INTERACTION OF POLYMERS, NATURALLY OCCURRING ORGANICS AND CHLORINE IN THE DIRECT FILTRATION OF WATER FROM A SURFACE SUPPLY SOURCE

E-021

Completion Report
to
Water Research Center
Project No. 1-1-50660 (R)
August 1983

By

John N. Veenstra
Assistant Professor
Civil Engineering

and

Parweiz A. Khan
Graduate Student

FY 1983
Water Research Center
UCWR

INTERACTION OF POLYMERS, NATURALLY OCCURRING ORGANICS AND CHLORINE IN THE DIRECT FILTRATION OF WATER FROM A SURFACE SUPPLY SOURCE

Summary

The applicability of the direct filtration process to Lakes Carl Blackwell and McMurtry was evaluated. The study was conducted in two phases. During the first phase, 40 different polymers were tested by jar tests to see how they performed as the sole coagulant or as a coagulant aid to aluminum sulfate. On the basis of the jar tests, three nonionic, four anionic, and seven cationic polymers were selected for pilot plant testing. For both the jar tests and initial pilot plant tests, the physical variables (detention times and mixing intensitites) were kept constant. Alum and a low molecular weight cationic polymer, Magnifloc 572C, were found to be the best combination of coagulants in both the jar tests and pilot plant. The optimum dosages obtained from the jar tests were slightly higher than from the direct filtration process. After evaluation of the chemical requirements, the physical variables in the direct filtration pilot plant were optimized. The physical and chemical variables optimized were as follows:

Alum dosage = 8.0 mg/ℓ (summer)
= 12 mg/ℓ (winter)
Polymer = 0.4 mg/ℓ (winter and summer)
Rapid mix time = 1.5 minutes (winter and summer)

Rapid mix "G" = 900 sec^{-1} (winter and summer)

Flocculation time = 12 minutes (winter and summer)

Flocculation "G" = 20 sec^{-1} (winter and summer)

Filtration rate = up to 7 gpm/ft^2 (winter and summer)

The finished water quality of both the conventional and direct filtration plant was comparable. Both processes had excellent turbidity and bacterial removals. However, the direct filtration pilot plant was unable to produce an effluent turbidity below one NTU when the raw water turbidity was greater than 60 NTU. The levels of THMs for both the processes were greater than the EPA allowable limit of 100 $\mu g/\ell$. Of the THM control methods investigated, ammonification at a ratio of 1:4 (NH_4:Cl) by weight was found to be the most effective.

Statement of the Problem

The primary objective of this research was to evaluate the feasibility of using the direct filtration process to treat water from Lakes Carl Blackwell and McMurtry, the current raw water supply for the City of Stillwater, Oklahoma.

To reach this objective a multifacted approach was taken which involved the optimization of both the chemical and physical variables of a direct filtration pilot plant. More specifically, individual items addressed while conducting this overall evaluation of the direct filtration process are as follows:

1. The ability of synthetic polymers (cationic, anionic, and nonionic of various molecular weight ranges) to act as coagulants or coagulant aids with alum.

2. Compare the coagulant dosages obtained from the jar tests (batch system) and the pilot plant (continuous system).
3. Determine the effect of operational parameters, flow rates, detention time, and power input on the performance of the direct filtration process.
4. Determine the THM production in the finished water that results from different points of chlorine injection and/or ammonification.
5. Investigate the removal of naturally occurring organics, based on molecular weight, in the units of both the conventional and direct filtration process.
6. Compare the dewaterability of backwash water sludges for different coagulants (alum, polymer, and alum plus polymer).
7. Compare the finished water quality of both the conventional and direct filtration systems with respect to TOC, THM, turbidity, and bacteria.
8. Undertake an economic evaluation of the operational costs of both the direct filtration and conventional filtration process.

Another general question answered by the research is whether the direct filtration is a feasible process for the type of water found in the midwest. To date most of the full scale direct filtration plants are located in the eastern United States where the water is usually very low in turbidity, but contains moderate color. Most waters located in the Midwest contain moderate turbidity, but are fairly low in color. Of course the feasibility of this process at any location will depend on the unique characteristics of the water to be treated.

INTERACTION OF POLYMERS, NATURALLY OCCURRING ORGANICS AND CHLORINE IN THE DIRECT FILTRATION OF WATER FROM A SURFACE SUPPLY SOURCE

Introduction

Direct filtration is defined by the Direct Filtration Subcommittee of the AWWA Filtration Committee as a process train with coagulant addition, some flocculation with no settling, followed by filtration (1). Since this system excludes the sedimentation process found in conventional water treatment plants, it would allow for a savings in capital costs, approximately 30% relative to the conventional treatment process (2), by the construction of fewer basins in the plant. Besides lower capital costs, a direct filtration plant has reduced space requirements and sludge production (3). Wagner and Hudson (3) further state that direct filtration may offer surprisingly large reductions in coagulant chemical dosages and costs. Culp (4) stated that with direct filtration there may be a savings of 10-30% in chemical costs. With the potentially favorable economics of direct filtration, both in terms of capital and operating costs, it becomes an attractive treatment alternative during these times of rising capital and chemical costs.

Potentially amenable waters for the direct filtration process are low in both turbidity and color. The exact limits for turbidity and color, as seen in the literature, cover a wide range, as illustrated in Table 1. The AWWA Direct Filtration Committee (1) states that color exceeding 30-40 Hazen units or turbidity greater than 15 FTU (formazin turbidity units) on a continuing basis could be expected to give problems. Baumann (9) states

Table 1. Recommended Raw Water Quality Maximums for Direct Filtration

Investigator	Max. Turbidity	Max Color	Conditions
Culp (4)	25 NTU	25 Units	
	200 NTU	--	Low color
	--	100 Units	Low turbidity
Amy (5)	10 NTU	--	
Kawamura (6)	10 NTU	--	
Tredgett (7)	50 NTU	--	
Walder *et al.*(8)	25 - 30 NTU	--	
Baumann (9)	50 - 60 NTU	--	
Hutchinson (10)	20 - 25 NTU	--	Using alum
	150 NTU	--	Using cationic polymers
AWWA Filt. Comm. (1)	15 NTU	30-40 Units	
McCormick and King (11)	25 NTU	--	Low color and algae

that direct filtration is a currently accepted technology for producing potable water from raw water with turbidity to 50 - 60 TU, or color greater than 100 units. Criteria for potential applications of direct filtration are simply "ball park" figures and other variables, such as water pH and temperature, may also influence filtration capabilities. Since so many variables seem to influence this process, each water subject to treatment will have its own unique characteristics.

To date the direct filtration process has had limited, if any, opportunity to be tried on Oklahoma waters. New more stringent turbidity limits, set by the National Interim Drinking Water Regulations, may account for the reluctance to try this process. A limit of one turbidity unit could be difficult to achieve without a sedimentation basin. The new turbidity limit of 1.0 NTU has imposed a greater burden upon communities which heretofore had water supplies which were potable with little or no treatment other than disinfection. To meet the new standards will necessitate the construction of expensive new water treatment plants. Direct filtration of water results in the elimination of costly sedimentation basins and, at time, flocculation basins as well. The characteristics of the direct filtration process makes it an attractive treatment alternative for communities with high quality raw water sources facing the construction of new water treatment facilities.

In an attempt to determine if this process could perform satisfactorily on an Oklahoma water supply, a pilot plant was constructed to treat the waters from Lakes Carl Blackwell and McMurtry. A preliminary review of water quality data indicates a turbidity value of 24 or less turbidity units has a 50% probability of occurrence and a value of 46 or less turbidity units has a 95% probability of occurrence (12). These characteristics indicate that these waters could be likely candidates for direct filtration for removal of turbidity.

Another concern for direct filtration technology is the regulation promulgated by the U.S. EPA on November 29, 1980 that will limit trihalomethanes (THM's) to 100 μg/ℓ in supplies serving over 10,000 people. The THM's are formed upon chlorination of a water to affect disinfection. The chlorine reacts with humic and fulvic acids already present in the water to form THM's (13). In a conventional water treatment train, the coagulation, flocculation, and sedimentation processes are used to remove the precursors from the water. The question then arises, how efficient is direct filtration in removing these precursors so as to limit subsequent THM production? If the process is able to adequately remove these precursors, it would be a big plus for the direct filtration. The potential savings that could be achieved by direct filtration give sufficient reason to pursue this research to see if the turbidity and THM standards can be met by this process.

Objectives

The primary objective of this research was to evaluate the feasibility of using the direct filtration process to treat water from Lakes Carl Blackwell and McMurtry. Jar tests were used to screen various polymers in order to determine the most effective type for turbidity removal. The jar tests were also used to establish the optimum dosage for both aluminum sulfate and the selected polymers. The optimum dosages for the coagulants established in the jar tests will then be tested on pilot scale direct filtration plant in order to see how well the jar test data predict the performance of a continuous flow system. Stumm and Novak (14) state that jar tests data cannot be used to select polymers for direct filtration. Other factors which possibly influenced the results of direct filtration will be examined. This will include turbidity and color, along with the precursor material for THM's.

Also investigated will be the effects of mixing intensity, application rates (gpm/ft^2) and detention time in the individual units on the total performance of the direct filtration plant. How these variables affect filter performance were indicated by head loss, filter water turbidity, length of filter run and volume of water filtered. Sludge produced by the pilot plant will also be examined for dewaterability.

The ability of a direct filtration plant to remove THM precursors will also be investigated. This part of the study will also involve moving the point of chlorination to reduce THM formation. Since this could affect the bacterial safety of the treated water, bacterial plate counts will be run to see if this adversely affects water quality.

Materials and Methods

The water used for this study was taken from the influent to the OSU water treatment plant. The plant draws its raw water from Lakes Carl Blackwell and McMurtry. Although subject to rather wide fluctuations in turbidity, the quality of the water appears to be acceptable for a direct filtration system. Table 2 contains a summary of raw water quality data for the OSU plant (12).

Prior to pilot-scale plant trials, jar tests were used to screen polymers and determine the optimum dose for filtration applications. This is the traditional method for determining the optimum chemical

Table 2. Statistical Analysis of Raw Water Quality, Water Treatment Plant, Oklahoma State University, January 1974 through November 1979 (12).

Parameter	% Less than or Equal to Probability of Occurrence	
	50%	95%
Turbidity (NTU)	24	46
Total Hardness (mg/ℓ)	156	192
Total Alkalinity (mg/ℓ)	108	142
pH	7.9	8.3

(inorganic or organic) dose for plant operation for flocculation and sedimentation, and it is used in most plants in the United States (15). The main drawbacks of the jar test are: (1) the difficulty of reproducing conditions existing in the full-scale process in such a small-scale mixing device and this does not represent a true hydraulic model of the full-scale plants, and (2) subjective nature of the floc evaluation if determined visually. Despite these disadvantages, jar testing is a simple batch process that is quick and easy to run and does not involve the use of any sophisticated equipment. It has been used in a number of studies to determine the optimum dose of polymer for the filtration processes (16, 17, 18).

Laboratory jar tests were performed on raw water using alum, polymers, and alum plus polymers. All jar tests were conducted on a Phipps and Bird multiple lab stirrer, using one liter beakers with a sample volume of 1000 mℓ. Mixing paddles were positioned one inch above the bottom of the beakers. Paddles had a three square inch surface area (three inches wide by one inch high). The jar test procedure included two-minute rapid mix period at 100 rpm after the addition of predetermined amounts of coagulant. Subsequently, the rate was reduced to 30 rpm for a twenty-minute flocculation period. A final thirty-minute sedimentation period was employed to allow the particle aggregates to settle from the suspension. A 50 mℓ sample of supernatant was then withdrawn from 1.0 inch below the surface of the liquid and used for residual turbidity analyses.

Residual turbidity analyses were determined with a Hach ratio turbidimeter model 2100 A. Turbidity units were recorded as Nephelometric turbidity Units (NTU). The turbidimeter was calibrated daily using calibration standards commercially prepared by Hach Chemical Company.

The tests used to characterize the raw and filtered water were analyzed by the procedures described in the fourteenth edition of APHA's Standard Methods (19). The test procedures were alkalinity and hardness.

Electrophoretic mobility was measured with a Zeta meter manufactured by Zeta-Meter, Inc. Particle charge was evaluated during filter runs and jar tests. Particle charge and migration velocity were observed under the microscope and the electrophoretic mobility was determined according to manual supplied by company (20).

A small pilot plant direct filtration water treatment plant was constructed in the laboratory to allow for data collection and to facilitate the objectives described earlier. In general, the treatment units were constructed out of 1/4" thick plexiglass sheets. The treatment units and the flow schemes employed are as shown in Figure 1. The raw water was pumped from the intake structure of the Oklahoma State University (OSU) water treatment plant and to a constant head tank. The constant head tank had a capacity of 13.2 gallons. The pumping rate was approximately 1.5

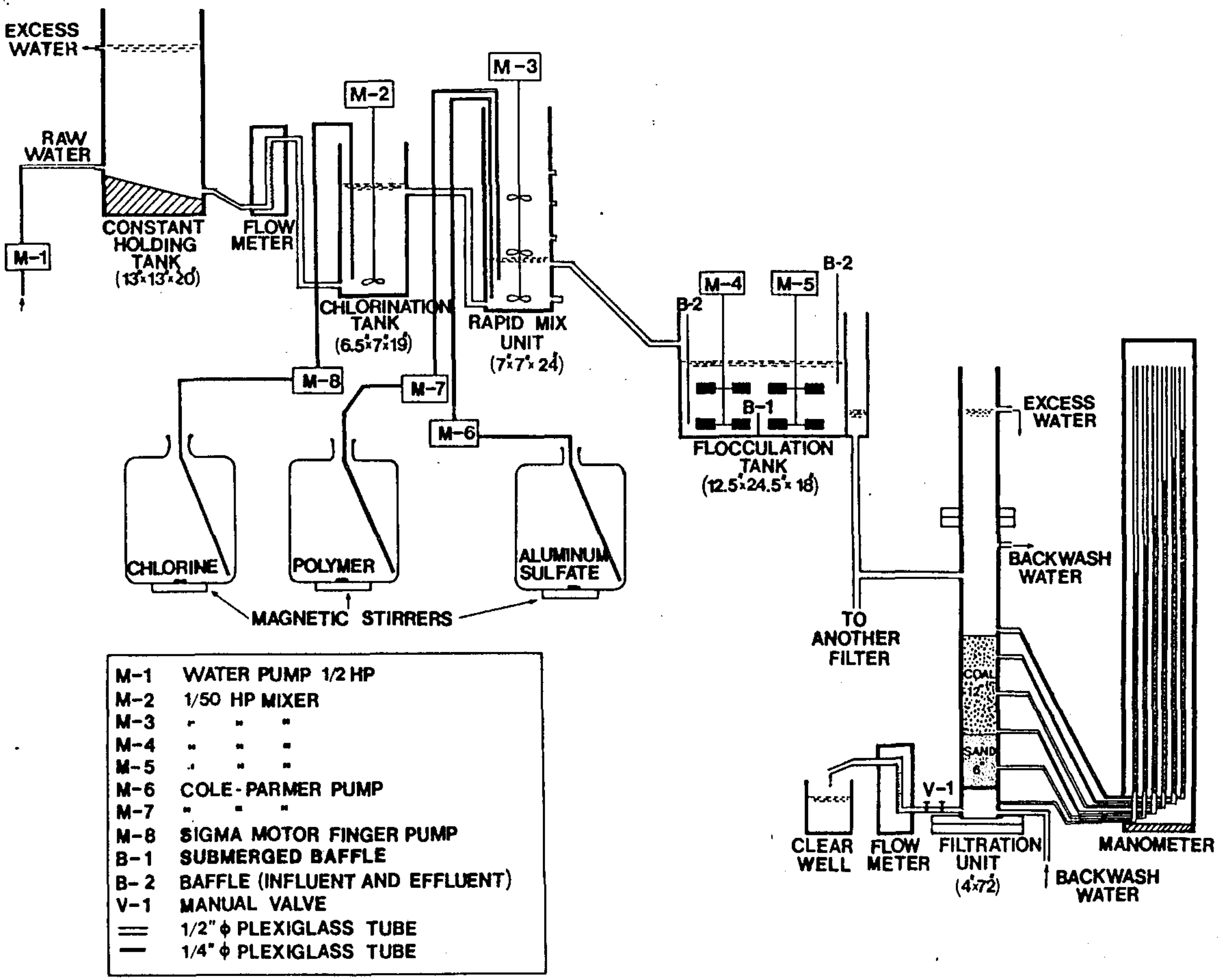

Figure 1. Schematic of pilot-scale direct filtration system.

gallons per minute. Overflow from the constant head tank was returned to the OSU water treatment plant sludge holding tank through an overflow port at the top of the constant head tank. No mixing was provided in the constant head tank, as sedimentation was observed to be minimal.

