of 61 cm (24 in.) of anthracite coal (effective size of 1.1 mm and uniformity coefficient of 1.37) over 30.5 cm (12 in.) of silica sand (effective size of 0.57 mm and uniformity coefficient of 1.2). The filter media were supported by a 50.8 cm (20 in.) layer of graded gravel. In the design of the media, size range was restricted, as indicated by the low uniformity coefficient, in an effort to provide as uniform a size as possible. The literature on filtration indicate that more uniform media size not only reduces the backwash water flow rate required to fluidize the coarser bottom layers of each component of the filter media, but also may have some beneficial effect on the filter performance. The media cost, however, will be increased by the size restriction specified.

The mixed-media filter, shown in detail in Figure 3, used a configuration specified by Neptune-Microfloc, Inc. The media consisted of 57.2 cm

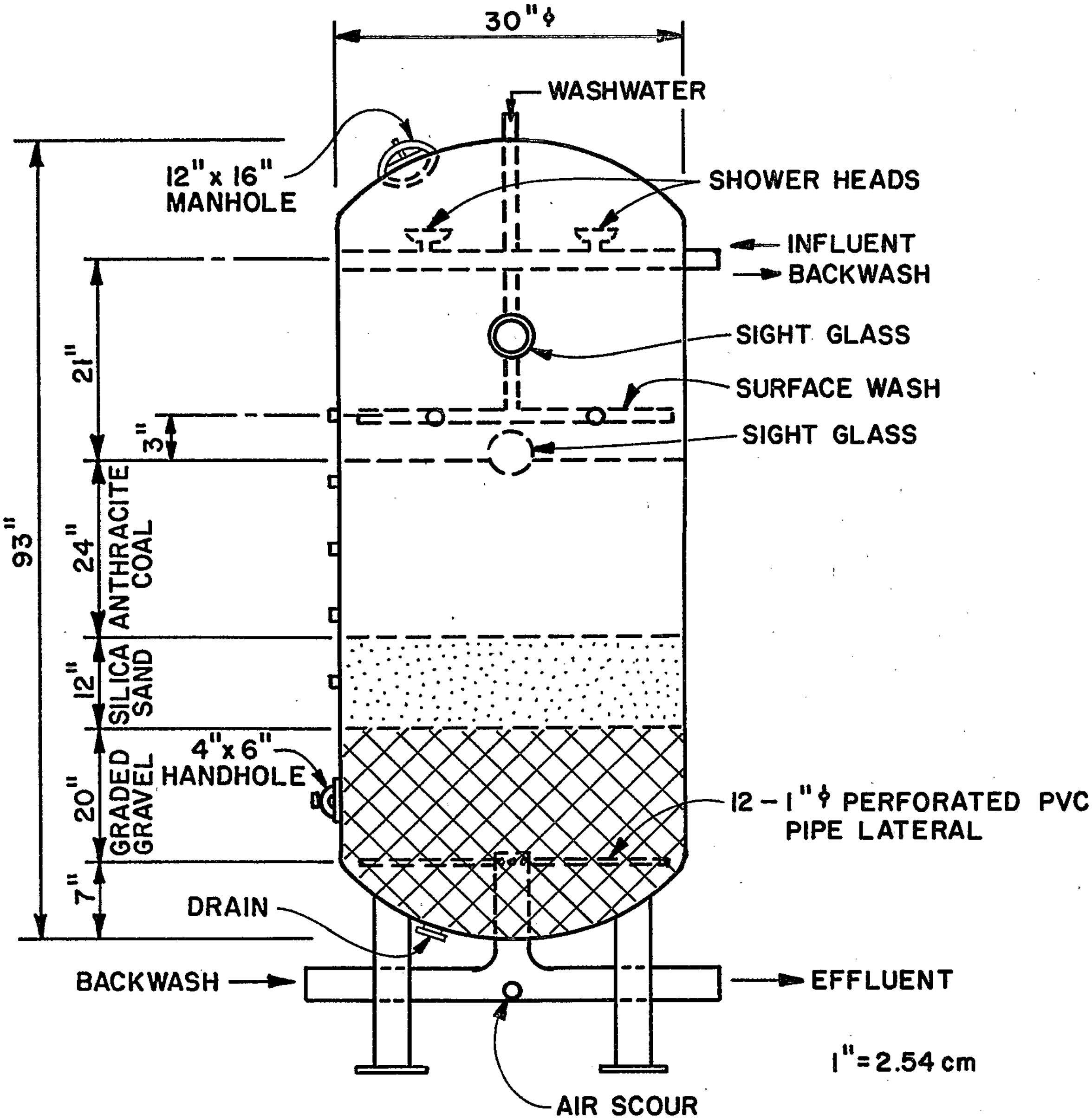


Figure 2. Pressure filter detail with dual-media.

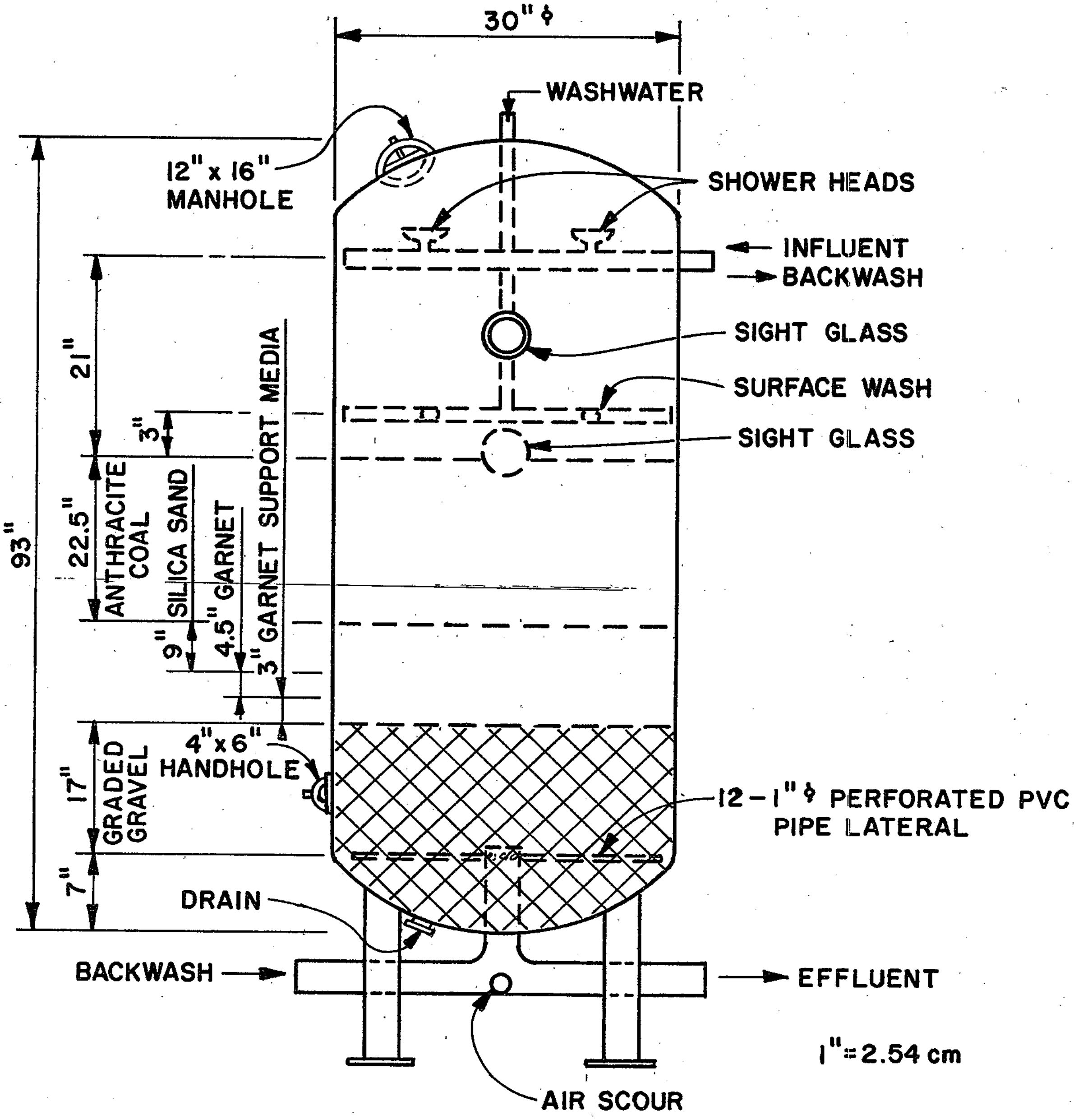


Figure 3. Pressure filter detail with mixed-media.

(22.5 in.) of anthracite coal over 22.9 cm (9 in.) of silica sand and 11.4 cm (4.5 in.) of garnet sand. The filter media were supported by a 7.6 cm (3 in.) layer of coarse garnet sand support media and 43.2 cm (17 in.) layer of graded gravel. The filter media specifications for both dual-media and mixed-media filters are presented in Table 1.

SAMPLING AND TESTING PROGRAM

In this study, refrigerated 24-hour composite samples of influent and effluent from each treatment unit of Schemes A, B, and C were automatically collected five days a week using timer-controlled solenoid valves. Starting from the 9th month of the study, 16-hour composite samples were collected instead of 24-hour composites. This change in sampling duration was necessary in order to meet the sampling schedule of another project dealing with virus removal.

The composite samples were analyzed daily for suspended solids, turbidity, color, and two to three times a week for total chemical oxygen demand (TCOD), dissolved chemical oxygen demand (DCOD), total aluminum, and total phosphate. The samples were also analyzed periodically for total dissolved solids (TDS) and alkalinity. Tests for pH and temperature were performed two to three times a week on grab samples.

Analytical Methods

All physical and chemical analyses were performed in accordance with the 13th edition of Standard Methods (3) or the FWPCA Methods for Chemical Analysis (4) unless otherwise specified. Turbidity tests for composite samples were conducted using a Hach Model 2100 Turbidimeter.

TABLE 1. FILTER MEDIA SPECIFICATIONS

Media	Dual-Media*			Mixed-Media+		
Composition	Depth, cm	Effective Size, mm	Efficient Coefficient	Depth, cm	Effective Size, mm	Uniformity Coefficient
Anthracite Coal	61.0	1.10	1.37	57.2	1.00	1.62
Sand	30.5	0.57	1.20	22.9	0.43	1.46
Garnet				11.4	0.33	1.49
Total Media Depth	91.5			91.5		

* Specially prepared by Pomona Research Facility
+ Supplied by Neptune-Microfloc, Inc.

SECTION 5

DISCUSSION OF EXPERIMENTAL RESULTS

For convenience in the discussion of experimental results, the pilot plant evaluation is divided into three phases. In the first phase of the study, which covered about four months, the two dual-media filters were operated at flow rates of 3.4 and 6.8 $l/sec/m^2$ (5 and 10 gpm/ft^2) with or without chemical addition. During this phase of the study, two filter bed cleaning procedures; namely, surface wash-water backwash and air scour-water backwash, were evaluated. The second phase of the study covered approximately four months during which time three experimental test series were conducted. It should be pointed out that each test series consists of several filter runs. The first test series entailed the comparative evaluation of a dual-media filter with two types of pretreatments; namely, a chemical coagulation-sedimentation pretreatment (Scheme A) and an in-line coagulation pretreatment (Scheme B or C). After the completion of the first test series, the mixed-media filter was converted into a dual-media filter. In the second test series the two dual-media filters were operated in parallel with one filter operated with Scheme A pretreatment and the other filter with Scheme B pretreatment. This test series was performed for the purpose of selecting the optimum chemical dosage to be used in subsequent long-term filter evaluation. During the third test series, a number of special short-term filter runs were conducted using Scheme B pretreatment at various levels of polymers alone and in combination with high levels of alum. The third and final phase of the filtration study dealt with the long-term evaluation of the effect of type of pretreatment on the dual-media filter performance. In this phase of the study, the filter pretreatment systems were operated at the optimum chemical dosage obtained in the second phase.

It should be pointed out that during the entire second and third phases of the study, the filters were operated at a filtration rate of 3.41 $l/sec/m^2$ (5 gpm/ft^2) and they were automatically air scoured-water backwashed once every 24 hours or whenever a preset terminal headloss of 1.41 Kg/cm^2 (20 psi) was reached. Moreover, in the course of each filter run, the filter influent and effluent turbidities were continuously monitored using in-line turbidimeters (Hach Model 1720 Low Range Turbidimeter) each equipped with a Rustrak recorder. The turbidity data used in evaluating the performance of the dual-media and the mixed-media filters during the second phase of the study were taken from the turbidity recorders. During the first and third phases, however, the turbidity data used for evaluating the filters were based on the laboratory tests (Hach Model 2100 turbidimeter) of composite samples (24-hour composite for the first phase and 16-hour composite for the third phase) rather than those from the in-line turbidity recorders. This change was made in order to be on the same basis as the test results of other parameters, such as suspended solids, color, chemical oxygen demand (COD), total dissolved solids (TDS), alkalinity, and total phosphate, which were based on composite samples.

PHASE I TEST RESULTS

Test Series I - Effect of Filtration Rate and Chemical Injection on Filter Performance.

During the first test series, four different sets of runs of about one to two weeks duration per set, were conducted. In the first two sets of runs, both dual-media filters were operated without chemical addition, with one filter operated at 6.8 l/sec/m^2 (10 gpm/ft^2) and the other at 3.4 l/sec/m^2 (5 gpm/ft^2). For the third and fourth sets of run, the filters were operated at an identical flow rate of 6.8 l/sec/m^2 (10 gpm/ft^2) with direct injection of 10 mg/l alum. An anionic polymer (Calgon WT-3000) was also fed as a filter aid to the filter influent lines at a dosage of 0.1 mg/l to one filter and 0.2 mg/l to the other.

Throughout the first test series, both dual-media filters were automatically backwashed at the end of a 30-hr filter run or whenever a preset terminal headloss of 1.40 Kg/cm^2 (20 psi) was reached. The filter backwash sequence consisted of three minutes surface wash at 1.7 l/sec/m^2 (2.5 gpm/ft^2) followed by five minutes of water backwash at 13.6 l/sec/m^2 (20 gpm/ft^2).

Table 2 presents a summary of the filter performance during the first test series. In evaluating the data in Table 2, the following observations can be made:

1. Without chemical addition, filter performance was essentially the same at filtration rates of 3.4 l/sec/m^2 (5 gpm/ft^2) and 6.8 l/sec/m^2 (10 gpm/ft^2).

2. At filtration rate of 6.8 l/sec/m^2 (10 gpm/ft^2) with direct chemical injection of 10 mg/l alum, the filter performance with polymer dosage at 0.1 mg/l was about the same as that with polymer dosage at 0.2 mg/l.

3. Based on filter effluent quality and filter run length, the filter performance with plain filtration (no chemicals) was markedly better than that with direct chemical injection of alum and polymer. Moreover, headloss levels were lower with terminal headloss of 1.4 Kg/sq cm not reached even after 30 hours filter run. This observation was anticipated because of the low levels of turbidity and suspended solids in the filter feedwater. It must be pointed out, however, that changes in the concentration and/or characteristics of the filter influent could bring about a significant change in the filter performance.

TABLE 2. DUAL-MEDIA FILTER PERFORMANCE WITH DIRECT CHEMICAL INJECTION*

Run No.	Chemical Dosage mg/l Alum	Chemical Dosage mg/l Polymer+	Filtration Rate (l/sec/m²)	Water Quality Parameters ++	Filter Influent	Filter Effluent	Removal (%)	Filter Run,§ (hrs.) Range / Avg.
1	0	0	3.4	pH				30 (30)
				Temperature, °C	25.0			
				Color, units	34.6	35.4		
				Turbidity, FTU	4.1	0.4	90.2	
				Susp. Solids, mg/l	4.3	0.8	81.4	
				Total COD, mg/l	37.8	32.7	13.5	
N=3				Diss. COD, mg/l	28.7	28.7	0.0	
2	0	0	6.8	pH	7.2	7.2		30 (30)
				Temperature, °C	24.7			
				Color, units	31.7	31.9		
				Turbidity, FTU	3.0	0.5	83.3	
				Susp. Solids, mg/l	2.6	0.3	88.5	
				Total COD, mg/l	32.9	29.8	9.4	
N=5-8				Diss. COD, mg/l	27.5	27.1	1.5	
3	10	0.10	6.8	pH	7.2	7.3		13-19 (14.9)
				Temperature, °C	28.0			
				Color, units	35.9	33.0	8.1	
				Turbidity, FTU	2.3	1.6	30.4	
				Susp. Solids, mg/l	4.5	3.1	31.1	
				Total COD, mg/l	37.9	33.7	11.1	
N=3				Diss. COD, mg/l	30.2	27.9	7.6	
4	10	0.20	6.8	pH	7.3	7.3		12-18 (14.9)
				Temperature, °C	28.0			
				Color, units	35.5	32.6	8.2	
				Turbidity, FTU	3.1	1.7	45.2	
				Susp. Solids, mg/l	4.9	3.0	38.8	
				Total COD, mg/l	37.6	34.8	7.4	
N=4				Diss. COD, mg/l	30.7	28.0	8.8	

* Without static mixer or rapid mixer   + Anionic polymer (Calgon WT-3000).

++ Based on 24-hour composite samples; N=No. of observations averaged; All filter influent samples were taken upstream of chemical injection point.   § At terminal headloss of 1.4 Kg/sq cm. Backwash sequence consisted of 3 min. surface wash at 1.7 l/sec/m² followed by 5 min. backwash @ 13.6 l/sec/m².

Test Series II - Effect of Type of Backwash Auxiliary on Filter Performance

During the second test series, which covered approximately six weeks, the filters were operated at an identical filtration rate of 6.8 $l/sec/m^2$ (10 gpm/ft^2). Both filters were operated with direct injection of alum at a dosage of 5 and 10 mg/l. An anionic polymer (Calgon WT-3000) was also injected directly into the filter influent lines at three levels of concentrations; namely, 0, 0.1, and 0.2 mg/l.

As in the first test series, the filters were automatically backwashed every 30 hours of filter run or whenever a preset terminal headloss of 1.4 Kg/cm^2 (20 psi) was reached. In an effort to determine the effect of backwashing procedure on headloss development and filter effluent quality, two filter bed cleaning procedures were evaluated. These two bed cleaning procedures were surface wash-water backwash and air scour-water backwash.

Table 3 presents a summary of the average performance of the filters in terms of the removal of turbidity, suspended solids, COD and color. The range and average lengths of filter run are also included in Table 3. The data show that in general the filter effluent quality parameters for the various experimental runs were about the same level when alum at 5 mg/l was used in combination with polymer at dosages of 0.1 and 0.2 mg/l. The filter effluent quality, however, was poor when alum alone at a dosage of 9.7 mg/l was used for filter pretreatment. The data in Table 3 further show that at 5 mg/l alum and polymer at either 0.1 or 0.2 mg/l, the average filter run length with air scour-water backwash procedure was longer compared to that with surface wash-water backwash procedure. Moreover, in comparing run No. 1 with run No. 3 and run No. 2 with run No. 4, it is apparent that at an alum dose of 5 mg/l, the filter run length with polymer at 0.1 mg/l was about three times longer than that observed with polymer at 0.2 mg/l. It is also apparent in comparing runs No. 1, 3, and 6 that at alum dose of 5.2-5.3 mg/l, the average filter run length with no polymer filter aid was longer than those with polymer addition. Additional filtration data which are not included in Table 3 indicate that at an alum dose of 5 mg/l, the filter effluent quality with polymer at 0.02 mg/l was about the same as that observed with polymer at 0.2 mg/l. The average filter run length, however, was longer at the lower polymer dose.

Figure 4 presents the effect of chemical dosage and type of filter bed cleaning procedure on the headloss buildup through the dual-media filters. Each test run shown in the figure covered a period of one week. The data show that for all test runs evaluated, headlosses across the filters with surface wash auxiliary were higher than those observed with an air scour auxiliary. These results were in accord with the findings of other investigators (5,6). Thus, it was decided to use the air scour-water backwash procedure in all subsequent filtration runs starting from the fourth month of the pilot plant study.

In Figure 5 are presented the effect of alum and polymer additions on the headloss buildup across the filter. The figure shows that with 5 mg/l alum, the headloss levels were generally higher with higher concentrations of

TABLE 3. EFFECT OF CHEMICAL INJECTION AND BACKWASH ON DUAL-MEDIA FILTER PERFORMANCE*

Run No.	Dosage, mg/l Alum	Dosage, mg/l Polymer+	Backwash$^{\Phi}$ Sequence	Water Quality Parameters §	Filter Influent	Filter Effluent	Removal (%)	Filter Run,# (hrs.) Range (Avg.)
				pH	7.0	7.0		
				Temperature, °C	27.4			
			Air	Color, units	29.8	28.0	6.0	11-27
1	5.3	0.1		Turbidity, FTU	3.3	0.6	81.8	(19.2)
			Scour	Susp. Solids, mg/l	7.5	2.8	62.7	
				Total COD, mg/l	32.9	27.9	15.2	
N=5-6				Diss. COD, mg/l	26.2	25.5	2.7	
				pH	7.3	7.2		
				Temperature, °C	28.9			
				Color, units	33.0	31.2	5.5	9-18
2	5.8	0.1	Surface	Turbidity, FTU	3.2	1.0	68.8	(14)
				Susp. Solids, mg/l	9.1	4.8	47.3	
			Wash	Total COD, mg/l	37.2	33.3	10.5	
N=4-5				Diss. COD, mg/l	29.1	28.6	1.7	
				pH	7.1	7.1		
				Temperature, °C	27.3			
				Color, units	29.6	28.6	3.4	4.5-8
3	5.2	0.2	Air	Turbidity, FTU	1.7	0.5	70.6	(6)
				Susp. Solids, mg/l	4.4	2.0	54.5	
			Scour	Total COD, mg/l	32.2	29.6	8.1	
N=5-6				Diss. COD, mg/l	26.9	27.2	--	
				PH	7.2	7.2		
				Temperature, °C	27.9			
				Color, units	33.7	31.7	5.9	4.5-6
4	5	0.2	Surface	Turbidity, FTU	3.7	0.6	83.8	(5.3)
				Susp. Solids, mg/l	13.1	3.2	75.6	
			Wash	Total COD, mg/l	42.1	33.3	20.9	
N=5				Diss. COD, mg/l	30.1	29.3	2.7	

TABLE 3. (CONTINUED)

Run No.	Dosage, mg/l Alum	Polymer+	Backwash$^{\Phi}$ Sequence	Water Quality Parameters §	Filter Influent	Filter Effluent	Removal (%)	Filter Run,# (hrs) Range (Avg.)
				pH	7	6.9		
				Temperature, ^{o}C	26			
			Air	Color, units	29.5	26	11.9	8-30
5	9.7	0		Turbidity, FTU	2.0	2.0	0	(19.5)
			Scour	Susp. Solids, mg/l	4.1	4.5		
				Total COD, mg/l	28.0	27.3	2.6	
N=4-5				Diss. COD, mg/l	23.9	22.7	5.0	
				pH	7.0	6.9		
				Temperature, ^{o}C	26.3			
			Air	Color, units	29.6	27.4	7.4	13-30
6	5.2	0		Turbidity, FTU	2.2	1.0	54.5	(22.3)
			Scour	Susp. Solids, mg/l	3.7	2.7	27.0	
				Total COD, mg/l	28.5	25.9	9.1	
N=5				Diss. COD, mg/l	24.0	22.5	6.3	

* Without static mixer or rapid mixer; Filtration rate = 6.8 $l/sec/m^2$.
+ Anionic polymer (Calgon WT-3000).
Φ Backwash sequence consisted of:

Air Scour → 20.3 $l/sec/m^2$ air scour for 3 minutes followed by 13.6 $l/sec/m^2$ water backwash for 5 min.

Surface Wash → 1.7 $l/sec/m^2$ surface wash for 3 minutes followed by 13.6 $l/sec/m^2$ water backwash for 5 min.

§ Based on 24-hour composite samples; N=No. of observations averaged; all filter influent samples were taken upstream of chemical injection plant.

At terminal headloss of 1.4 Kg/cm^2.