The rapid mix unit was 7.0 in. (W) x 7.0 in. (L) x 24 in. (H). The influent line was 1/2 in. in diameter. The influent port, located one inch above the bottom of the unit, discharged closed to the mixer blades. Six effluent ports of the same diameter were located on the opposite wall of the unit at varying heights above the bottom. By using different effluent ports and different tank volumes, various detention times could be achieved without changing the influent flowrate. The unit mixer was a 1/50 HP mixer controlled by a voltage regulator. Cole-Parmer pumps were used to deliver both aluminum sulfate and the polymer to the tank. To prevent premature interaction between the polymer and aluminum sulfate, the polymer was delivered at a point approximately 1.0 inch below the water surface while the aluminum sulfate was delivered to a point close to the mixer blades and influent port. The water flowed out of the rapid-mix unit by gravity through 1/2" plexiglass tubing to the flocculation unit.

Dimensions of the flocculator were 12-1/2" (W) x 24-1/2" (L) x 18" (H). The flocculator operated with a similar flow pattern to the rapid-mix basin with effluent ports at varying heights to vary tank volume and detention time. Three baffles, one located in the center of the unit and the others located about one inch away from the influent port and discharge weir, prevented short curcuiting in the unit. Two mixers of 1/50 HP each provided a velocity gradient of 30 sec^{-1} in each of the units two compartments.

The effluent from the flocculator entered a Y tube that allowed the flow to be directed to two dual media filters of equal dimensions. The two filter media employed in the study were coal and sand. The media characteristics were as follows. The effective size of the sand was 0.4 - 0.5 mm with a coefficient of uniformity of 1.5. The coal used was "anthrafilt", an anthracite coal obtained from the OSU water treatment plant. The effective size of the coal was 0.8-1.0 mm with a uniformity coefficient of 1.2. The depth of sand in the filters was 6 inches, while the coal depth was 12 inches. In place of underdrain material, a stainless steel net of 40 U.S. sieve size was used. Underneath the stainless steel net was a plexiglass plate with a random pattern of 1/4 inch holes to allow drainage.

The filters were constructed of plexiglass columns 72 inches tall and 4 inches in diameter. Manometer tubes were connected at four inch intervals to determine head loss profiles throughout a filter run. The flow rate was monitored by Fisher flow meters. The flow rate was adjusted and was controlled by a manual valve. The filtration system was run under constant head and variable flow rate. Filtration experiments were terminated when an overall head loss of 24 inches (60 cm) developed or when the effluent contained a turbidity of greater than 1.0 NTU. Backwashing consisted of washing with tap water for 15 minutes at a rate of 15 gpm/ft^2.

The various velocity gradients, $\bar{G}$, were determined by measuring the impeller rotational speed, N, and the net torque, T, and then calculating the value according to the following expression given by Camp (21).

$$\bar{G} = \frac{\pi N T^{\frac{1}{2}}}{30 V \mu}$$

where

N = paddle speed (rpm)

T = input torque (dyne-cm)

V = mixing chamber volume (cm^3)

μ = absolute viscosity of fluid (g/cm sec)

Torque measurements were made by mounting a torque-meter between the motor and mixing rotor. The torque and rpm were directly evaluated with a strobe light.

The motor drives were of a variable speed type that could be varied from 100 rpm to 1800 rpm. The shaft mounted torque-meter, made by Power Instruments, Inc., was functional between one and ten oz-inches.

For samples of backwash water, capillary suction time (CST) was used to determine the dewatering properties of the residue. During the experiments the 5 mℓ sample size and the standard grade filter paper were kept constant. The CST is quantitatively related to the filtration characteristics of the sludge. The lower the CST the better the filtrability of the sludge (22). The CST instrument used was a product of Triton Electronics, LTC.

Depending on the filter run length anticipated, 10 or 20 liters of the constant feed stock solution was prepared. The aluminum sulfate was obtained from the OSU water treatment plant. The concentrations of 4 gm/ℓ in the stock solution was kept consant throughout the jar test and continuous-flow system.

The amount of polymer required to produce a feed stock solution of a predetermined concentration was calculated based on feed pump rate and flow through the filters. This amount of polymer was dissolved in two liters of water, which was constantly mixed. To insure that the polymer was dissolved completely, the solution was mixed for one hour and then diluted to 10 liters.

in a feed bottle. It was mixed for two hours in the feed bottle before use.

Samples of water for the analysis of the molecular weight of the naturally occurring organics and total coliform counts were collected in one-liter glass bottles with plastic screw-on caps containing a Teflon sealing liner. Bacterial samples were run in accordance with the Most Probable Number (MPN) Technique set out in Standard Methods (19). The samples collected for molecular weight determinations were concentrated by lyophilization. A dextran gel (Sephadex), G-75 manufactured by Pharmacia Fine Chemicals of Uppsala Sweden was used to effect the molecular weight fractionation in this study. The organics eluting off the Sephadex Column were measured by ultraviolet observance at 254 nm.

Samples for THMs analysis were collected in 40 mℓ vials with plastic screw-on caps containing a Teflon sealing liner. Samples for instantaneous THMs were treated with sodium thiosulfate to stop the THM formation. Samples collected for terminal THM analysis were stored at 20°C for 72 hours and then quenched with sodium thiosulfate. The THM analysis were conducted following a liquid-liquid extraction (23) on a Hewlett Packard Model 7226A gas Chromatograph equipped with a Ni63 electron capture detector. A 6 foot x 1/4 inch glass column packed with 4% SE-30 and 6% OV-210 on 80-100 mesh gas chrom Q was used to perform the separation.

Results and Discussion

Raw Water Quality

The key variable in any water treatability study is the quality of the raw water to be treated. The quality of the raw water at the Oklahoma State University water treatment plant varies throughout the year, depending on such factors as temperature and rainfall. Chemical requirements at the treatment plant are dependent on these seasonal variations.

Figure 2 illustrates the variation in water quality using monthly average values for a six-year period, taken from the OSU water treatment plant records for selected raw water quality parameters. Of the parameters shown in Figure 2, only water temperatures displays a repeatable seasonal pattern. The water quality parameters affecting this study, both the jar tests and pilot plant work, were those observed between July 1981 and December 1982. Water quality parameters not usually measured during normal treatment plant operations, but measured in this study, were the apparent molecular weight distribution of the naturally occurring organic compounds, Ultraviolet (U.V.) absorbance (254 nm), total organic carbon (TOC), and bacterial counts (MPN).

Chemical Selection

A preliminary screening of coagulants, and their required doses, to be used in this study was conducted by using jar tests. The coagulants screened were alum, polymer, and alum plus a polymer. The polymers in the jar tests, alone or in combination with alum, are listed in Table 3. This list includes 22 cationic polymers, 13 anionic polymers and 7 nonionic polymers. The total number of jar test observations made during this screening process was over 1200.

The jar tests were run between July 1981 and December 1981. Representative data from jar tests at raw water temperatures ranging from 5 to 23°C, using only alum as the coagulant has been plotted as shown in Figure 3. This figure shows that the alum dosage required for optimum turbidity removal is between 20 and 25 mg/ℓ for all temperatures. At those dosages,

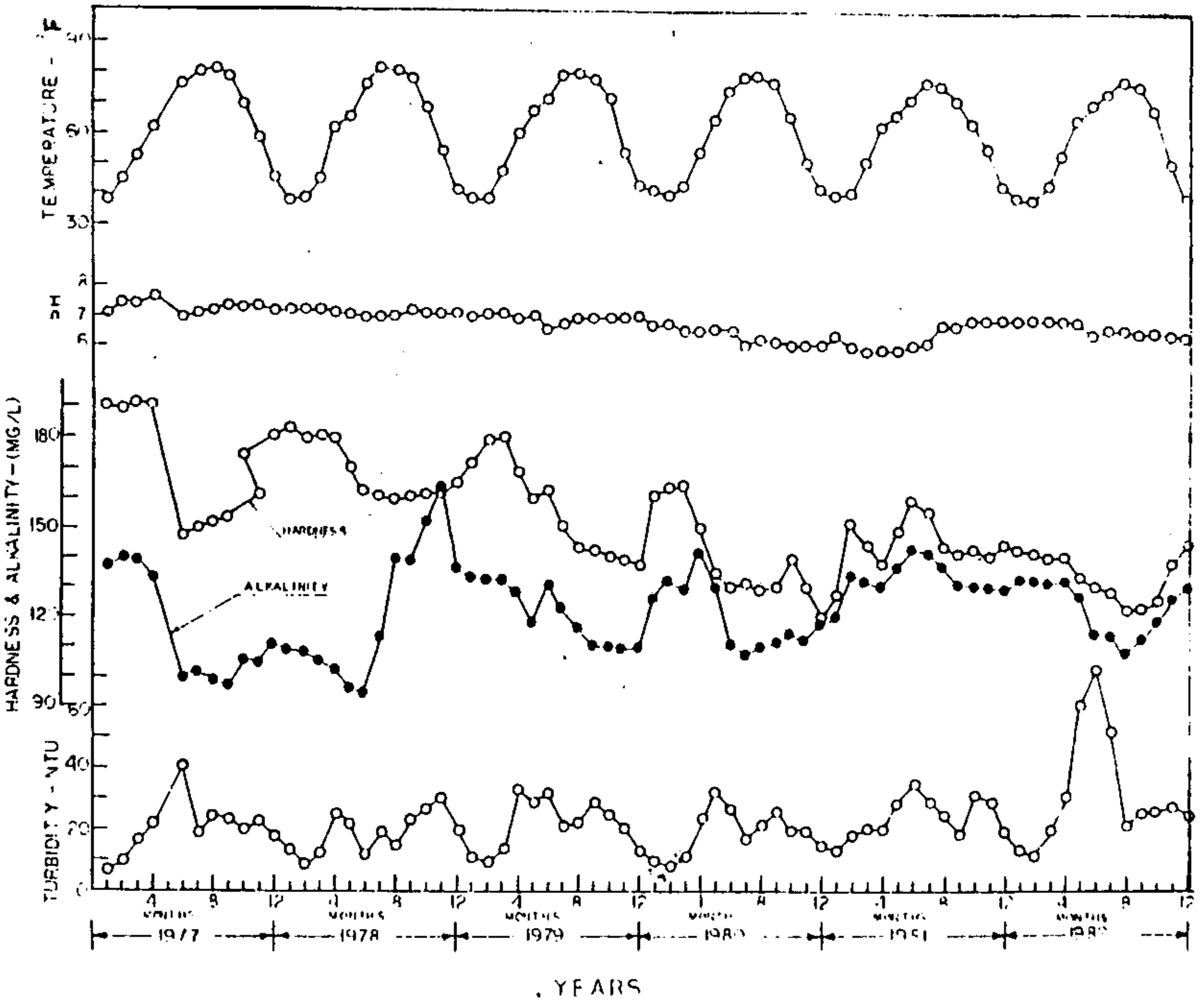

Figure 2. Variations of Raw Water Quality Characteristics

Table 3. Characteristics of Polymers

Polymer	Type	Molecular Weight	Allowable Dosage mg/ℓ
American Cynamid Co.			
Magnifloc 587C	Cationic	200,000	50.0
Magnifloc 579C	Cationic	≈1 x 10^6	20.0
Magnifloc 572C	Cationic	20,000	20.0
Magnifloc 517C	Cationic	NA	40.0
Magnifloc 521C	Cationic	NA	10.0
Magnifloc 515C	Cationic	≈10,000	50.0
Magnifloc 505C	Cationic	NA	50.0
Nalco Co.			
Nalcolylē 8101	Cationic	Moderate	50.0
Nalcolylē 8102	Cationic	Moderate	50.0
Nalcolylē 8103	Cationic	Moderate	50.0
Nalcolylē 8104	Cationic	Moderate	75.0
Nalcolylē 8105	Cationic	Low MW	20.0
Nalcolylē 8106	Cationic	Low MW	30.0
Nalco 2103-288BX	Cationic	50,000	50.0
Calgon Co.			
Catfloc T-1	Cationic	NA	5.0
Catfloc 121	Cationic	NA	6.0
Catfloc T	Cationic	NA	50.0
Catfloc C	Cationic	NA	NA
Catfloc	Cationic	NA	NA
Catfloc 21	Cationic	NA	15.0
Betz Co.			
Betz 1160	Cationic	3 x 10^6	1.0
Betz 1190	Cationic	50,000	10.0

(continued)

Table 3. (Continued)

Polymer	Type	Molecular Weight	Allowable Dosage mg/ℓ
American Cynamid Co.			
Magnifloc 1839A	Anionic	≈15 x 10^6	4.0
Magnifloc 844A	Anionic	High	1.0
Magnifloc 845A	Anionic	High	1.0
Magnifloc 846A	Anionic	High	1.0
Magnifloc 847A	Anionic	High	1.0
Calgon Co.			
Coagulent Aid 243	Anionic	High	1.0
Coagulent Aid 253	Anionic	Moderate	1.0
L-675	Anionic	NA	1.0
Nalco Co.			
Nalco-2103-288E	Anionic	10-15 x 10^6	NA
Nalco-2103-288F	Anionic	10-15 x 10^6	NA
Betz Co.			
Betz 1100	Anionic	5 x 10^6	1.0
Betz 1110	Anionic	High	1.0
Betz 1120	Anionic	High	1.0
American Cyanamid Co.			
Magnifloc-1986 N	Nonionic	≈15 x 10^6	4.0
Magnifloc-985 N	Nonionic	>20 x 10^6	1.0
Magnifloc-990 N	Nonionic	>20 x 10^6	1.0
Nalco Co.			
Nalco 2103-288 G	Nonionic	≈15 x 10^6	NA
Betz Co.			
Poly Floc 3	Nonionic	High	30.0
Calgon			
Coagulent Aid 233	Nonionic	High	1.0
Calgon-L-650 E	Nonionic	High	NA

the natural zeta potentials (ZP) of the raw water has decreased from 20 to 30 mv down to -1 to -12 mv.

Jar tests using 42 different polymers as the sole coagulant were studied. Figure 3 also serves to illustrate the type of data obtained from the various types of polymers tested. The results showed that only four of the 42 polymers tested were able to reduce the turbidity to 1 NTU or less. The four best performing polymers in the jar tests (Figure 3) were Magnifloc 572C, Magnifloc 587C, Nalco 8104, and Nalco 2103-288B. Nalco 2103-288B was furnished as a polymer suitable for use in potable water, however, upon rechecking with Nalco Chemical Company after the test work had been completed it was discovered that the polymer was suitable for use in wastewater only. Since the polymer was used throughout the study, the results are presented.

All four of these polymers are cationic in nature. There molecular weights ranged from 20,000 for Magnifloc 572C to 200,000 for both Magnifloc 587C and Nalco 8104. Nalco 2103-288B had a molecular weight of 50,000. The polymers exhibited optimum dosages, lowest residual turbidities, between 2.25 and 2.75 mg/ℓ at all temperatures tested. All 13 anionic polymers screened by the jar test procedure failed to reduce the turbidity below 4 NTU. Likewise, all 7 nonionic polymers used in this part of the study were unable to reduce the turbidity below 8 NTU. Figure 3 also shows the jar test results of 3 anionic and 2 nonionic polymers. The results portrayed are typical of those obtained when the remaining anionic and nonionic polymers were screened. The molecular weights of all the anionic and nonionic polymers were between 5 and 20 million.

Jar tests using the same 42 polymers mentioned earlier were also

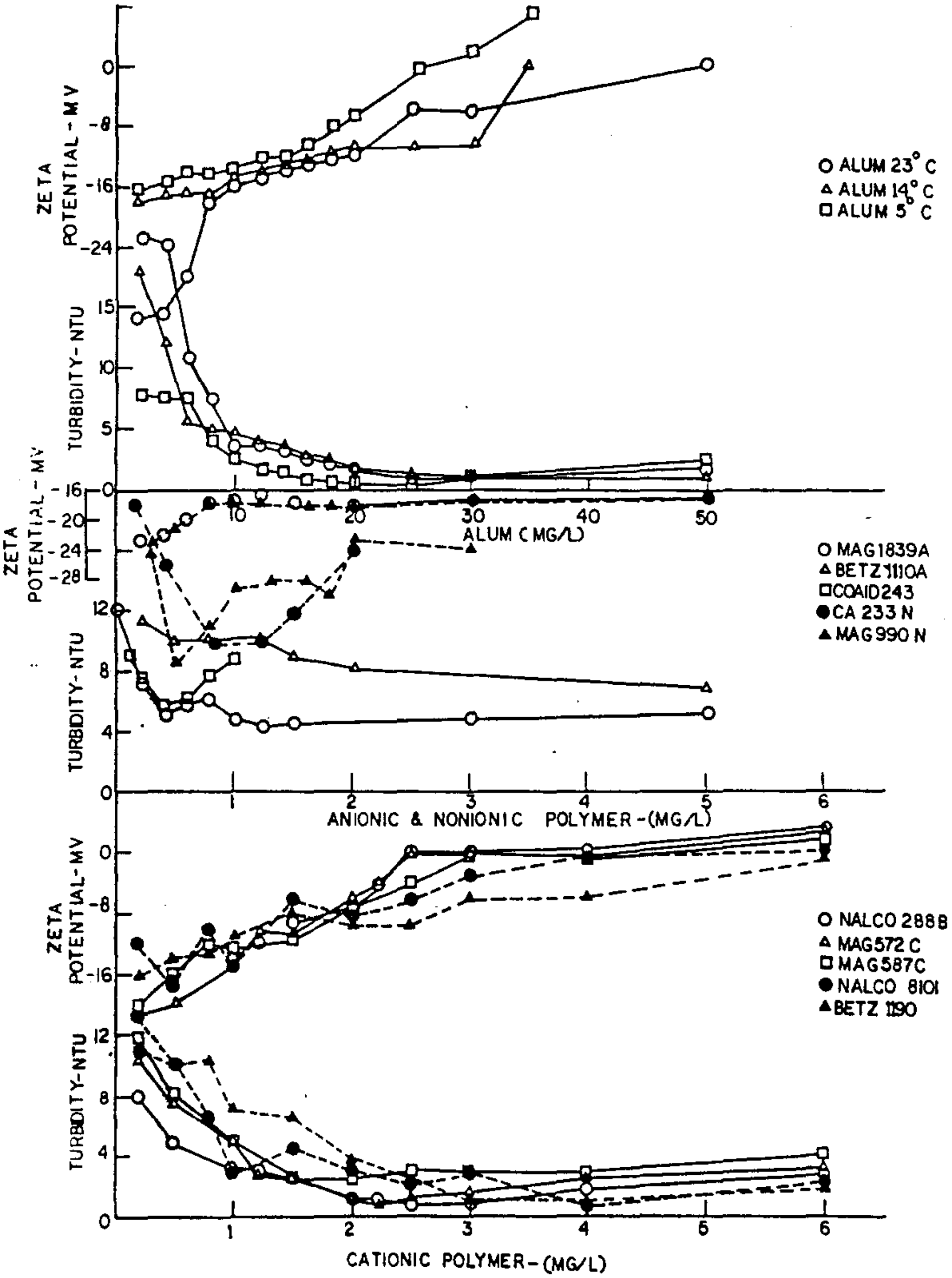

Figure 3. Results of Jar Tests using Various Coagulants.

tested for use as a coagulant and with alum. During this phase of the jar testing, preliminary work was carried out to determine the optimum dosage of alum for use with polymers. This alum dosage was then kept constant during the remaining tests for evaluating the optimum dosage of the polymers. To find the optimum alum dosage, raw water was coagulated with alum concentrations of 4, 8, 12, and 16 mg/ℓ and polymer concentrations ranging from zero to the maximum allowable limits as set by EPA. From Figure 4 it can be seen that alum dosages in excess of 8.0 mg/ℓ have a correspondingly decreasing effectiveness for each mg/ℓ added. An 8.0 mg/ℓ alum dose plus polymer doses around 0.4 to 0.6 mg/ℓ reduced the turbidity to about 1.0 NTU while larger alum doses at the same polymer dose produced very little improvement in the residual turbidity (≈0.5 NTU). When optimizing the polymer dosage, the 8.0 mg/ℓ alum dose was used with a wide variety of polymers of varying molecular weights and charges.

The results, as partially illustrated in Figure 5, reveal that only four cationic polymers acting as coagulant aids were able to reduce the turbidity to 1 NTU or less. The four polymers, Magnifloc 572C, Magnifloc 587C, Nalco 2103-288B, and Nalco 8104, were also the best performing polymers when acting as the sole coagulant. The optimum dosages for the polymers were between 0.2 and 0.6 mg/ℓ when used with an alum dosage of 8.0 mg/ℓ. All thirteen anionic polymers screened as coagulant aids failed to reduce the turbidity below 2 NTU. All seven nonionic polymers in combination with alum tended to increase the turbidity when compared to the residual turbidity resulting from an 8.0 mg/ℓ alum dosage.

Following completion of the jar testing section of the study, 14 out of the original 42 polymers were further considered for pilot plant studies.

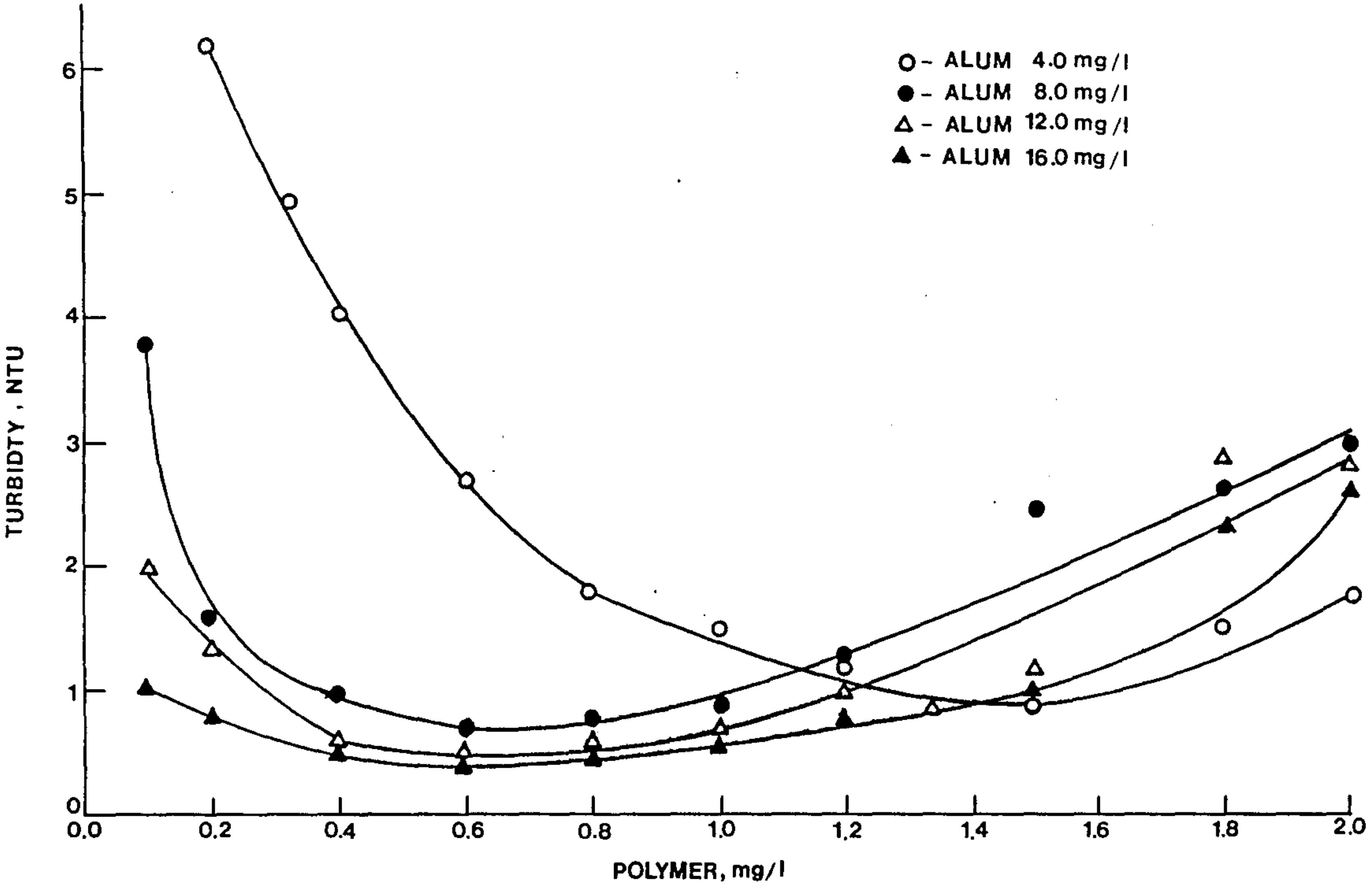

Figure 4. Determination of Alum Dose to Use with Polymers Acting as Coagulant Aid.

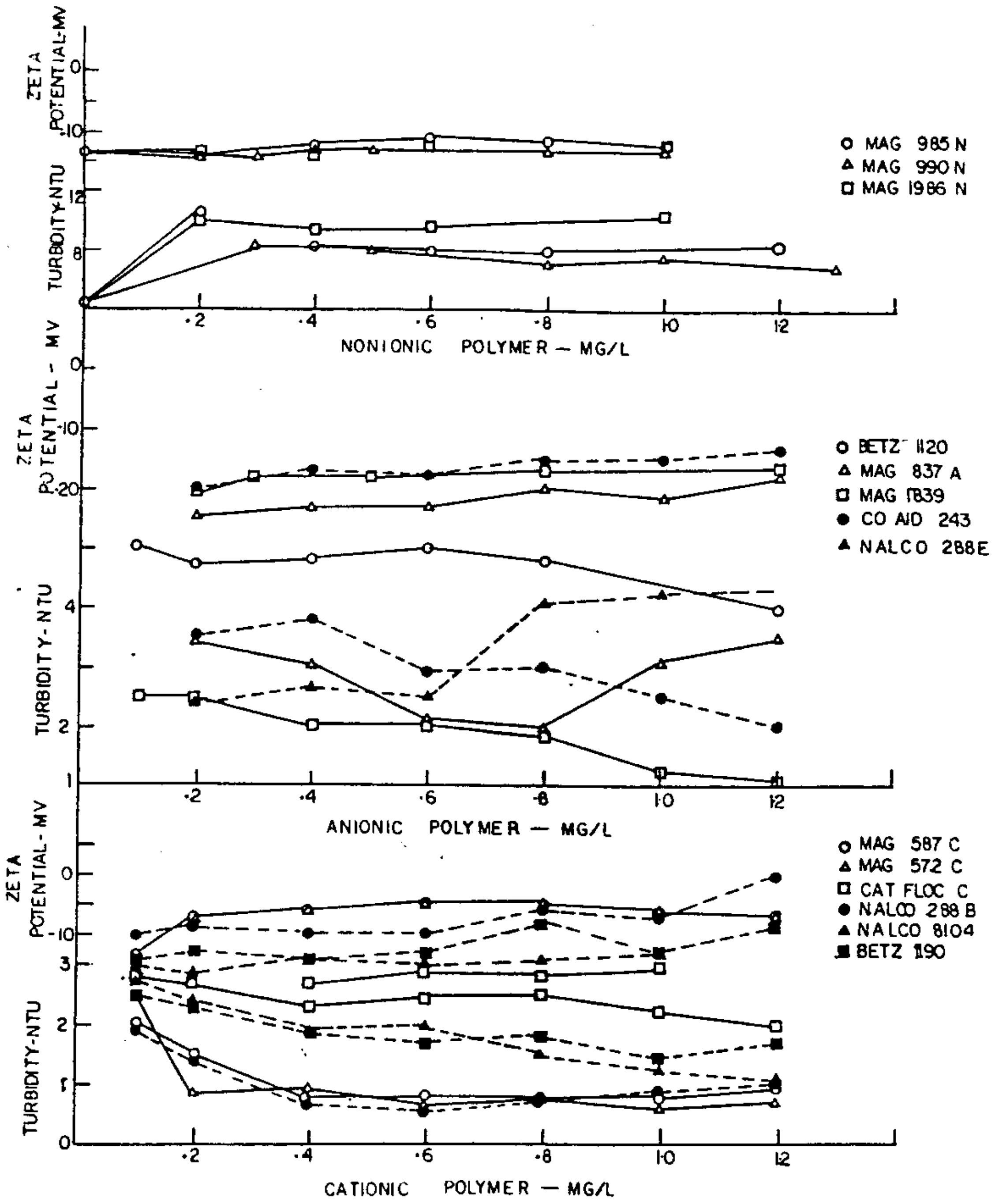

Figure 5. Optimization of Polymers as a Coagulant Aid at an Alum Dose of 8 mg/ℓ by Jar Tests.