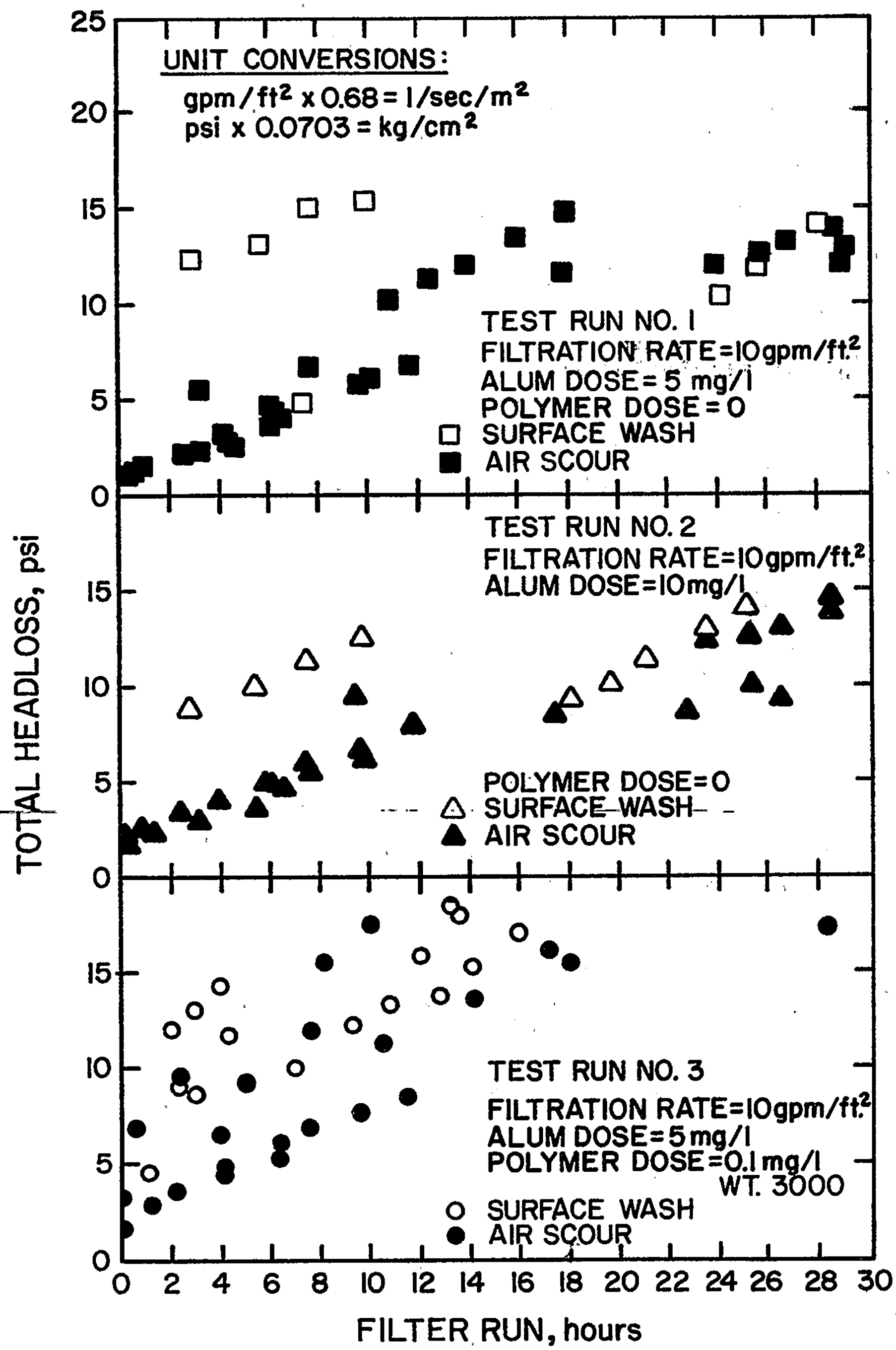


Figure 4. Effect of type of auxiliary backwash on headloss.

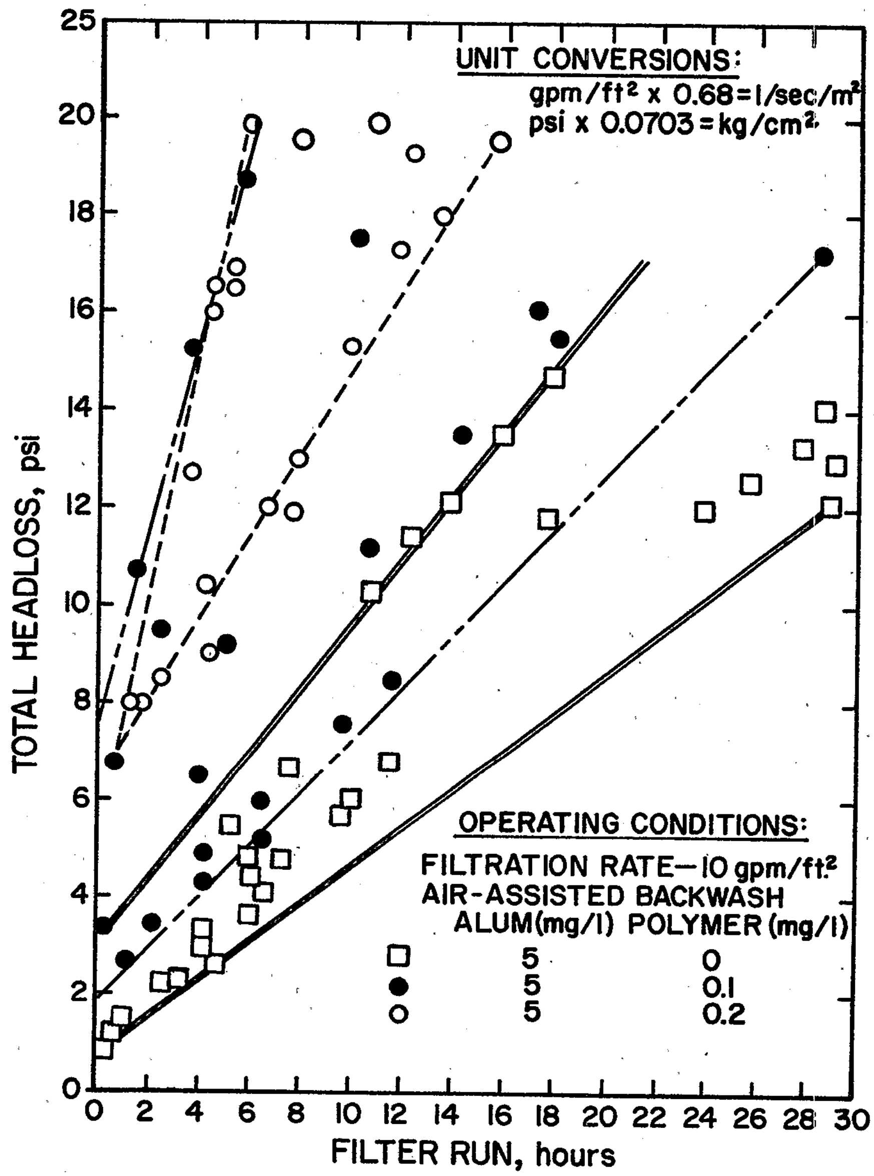


Figure 5. Effect of alum and polymer addition on headloss.

polymer. This is clearly indicated by comparing the headloss obtained at 0.5 mg/l polymer with that obtained without polymer addition. This observation is significant in that while the use of polymer filter aid is desirable in enhancing the attachment of solids on the media surface thereby precluding premature solids breakthrough, higher levels of polymers could cause rapid headloss buildup across the filter. This phenomenon had been observed by a number of investigators (7,8,9,10). Therefore, a judicious choice of polymer type and concentration must be made in an effort to effect relatively long filter runs consistent with the production of a good quality filter effluent.

The headloss data for test runs No. 1 and 2 (with an air scour auxiliary) in Figure 4 is replotted in Figure 6 and compared with data obtained with plain filtration. As indicated in Figure 6, the range of headloss across the filter with 5 mg/l alum was essentially the same as that with 10 mg/l alum. Nevertheless, the data clearly demonstrate the relatively much lower headloss obtained without chemical addition.

It should be pointed out that during the first two months of pilot plant study alum was injected directly into the suction line of the filter feed pump without any other auxiliary pre-mixing. In an effort to provide improved mixing condition a static mixer was installed and used during the last month of Phase I. Starting with the second phase of the study, the static mixer was replaced with a rapid mixer, which was installed ahead of the filter feed pump and this rapid mixing set-up was used in all subsequent experimental runs for Schemes B and C.

The results of selected test runs with the use of static mixer are summarized in Table 4. The data show that there appears to be no significant difference in filter performance with or without the use of static mixer. Nevertheless, in comparing run No. 2 in Table 4 with run No. 5 in Table 3, it is apparent that the average filter run length was longer when a static mixer was used. Direct comparison of the results, however, is limited by the fact that the runs were not conducted in parallel and consequently, factors other than the type of pre-mixing could have caused the difference in the average length of the filter run.

PHASE II TEST RESULTS

Test Series I - Comparison of Dual-Media and Mixed-Media Filter Performance

A. With Scheme A Pretreatment

During the parallel filtration run, the chemical clarification system was operated at a constant flow rate of 3.47 l/sec (55 gpm). Alum was added at two levels of dosages; namely, 55 and 110 mg/l, with 0.20 mg/l of anionic polymer (Calgon WT-3000) added as a coagulant aid. An anionic polymer at a dosage varying from 0 to 0.20 mg/l was injected as a filter aid to the influent line of each filter. Both filters were operated at an identical filtration rate of 3.4 l/sec/m^2 (5 gpm/ft^2).

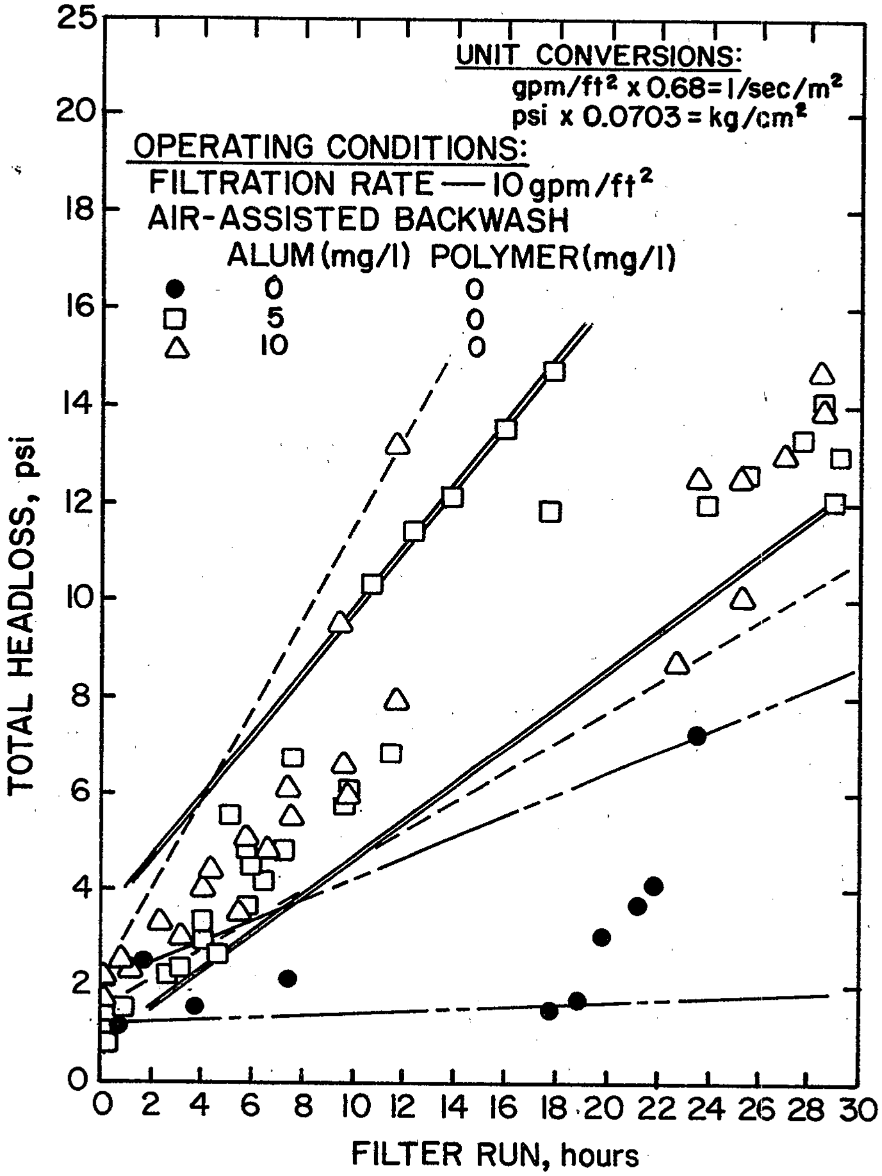


Figure 6. Effect of alum addition on headloss.

TABLE 4. DUAL-MEDIA FILTER PERFORMANCE WITH DIRECT CHEMICAL INJECTION*

Run No.	Chemical Dosage mg/l Alum	Chemical Dosage mg/l Polymer+	Filtration Rate ($l/sec/m^2$)	Water Quality Parameters ++	Filter Influent	Filter Effluent	Removal (%)	Avg. Filter Run § (Hrs.)
				pH	7.1	7.1		
				Temperature, °C	26.0			
				Color, units	31.7	29.8	6.0	27.3
1	10	0.02	6.8	Turbidity, FTU	4.1	3.3	19.5	
				Susp. Solids, mg/l	3.9	5.0	--	
				Total COD, mg/l	28.9	27.1	6.6	
N=9				Diss. COD, mg/l	23.4	21.9	6.4	
				pH	7.07	6.9		
				Temperature, °C	26.3			
				Color, units	28.8	25.9	10.0	29
2	10	0	6.8	Turbidity, FTU	3.3	2.9	12.1	
				Susp. Solids, mg/l	3.9	4.6	--	
				Total COD, mg/l	28.3	24.7	14.2	
N=5				Diss. COD, mg/l	21.4	20.2	5.6	
				pH	7.1	7.1		
				Temperature, °C	23.5			
				Color, units	35.0	32.8	6.3	30
3	0	0.05	3.4	Turbidity, FTU	2.9	0.8	72.4	
				Susp. Solids, FTU	5.3	1.5	71.7	
				Total COD, mg/l	28.7	25.6	10.8	
N=4				Diss. COD, mg/l	24.8	23.4	5.6	
				pH	--	7.2		
				Temperature, °C	21.0			24
				Color, units	33.8	32.0	5.3	
4	8.4	0.05	3.4	Turbidity, FTU	3.0	1.2	60.0	
				Susp. Solids, mg/l	10.3	3.4	67.0	
				Total COD, mg/l	30.0	23.7	21.0	
N=4				Diss. COD, mg/l	22.2	22.8	--	

* With static mixer.

§ At terminal headloss of 1.4 Kg/sq cm. Backwash sequence consisted of 3 minutes air scour at 20.3 $l/sec/m^2$ followed by 5 minutes water backwash at 13.6 $l/sec/m^2$.

\+ Anionic polymer (Calgon WT-3000) for runs 1 & 2; Cationic polymer (Calgon WT-2640) for runs 3 & 4.

++ Based on 24-hour composite samples; N=No. of observations averaged; all filter influent samples were taken upstream of chemical injection point.

Figure 7 presents the results of the parallel filtration runs. The first seven runs represent the data with alum dose of 55 mg/l in the clarification system. In comparing runs No. 1 through 3 with runs No. 4 through 7, it is apparent that the turbidity removals by the filters were essentially the same at polymer filter aid dosages ranging from 0 to 0.2 mg/l. The headlosses, however, at filter aid levels of 0.10 to 0.20 mg/l, were definitely higher than those at 0 to 0.08 mg/l. The effect of polymer filter aid dosages on the headloss buildup is further shown by comparing runs No. 8 through No. 11 and run No. 14 with runs No. 12 and 13. These observations suggest that while polymer filter aids are desirable in strengthening weak chemical floc thus preventing premature solids breakthrough, the polymer filter aid doses must be kept as low as possible to avoid excessive headloss buildup.

In evaluating the performance of the filters as shown by the data in Figure 7, two conclusions could be drawn. First, the turbidity removal performance of the dual-media filter was consistently better than that of mixed-media filter. The data also indicate patterns of improved turbidity removal during the early part of the filter run. Secondly, the headloss buildup through the mixed-media filter was definitely and consistently higher than that observed in the dual-media filter. Moreover, the data show, that with the exception of run No. 1, the headloss buildup through the filter varied linearly with filtration time which is indicative of an in-depth filtration.

B. With Scheme B Pretreatment

In the comparative evaluation of the filters with in-line coagulation pretreatment, the alum solution was added to a rapid mixing unit where mixing for approximately 1.5 minutes was provided. The alum-coagulated secondary effluent was then pumped directly to both multi-media pressure filters at a flow rate to maintain a filtration rate of 3.4 $l/sec/m^2$ (5 gpm/ft^2). An anionic polymer (Calgon WT-2700 or WT-3000) was injected directly into the influent line of each filter. In evaluating the filters, the turbidity removal in the course of the filter run was used as the primary parameter for comparing the filter performance.

The comparative performance of the filters with an in-line coagulation pretreatment using various levels of alum and polymer, is presented in Figure 8. It is apparent from the data that for the secondary effluent being treated, high alum dose definitely caused poor filter effluent quality. The response of the filters with an increase or a decrease in alum dose is clearly shown in the figure. The data show that at zero and low alum doses the turbidity removal performance of the dual-media filter was slightly better than that of the mixed-media filter. Moreover, in the absence of alum, turbidity removal with or without polymer appears to be the same. The results also show that the performance of the filters with direct chemical injection of an anionic polymer WT-2700 was about the same as that obtained with an anionic polymer WT-3000.

In the course of the evaluation, the filters were also operated using a nitrified secondary effluent feedwater (Scheme C) in an effort to determine what effect, if any, different type of feedwater would have on the performance of the filters. Figure 9 presents the performance of the filters with

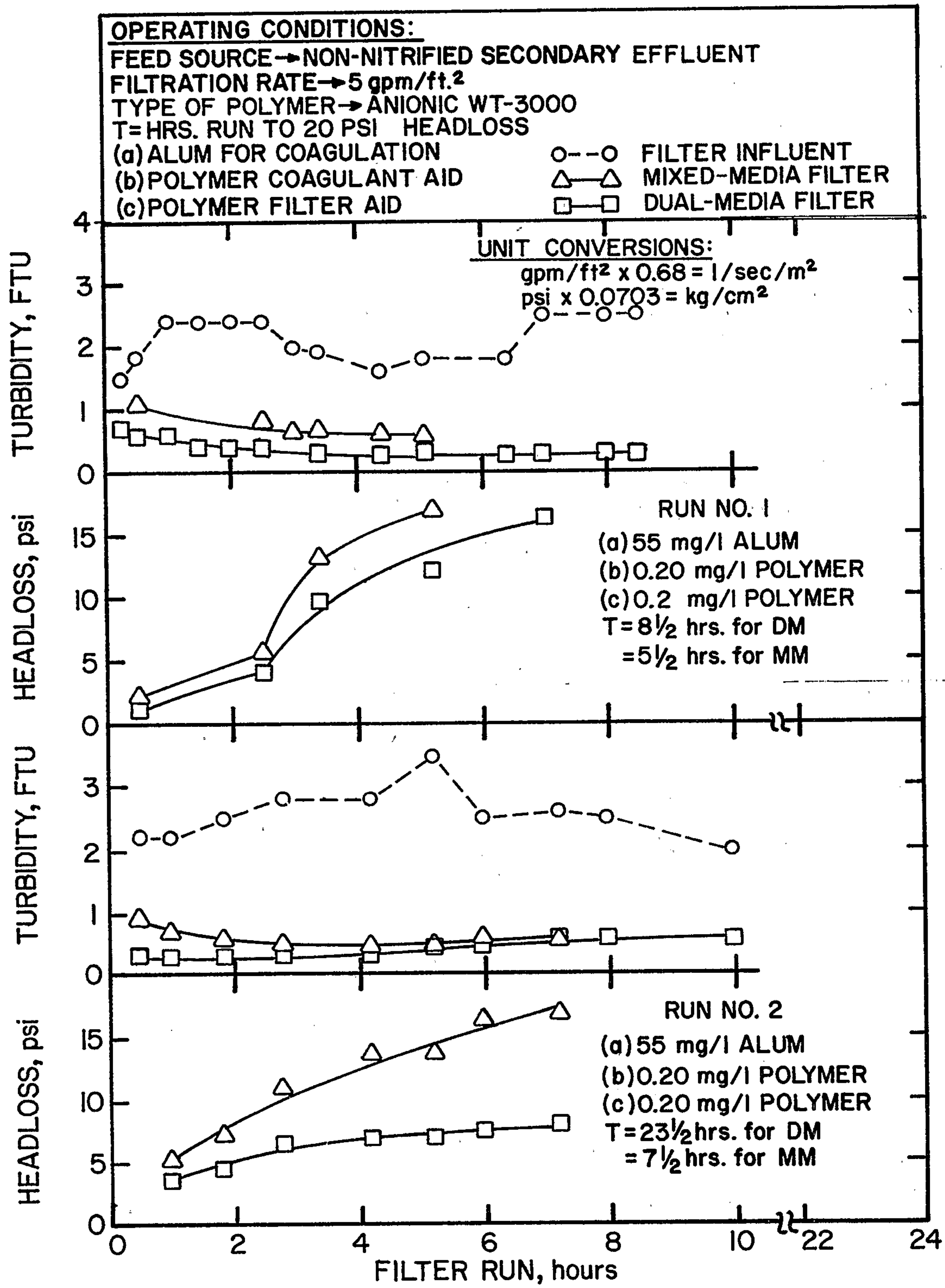


Figure 7. Performance of filters with chemical coagulation-sedimentation pretreatment.

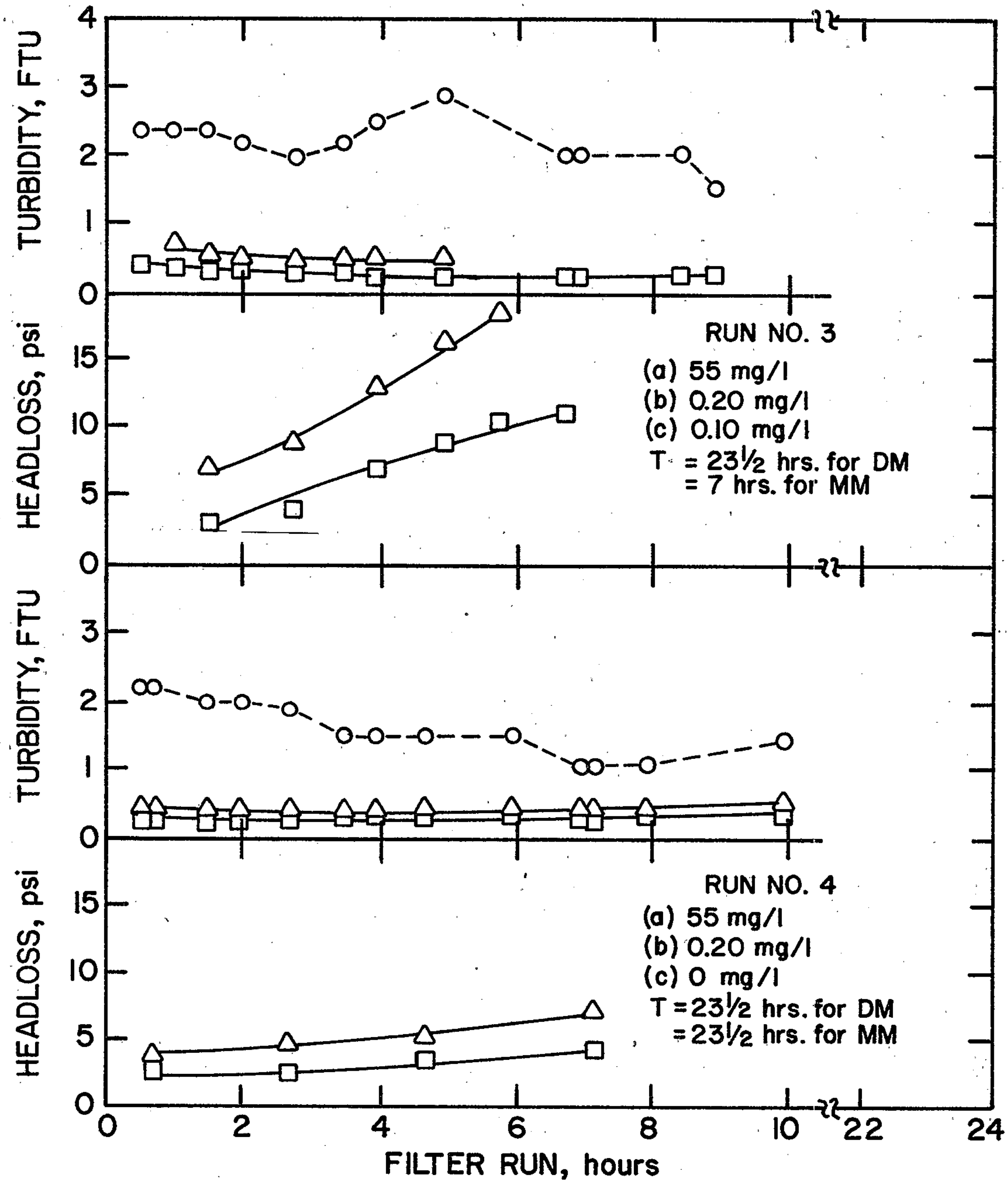


Figure 7. Continued.