The polymers selected to be tested as a sole coagulant or as a coagulant aid with alum are listed in Table 4. The selection of fourteen polymers, whose performance in the jar tests varied widely, was done in order to determine if a correlation between the results of the jar tests and the pilot plant could be found. It was also to determine if the jar test results can be used to predict the dosage required by the pilot plant. During the pilot plant runs to evaluate chemical dosages, the physical variables such as detention time of rapid mixing and flocculation were kept constant at 2.0 minutes and 12.0 minutes respectively. Mixing intensities (G-Values) were held at 1000 sec^{-1} for the rapid mix and 30 sec^{-1} for flocculation. This part of the overall study was conducted from July 1981 until December 1981.

Using alum as the sole coagulant, a total of 18 pilot plant runs were conducted. The 18 runs spanned an eight month period of time and included a range of water temperatures from 5 to 20°C. The maximum effluent turbidities varied from 0.6 to 1.0 NTUs at all temperatures tested. In this phase of the work, all the filter runs were terminated due to turbidity breakthrough. The length of filter runs achieved at the determined optimum dosage varied from 3.0 hours at 18°C to 4.0 hours at 6°C. Of the 60 cm maximum allowable head loss only 14.5 to 24.0 cm was used before filter termination at the warmer temperatures while 15.9 to 26.8 cm was utilized before termination of the filter run at the cooler temperatures. An optimum alum dosage was determined at both the cold and warm water condition For the cold water condition the optimum alum dosage was 16 mg/ℓ. The alum dosage of 12 mg/ℓ was found to be the optimum for the warm water temperatures. Figure 6 summarizes part of the results obtained when alum was used as the

Table 4. Polymers Selected for Direct Filtration Pilot Plant Testing

Name	Type	Turbidity After Jar Test
Magnifloc 572C	Cationic	<1.0
Magnifloc 587C	Cationic	<1.0
Cat Floc C	Cationic	3.0
Nalco 2103-288B	Cationic	<1.0
Nalco 8104	Cationic	1.0
Betz 1190	Cationic	1.5
Magnifloc 837A	Anionic	2.0
Magnifloc 1839	Anionic	1.2
Coagulant Aid 243	Anionic	2.0
Nalco 2103-288E	Anionic	2.2
Betz 1120	Anionic	>5.0
Magnifloc 985N	Nonionic	>5.0
Magnifloc 990N	Nonionic	>5.0
Magnifloc 1986N	Nonionic	>5.0

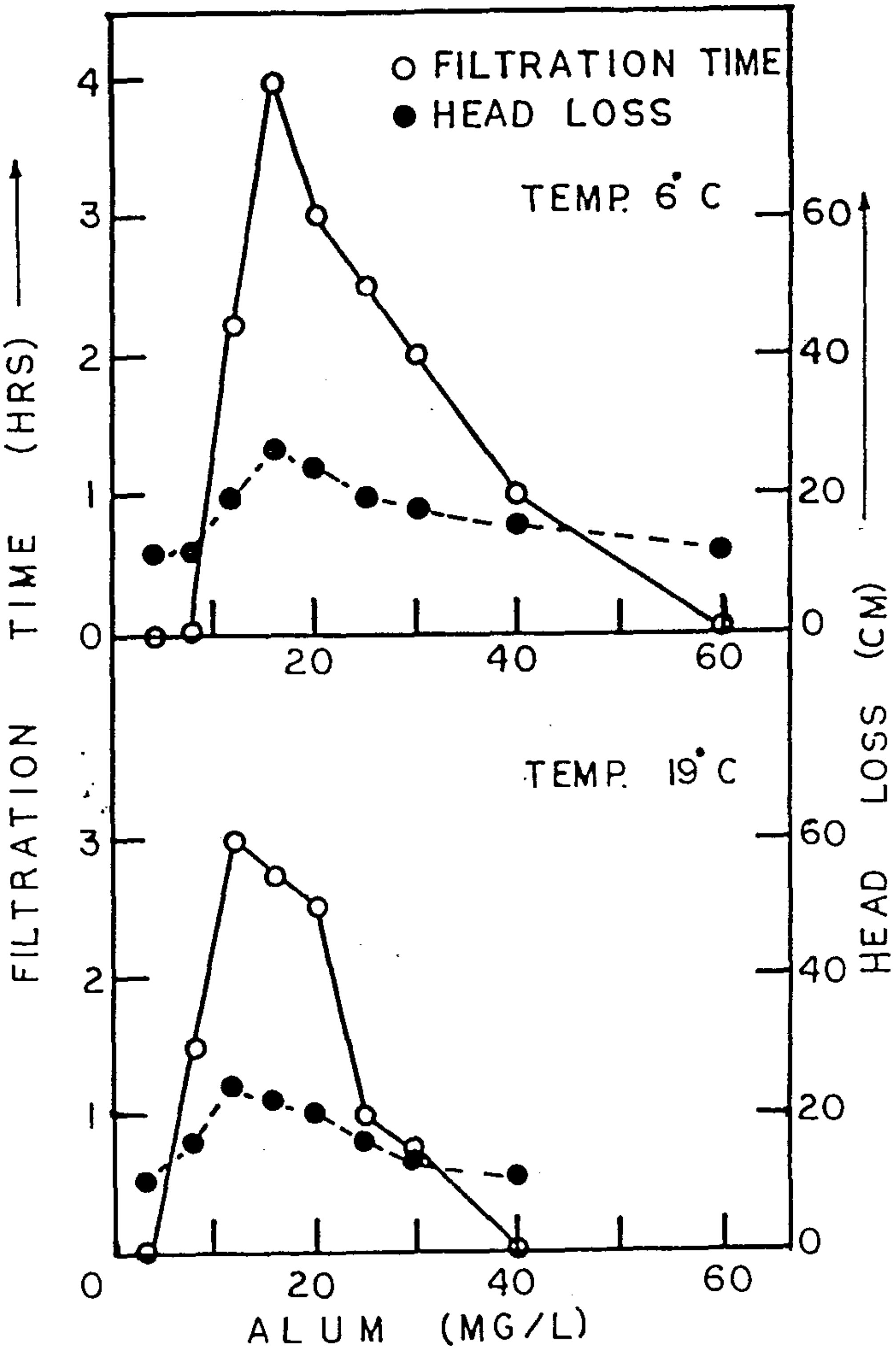

Figure 6. Optimization of Alum Dose Acting as a Sole Coagulant by Pilot Plant Direct Filtration Process

sole coagulant. This figure shows filter run times along with filter head loss as a function of alum dosage at both 6 and 19°C.

Various polymers were also tested in the direct filtration pilot plant as the sole coagulant. In this phase of the work, a total of 169 pilot plant runs were conducted. The runs in this part of the study, as with alum alone, were also run at cold and warm water temperatures.

Out of the 14 polymers used as the sole coagulant in the pilot plant, two cationic polymers, Nalco 2103-288B and Magnifloc 572C were found to result in the lowest residual turbidities. By contrast, the seven anionic and three nonionic polymers were unable to reduce the turbidity to less than 1.0 NTU under any of the conditions tested. The optimum dosage of both cationic coagulants, Nalco 2103-288B and Magnifloc 572C, at both warm and cold water temperatures, was found to be 2.0 mg/ℓ At this dosage, the filter effluent turbidity was 0.2 to 0.3 NTU's. The filter runs under those conditions were terminated due to head loss and not turbidity breakthrough. The filter runs at the optimum dose for both polymers ranged from about 6 hours at the cold temperatures (8°C) to around 5 hours at the warmer temperatures (15-18°C). Figure 7 summarizes part of the data for this section of the study. The figure shows the filter run time and head loss as a function of polymer dosages for three different cationic polymers at 6 and 19°C.

After the evaluation of alum and various polymers as sole coagulants in the direct filtration pilot plant, a combination of the two coagulants was next evaluated. In this part of the study the polymer was evaluated as a coagulant aid to alum. The first step in this part of the work involved selecting the appropriate alum dosage to be used while varying the polymer

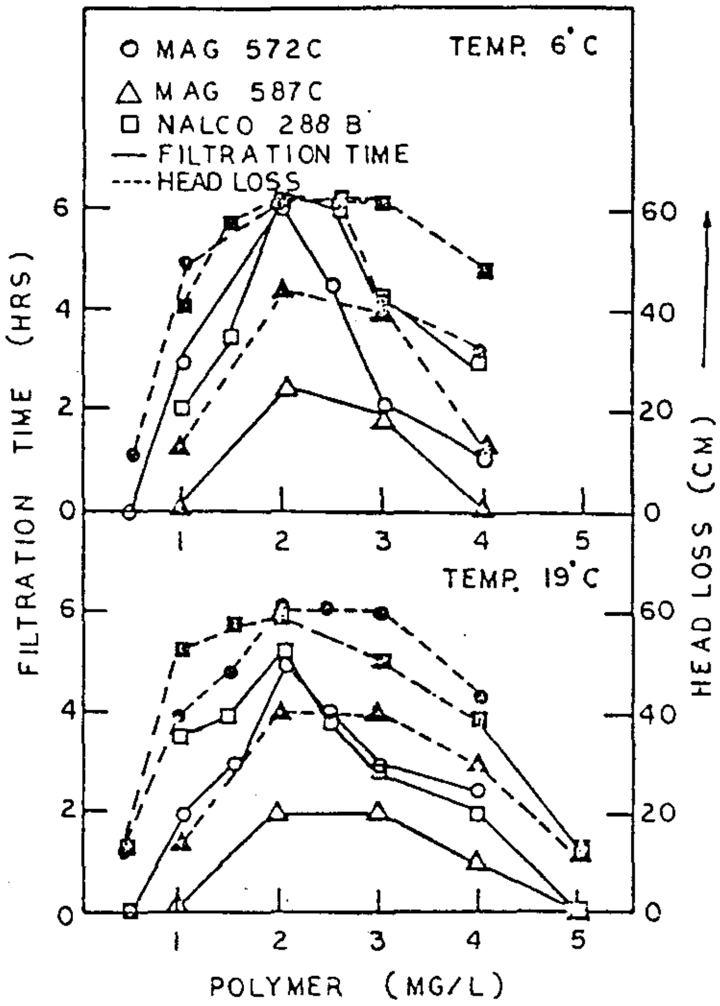

Figure 7. Optimization of Polymers as a Sole Coagulant by Pilot Plant Filtration Process

type and dosage. The results of this preliminary step are shown in Figure 8. From this date it was determined that 12 mg/ℓ alum dosage was the best at the colder water temperatures while 8 mg/ℓ was best for the warmer water temperatures. The two dosages were chosen since they produced a large reduction in the turbidity alone and continued addition of alum alone caused smaller reductions in the turbidity. These selected dosages would allow alum to remove a large proportion of the turbidity and allow the polymer to act as a coagulant aid to remove the rest of the turbidity.

In this portion of the study, a total of 176 pilot plant runs were made in order to evaluate the best coagulant aids and their optimum dosage. The results from this section found that four cationic polymers, Magnifloc 572C, Cat Floc C, Nalco 2103-288B, and Magnifloc 587C, acting as coagulant aids were able to reduce the filtered water turbidity to 1 NTU or less. The remaining cationic polymers along with the five anionic and three nonionic polymers tested were unable to reduce the turbidity below 1 NTU when acting as a coagulant aid with alum.

Two of the polymers, Magnifloc 572C and Nalco 2103-288B were able to do so at lower dosages. For these two polymers, the optimum dosage was determined to be 0.4 mg/ℓ at both temperature extremes tested. At the combined dosage of 12 mg/ℓ alum and 0.4 mg/ℓ polymer, for the cold water conditions (5-8^{o}C) the filter run time for Magnifloc 572C was 15 hours and for Nalco 2103-288B it was 12.5 hours. This is illustrated in Figure 9. At the warm water conditions (18-21^{o}C) the optimum dosage of 8 mg/ℓ alum and 0.4 mg/ℓ, polymer produced filter run durations of 12 hours for both Magnifloc 572C and Nalco 2103-288B. Under these conditions the filter effluent turbidity varied from 0.2 to 0.4 NTUs. Filter runs operated using these dosages were terminated when the maximum head loss of 60 cm was reached.