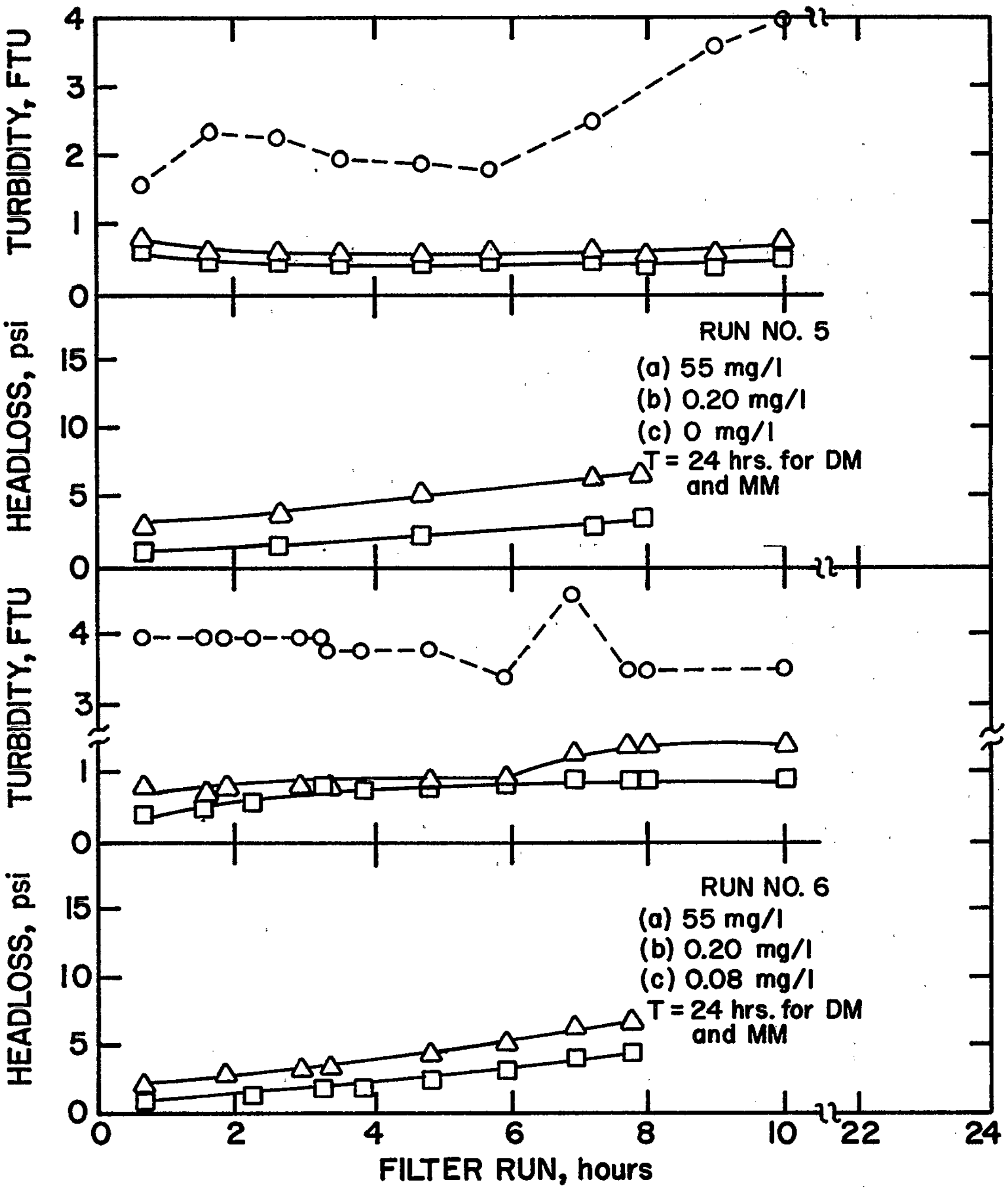
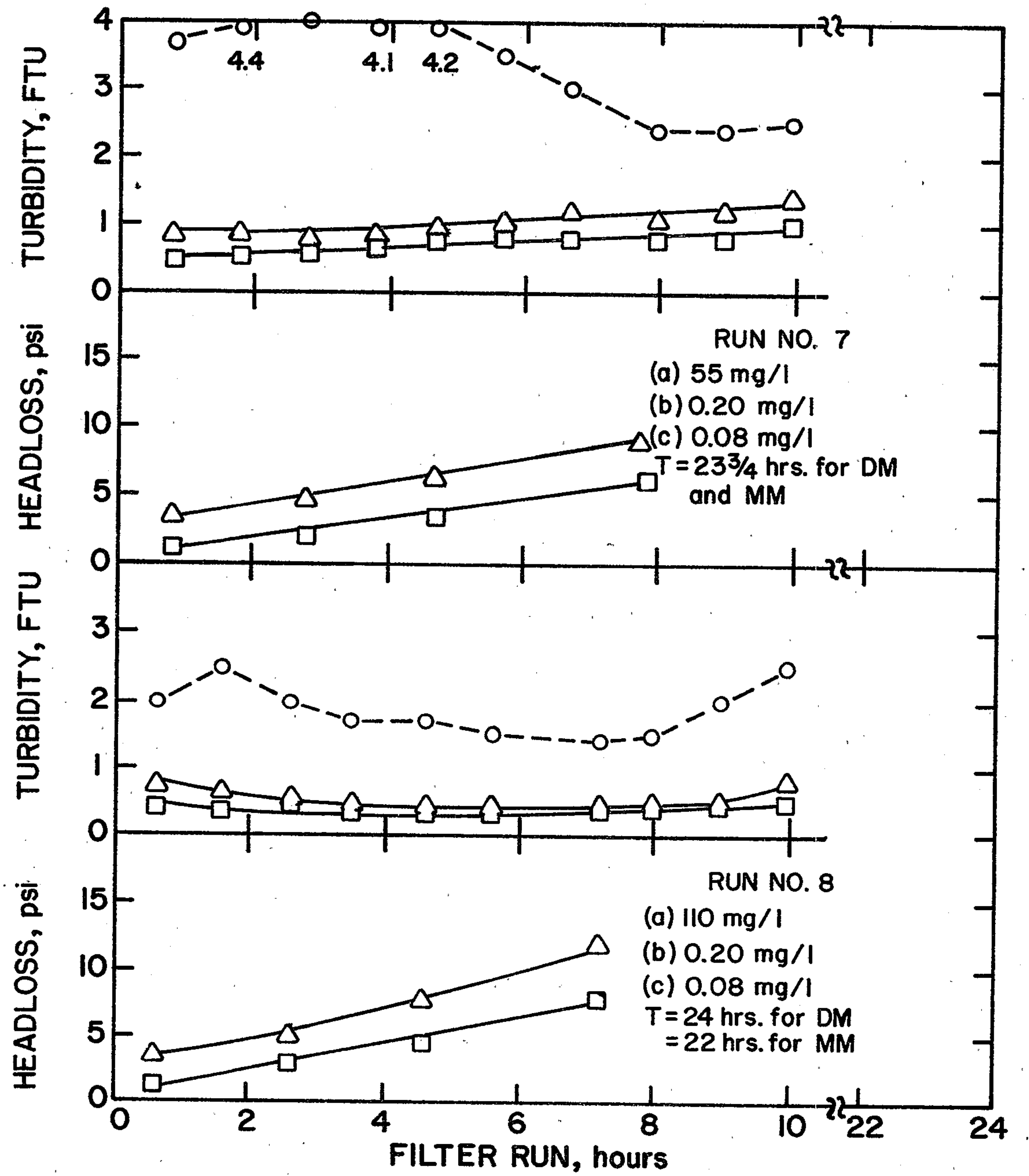


Figure 7. Continued.



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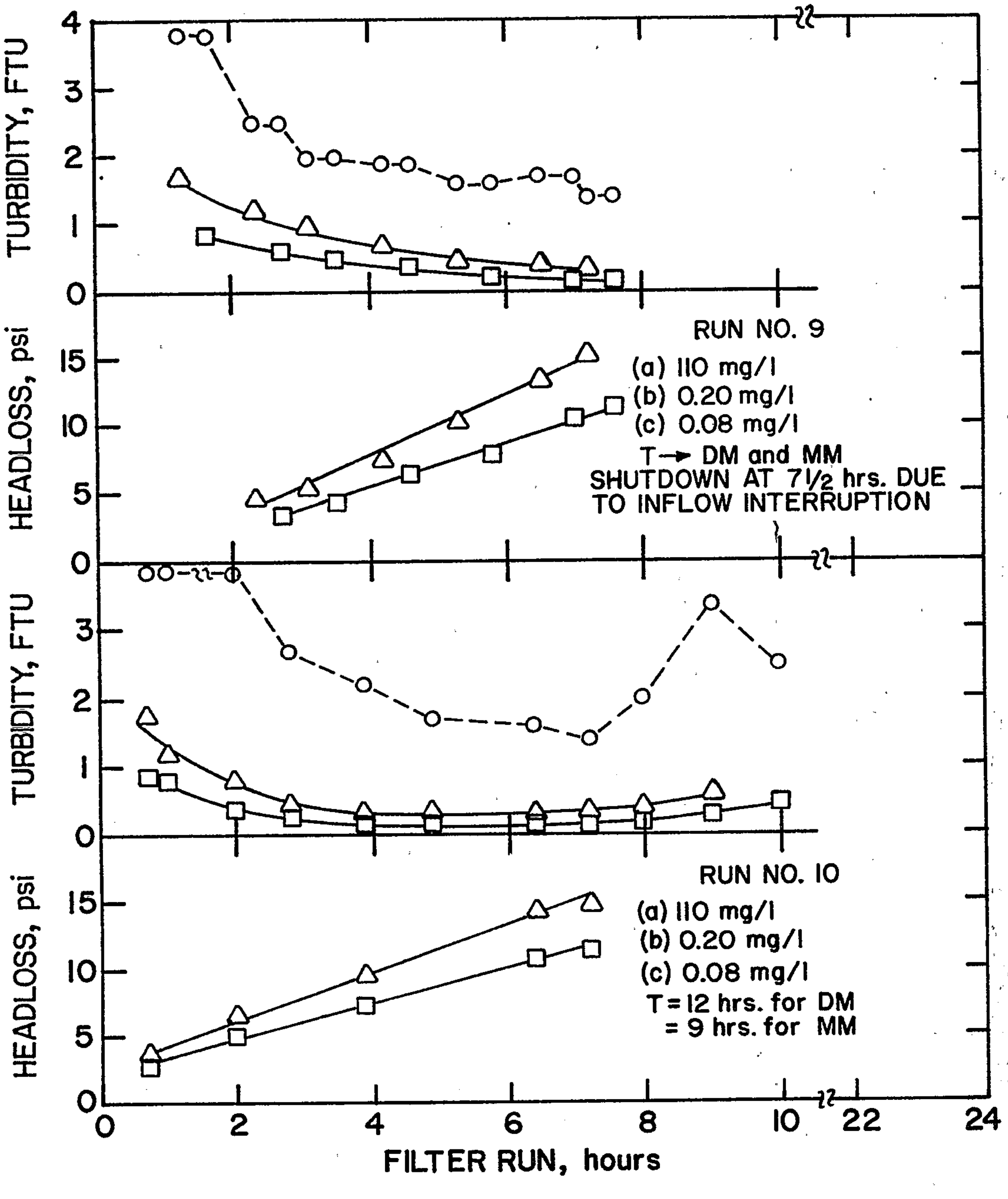

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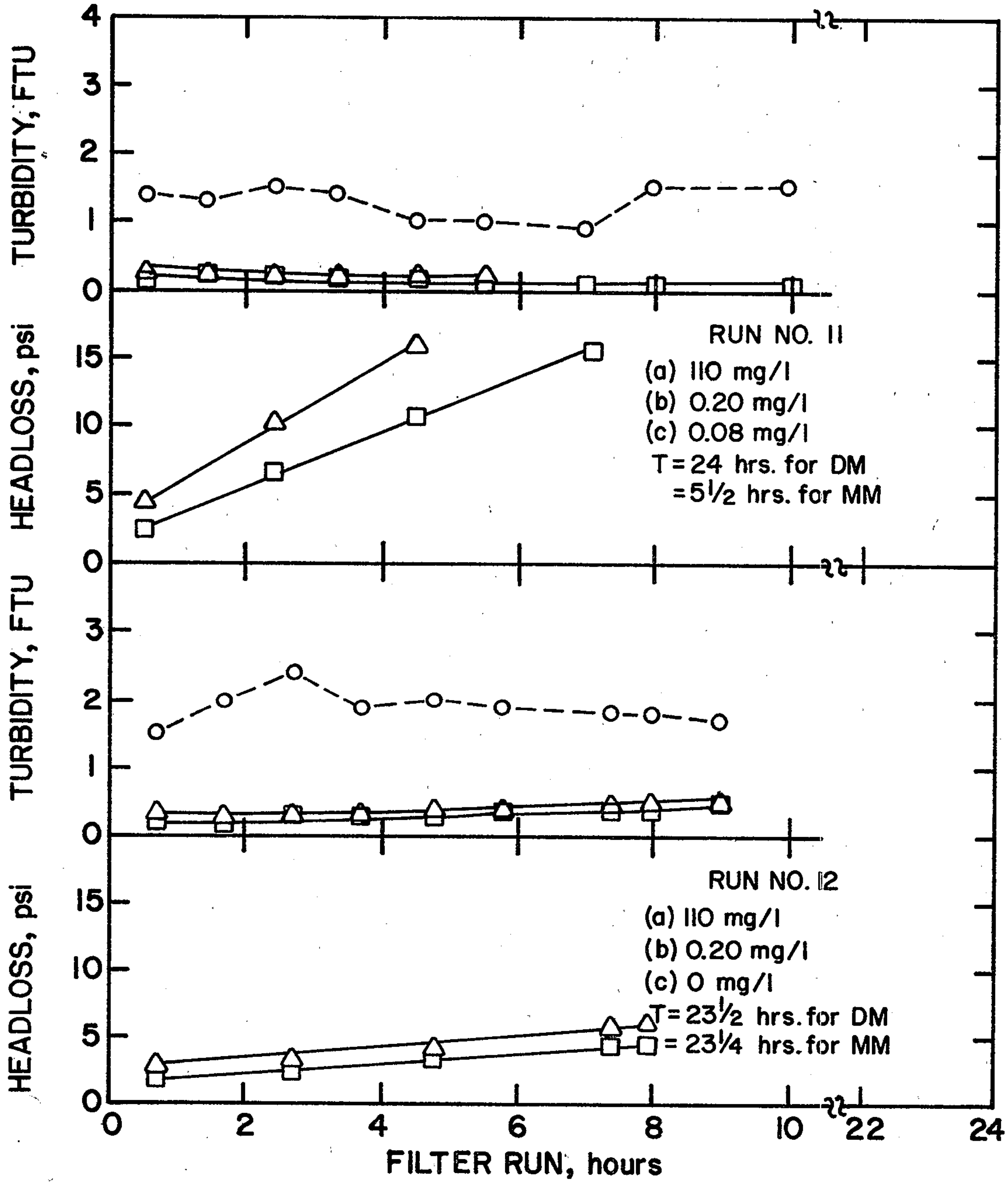
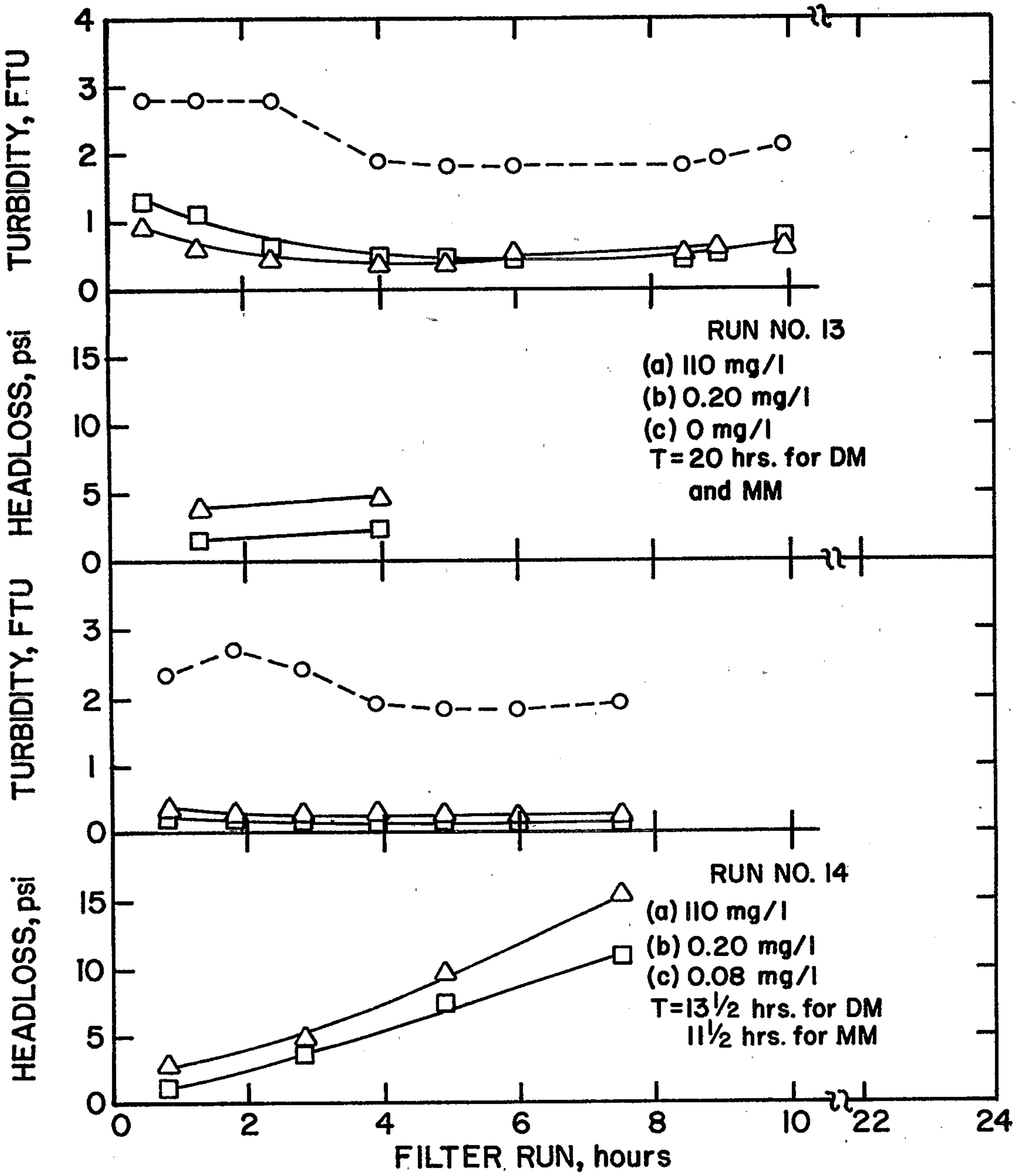


Figure 7. Continued.



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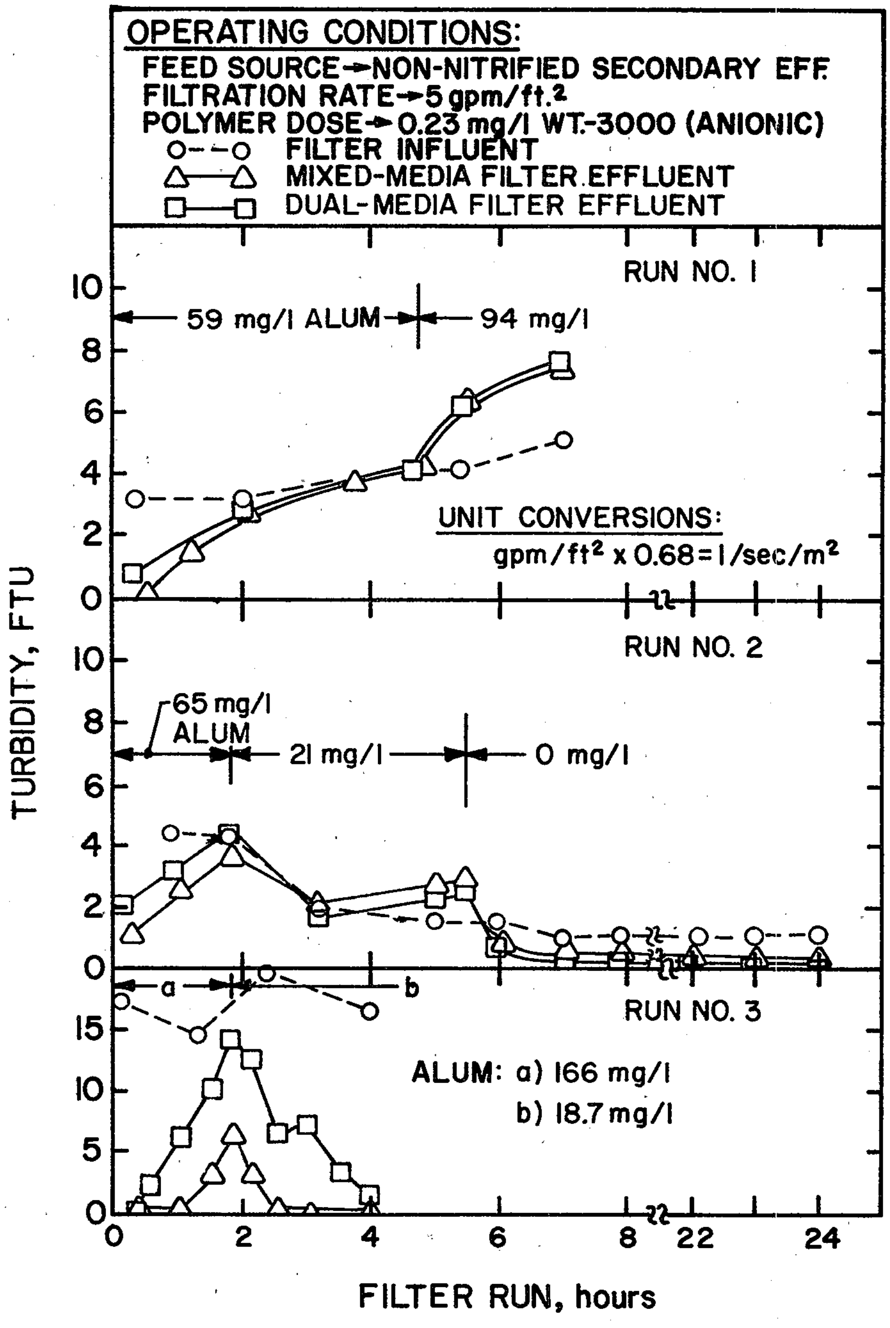

Figure 8. Effect of alum dose on turbidity removal with non-nitrified secondary effluent feed.

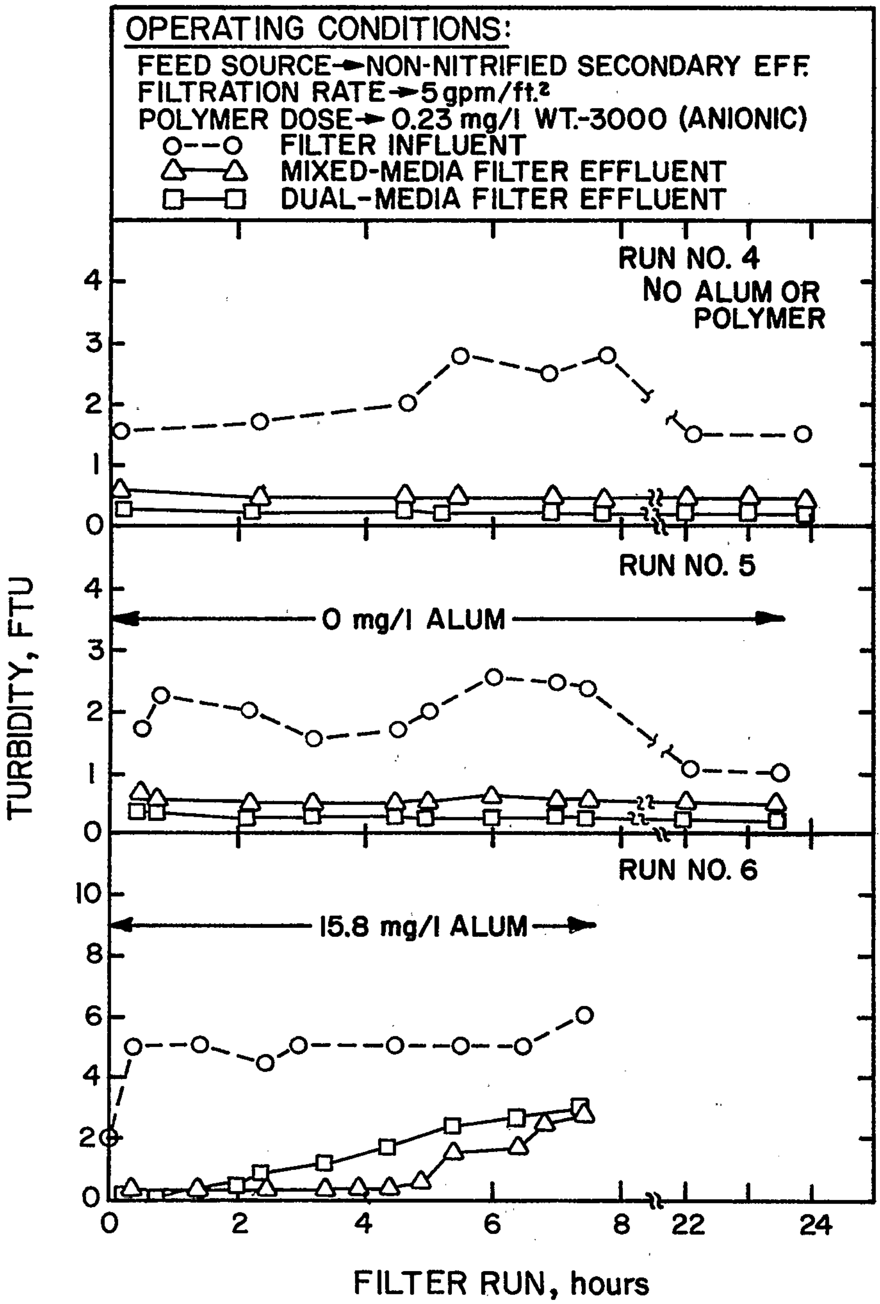

Figure 8. Continued.