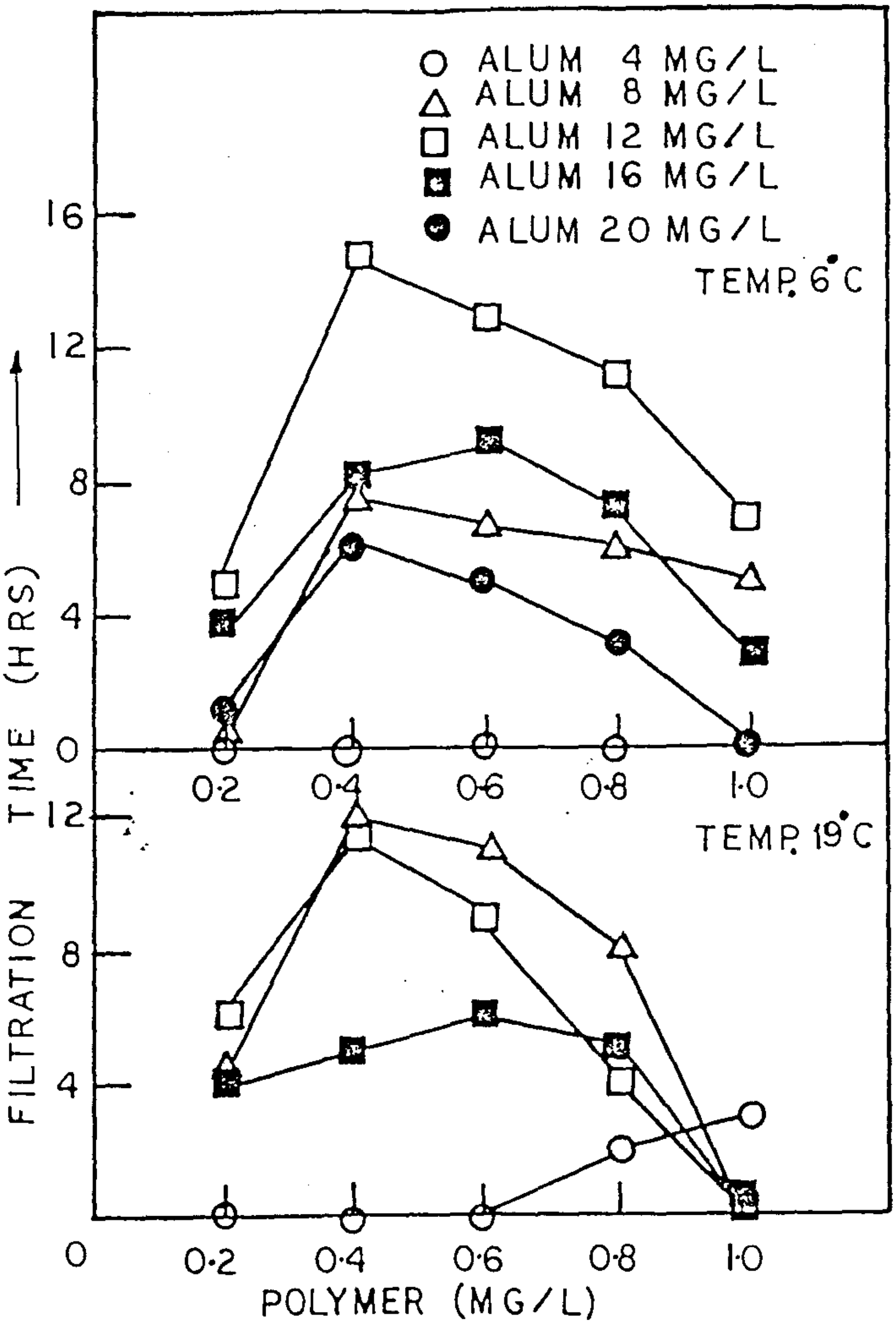

Figure 8. Optimization of Alum Dose for the Selection of Polymers as a Coagulant Aid by Direct Filtration Process

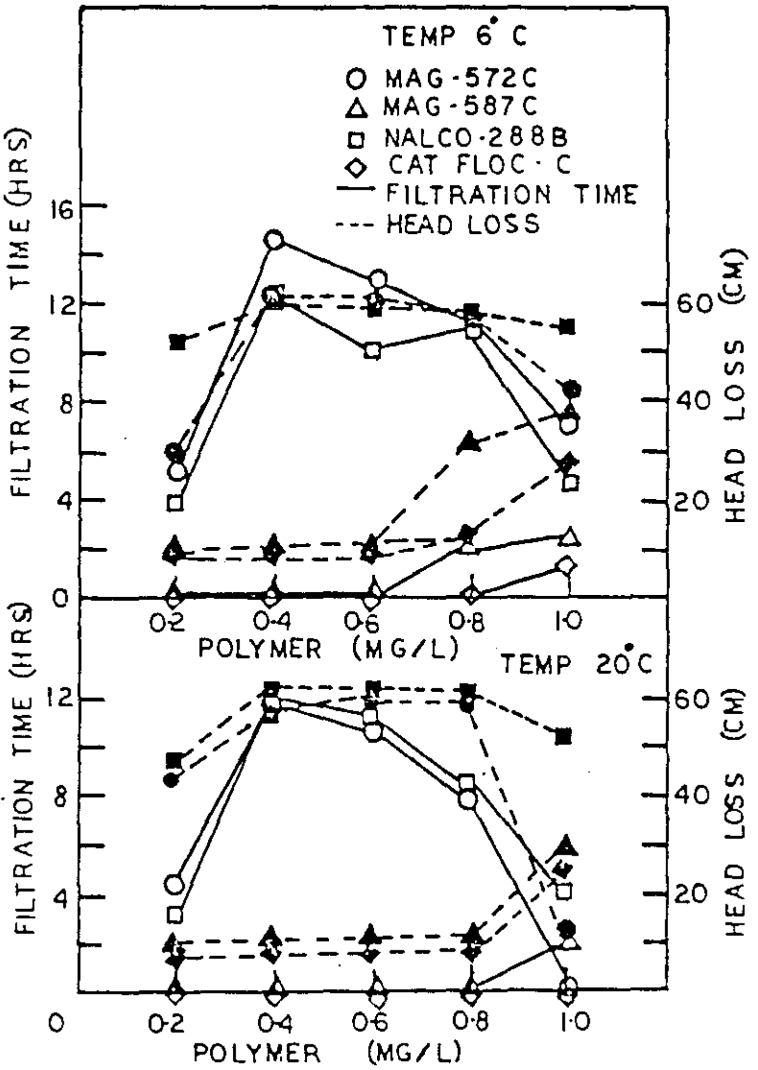

Figure 9. Evaluation of Polymers Acting as Coagulant Aid With Alum of 12.0 mg/ℓ by Pilot Plant Direct Filtration Process

Selection of Physical Variables

After optimizing the chemical requirements, the physical variables, such as detention time and mixing energy of the rapid mix and flocculation units were optimized. The physical variables were studied on 68 pilot plant runs between December 1981 and February 1982. Therefore, the coagulant dosages used were those found to be the optimum for colder water. During these optimization studies, an alum dose of 12 mg/ℓ and a polymer (Magnifloc 572C) dose of 0.4 mg/ℓ were used. During the optimization of the chemical and physical variables more than 300 filtration runs were conducted.

The experimental design for this part of the research is shown in Table 5. During each phase of the study two parameters were varied while two remained constant. The flow rate through the filters was kept constant at 3.5 gpm/ft^2 throughout this part of the study.

The data for filtration time as a function of both rapid mixing and flocculation detention times (Phase I) are shown in Figure 10. In this initial part of the study the rapid mixing intensity and flocculation intensity were held constant at 1000 and 30 sec^{-1} respectively. The optimum time, the time yielding the longest filter runs, for the rapid mix and flocculation units was observed to be 1.5 to 2.0 minutes and 12 to 16 minutes respectively. At these optimum values, the maximum head loss was reached first. Hence, the filter runs were terminated on head loss and not turbidity breakthrough. The filter effluent turbidity observed varied from 0.3 to 0.6 NTUs while the filter run length varied from 10 to 16 hours.

The data for filtration time as a function of both flocculation detention times and rapid mixing intensities are shown in Figure 11. During this part of the study, Phase II, the optimum, best unit performance, mixing

Table 5. Experimental Design for Physical Variable Studies

Variables	Constants	Phase
RMT	RMI	I
FT	FMI	I
FT	FMI	II
RMI	RMT	II
RMI	RMT	III
FMI	FT	III

RMT = Rapid mixing time

FT = Flocculation time

RMI = Rapid mixing intensity

FMI = Flocculation mixing intensity

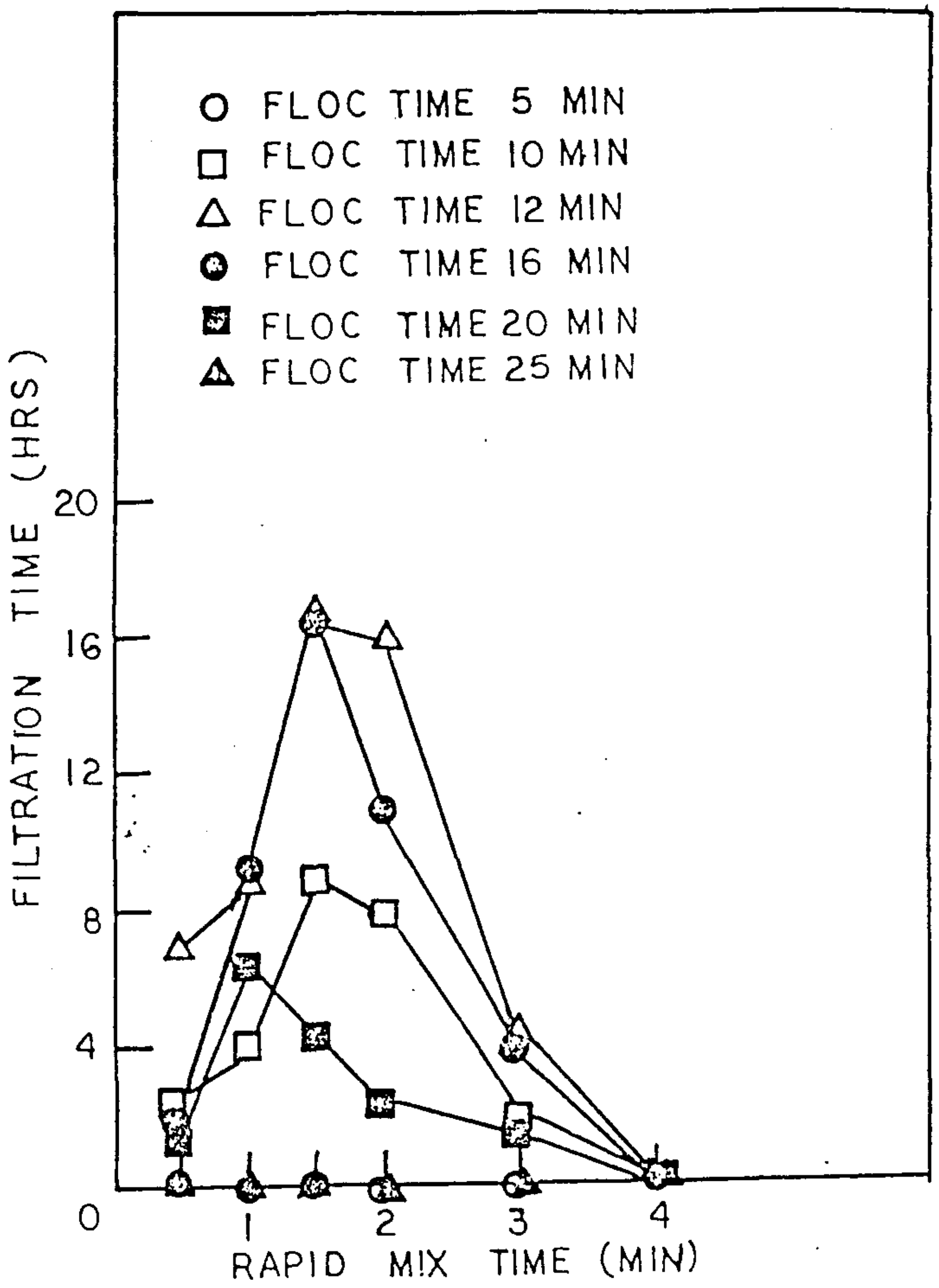

Figure 10. Optimization of Rapid Mix Time Using Alum 12.0 mg/ℓ and Polymer 0.4 mg/ℓ by Pilot Plant Direct Filtration Process

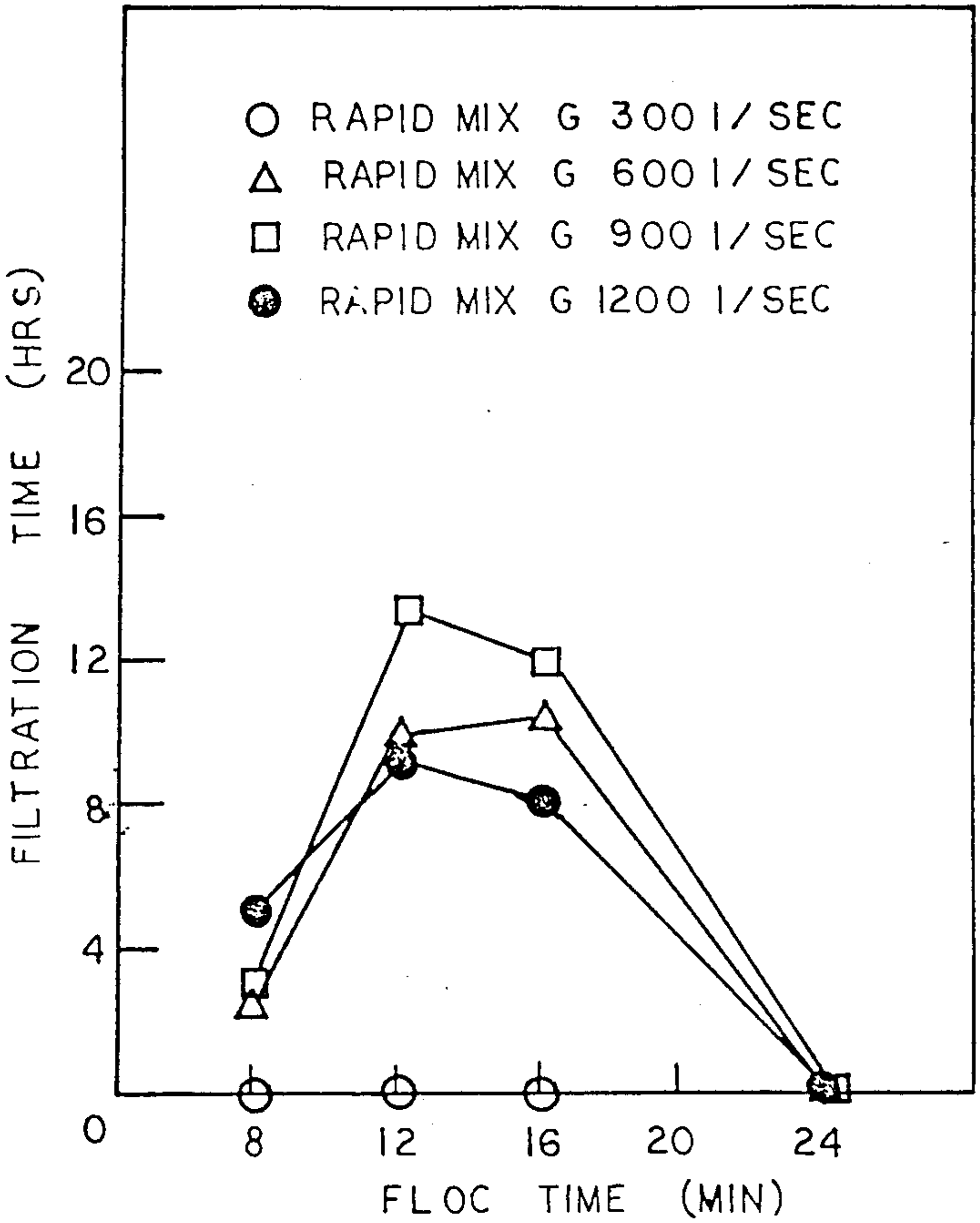

Figure 11. Optimization of Rapid Mix Mixing Intensity Using Alum of 12.0 mg/ℓ and Polymer 0.4 mg/ℓ by Pilot Plant Direct Filtration Process

intensity for rapid mixing was observed to be 900 sec^{-1} at a flocculation time of twelve minutes. Operating at these optimum values, the maximum head loss occurred before turbidity breakthrough. The filter duration and effluent turbidity observed at these optimum conditions were thirteen hours and 0.2 to 0.3 NTU, respectively.