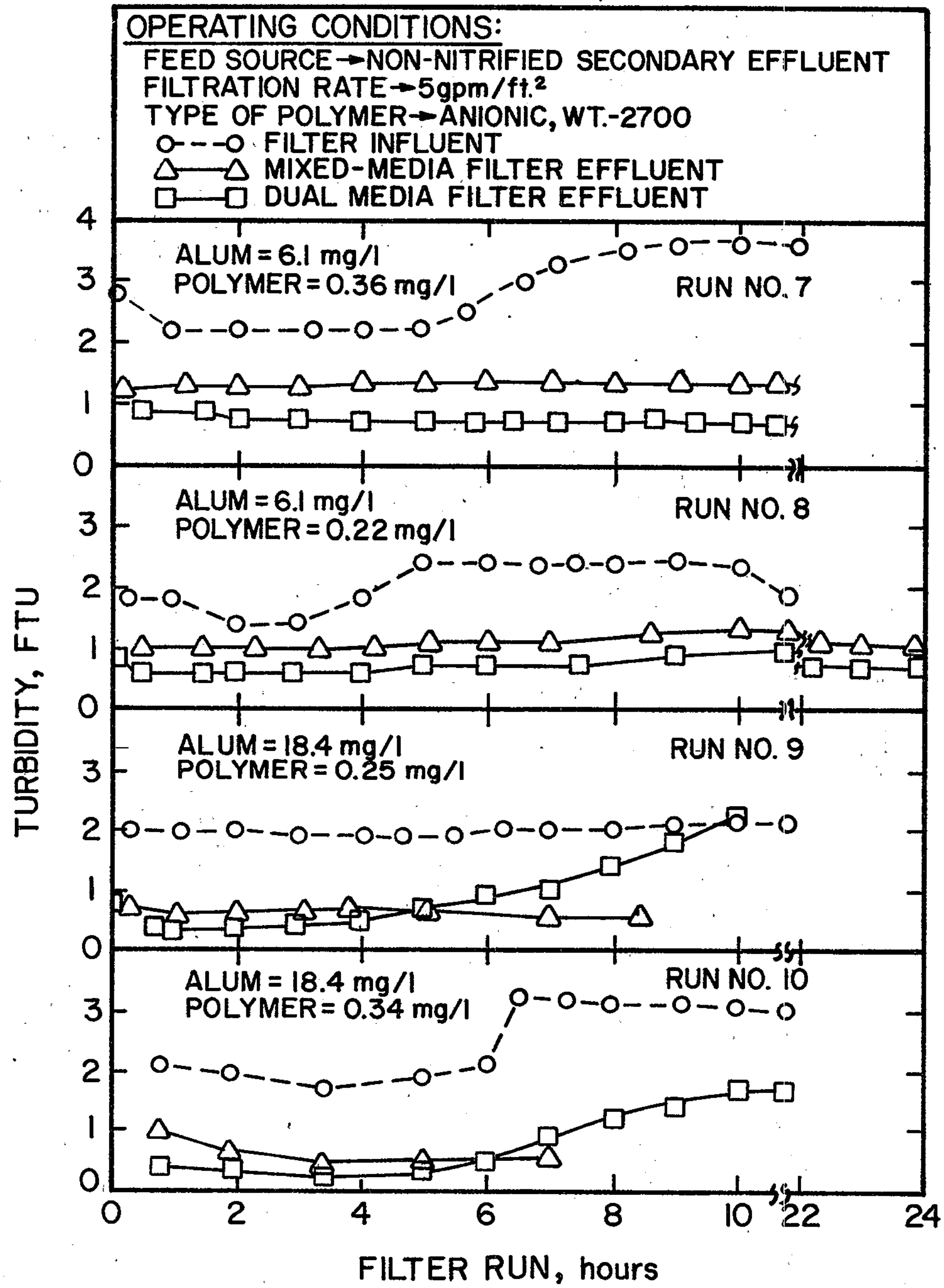

Figure 8. Continued.

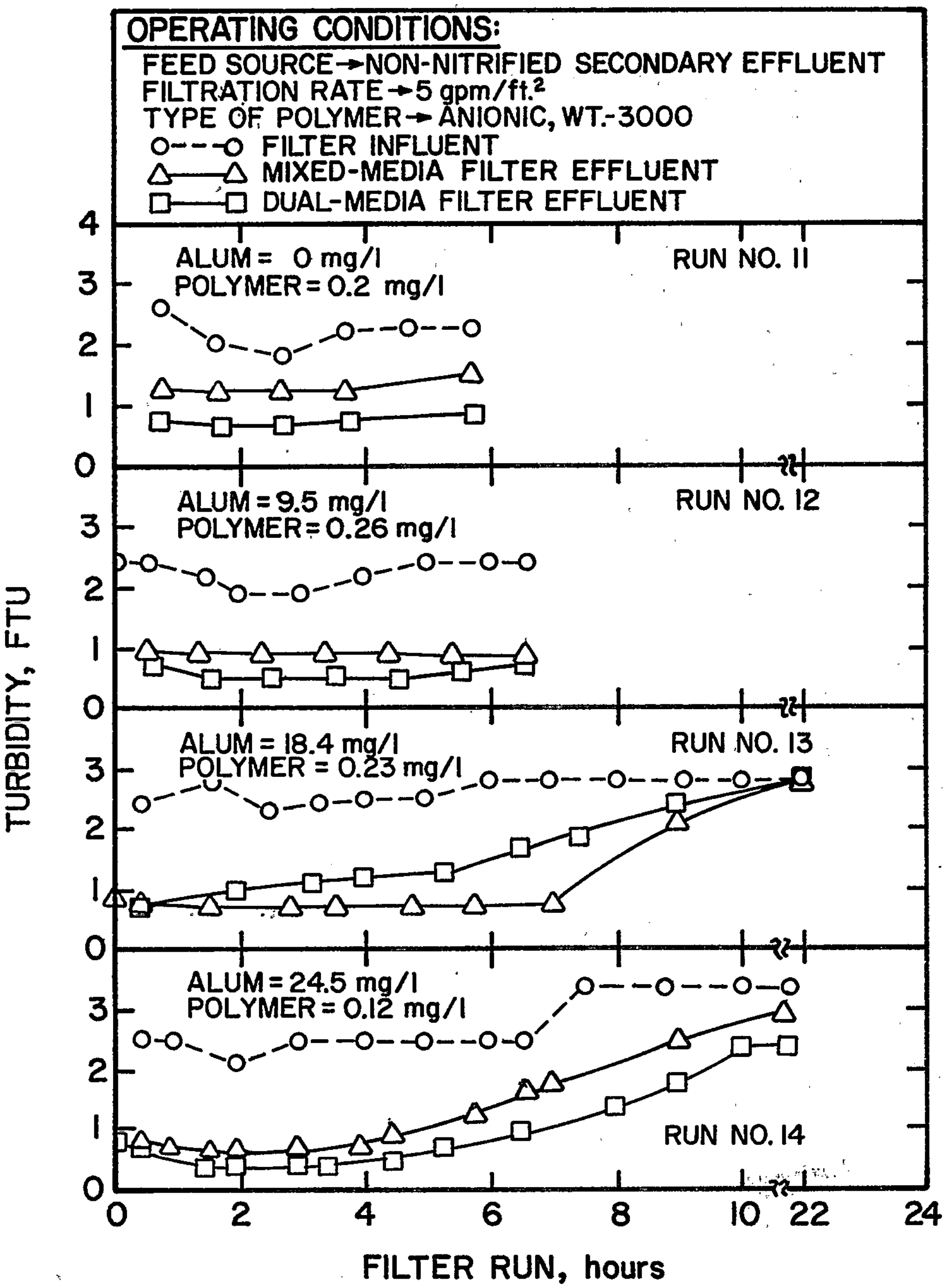

Figure 8. Continued.

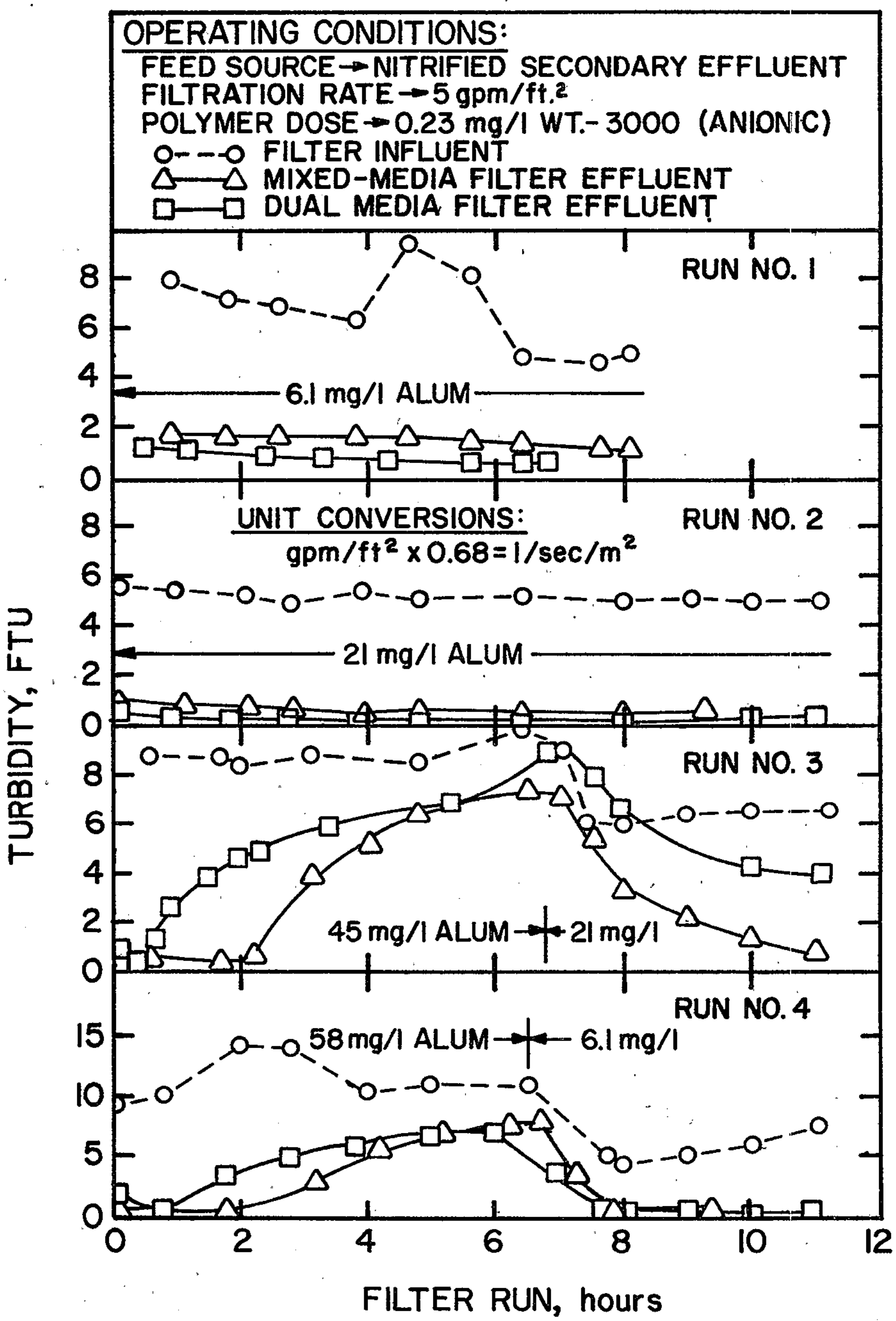

Figure 9. Effect of alum dose on turbidity removal with nitrified secondary effluent feed.

nitrified secondary effluent feedwater. The results shown in the figure demonstrate similar trend as in Figure 8, that is, high effluent turbidity at high alum dose.

Based on the above observations, which show that the overall performance of the dual-media filter was equal to or better than that of the mixed-media filter, all subsequent filter evaluations were confined to the use of the dual-media configuration.

Test Series II - Dual Media Filter Performance

A. With Scheme A Pretreatment

As discussed in the Test Series I-A, when the dual-media filter was evaluated in parallel with the mixed-media filter, the chemical clarification system was operated at a flow rate of 3.47 l/sec (55 gpm). After the completion of the comparative filter evaluation, the flow through the clarification system was reduced to 2.42 l/sec (40 gpm) thus providing mean hydraulic residence times of 4.1, 62.5 and 126 minutes in the rapid mixing, flocculation and sedimentation tanks, respectively. Alum was continuously added to the rapid mixing tank at a dosage ranging from 55 to 225 mg/l. An anionic polymer (Calgon WT-3000) at an average dosage of 0.20 mg/l was added as a coagulant aid to the flocculation tank. The chemically clarified secondary effluent was pumped to the dual-media filter at a flow rate of 1.58 l/sec (25 gpm) which was equivalent to a filtration rate of 3.41 l/sec/m^2 (5 gpm/ft^2). The remaining clarified effluent flow was then diverted to waste.

The experimental data presented in this section include all the results obtained with the clarification system operated at 3.47 l/sec (55 gpm) and 2.52 l/sec (40 gpm). Thus, the dual-media filter performance data presented in Test Series I-A with alum dosage of 55 and 110 mg/l in the clarification system are also included in the summary data in this section.

Table 5 presents a summary of the dual-media filter performance with chemical coagulation-sedimentation pretreatment. In the operation of the filters, an anionic polymer (Calgon WT-3000) at a dosage varying from 0 to 0.20 mg/l was injected as a filter aid to the filter influent line. As indicated by the data, the turbidity removal at a given alum dose remains essentially the same with or without polymer filter aid. The headloss data across the filter, however, is definitely higher with the use of a polymer filter aid.

In Figure 10 is shown a number of dual-media filter runs with the clarification system operated at an alum dose of 110 mg/l and polymer at 0.20 mg/l. The figure shows the fluctuation in the effluent turbidity in the course of the first 7.5 to 10 hours of filter run. Although in most runs effluent turbidity of 0.5 FTU or less was attained, there were days when higher effluent turbidity levels were observed. Moreover, the headloss level also varied from run to run with an observed range of 0.55 to 1.1 Kg/cm^2 (7.8 to 15.6 psi) at the end of the first 7.5 hours of filter run. Figures 11 and 12 show a similar plot to Figure 10 except at higher alum doses in the

TABLE 5. DUAL-MEDIA FILTER PERFORMANCE WITH COAGULATION-SEDIMENTATION PRETREATMENT*

Test Series No.	No. of Runs	Dosage for Chemical Coagulation, mg/l		Polymer+ Filter Aid mg/l	Avg. for the first 7.5-7.8 Hrs. Filter Run			Average Headloss at the end of 7.5 Hrs. Run Kg/cm^2 ++
		Alum	Polymer+		Influent Turb.,FTU	Effluent Turb.,FTU	Turbidity Removal,%	
1	2	55	0.20	0.20	2.4	0.40	83.3	.88 (.56-1.2)
2	4	55	0.20	0.08	3.7	0.80	78.4	.42 (.32- .56)
3	2	55	0.20	0	2.0	0.40	80.0	.28 (.25- .3)
4	3	65	0.20	0.08	3.4	0.70	79.4	.58 (.56- .61)
5	9	110	0.20	0.08	2.4	0.35	85.4	.72 (.55- .85)
6	2	110	0.20	0	2.3	0.40	82.6	.27 (.21- .32)
7	4	95	0.20	0.08	2.3	0.24	89.5	.72 (.62- .79)
8	3	155	0.20	0	2.1	0.23	89.0	.23 (.18- .25)
9	2	155	0.20	0.08	2.5	0.22	91.2	.47 (.35- .59)
10	2	225	0.20	0	2.0	0.35	82.5	.15 (.13- .15)
11	2	225	0.20	0.07	2.5	0.38	84.8	.95 (.88- .98)

* Chemical clarification system flow: 3.47 l/sec for test series No. 1 through No. 6; 2.52 l/sec for runs No. 7 through 11. Filtration rate at 3.4 $l/sec/m^2$.

\+ Anionic Polymer (Calgon WT-3000).

++ Headloss values enclosed in parenthesis are the range at the end of 7.5 Hrs. filter run.

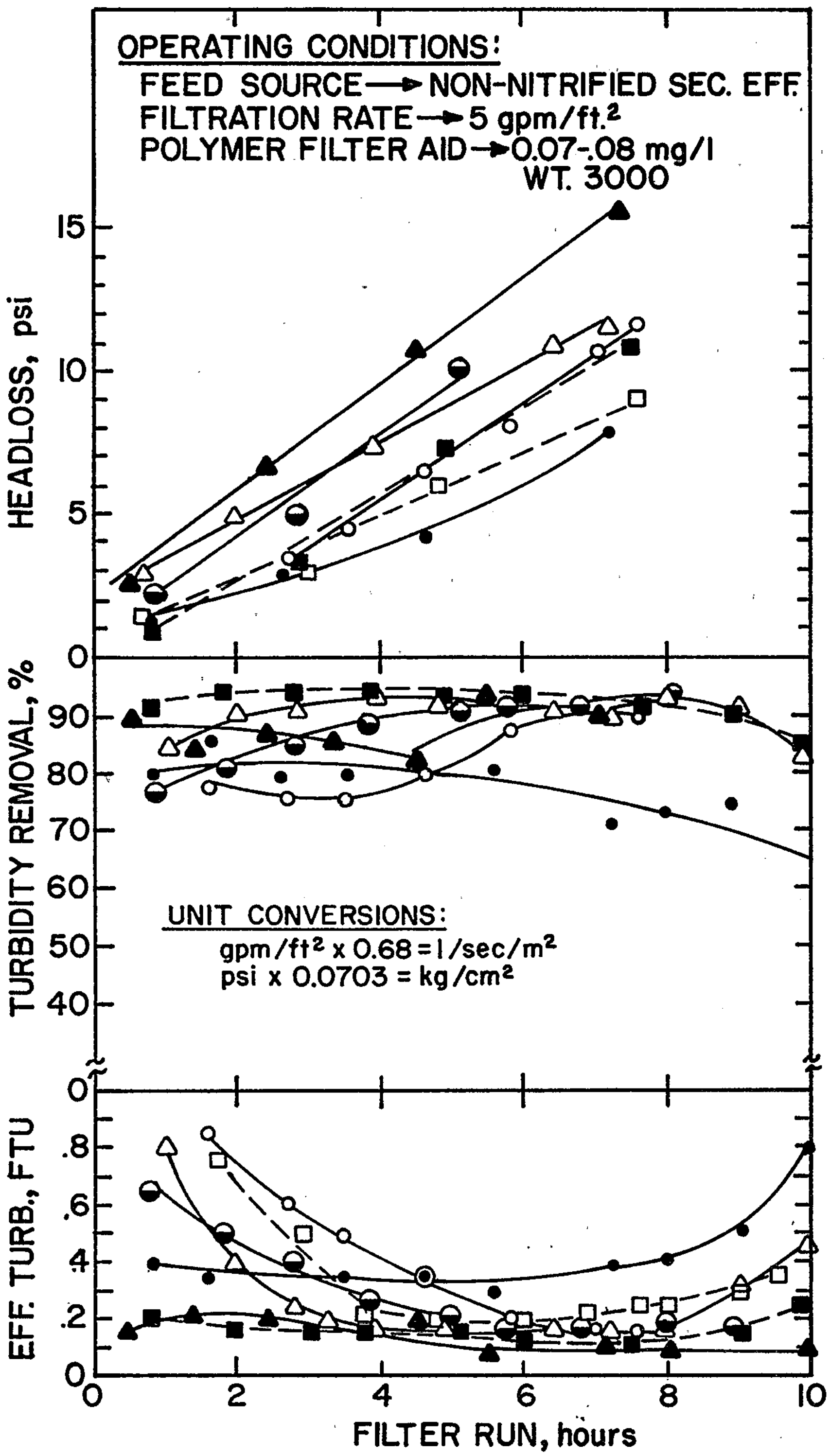

Figure 10. Dual-media filter performance with 110 mg/l alum and 0.2 mg/l polymer in the clarification system.

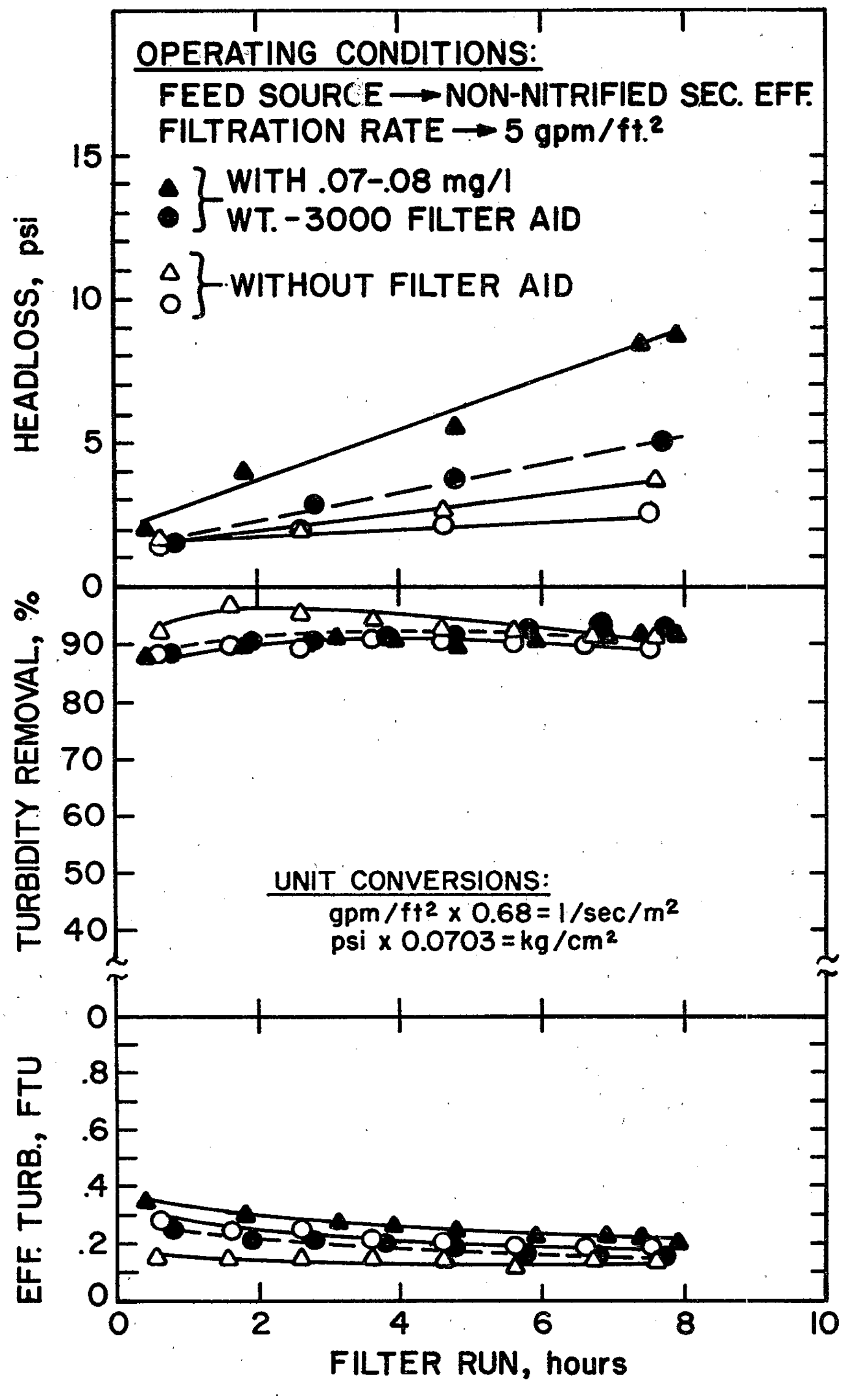

Figure 11. Dual-media filter performance with 155 mg/l alum and 0.2 mg/l polymer in the clarification system.