During Phase III of this study, that sought to optimize the flocculation mixing intensity, the detention times for the rapid mix and flocculation units were kept constant at 1.5 and 12 minutes respectively. The data for filtration times as a function of both rapid mix and flocculation intensities are shown in Figure 12. The optimum observed mixing intensity for the flocculation unit was 20 sec^{-1} when the rapid mix intensity was 900 sec^{-1}. Running at the optimum values, filter runs were terminated due to maximum head loss. The filter duration and effluent turbidity observed were 13.5 hours and 0.3 NTU, respectively.

After optimizing the physical and chemical variables mentioned earlier, the flow rates through the filter were evaluated over the range from 1.5 to 9.0 gpm/ft^2. During this phase of the study the optimum values for the various physical and chemical variables were used and are shown in Table 6. The data for filtration time and head loss versus flow rate are shown in Figure 13. The filter runs for the flow rates of 1.5 to 3.5 gpm/ft^2 were terminated due to maximum head loss. At higher flow rates, 5 to 9 gpm/ft^2, turbidity breakthrough occurred before maximum head loss was reached. Above a flow rate of 7 gpm/ft^2 the filtration process was unable to reduce the filtered water turbidity below 1 NTU at any time.

One must also consider operational variables before making the choice of what coagulant(s) to use. Three major operational variables that were

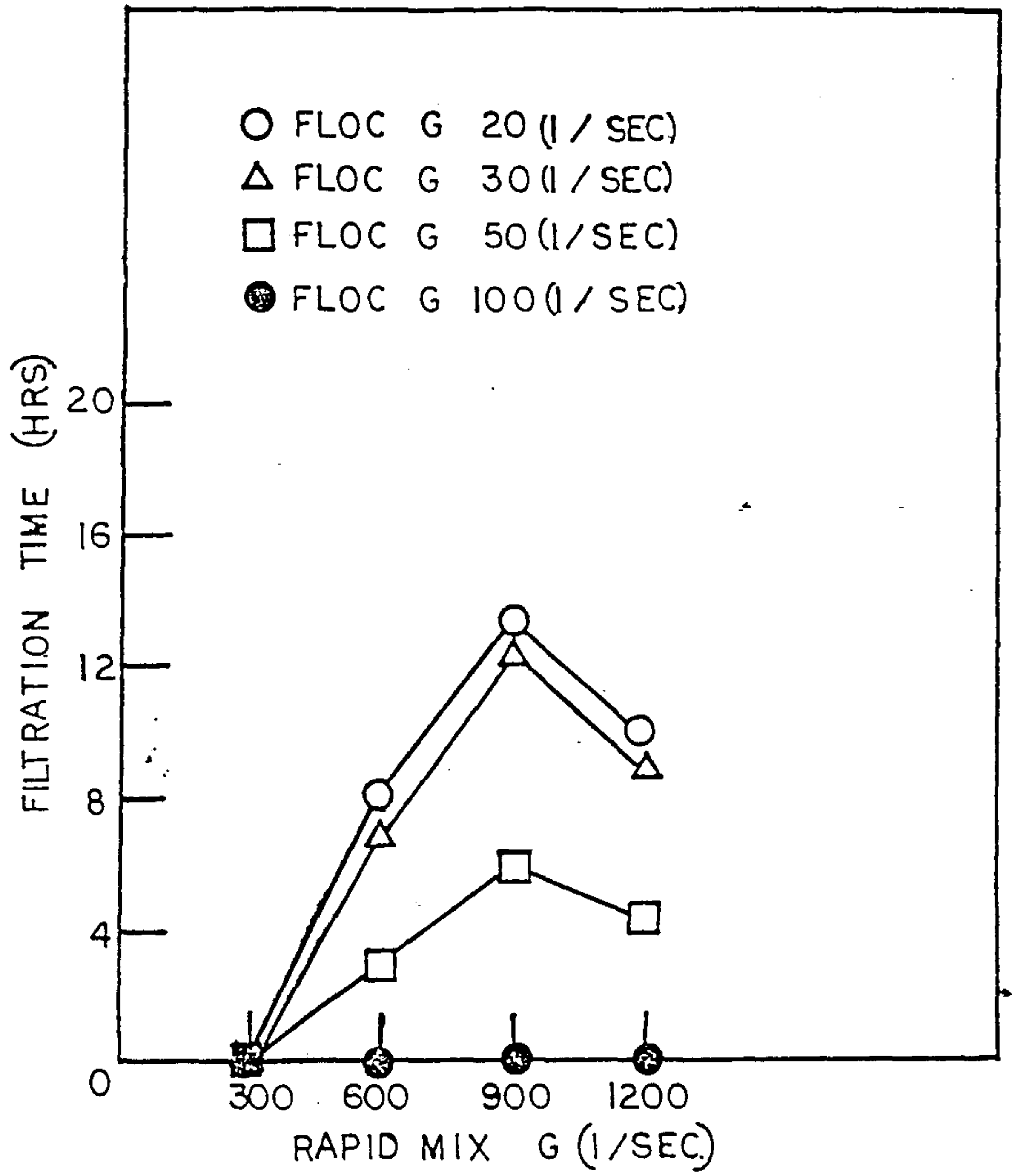

Figure 12. Optimization of Flocculation Mixing Intensity Using Alum of 12.0 mg/ℓ and Polymer of 0.4 mg/ℓ by Pilot Plant Direct Filtration Process

Table 6. Optimum Physical and Chemical Variables Used in Evaluating Various Filtration Rates

Parameter	Value
Alum	12.0 mg/ℓ
Polymer (Magnifloc 572C)	0.4 mg/ℓ
Rapid mixing time	1.5 minutes
Flocculation time	12.0 minutes
Rapid mixing intensity	900 sec^{-1}
Flocculation intensity	20 sec^{-1}

observed during the pilot plant runs are as follows. One, the water production or filter run time was observed to be over double the time when compared to polymer or alum alone. This is illustrated in Figure 14. As stated earlier the runs with alum alone were terminated due to turbidity breakthrough while the runs with polymer alone or alum plus a polymer were terminated due to maximum head loss. Two, the mixed alum plus polymer sludge produced after backwash was less resistant to dewatering than alum sludge, but more resistant than polymer alone sludge. Three, there were no mudballs present following the use of alum plus a polymer, which had been observed when using polymers alone. A potential problem with mudballing has been mentioned by others when using polyelectrolytes as the coagulant (1). In addition to this, a recent survey by the Filtration Committee of the American Water Works Association indicated that most direct filtration plants use alum plus polymer(s) further supports the selection of both of these coagulants for the direct filtration system under study.

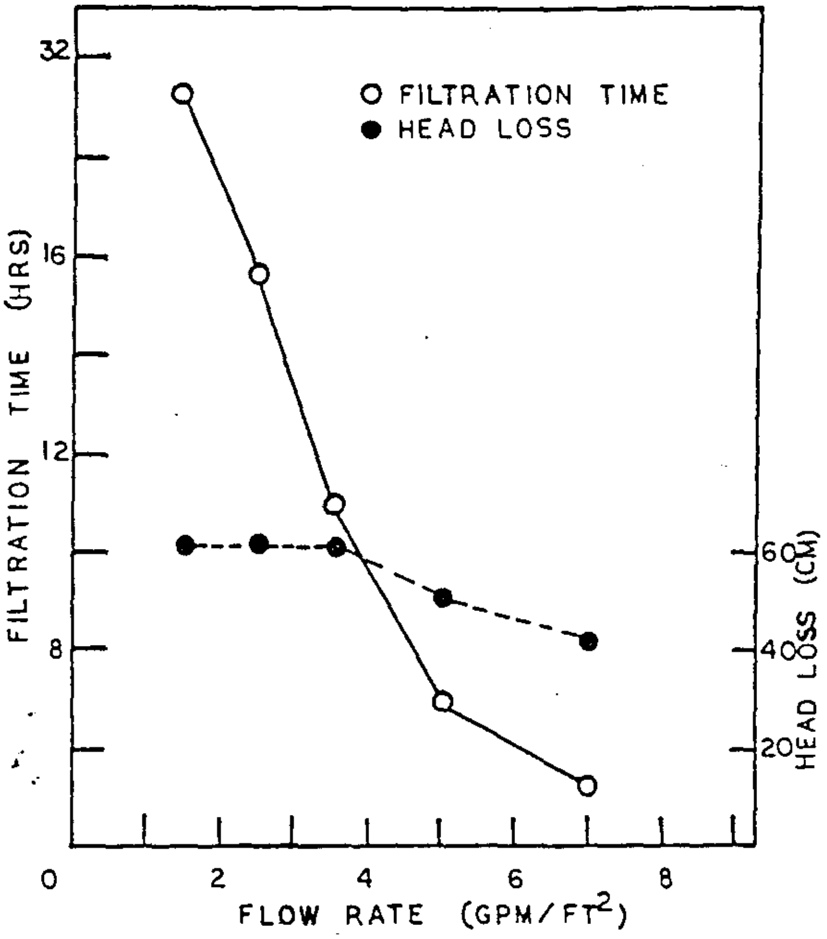

Figure 13. Variation of Flow Through the Filter Using Alum of 12 mg/ℓ and Polymer of 0.4 mg/ℓ by Pilot Plant Direct Filtration Process

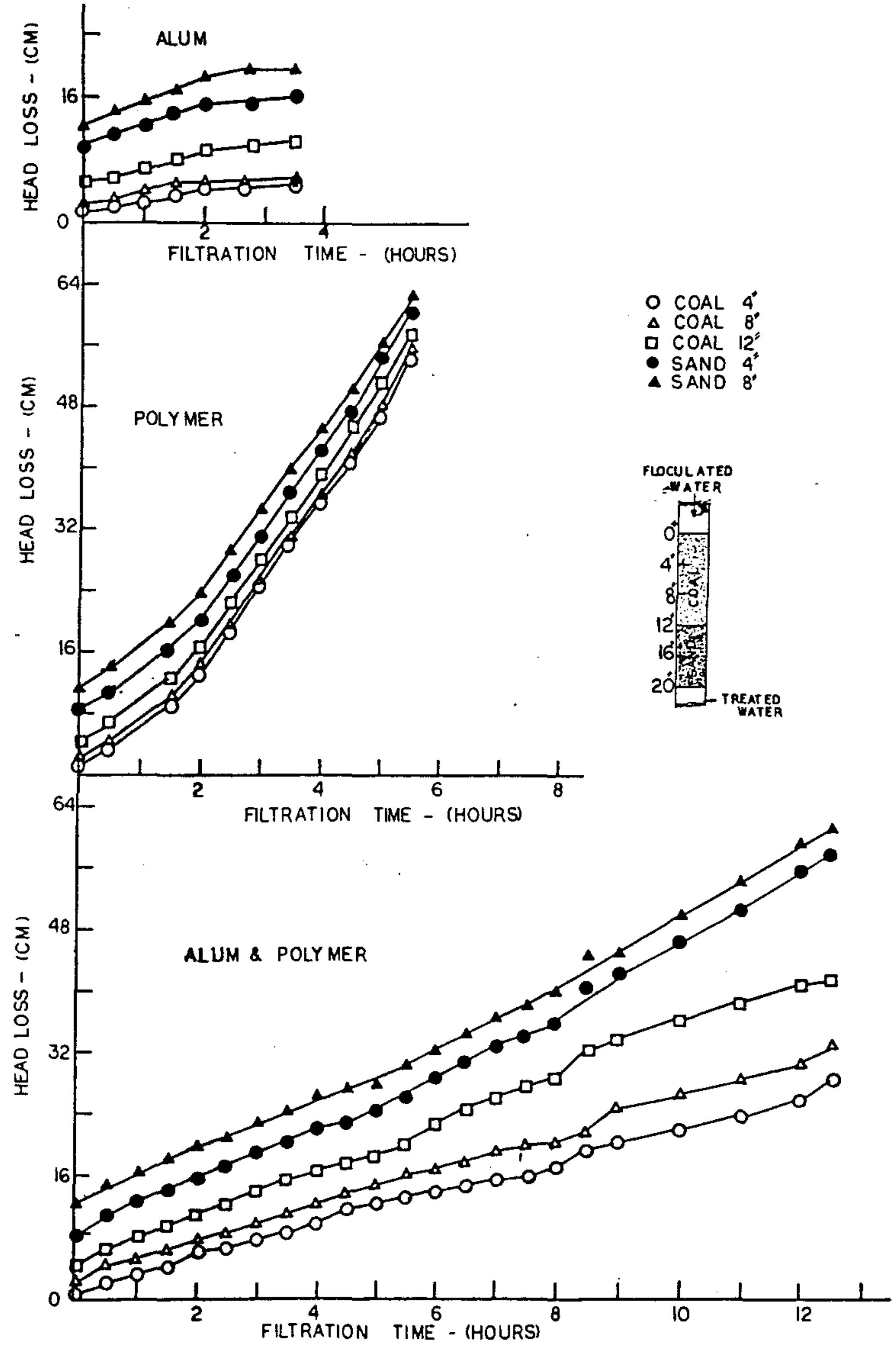

Figure 14. Development of Head Loss Through the Media with Time for Alum, Polymer, and Alum plus Polymer.

While screening the coagulants, the jar tests (batch system) were found not only to be useful in predicting the optimum doses, but also the type of polymers (charge and mw) suitable for the direct filtration process. However, the jar tests were unable to determine the most suitable coagulant among alum, polymer, and alum plus polymer. To find the best coagulant and coagulant aid, the use of the pilot plant direct filtration process was helpful in this study.

The physical variables that were optimized during cold water conditions were later checked at warm water temperatures and found again to be the optimum. At the warm water temperatures, the optimum coagulant dosages of 8.0 mg/ℓ alum plus 0.4 mg/ℓ polymer were used.