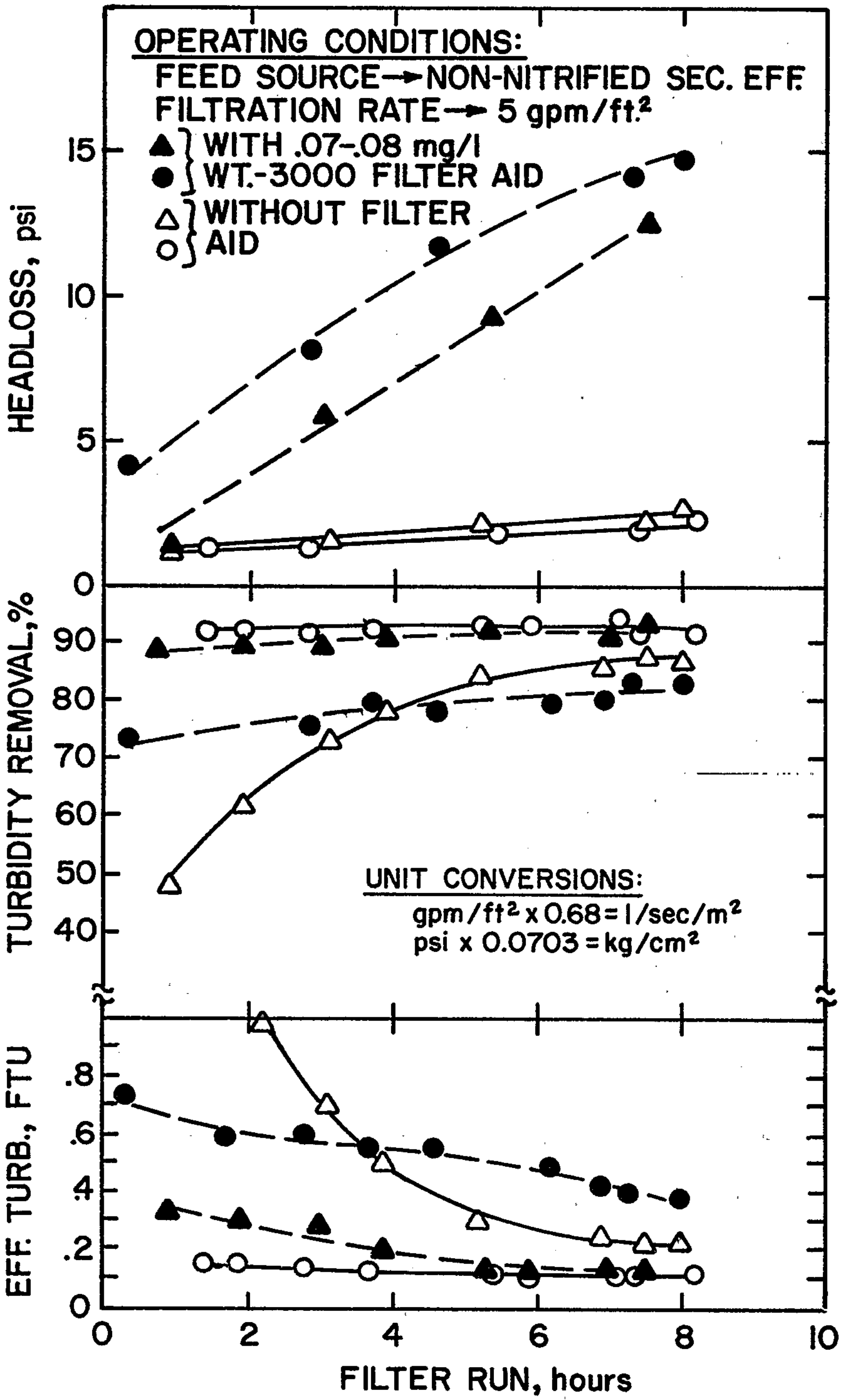

Figure 12. Dual-media filter performance with 225 mg/l alum and 0.2 mg/l polymer in the clarification system

clarification system. The data in these figures also include the runs without the use of polymer filter aid. The results presented in Figures 10 through 12 show that effluent turbidities ranging from 0.1 to 0.5 FTU were obtained in all the three alum doses evaluated. It is evident from the figures, however, that except at the alum dose of 155 mg/l, the filter effluent turbidities varied from run to run. The data shown in Figures 11 and 12 indicate that the turbidity removal performance of the dual-media filter was about the same with or without the use of a polymer filter aid. Moreover, it is apparent that the headloss buildup was markedly higher with the use of a polymer filter aid.

Figure 13 presents the effect of alum dose in the clarification system on the performance of dual-media filter. Each headloss data point in this figure represents the observed headloss at the end of the first 7.5 hours of each filter run. The effluent turbidity and percent turbidity removal data are the average of hourly values obtained during the course of the first 7.5 to 7.8 hours of each filter run. Based on the experimental data summarized in Figure 13 along with those presented in Table 5, the following conclusions about filter performance with Scheme A pretreatment were drawn:

1. A filter effluent turbidity of 0.2-0.4 FTU was achieved at an optimum alum dose of 150 mg/l and an anionic polymer coagulant aid of 0.20 mg/l (Calgon WT-3000) in the chemical clarification system.

2. The turbidity removal efficiency in the dual-media filter was essentially the same with or without the use of a polymer filter aid.

3. With the use of a polymer filter aid, the headloss across the filter was higher at higher alum dose in the clarification system. In addition, at a given alum dose, the headloss across the filter with the use of 0.06 to 0.08 mg/l polymer filter aid (Calgon WT-3000) was higher than that without filter aid.

On the basis of the above findings, all subsequent filtration runs were conducted with the clarification system operated at an alum and polymer dosages of 150 mg/l and 0.20 mg/l, respectively. In addition, no polymer filter aid was used.

B. With Scheme B Pretreatment

In the evaluation of the dual-media filter with an in-line coagulation pretreatment, a number of experimental test runs were conducted using various levels of alum in combination with an anionic polymer (Calgon WT-3000). Figure 14 presents the results of selected filtration runs with alum levels ranging from 0 to 18.4 mg/l and with an anionic polymer from 0 to 0.23 mg/l. The test results shown in Figure 14 along with the summary data presented in Figure 15 show that with in-line coagulation pretreatment, filter effluent turbidity levels obtained were greater than 0.5 FTU for all the alum and polymer

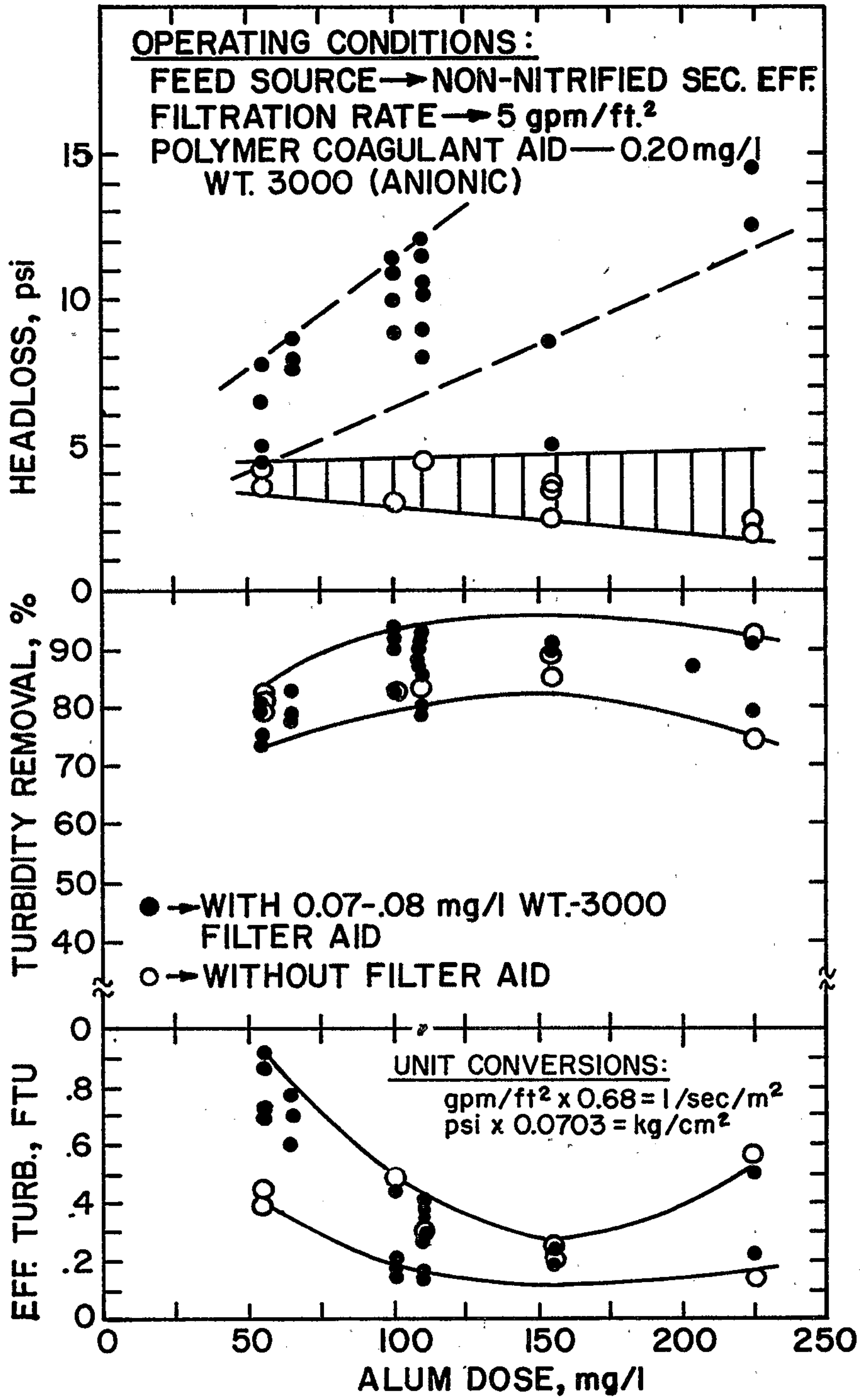

Figure 13. Effect of alum dose in the clarification system on the dual-media filter performance.

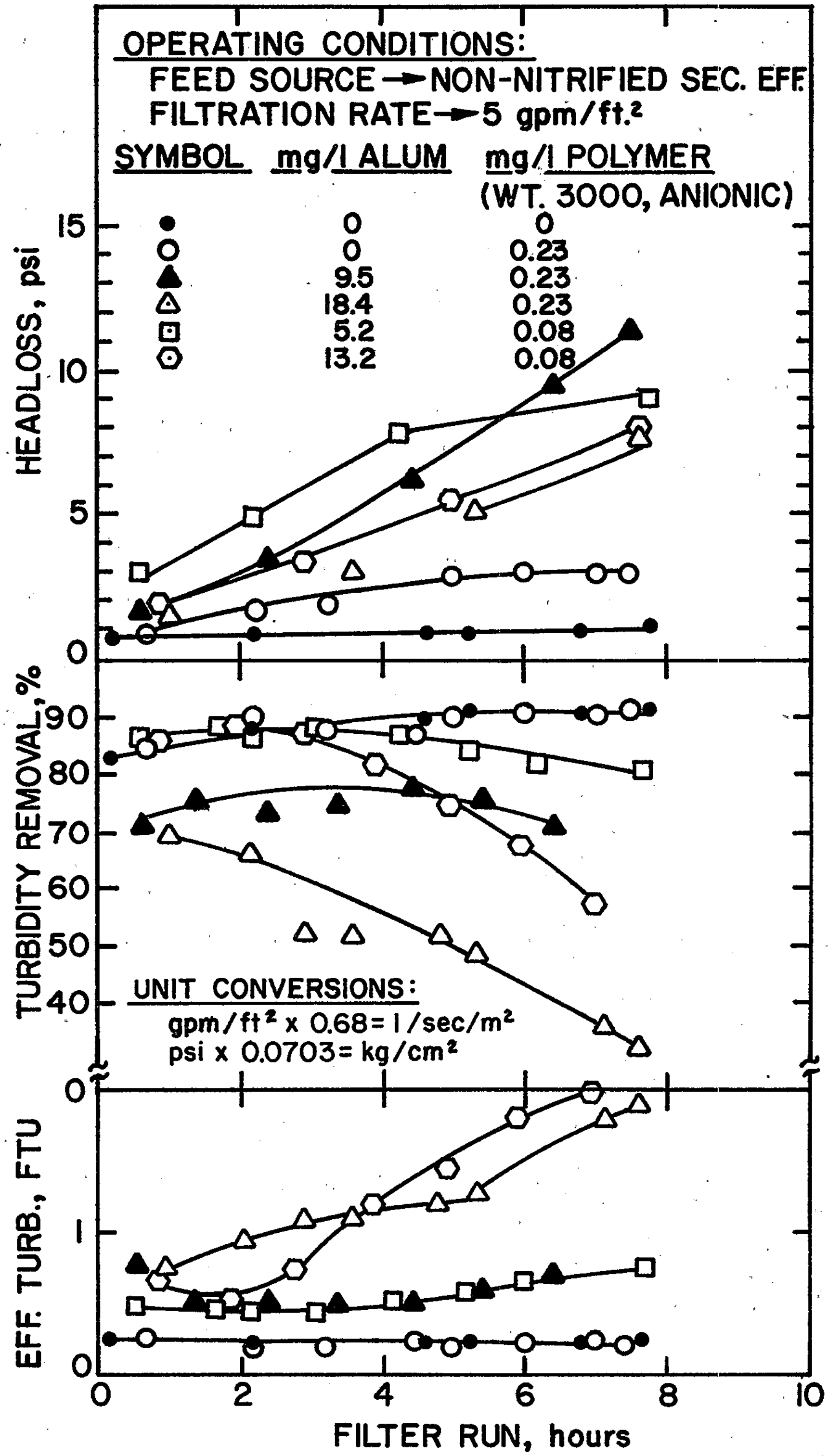

Figure 14. Dual-media filter performance with in-line coagulation pretreatment.

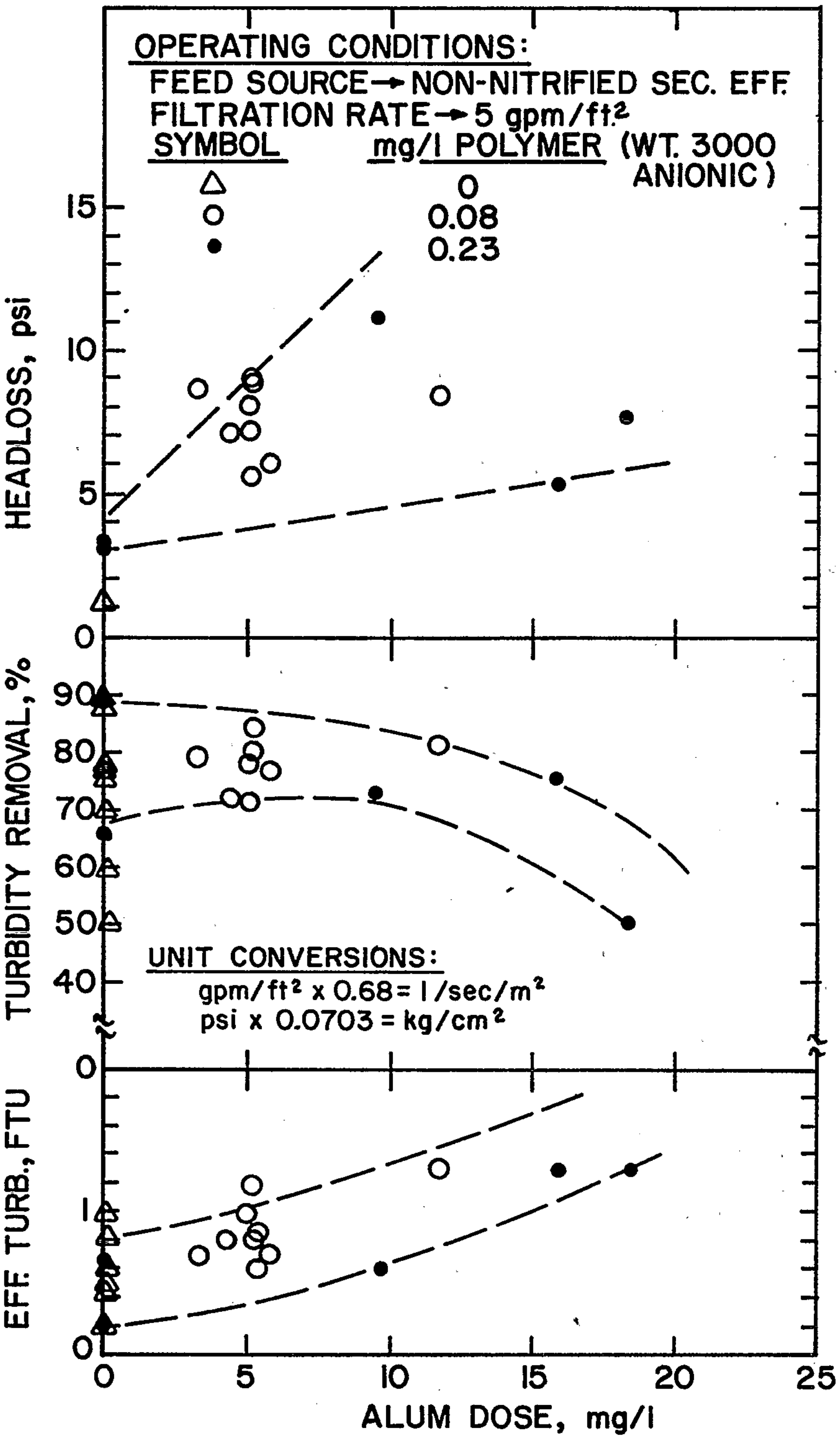

Figure 15. Effect of alum dose in the in-line coagulation system on the dual-media filter performance.

doses evaluated. The average filter effluent turbidity in the first 7.5 to 7.8 hours of filter run varied from 0.6 to 1.2 FTU. In the absence of alum, however, filter effluent turbidities ranging from 0.2 to 0.8 FTU were observed. Moreover, in the absence of alum, turbidity removal with or without polymer injection was about the same. These results confirmed previous Pomona filtration data which showed that based on filter effluent quality and filter run length, the filter performance with plain filtration (no chemical) was equal to or better than that with the addition of alum and polymer.

Test Series III - Special Short-Term Filtration Runs with Scheme B Pretreatment.

In the course of the dual-media filter evaluation with an in-line coagulation pretreatment, two sets of special filtration runs were conducted. In the first set of runs, the dual-media filter was operated with the use of a cationic polymer (Calgon Cat-Floc T) alone for pretreatment. Figure 16 presents the results of selected filtration runs with the cationic polymer dosage as high as 2.4 mg/l. A summary of the effects of cationic polymer dose on the dual-media filter performance is presented in Figure 17. Each headloss data in this figure represents the observed headloss at the end of the first 7.5 hours of each filter run. The effluent turbidity and percent turbidity removal data represent the average of hourly observations obtained during the first 7.7 to 8 hours of filter run. As indicated by the data in Figure 17 the apparent optimum polymer dosage ranged from 0.05 to 0.5 mg/l. At this range of polymer dose, the average filter effluent turbidity in the first 7.8 to 8 hours of run varied from 0.8 to 0.9 FTU. For the dosage range evaluated, the headloss at the end of 7.5 hours of run was low and ranged from 0.09 to 0.23 Kg/cm^2 (1.3 to 3.3 psi).

The second set of the special filtration runs entailed the use of high alum dose (40.5 to 182 mg/l) in the in-line coagulation system in combination with a non-ionic polymer (American Cyanamid Magnifloc 985 N) filter aid at a dosage of 0.7 to 2.1 mg/l. The results of the filtration runs are presented in Figure 18. As shown in the figure, for the alum dose of 160 to 182 mg/l in combination with 1.2 to 2.1 mg/l non-ionic polymer (Test No. 1 to 4), filter effluent turbidity levels of 0.3 to 0.4 FTU were attained. At this high chemical dose, however, the length of the filter run to a terminal headloss of 1.4 Kg/cm^2 was very short and ranged only from 20 to 75 minutes. Moreover, it required a period of about 15 to 20 minutes (so-called "ripening period") from the start of the filtration run to reach the stable filter effluent turbidity level of 0.3 to 0.4 FTU. Although this ripening period is short, it constitutes a significant portion of the total filter run. Thus, the test results show that although low filter effluent turbidity could be achieved at very high alum and polymer doses in the in-line coagulation pretreatment, the resulting run length was too short to be economically feasible. The last three runs (Test Nos. 5 to 7) in Figure 18 show the turbidity removal data at alum dose of 40.5 to 111 mg/l and non-ionic polymer dose of 0.7 to 1.3 mg/l. As indicated in the figure, the filter effluent turbidity was high throughout the filter run.

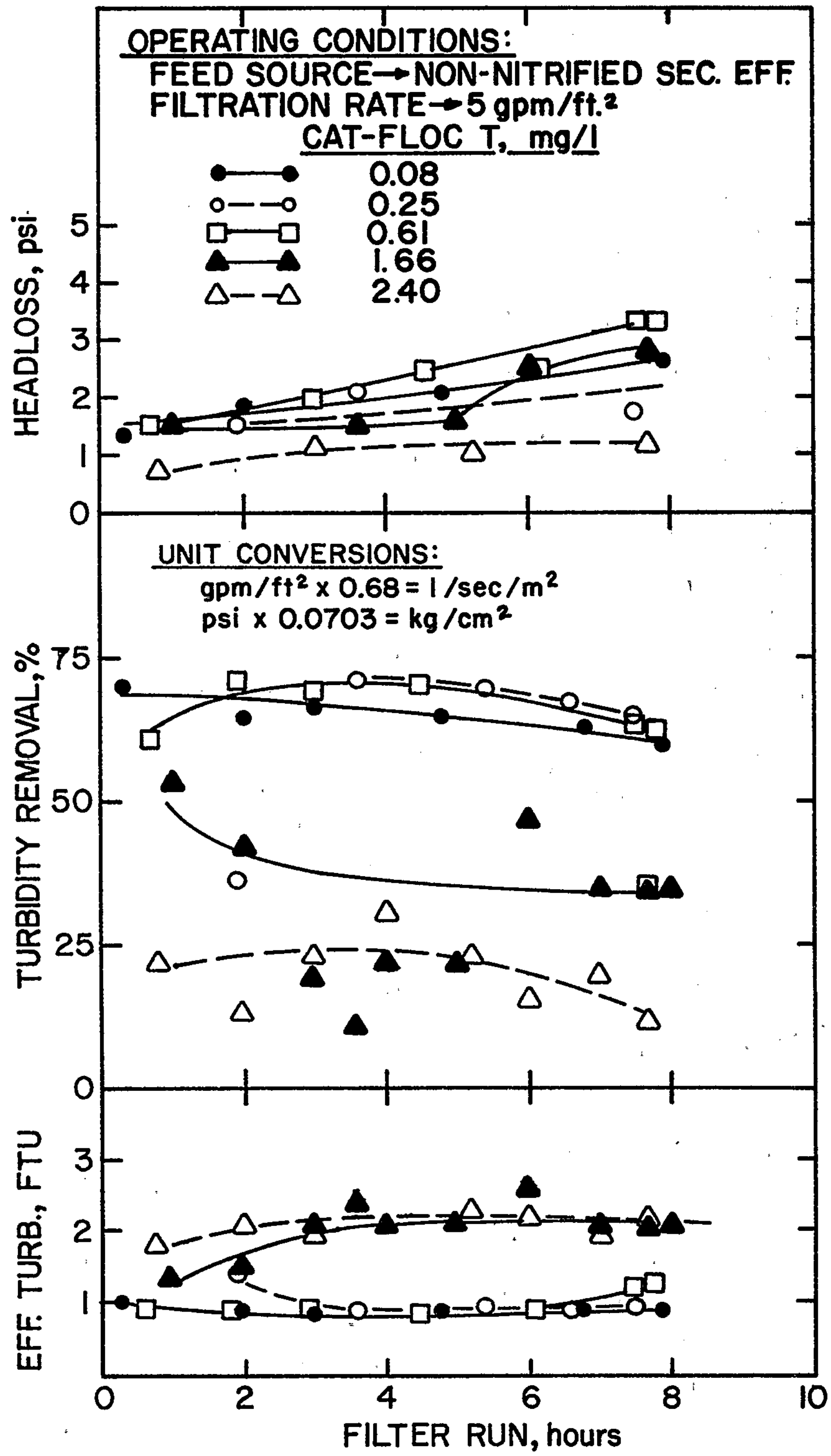

Figure 16. Dual-media filter performance with direct cationic polymer injection.