Water Quality Analysis

After selecting the optimum chemical and physical variables for the direct filtration process over the various extremes in temperature and turbidity, the direct filtration process was monitored for filtered water quality. At the same time, samples from the OSU conventional water treatment plant were analyzed for similar water quality parameters. The main parameters considered were Trihalomethanes (THMs), TOC, U.V., Turbidity, MPN, and apparent molecular weights for both raw and finish water. The main goal during this phase of the study was to evaluate the effectiveness of the direct filtration process for providing potable water.

A total of 42 filter runs, 16 using only alum, 13 using only a polymer and 15 using alum plus a polymer were performed from May until December 1982, for effluent water quality monitoring. The direct filtration process was operated at the optimum conditions that were obtained and discussed previously. Both plants were operated at a 4.5 mg/ℓ pre-chlorine dosage.

Due to an abnormally heavy rainfall, 22 inches of rain in two weeks, in late May 1982 the raw water turbidity increased from 30 NTU to 120 NTU. The turbidity remained higher than 60 NTU until July 10, 1983. During these two months, the direct filtration process was unable to reduce the filtered water turbidity to less than 1 NTU, under all conditions tested. The TOC, U.V., Turbidity, and MPN percent removed using alum, polymer, and alum plus polymer are shown in Table 7. Table 7 shows that the average percent removals achieved by the OSU plant and the direct filtration plant are very close.

Table 7. Average Percent Removal for Different Water Quality Parameters Direct Filtration Process.

Parameter	Alum	Polymer	Alum + Polymer
TOC	18.9	7.1	16.5
U.V.	89.8	90.8	72.0
Turbidity	98.6	99.2	99.0
MPN	100.0	100.0	100.0

Oklahoma State University Water Treatment Plant

Parameter	Alum + Lime
TOC	19.0
U.V.	92.0
Turbidity	99.0
MPN	100.0

The observation of naturally occurring organics, usually measured by TOC and U.V. were also conducted by measuring the apparent molecular weight. Figure 15 illustrates a U.V. absorbance chromogram for a sample of raw water that has undergone molecular weight fraction on a calibrated Sephadex column. The large peak, which predominated through the study, contains organics in the apparent molecular weight range of 1000 to 9000. The second smaller peak contains organics with an apparent molecular weight of greater than 50,000.

Samples were collected from the various unit processes in both the direct filtration pilot plant and the OSU plant. Figure 16 illustrates U.V. absorption profiles of samples fractionated on a Sepadex column. The figure includes samples from the direct filtration pilot plant, using either alum, polymer, or alum plus polymer as a coagulant as well as samples from the OSU plant, that use alum and lime as its coagulants. A complete removal of the peak, representing high molecular weight (>50,000) was observed when the raw water passed through the chlorination, rapid mix, and flocculation units in both plants regardless of the coagulant(s) used. The second dominant peak (1000-9000 AMW) showed a partial reduction in its size as the water passed through the flocculation and filtration process in both plants. Comparing the molecular weight removed for both systems, a statistical analysis showed there was no significant difference ($P = .05$) between the two processes, and also among the alum, polymer, and alum plus polymer used in the direct filtration process. The statistical analysis consisted of analyzing the data using the packaged computer program entitled Statistical Analysis System (SAS) on the OSU IBM 3801D computer.

The next phase of the study dealt with the THM forming potential of

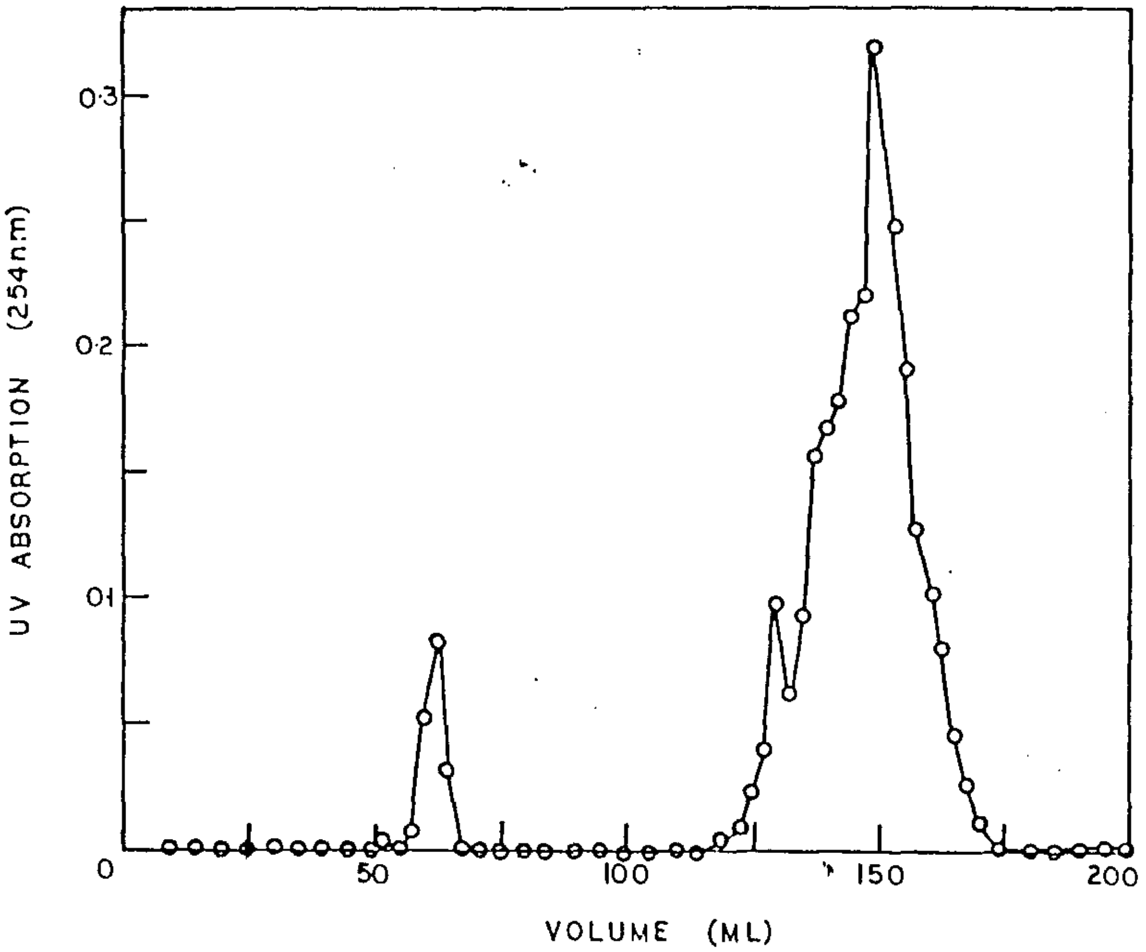

Figure 15. UV Absorbance Chromatogram to Find Apparent Molecular Weight for the Sample Collected in Sep. 1, 1982

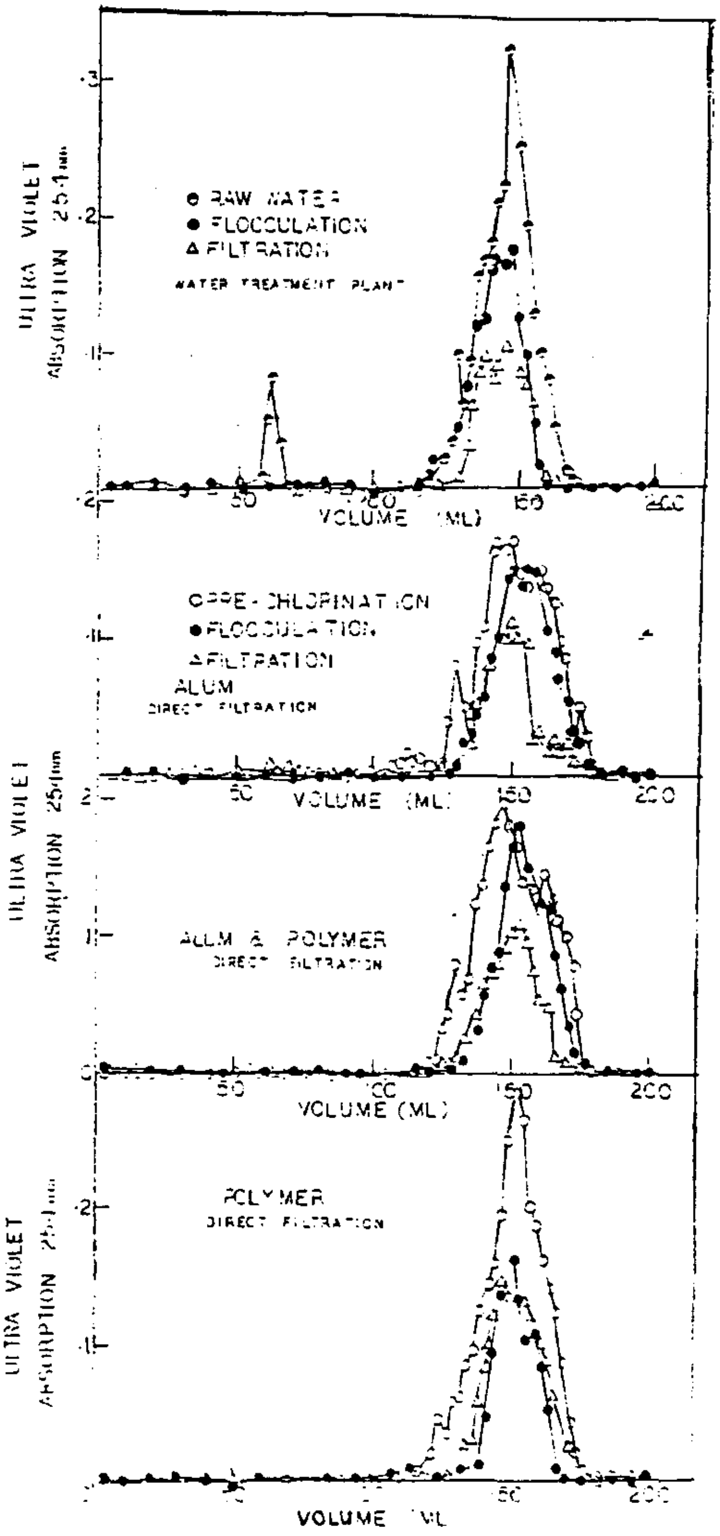

Figure 16. Sephadex Chromatogram for Determination of Apparent Molecular Weight at Different Unit Processes for Water Treatment Plant and Direct Filtration Process

the water and various methods to limit its formation to the current EPA limits of 100 μg/ℓ. As seen in the previous section of this report, Figures 15 and 16, the water contains naturally occurring organic matter. It was discovered by Rook (13) in 1974 that upon chlorination of waters that contain this organic matter, humic and fulvic acids, trihalomethanes are formed. We saw earlier in Figure 16 that part of this organic matter was removed in the process of treating the raw water by either plant. The question arises, are enough precursor organics removed so as to limit the THMs formed by the reaction of chlorine and these organics to stay below the 100 μg/ℓ limit?

Figure 17 shows the monthly average data for instantaneous and terminal THMs in the various unit processes for both the OSU water treatment plant and the direct filtration pilot plant. A gradual increase in the instantaneous THMs was observed through the units in both systems. The instantaneous THM values in the direct filtration plant were always less than 100 μg/ℓ, regardless of the coagulant used. The OSU plants filter effluent instantaneous THMs were usually greater than 100 μg/ℓ. This could reflect the large difference in contact time with free chlorine. For OSU it is five hours while the filter effluent from the direct filtration process has been in contact with free chlorine for only twenty to thirty minutes. The terminal THMs from both systems always exceed the 100 μg/ℓ limit. The fact that the THMs eventually exceeded the 100 μg/ℓ limit is not so surprising since Figure 16 shows that the treatment units were only removing part of of the precurser organics.

Since the terminal THMs for both processes were found to be higher than the EPA regulation of 100 μg/ℓ, two methods were evaluated to control

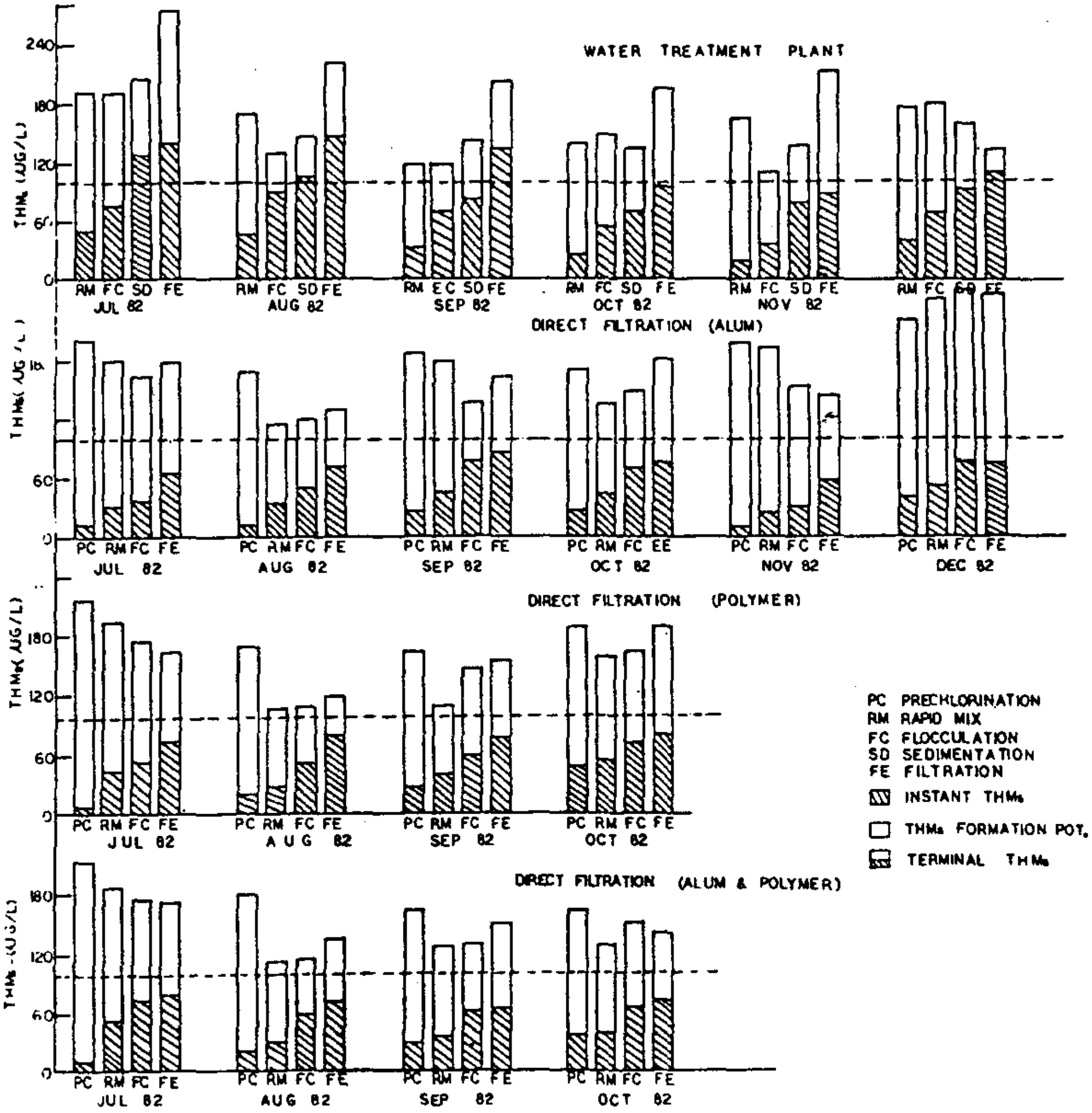

Figure 17. Average Monthly Instantaneous and Terminal THMs Concentration at Different Treatment Unit Processes for the OSU Plant and Direct Filtration Pilot Plant.

the THMs. These methods involved moving the point of prechlorination from the prechlorination basin to directly ahead of the filters, and the use of chloramines created by the addition of ammonia to the system. Since at the OSU plant there was no provision made to move the point of prechlorination to directly ahead of the filters, this technique was applied only to the direct filtration pilot plant. The chloramine process was tested on both plants.