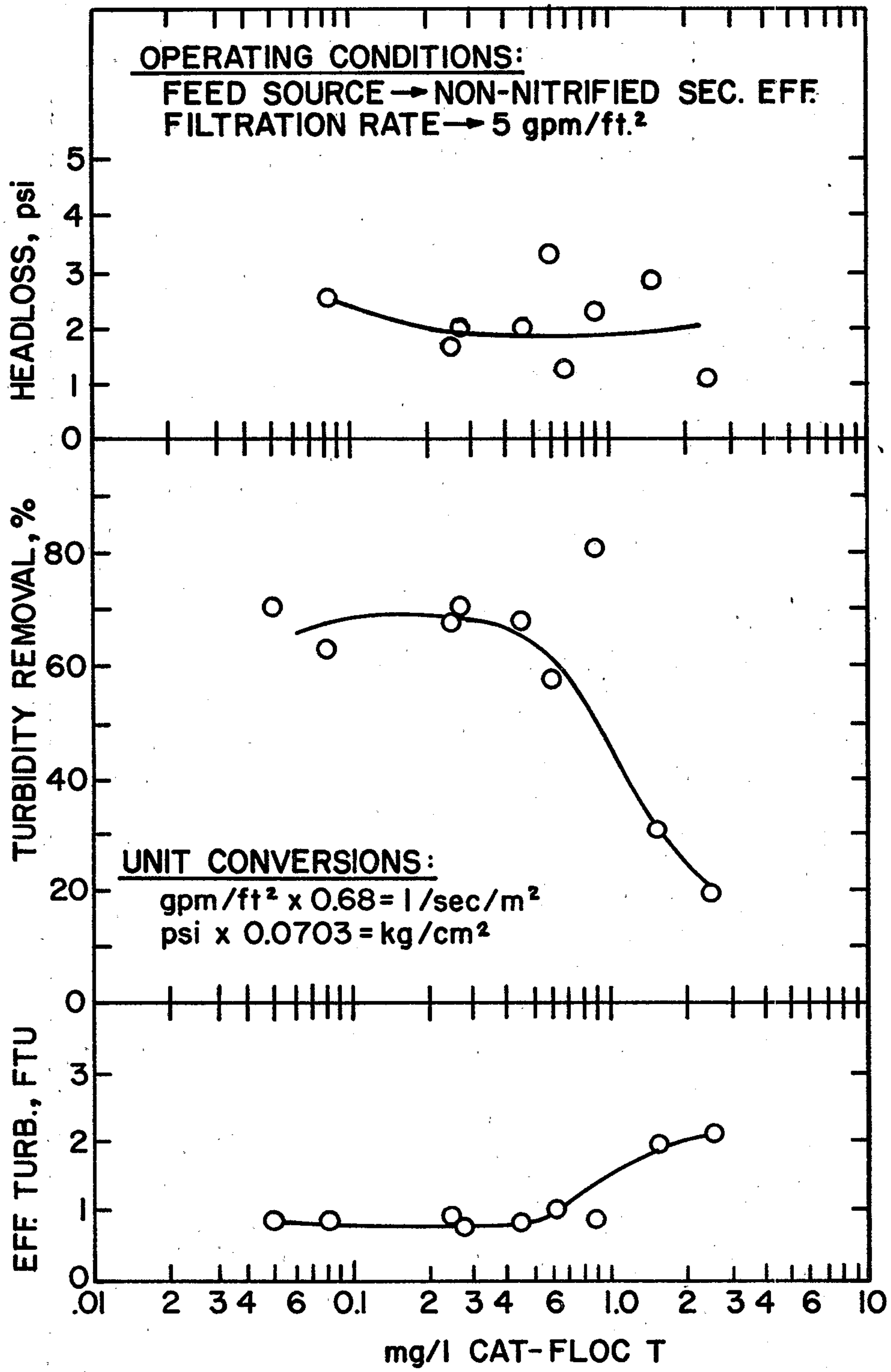

Figure 17. Effect of cationic polymer dose on the dual-media filter performance.

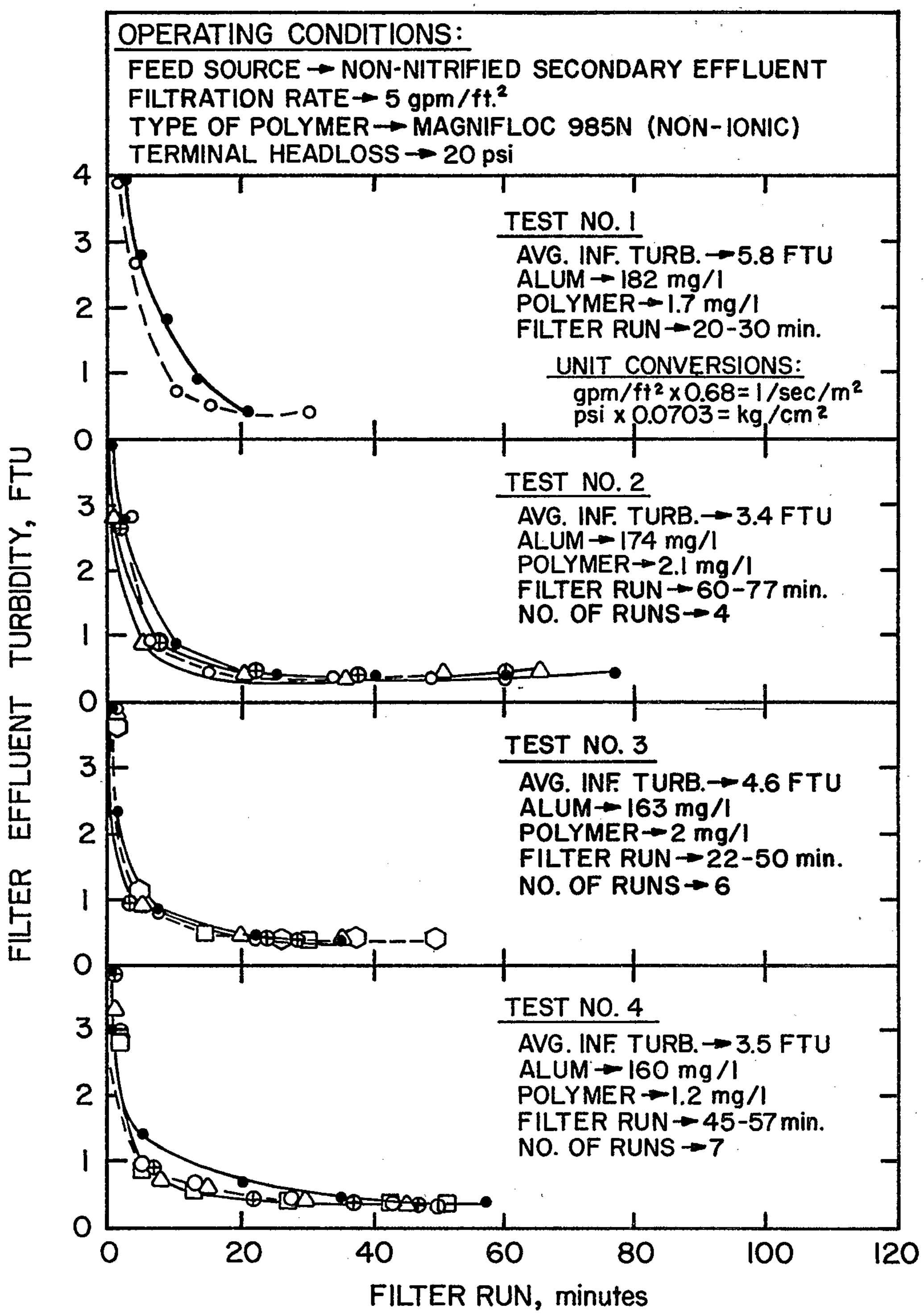

Figure 18. Effect of high alum and polymer doses on the dual-media filter performance.

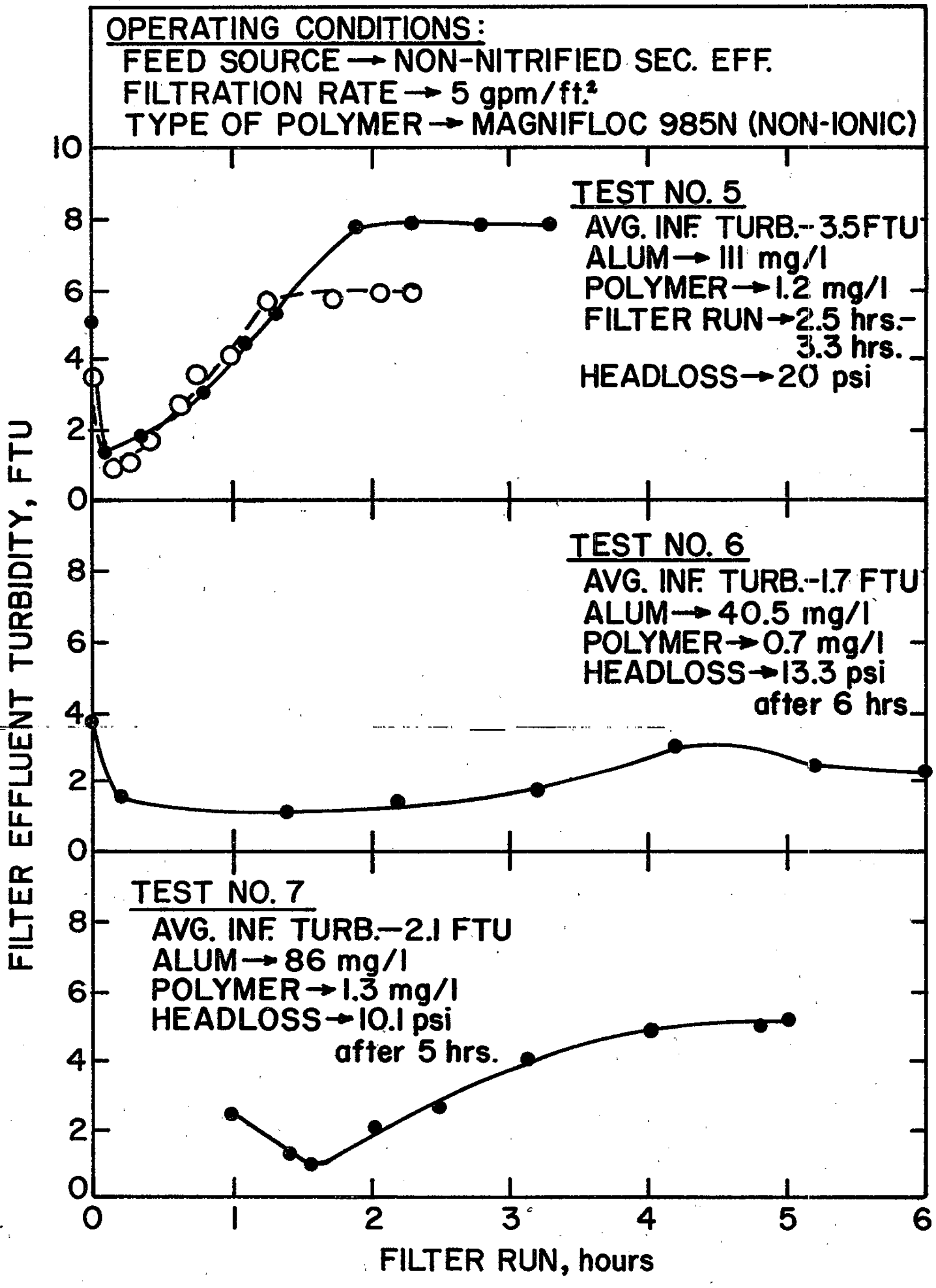

Figure 18. Continued.

PHASE III TEST RESULTS

The data presented in this section of the report include the results of a long-term filtration run encompassing a total period of about eight months. During this period, the dual-media pressure filters were operated continuously in parallel at an identical filtration rate of 3.41 l/sec/m^2 (5 gpm/ft^2). One filter was operated with a chemical coagulation-sedimentation pretreatment (Scheme A) using about 150 mg/l alum and 0.20 mg/l anionic polymer (Calgon WT-3000) in the chemical clarification system. The other filter was operated with an in-line coagulation pretreatment (Scheme B or C) in which approximately 5 mg/l alum was added to the rapid mixing unit and 0.05 to 0.08 mg/l anionic polymer (Calgon WT-3000) injected into the filter influent line as a filter aid.

Filter Effluent Quality

The average water quality parameters for each treatment unit of Scheme A are presented in Table 6. The test results in Table 6 show that the suspended solids level in the clarified effluent was higher than those in the secondary effluent. This was due to poor solids-liquid separation in the sedimentation tank resulting in chemical floc being carried-over with the clarified effluent. Nevertheless, as indicated by the data, solids removal by the filter was excellent. The average filter effluent suspended solids and turbidity were 1.3 mg/l and 0.7 FTU, respectively. This corresponds to an average removal efficiency of 90.6 percent for suspended solids and 83.3 percent for turbidity. Moreover, in the course of chemical clarification and subsequent filtration, total phosphate was reduced about 89 percent, resulting in a filter effluent with total phosphate concentration of 0.9 mg/l P. Total COD and color were reduced 48 percent and 38 percent, respectively. The total dissolved solids (TDS) was slightly increased in the filter effluent as a result of the high alum dosage in the chemical clarification system.

Tables 7 and 8 present the summary of the average water quality parameters for Schemes B and C. As shown by the data in Table 7, the filter removed 80 percent of the suspended solids and turbidity, resulting in a filter effluent with average suspended solids of 2.7 mg/l and turbidity of 1.2 FTU. The suspended solids removal efficiency in Scheme C was about the same as that in Scheme B. In addition to turbidity and suspended solids removal, color, total COD and total phosphate were also slightly reduced by the filter in both Schemes B and C.

In Figure 19 is presented a plot of the filter effluent turbidity and percent turbidity removal as a function of experimental run for Scheme A. The turbidity data presented in this figure are based on 113 days run. The figure shows that the filter effluent turbidity levels remained stable throughout the pilot plant study. Analysis of the filter effluent turbidity data show that the median and mean values of the filter effluent turbidity were 0.6 to 0.7 FTU, respectively.

TABLE 6. SUMMARY OF FILTER PERFORMANCE WITH SCHEME A PRETREATMENT

Chemical Dosage, mg/l Alum	Chemical Dosage, mg/l Polymer*	Water Quality Parameters+		Secondary Effluent	Clarified Effluent	Filter Effluent	Removal, % Filtration	Removal, % Overall
148.5 (N=108)	0.20 (N=108)	pH	(N= 77)	7.32	6.94	6.86		
		Temperature, ^{o}C	(N= 32)	23.7				
		Suspended Solids, mg/l	(N=107)	10.8	13.9	1.3	90.6	
		Turbidity, FTU	(N=108)	4.6	4.2	0.7	83.3	
		Color	(N=110)	30.6		19		37.9
		Total COD, mg/l	(N= 36)	37.6		19.5		48.1
		Total phosphate, mg/l P	(N=105)	8.2		0.92		88.8
		Aluminum, mg/l Al	(N= 95)		1.3	0.17	86.9	
		TDS, mg/l	(N= 35)	544		590		
		Alkalinity, mg/l	(N= 36)	176.3	99.5	9.52		

* Anionic Polymer (Calgon WT-3000)
+ Based on 16-hr composite samples; temperature was run on grab samples. N = No. of observations averaged.

TABLE 7. SUMMARY OF FILTER PERFORMANCE WITH SCHEME B PRETREATMENT

Chemical Dosage, mg/l Alum	Chemical Dosage, mg/l Polymer*	Water Quality Parameters+		Secondary Effluent	Filter Effluent	Removal %
5.6 (N=102)	0.06 (N=102)	pH	(N=47)	7.4	7.36	
		Temperature, °C	(N=45)	23.7		
		Suspended Solids, mg/l	(N=97)	13.6	2.7	80.1
		Turbidity, FTU	(N=97)	6.0	1.2	80.0
		Color	(N=50)	30.0	27.3	9.0
		Total COD, mg/l	(N=51)	41.9	24.3	42.0
		Total Phosphate, mg/l P	(N=44)	8.3	7.5	9.6
		Aluminum, mg/l Al	(N=45)		0.17	
		TDS, mg/l	(N=47)	544	558	
		Alkalinity, mg/l	(N=48)	164.5	161.9	

* Anionic Polymer (Calgon WT-3000)
+ Based on 16-hour composite samples; Temperature was run on grab samples. N = No. of observations averaged.

TABLE 8. SUMMARY OF FILTER PERFORMANCE WITH SCHEME C PRETREATMENT

Chemical Dosage, mg/l Alum	Chemical Dosage, mg/l Polymer*	Water Quality Parameters+		Secondary Effluent	Filter Effluent	Removal %
6.1 (N=39)	0.06 (N=39)	pH	(N=33)	7.4	7.3	
		Temperature, ^{o}C	(N=30)	23.5		
		Suspended Solids, mg/l	(N=38)	12.6	2.8	77.8
		Turbidity, FTU	(N=33)	6	1.5	75
		Color	(N=32)	32.5	28.1	13.5
		Total COD, mg/l	(N=32)	36.5	25.2	31
		Total Phosphate, mg/l P	(N=32)	7.9	6.8	13.9
		Aluminum, mg/l AL	(N=32)		0.11	
		TDS, mg/l	(N=33)	601	580	
		Alkalinity, mg/l	(N=32)	145.7	144.1	

* Anionic Polymer (Calgon WT-3000)
\+ Based on 16-hr composite samples; Temperature was run on grab samples. N = No. of observations averaged.

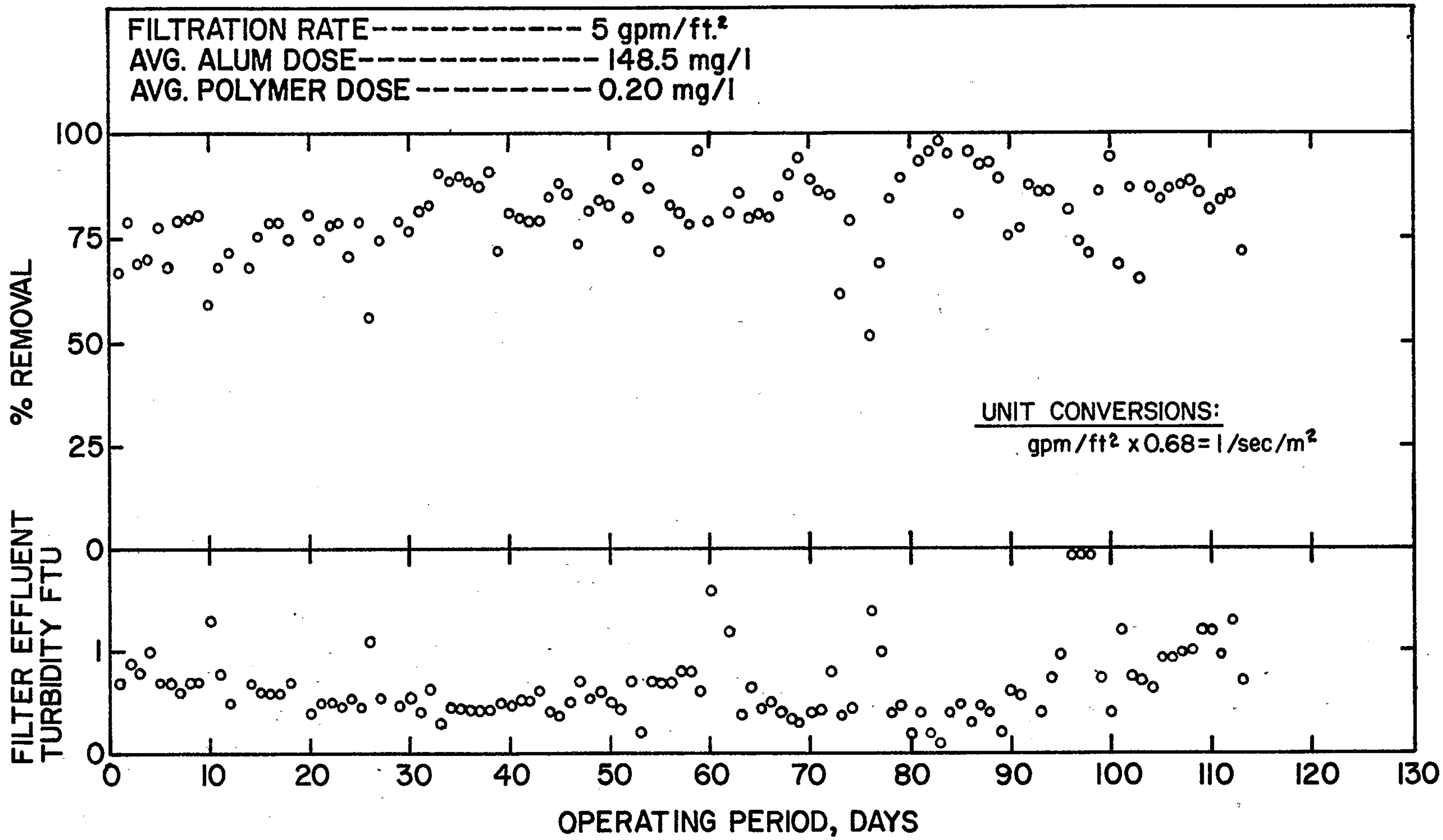

Figure 19. Turbidity removal through the filter with Scheme A pretreatment.

The daily variations in the filter effluent turbidity and turbidity removal are shown in Figure 20 for Scheme B and Figure 21 for Scheme C. The turbidity data presented in the figures are based on 112 observations for Scheme B and 38 observations for Scheme C. The median and mean values of the filter effluent turbidity for Scheme B were 1.1 and 1.2 FTU, respectively. For Scheme C, the median and mean filter effluent turbidity values were 1.3 and 1.4 FTU, respectively. The results presented show that for the pretreatment Schemes A, B, and C, the filter operations remained quite stable during the entire period of pilot plant study.

The daily variations in the filter effluent and effluent turbidity levels for pretreatment Schemes A, B, and C are presented as frequency curves in Figure 22. The observed turbidity data are fitted approximately by a geometrically normal distribution and thus the line of best fit is plotted as a straight line in log-probability paper. The turbidity data in Figure 22 are based on 113 days run for Scheme A, 112 days run for Scheme B, and 38 days run for Scheme C. As the frequency curves indicate, the turbidity levels of the filter influent and effluent with Scheme A pretreatment were consistently lower than those with Schemes B and C pretreatments. The filter influent turbidity ranged from 1.0 to 15 FTU for Scheme A, 1.5 to 16 FTU for Scheme B, and 2.8 to 32 FTU for Scheme C. Turbidity of the filter effluent ranged from 0.2 to 2.4 FTU for Scheme A, 0.3 to 3.7 FTU for Scheme B, and 016 to 3.7 FTU For Scheme C. Moreoever, the frequency curves show that 50 percent of the time the filter effluent turbidities were equal to or less than 0.6, 1.1, and 1.3 FTU for Schemes A, B, and C, respectively. The observed median values of the filter effluent were about the same as the geometric means (50 percent observations) indicated above. The log standard deviations of the filter effluent were 1.7, 1.6, and 1.4 FTU for Schemes A, B, and C, respectively.

Figure 23 presents a log-probability plot of suspended solids removal data through the dual-media filter for the three pretreatment Schemes A, B, and C. The frequency curves show that although the filter influent suspended solids concentrations were approximately of the same level in the three pretreatment schemes, the filter with a chemical coagulation-sedimentation pretreatment (Scheme A) consistently showed lower levels of effluent suspended solids than those with an in-line coagulation pretreatment (Schemes B and C). Moreover, the frequency curves show that 50 percent of the time the filter effluent suspended solids concentrations were equal to or less than 0.95, 2.3, and 2.5 mg/l for Schemes A, B, and C, respectively. The median values of the filter effluent suspended solids were approximately the same as the geometric means indicated above. The log standard deviation of the filter effluent suspended solids was 2.3 mg/l for Scheme A, 2.0 mg/l for Scheme B, and 1.8 mg/l for Scheme C.

It is recognized that of the many variables in filtration, the concentration as well as the physicochemical nature of the influent solids are the primary determining factors that influence the overall filter performance. Thus, any pretreatment could drastically alter the physicochemical make-up of the influent solids which could cause a corresponding change in the filter performance. With this in mind, a regression analysis was performed to determine

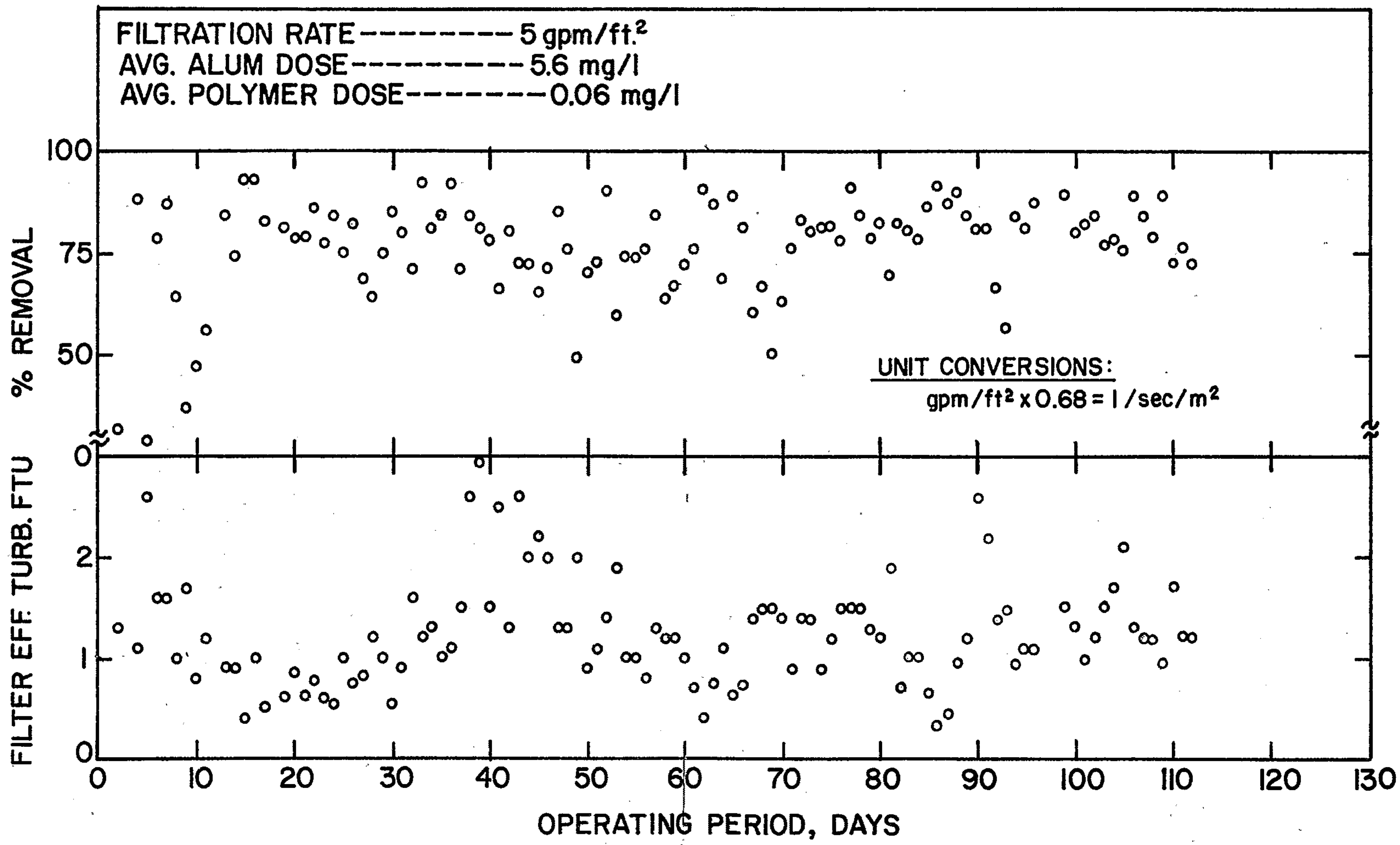

Figure 20. Turbidity removal through the filter with Scheme B pretreatment.

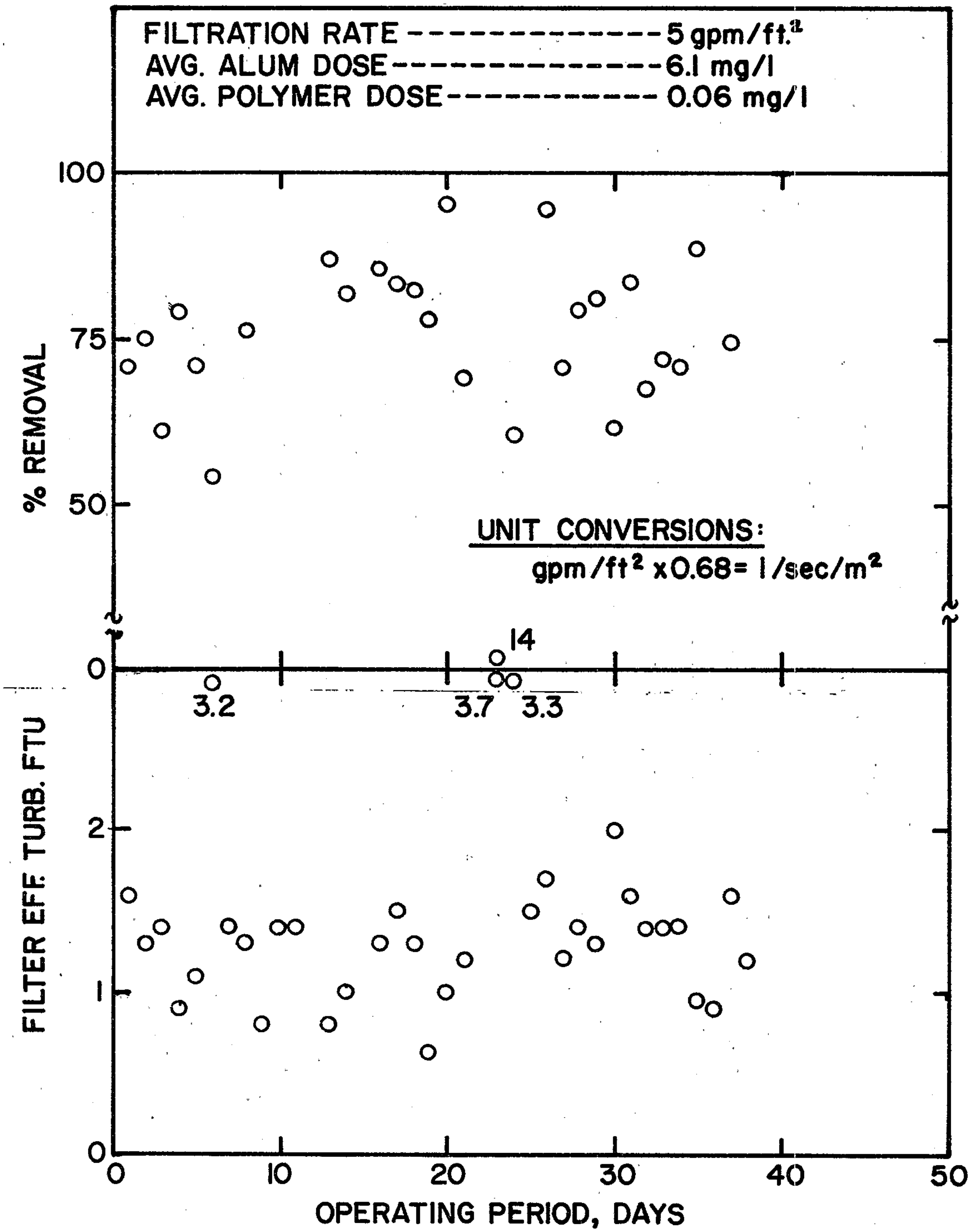

Figure 21. Turbidity removal through the filter with Scheme C pretreatment.

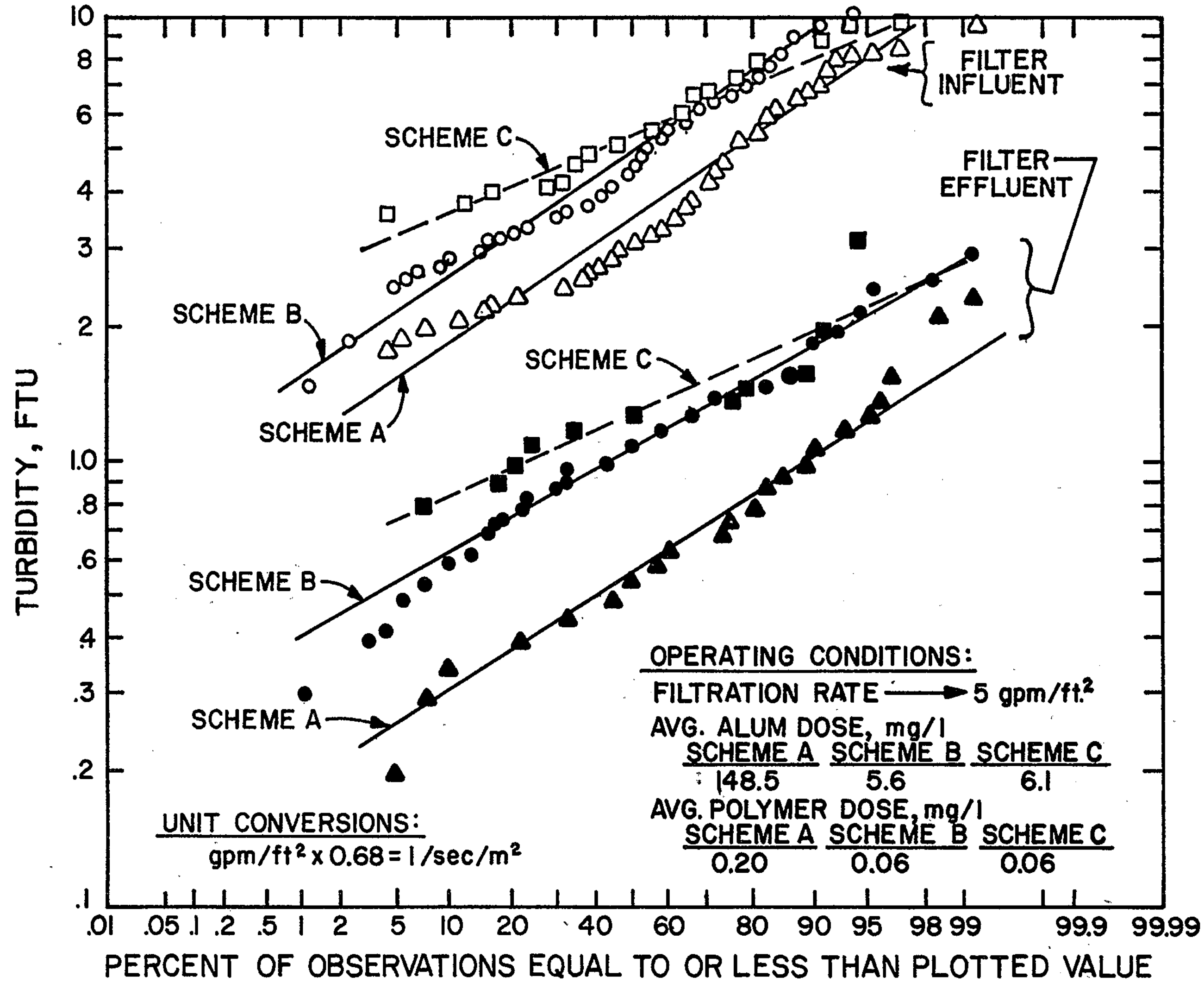

Figure 22. Frequency distributions of filter influent and effluent turbidity levels.

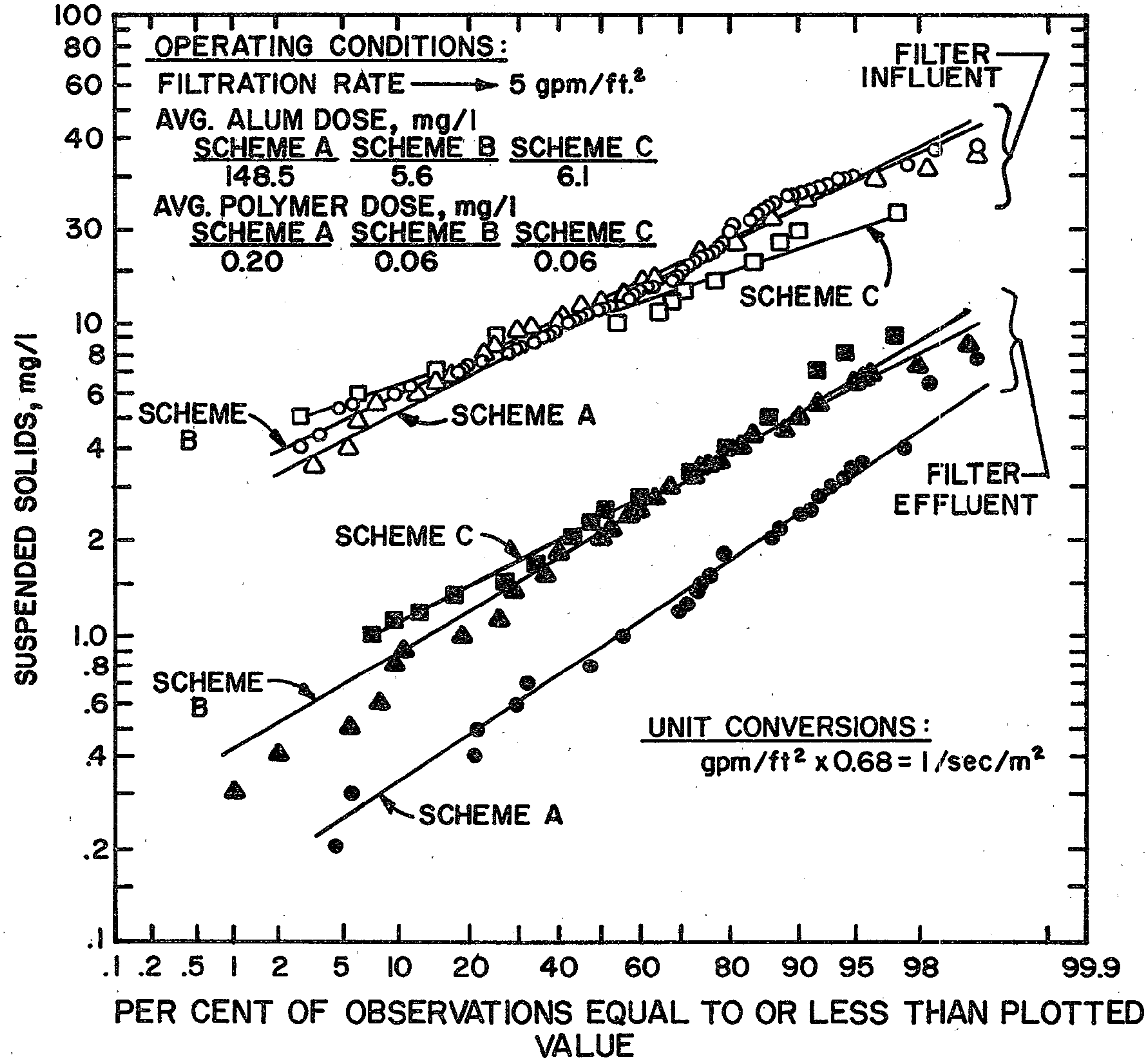

Figure 23. Frequency distributions of filter influent and effluent suspended solids.

the relationship between the filter influent and effluent suspended solids for the three types of pretreatment schemes. Figure 24 presents the straight line of best fit obtained by least squares linear regression analysis. In examining the plots in Figure 24, two observations are evident. First, for any of the three pretreatment schemes, the filter effluent suspended solids levels increase with increasing influent suspended solids concentration. Secondly, the plots demonstrate the effect of type of filter pretreatment on the filter performance. For instance, for any given filter influent suspended solids concentration, the Scheme A pretreatment show consistently better filter performance than those of Schemes B and C. Moreover, for the three pretreatment schemes, the correlation coefficients exceed the 95 percent confidence coefficient. This would indicate that, with 5 percent chance of error, effluent suspended solids is dependent on influent suspended solids levels.

In Figure 25 are presented the relationship between filter effluent and effluent turbidities similar to those shown in Figure 24. The straight line plots in this figure, which were determined by least square analysis, show similar trends as those with suspended solids. The results of the regression analysis indicate that at the 95 percent confidence levels, only Schemes A and B show significant correlation. Scheme C did not show significant correlation even at the 90 percent confidence level and this is clearly indicated by the regression line with almost zero slope.

<u>Headloss Data</u>

The headloss buildup through a granular filter media is influenced by several factors, the more significant of which are hydraulic surface loading rate, the nature and concentration of influent solids, media size and frequency and type of filter backwash. In the course of the long-term filter evaluation, the two dual-media pressure filters were operated in parallel under identical conditions of hydraulic surface loading rate and backwash procedure. Thus, the magnitude of pressure drop across the inert media filters would depend primarily on the nature and concentration of influent suspended solids. Cognizant of this, a linear regression analysis was performed in an attempt to determine the relationship between the influent solids concentration and the headloss buildup. In performing the regression analysis, the influent solids concentration was expressed in three different parameters; namely, turbidity in FTU, suspended solids in mg/l, and solids capture in lbs/ft^2/run. For the three pretreatment schemes, attempts were made to correlate each of the three influent solids parameters with the total headloss across the filter after 16 hours of filter run. The results of the regression analysis indicate that only Scheme A showed significant correlation, at 95 percent confidence level, of all the three influent solids parameters with total headloss. In Schemes B and C there was no correlation found between the headloss and any of the three influent solids parameters. Figure 26 presents the correlation between filter influent suspended solids and total headloss. A plausible explanation for the absence of correlation in Schemes B and C between the influent solids parameters and total headloss could be attributed to the variability of the physicochemical characteristics and concentration of the influent solids during the course of the filter runs. It is important to recognize that because

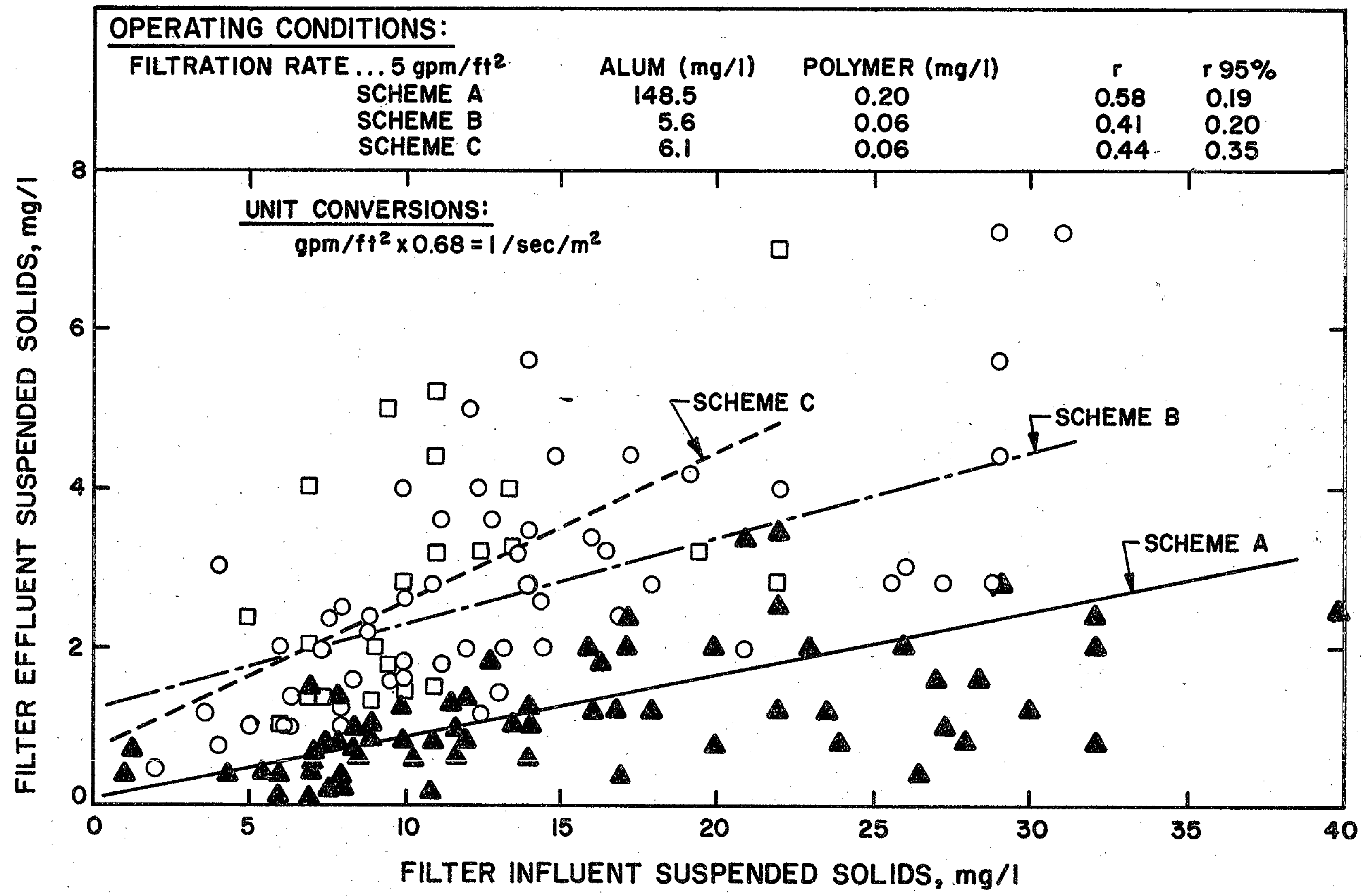

Figure 24. Correlation between filter influent and effluent suspended solids.

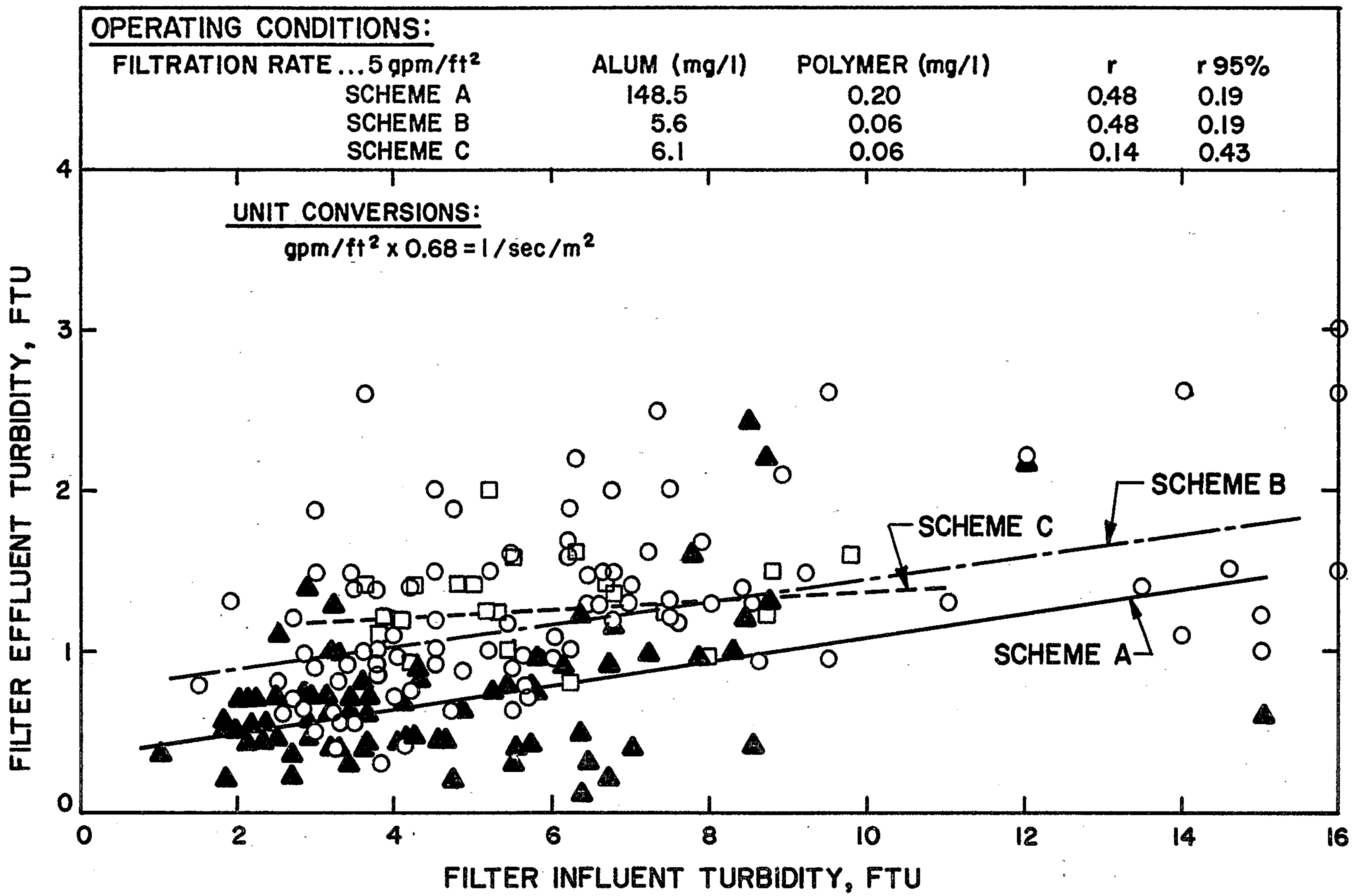

Figure 25. Correlation between filter influent and effluent turbidities.