Table 8 contains the average instantaneous and terminal THM values for the different methods used to reduce THMs. As can be seen from the data presented in the table, moving the point of chlorination further back in the treatment did not reduce the terminal THM to less than 100 μg/ℓ. The use of chloramines, created by the addition of ammonium sulfate at a weight ratio of 1:4 (NH_4:Cl_2), did reduce the THM levels in the direct filtration system. The effluent THM levels were held to levels of 75 μg/ℓ or less under all cases tested. When compared to the raw water terminal THM concentration of 180 μg/ℓ and the previous pilot plant run, where no ammonia was added, THM concentration of 150 μg/ℓ, it shows that, indeed, ammonia addition is an effective method for controlling THMs. The results of the ammonification studies in the direct filtration system found the average THM reduction to be about 60% regardless of which coagulant was used, alum, polymer, or alum plus polymer. Results of a statistical analysis of the data showed there was no significant difference among the THM levels produced using the different coagulants while ammonia was being added. The ablity to control THMs by ammonia addition to a direct filtration process, as shown by this study, is significant in that the literature contains no mention of this approach being used previous to this study.

Table 8. Results of THM Reduction Methods Evaluated

Types of Treatment		Pre-filter Chlorination		Prechlorination filter effluent ammonification		Prefilter Chlorination filter effluent ammonification	
		Total THMs		Total THMs		Total THMs	
		Instant	Terminal	Instant	Terminal	Instant	Terminal
Direct filtration Alum-160 mg/ℓ	PC	--*	--	42	160	--	--
	RM	--	--	54	133	--	--
	FC	--	--	70	140	--	--
	FE	64	153	66	67	73	71
Direct filtration polymer = 2.0 mg/ℓ	PC	--	--	30	167	--	--
	RM	--	--	67	135	--	--
	FC	--	--	76	133	--	--
	FE	70	158	68	70	70	73
Direct filtration Alum=12.0 mg/ℓ Polymer = 0.4 mg/ℓ	PC	--	--	36	170	--	--
	RM	--	--	52	137	--	--
	FC	--	--	70	145	--	--
	FE	68	167	68	70	60	63
Water treatment plant Alum = 24 mg/ℓ Lime = 12 mg/ℓ	RM	NA**	NA	20	85	NA	NA
	FC	NA	NA	67	70	NA	NA
	SD	NA	NA	80	80	NA	NA
	CW	NA	NA	82	148	NA	NA

* = non deductable

** NA = not available

PC = prechlorination

RM = rapid mix

FC = flocculation

FE = filter effluent

The results of bacterial test run while ammonia was being added to the direct filtration plant showed no coliform bacteria in the filter effluent. The results of this study showed that even with a short contact time between the water and a free chlorine residual the bacterial quality of the water was not compromised.

Chloramines as an alternative disinfectant in the distribution system was tried at the OSU water treatment plant for a few days. However, due to operational problems in the feeding of ammonia gas, the plant was unable to totally destroy the free chlorine residual in the distribution system. Therefore, the THMs levels observed were still higher than 100 μg/ℓ. Otherwise, it was expected that the water treatment plant will be able to reduce THMs levels by employing ammonification.

The final segment of the study was to determine the economic feasibility of operating the direct filtration process and to discuss the limitations that economics may place upon its use. There are many factors which affect the total cost of a given water treatment facility, some of which are very difficult to quantify for a general type of economic analysis. The following is a discussion of the operational cost savings using direct filtration as opposed to conventional water treatment processes.

The cost data for direct filtration, using alum, polymer, and alum plus polymer, and a conventional water treatment plant (OSU plant) using alum and lime are tabulated in Table 9. The flow rate for pilot plant using alum plus polymer was 3.5 gpm/ft^2 min with a backwash cycle of once every 12.0 hour, whereas the conventional water treatment plant flow rate was 1.7 gpm/ft^2 min and the backwash time was once every 24 hours. To produce 1 mg of water with both systems, the backwash water requirements would be the same for both since the pilot plants flow rate was twice that of the OSU

Table 9. Chemical Cost to Produce 1 MG Water (Net) for Direct Filtration and Water Treatment Processes

Feed Rate (mg/ℓ)			Filter Run Hours	Backwash Water Required 12 Hr (Gallons)	Total Water Produced	Cost = $			Total Cost $
Alum	Poly	Lime				Alum**	Polymer***	Lime****	
16.0	0.0	0.0	3.0	4 357,143	1,357,143	43.46	---	---	43.46
0.0	2.0	0.0	5.0	2.4 214,286	1,214,286	---	16.71	---	16.71
12.0	0.4	0.0	12.0	1 89,286	1,089,286	26.16	2.99	---	29.15
25.0*	0.0	12.0	12.0	1 89,286	1,089,286	54.50	---	10.36	64.86

Note: 1 MG treated in 12 hr at a rate of 3.5 gpm/ft^2 filtered area required is 396.825 ft^2. Backwash: 15 gpm/ft^2 for 15 minutes equals 225 gal/ft^2.

* Water treatment plant dosages.
** Alum = 24¢ lb.
*** Polymer = 82.5¢/lb.
**** Lime = 09.5¢/lb.

plant. The chemical costs for the direct filtration plant using alum plus polymer were \$29.15 per MG while the OSU water treatment plant costs were \$64.86 per MG. Table 10 also shows the cost for using only polymers in the direct filtration plant. This cost of \$16.71 per MG is cheapest of all chemical costs figured but it would not be the best choice since the filter runs were of short duration and the filters themselves experienced operational problems in the form of mudballing. Mudballing, if not controlled continuously, can cause serious damage to the filters. The savings obtained in this study are higher than those reported by Culp (4).

Effect of Raw Water Quality on Backwash Requirement

Raw water quality has a definite effect on backwash requirements, and as a result, raw water quality will be critical in an economic analysis of direct filtration. Raw water turbidity has been identified as the most important raw water quality parameter, especially in the absence of high color. During a period of 1.5 years, the raw water being supplied to OSU water treatment plant had a turbidity less than 45 NTU for 95 percent of the time. At this level the pilot plant was able to produce potable water and meet EPA drinking water standards. Furthermore, the backwash water requirement was 8 percent of the total filtered water. However, when raw water turbidity ranged from 45 to 60 NTU, the backwash water demands increased from 8 percent to 40 percent. On the other hand, the backwash water requirements for the OSU water treatment plant varies from 3 to 8 percent throughout the year.

Conclusion

From this study it was found that the direct filtration process is a feasible process for the treatment of Lakes Carl Blackwell and McMurtry waters. Based on the findings, a conclusion could be drawn that the OSU water treatment plant could be modified for use as a direct filtration plant. However, a provision should be made to use sedimentation basins in case of high turbidity.

While screening the coagulants, the jar tests (batch system) were found not only to be useful in predicting the optimum doses, but also the type of polymers (changes and MW) suitable for the direct filtration process. However, the jar tests were unable to determine the most suitable coagulant amont alum, polymer, and alum plus polymer. To find the best coagulant and coagulant aid, the use of pilot plant direct filtration process was helpful in this study.

The chemical cost for operating both the direct filtration and conventional system were calculated using the optimum dosages of various coagulant or coagulants. Based on the results of these calculations along with consideration for operation problems encountered when running the filters, it was concluded that the alum plus polymer had the fewest operational problems and was cheaper in cost than the chemical combination currently being used at the OSU plant.

The final optimized values for chemical and physical variables investigated in this study are as follows:

Alum dosage = 8.0 mg/ℓ (summer)
= 12.0 mg/ℓ (winter)

Polymer dosage = 0.4 mg/ℓ (winter & summer)

Rapid mix time = 1.5 minutes (winter & summer)

Rapid mix "G" = 900 sec^{-1} (winter & summer)

Flocculation time = 12 minutes (winter & summer)

Flocculation "G" = 20 sec^{-1} (winter & summer)

Filtration rate = up to 7 gpm/ft^{2} (winter & summer)

The finished water quality for both the processes was comparable. An excellent turbidity and bacteria removal was found by both the processes. There was no correlation found between TOC, UV absorbance and TTHMs. In addition to this it was found that TOC and UV absorbance as surrogate parameters for TTHMs should not be used for the City of Stillwater.

During this study period, the TTHM concentrations measured in direct filtration and OSU water treatment plant finished water was higher than 100 µg/ℓ. Therefore, after evaluating two different methods of THMs reduction, the ammonification at a ratio of 1:4 $(NH_4:Cl)$ by weight was found to be the most effective.

References

1. American Water Works Filtration Committee Report, "The Status of Direct Filtration," Jour. Amer. Water Works Assoc. 72:405-411 (1980).

2. Tate, C. H. et al., "Pilot Plant Test of Direct Filtration," JAWWA, 69(7)379 (1977).

3. Wagner, E. G. and Hudson, H. E., "Low-Dosage High-Rate Direct Filtration," Proc. AWWA Seminar, Coagulation and Filtration: Back to Basics, St. Louis, June 1981.

4. Culp, R. L., "Direct Filtration," Jour. Amer. Water Works Assoc. 69: 375-378 (1977).

5. Amy, W. T., "A Laboratory Study of Factors Affecting the Applicability of Direct Filtration Water Treatment," M.S. Thesis, Virginia Poly. Inst. and State Univ., Blacksburg, Virginia (1978).

6. Kawamura, S., "Design and Operation of High Rate Filters-Part 1," Jour. AWWA, 67:10:534 (1975).

7. Tredgett, R. G., "Direct Filtration Studies for Metropolitan Toronto," Jour. AWWA, 66:2:103 (1974).

8. Walder, E. J., et al., "World's Largest Direct Filtration Facility - The Proposed Prospect Water Treatment Plant," Jour. AWWA, 67:7:353 (1975).

9. Baumann, E. R., "Granular-Media Deep Bed Filtration," Chapter from Water Treatment Plant Design, Ann Arbor Science, Ann Arbor, Mich. (1979).

10. Hutchison, W. R., "High Rate Direct Filtration, "Jour. AWWA, 68:6:292 (1976).

11. McCormick, R. F. and King, P. H., "Factors that Affect Use of Direct Filtration in Treating Surface Waters," Jour. AWWA, 74:5:234 (1982).

12. Williams Brothers Engineering Company, "Water Treatment Plant Study," prepared for Stillwater Utilities Authority, Stillwater, OK (March 1980).

13. Rook, J. J., "Formation of Haloforms During Chlorination of Natural Waters," Water Treatment Examination. 23:234-243 (1974).

14. Stump, V. L. and Novak, J., "Polyectrolyte Selection for Direct Filtration," JAWWA, (June 1979).

15. Ockerhausen, R. W., "Coagulation Symposium I," Water Works Waste Engr. 2:53 (1965).

16. Adin, A. and Rebhun M., "High Rate Contact Flocculation Filtration with Cationic Polyelectrolytes," JAWWA, 66:109 (1979).

17. Stein, P. C., "Theory of Rapid Filtration of Water Through Sand," D.Sc Thesis, Massachusetts Inst. of Tech., Cambridge (1970).

18. O'Melia, C. R. and Stumm, W., "Theory of Water Filtration," JAWWA, 59(11)1393 (1967).

19. Standard Methods for Examination of Water and Wastewater, APHA, AWWA, WPCF, 14th Edition, Washington, DC, 1976.

20. Zeta-Meter, Inc., "Zeta Meter Manual", 1720 First Ave., New York, NY 10023.

21. Camp, T. R., "Coagulation and Flocculation Basins," ASCE, Trans. 120:1 (1955).

22. Baskerville, R. C. and Gale, R. S., "A Simple Automatic Instrument for Determining the Filtrability of Sewage Sludges," J. Inst. of Water Poll. Cont., No. 2 (1968).

23. Richard, J. J. and Junk, G. A., "Liquid Extraction for the Rapid Determination of Halomethanes in Water, JAWWA, 69: 62-64 (1977).

Contribution of Research

The work completed in this study represents one of the most complete optimization, chemical and physical, undertaken to date for the direct filtration process. The major contributions of this work include the following:

1. This study showed that the jar tests, despite some limitations, were able to predict close to the optimum dosage as well as the type of coagulants suitable for the continuous flow direct filtration pilot plant. The actually optimum doses found on the pilot plant were slightly lower than predicted by the jar tests. Sorting out which of the coagulants predicted by the jar tests was best for the pilot plant did require pilot plant testing.
2. It showed the direct filtration process to be feasible to treat water low in color but with moderate turbidity (Lakes Carl Blackwell and McMurtry).
3. It defined the optimum ranges of physical variables that can be controlled in a full scale plant. The work also developed a method to obtain these optimum physical variables.
4. It showed that both a conventional plant and a direct filtration plant remove the same molecular weight organics to approximately the same extent.
5. It also showed that the production of THM from a direct filtration plant was more effectively controlled by the addition of ammonia rather than moving the point of chlorination.

The work will be of benefit to any engineer who is faced with the problem of designing a direct filtration plant. It will be an addition to state agency personnel who must set design standards for a direct filtration plant.

Presentations

A paper based on part of the data collected from this project was presented at the 1983 American Water Works Conference in Las Vegas, Nevada. The paper was entitled "A Comparison Between Direct Filtration and Conventional Treatment for the Reduction of THM Precursors and THM-Forming Potential."