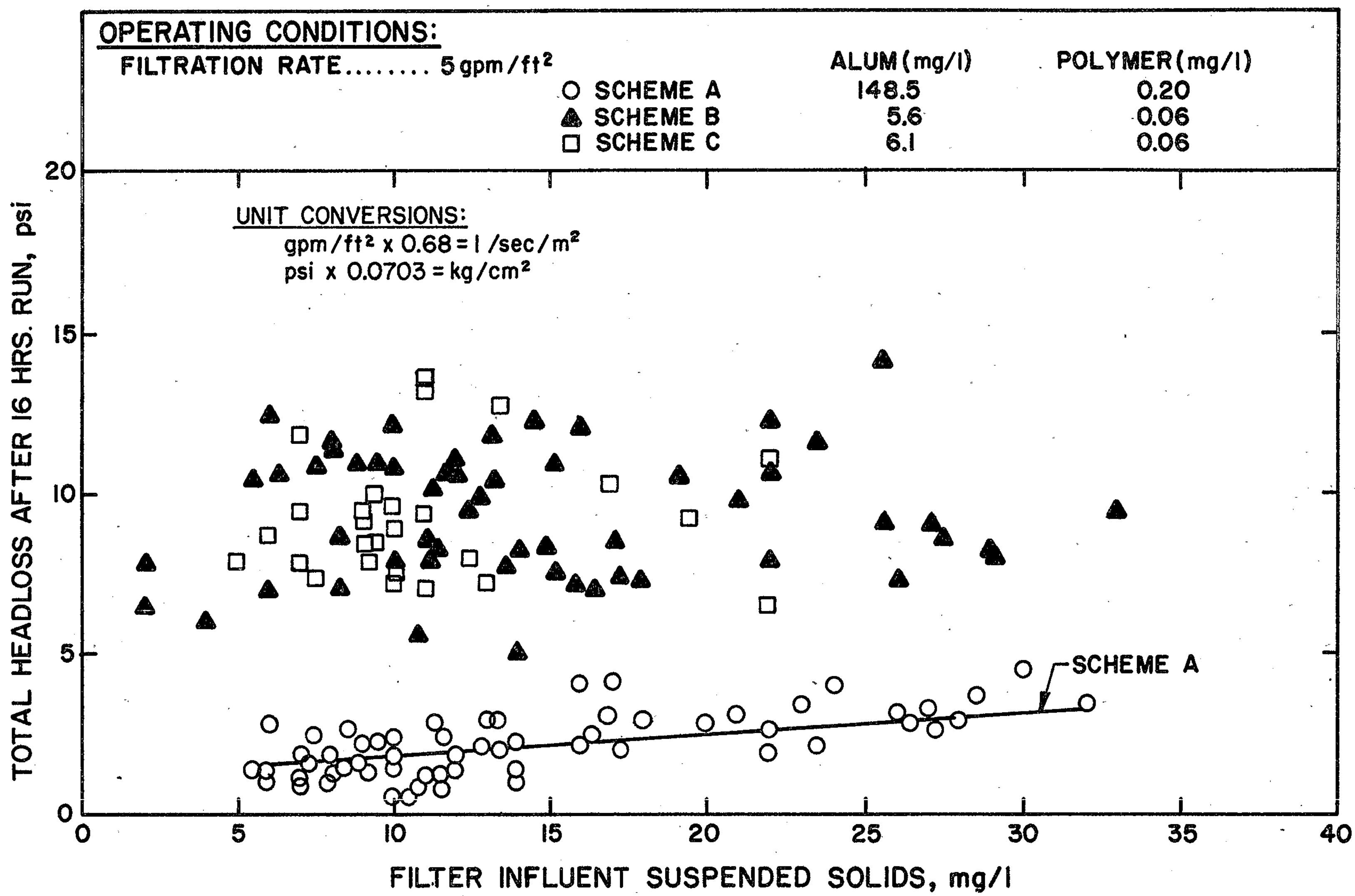

Figure 26. Correlation between filter influent suspended solids and headloss.

of this influent solids variability, a major portion of the resulting headloss buildup could have been triggered by high solid input to the filter during a certain period in the course of the filter run. The influent solids parameters used in the regression analysis were based on the test of 16-hour composite samples which in effect reflected the average solids concentration during the 16-hour period. With Scheme A pretreatment, variations in the secondary influent suspended solids were reduced by the equalizing effect of the chemical clarification-sedimentation system. Therefore, the influent solids concentration applied to the filter during the filter run was essentially constant and could be appropriately represented by the test of the 16-hour composite samples.

Figure 27 presents a plot of headloss buildup across the dual-media filter during the course of several selected filter runs for pretreatment Schemes A, B, and C. As shown in the figure, the headloss levels with coagulation-sedimentation pretreatment (Scheme A) were considerably lower than those of in-line coagulation pretreatment (Schemes B and C). For instance, at the end of 16 hours of filter run, the headloss across the dual-media filter ranged from 0.056 to 0.37 Kg/cm^2 (0.8 to 5.3 psi) for Scheme A, and 0.44 to 0.86 Kg/cm^2 (6.2 to 12.2 psi) for Schemes B and C. It is interesting to note that the range of headloss in Scheme B was essentially the same as that in Scheme C.

In Figure 28 are presented arithmetic-probability plots of total headloss across the filter after 16 hours of filter run. The headloss data presented in this figure are based on 103 days data for Scheme A, 93 days data for Scheme B, and 34 days data for Scheme C. As indicated by the frequency curves, the headloss levels in the filter with Scheme A pretreatment were appreciably lower than those observed in the filter with Schemes B and C pretreatments. The headloss across the filter ranged from 0.03 to 0.37 Kg/cm^2 (0.4 to 5.3 psi) for Scheme A, 0.32 to 0.99 Kg/cm^2 (4.5 to 14.1 psi) for Scheme B, and 0.32 to 0.93 Kg/cm^2 (4.5 to 13.3 psi) for Scheme C. Moreover, the frequency curves indicate that 50 percent of the time the headloss levels were equal to or less than 0.13 Kg/cm^2 (1.9 psi), 0.6 Kg/cm^2 (8.5 psi) and 0.62 Kg/cm^2 (8.5 psi) and 0.62 Kg/cm^2 (8.8 psi) for Schemes A, B, and C, respectively. The median filter headloss was 0.12 Kg/cm^2 (1.8 psi) for Scheme A, 0.58 Kg/cm^2 (8.3 psi) for Scheme B, and 0.62 Kg/cm^2 (8.8 psi) for Scheme C.

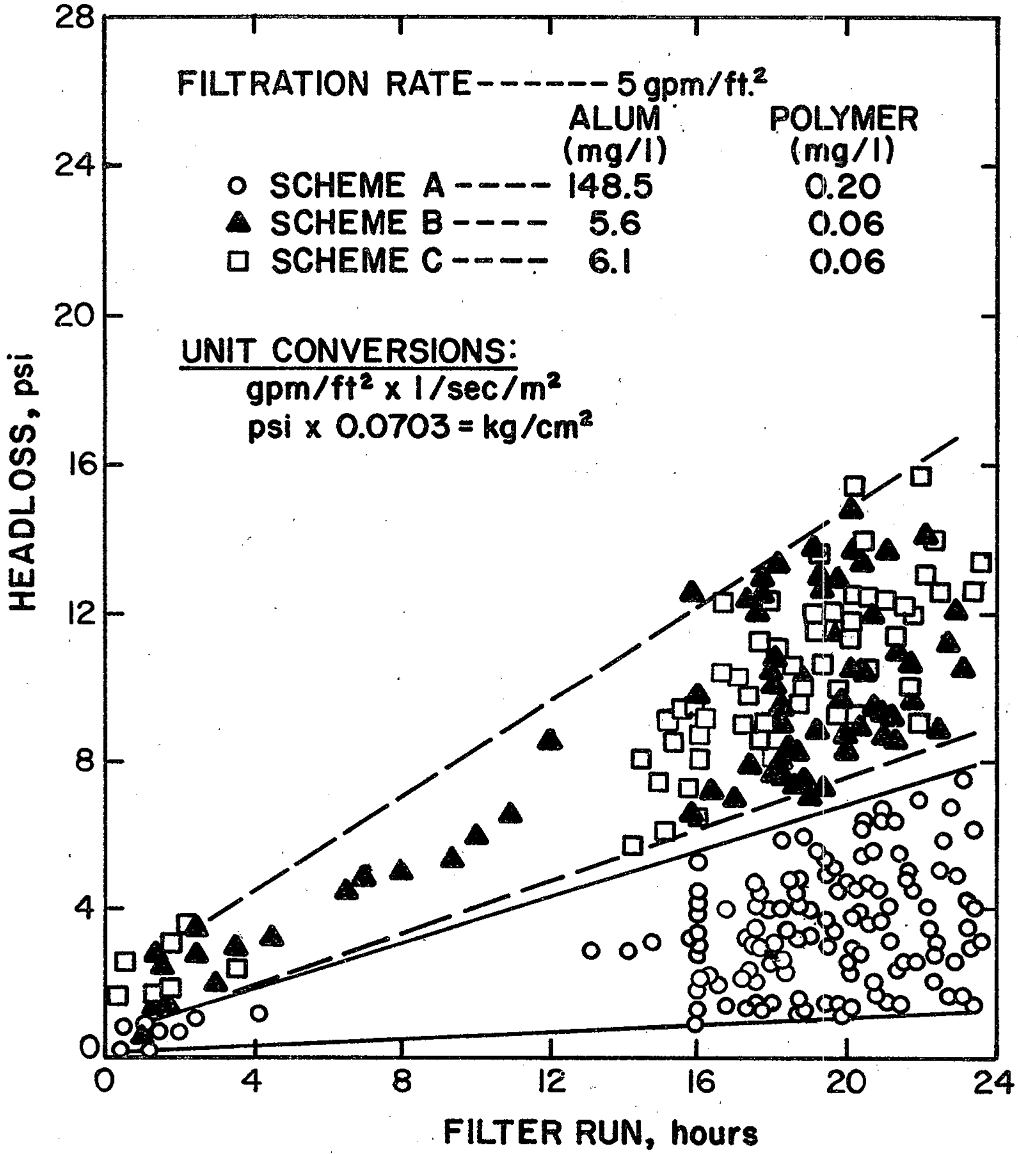

Figure 27. Effect of pretreatment on headloss.

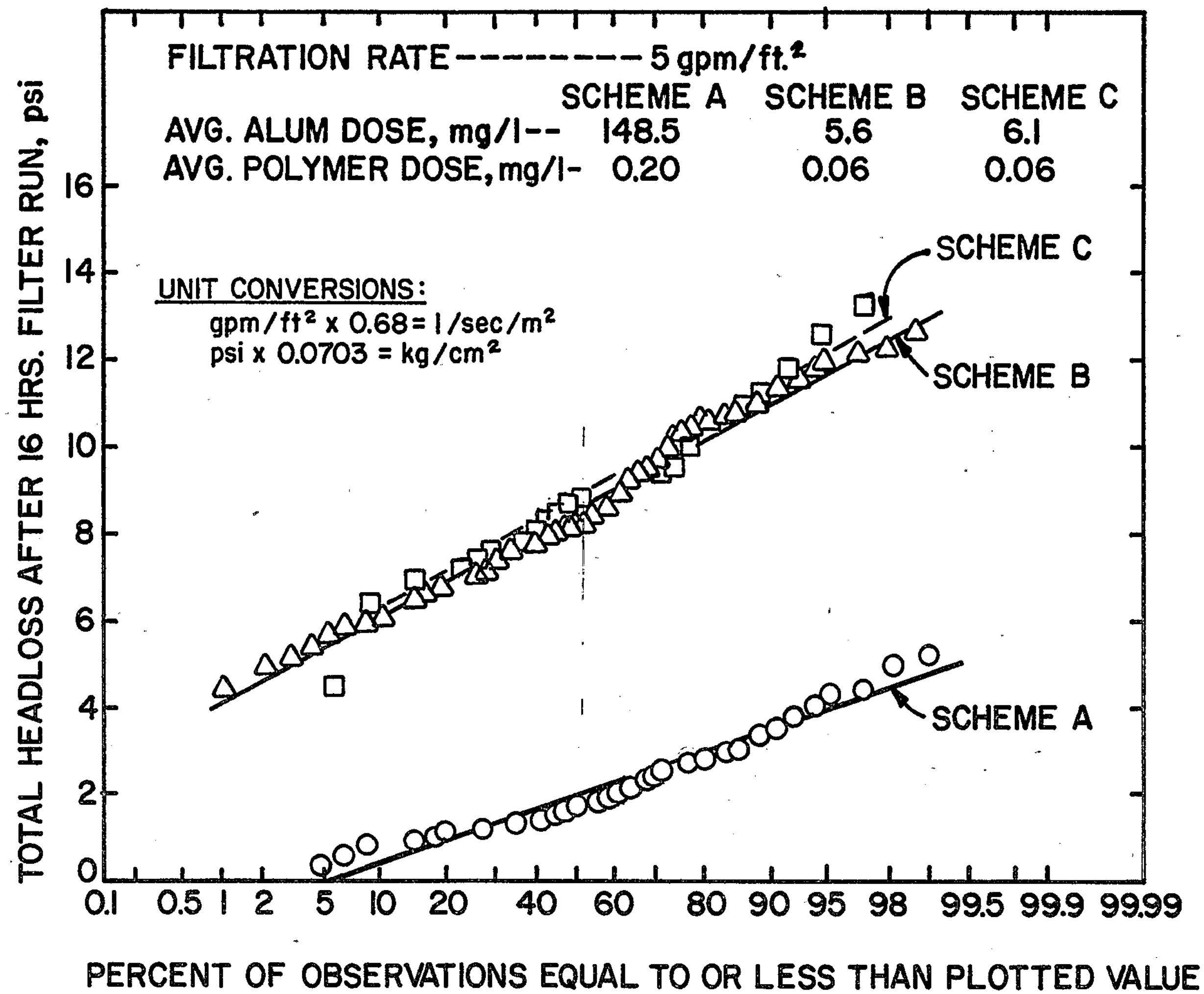

Figure 28. Frequency distribution of filter headloss.

SECTION 6

ECONOMIC ANALYSIS

The cost estimate presented in this section is based on the treatment of Pomona activated sludge plant effluent for an average design flow of 37,850 cu m/day (10 MGD) and a peak design flow of 52,990 cu m/day (14 MGD). The process design parameters for sizing the various treatment components are presented in Table 9. The unit costs for chemicals and other direct costs for estimating operation and maintenance (O/M) costs are summarized in Table 10. In Figure 29 is presented the schematic layout of the proposed filtration system with two types of filter pretreatment schemes. The various treatment units of the overall tertiary system, which are included in the cost estimate, are indicated in the figure. The capital cost estimates include the cost of all equipment, installation and construction costs, startup and testing, and a 20 percent allowance for contingencies, plus a 15 percent allowance for engineering costs. The cost of land, sludge treatment facility, chlorination system and interest during construction are not included in the cost estimate. In addition, the cost of unusual construction requirements such as rock excavation, site dewatering and extensive demolition work are not included in the cost estimate.

It must be recognized that the cost estimates presented in this report are preliminary in nature and are used only as basis to reflect the relative cost of the filtration system with two types of pretreatment schemes. The actual construction bid costs of three Sanitation Districts inert media filtration systems varying in size from 47,312 to 141,938 cu m/day (12.5 to 37.5 MGD) as well as data from literature (11,12,13) have served as a major basis in the preparation of the cost estimate. The estimate of construction costs presented are based on ENR construction cost index of 2584 for July, 1977.

In Table 11 is shown the complete cost breakdown of the inert media filtration system. The total treatment cost to produce filter effluent with characteristics similar to those presented in Tables 6 and 7 from a 37,850 cu m/day (10 MGD) plant is estimated at 4.27¢/m^3 (15.99¢/1000 gallons) for Scheme A, and 2.29¢/m^3 (8.58¢/1000 gallons) for Scheme B. The capital costs of the pretreatment system represent about 29 percent of the overall capital cost for Scheme A compared to only 6 percent for Scheme B. Moreover, in evaluating the O/M of each scheme, it is shown that, for Scheme A, the chemical cost alone represents about 63 percent of the O/M cost and about 36 percent of the total treatment cost. For Scheme B, on the other hand, the chemical cost represents only 9 percent of the O/M cost and about 3 percent of the total treatment cost. Thus, in comparing the effluent quality from the two schemes in

TABLE 9. FILTRATION SYSTEM DESIGN DATA

PRETREATMENT SYSTEM	
1. Rapid Mixing:	
Detention time, minutes	1.0
Chemical Dosage	
Alum, mg/l	150.0* (5.0)+
Polymer, mg/l	0.3* (0.06)+
2. Flocculation:	
Detention time, minutes	45.0
3. Sedimentation:	
Detention time, hours	1.5
Overflow rate, $m^3/day/m^2$	36.6
INERT MEDIA FILTRATION SYSTEM	
1. Filtration:	
Hydraulic Surface Loading, $l/sec/m^2$	2.7-4.1
Backwash Flow Rate, $l/sec/m^2$	12.2-13.6
Backwash Volume, % of plant flow	2.5* (5)+
Air scour, $l/sec/m^2$	15.2-25.4

* for Scheme A + for Scheme B

TABLE 10. UNIT COST FOR OPERATION AND MAINTENANCE ESTIMATE

CHEMICALS	
Alum, \$/Kg Al	1.00
Polymer, \$/Kg	4.40
OPERATING COSTS	
Power, ¢/Kwh	2.50
Backwash Water, ¢/m^3 (Backwash/day = 1 for Scheme A and 2 for Scheme B)	0.80
Operating and Maintenance Labor, \$/person-yr (4 for Scheme A and 3 for Scheme B)	12,000
Laboratory Personel, \$/person-yr	15,000
Maintenance Materials, \$/yr	20,000
CAPITAL COSTS	
Capital costs were amortized at 7% for 25 years	

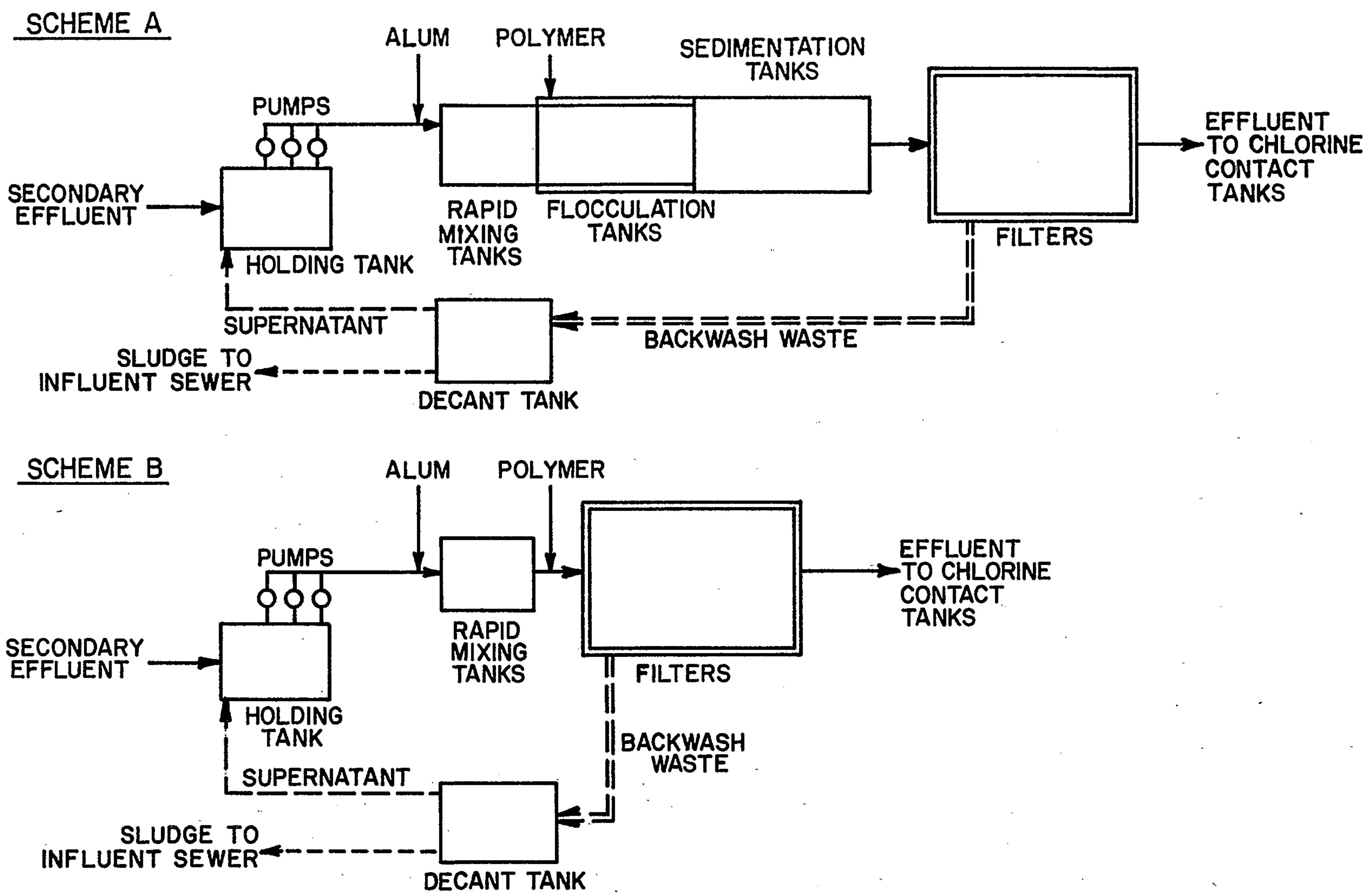

Figure 29. Schematic diagrams of proposed filtration system.

TABLE 11. ESTIMATED FILTRATION SYSTEM COST*

CAPITAL COSTS, (1000 of $)	Scheme A	Scheme B
1. PRETREATMENT SYSTEM		
Chemical Feeding System	113.70	102.00
Chemical Coagulation-Sedimentation System	506.00	--
Sub-Total	619.70	102.00
Contingencies (20%)	123.90	20.40
Sub-total	743.60	122.40
Engineering (15%)	111.50	18.40
Total Pretreatment System Costs	855.10	140.80
Amortized Cost, (¢/m^3)	0.54	0.09
2. FILTRATION SYSTEM		
Pumping Station	171.00	171.00
Inert Media Filtration System	1,330.00	1,330.00
Sub-total	1,501.00	1,501.00
Contingencies (20%)	300.20	300.20
Sub-total	1,801.20	1,801.20
Engineering (15%)	270.20	270.20
Total Filtration System Costs	2,071.40	2,071.40
Amortized Cost, (¢/m^3)	1.30	1.30
OPERATING AND MAINTENANCE COSTS (¢/m^3)		
Chemicals (Alum and Polymer)	1.54	0.08
Power	0.27	0.27
Backwash Water	0.02	0.04
Operating and Maintenance Labor	0.46	0.37
Maintenance Materials	0.14	0.14
Total Operating and Maintenance Costs	2.43	0.90
Total Treatment Cost (¢/m^3)	4.27	2.29

* Based on ENR construction cost index of 2584 (July, 1977) for a 37,850 cu m/day (10 MGD) plant.

addition to the economic analysis, it is apparent that an inert media filtration system with Scheme B pretreatment is the most practical and economically feasible choice for the removal of suspended and colloidal materials from an activated sludge plant effluent.

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16. ABSTRACT

A pilot study of filtration of secondary effluent was conducted. Turbidity and solids removal were similar for dual vs. trimedia filters, but headloss was higher across the latter. Coagulation-flocculation and sedimentation pretreatment resulted in a filter effluent superior to that when in-line coagulation alone was used and a lower rate of head loss build up. However, the latter produced acceptable results (s.s = 2.7 mg/l, FTU = 1.2) at much lower cost. Filtration rate in the range 5-10 gpm/ft^2 (3.4-6.8 l/sec/m^2) had no effect on performance except rate of headloss build up.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sewage Treatment Filtration Coagulation	Filter Media Suspended Solids Activated Sludge Effluent	13B

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