Filter ripening sequence reduction by physical and chemical variation of backwashing
by Kelly Orville Cranston

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering
Montana State University

Abstract:
The period of initial effluent quality degradation from water filtration systems is known to reduce the overall water quality produced by a filter plant. A limited amount of work has been conducted in the past to describe this phenomenon and to develop methods to reduce it. The research undertaken for this thesis was intended to further describe the mechanisms of the initial effluent degradation period and to investigate alternative methods of reducing it.

The research project utilized a dual media, in-line pilot filtration plant with varied primary coagulants and raw water sources. The effects of various coagulants injected into the backwash water and the variation of several physical aspects of backwashing on the initial effluent degradation periods were investigated. From the data gathered in this research a more comprehensive theory concerning the mechanisms and timing of events occuring in the initial period of degradation has been developed.

The following generalizations concerning the results can be made: 1. The backwash coagulant yielding the best results was generally the same as the primary coagulant system.

2. The optimum time of injection of this coagulant into the backwash water corresponded to the time required to completely displace the backwash water into the filter unit.

3. The backwashing volume required to minimize the initial degradation period is that required to displace the retained particles of filtration out of the filter unit.

4. Variation of the remnant volume above the media does not affect the magnitude of the initial period of degradation, only the timing at which events occur. In systems utilizing backwash coagulants, increasing this volume can enhance the effects of the backwash coagulants.

5. Incremental opening of a filter unit can substantially reduce the magnitude of the initial period of degradation when compared to an instantaneously opened filter.

FILTER RIPENING SEQUENCE REDUCTION BY PHYSICAL AND CHEMICAL VARIATIONS OF BACKWASHING

by

Kelly Orville Cranston

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Environmental Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

January, 1987

APPROVAL

of a thesis submitted by

Kelly Orville Cranston

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Jan. 4th, 1987
Date

Chairperson, Graduate Committee

Approved for the Major Department

9 Jan '87
Date

Head, Major Department

Approved for the College of Graduate Studies

January 12, 1987
Date

Henry L Parsons
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature ______________________

Date 1-12-87

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The period of initial effluent quality degradation from water filtration systems is known to reduce the overall water quality produced by a filter plant. A limited amount of work has been conducted in the past to describe this phenomenon and to develop methods to reduce it. The research undertaken for this thesis was intended to further describe the mechanisms of the initial effluent degradation period and to investigate alternative methods of reducing it.

The research project utilized a dual media, in-line pilot filtration plant with varied primary coagulants and raw water sources. The effects of various coagulants injected into the backwash water and the variation of several physical aspects of backwashing on the initial effluent degradation periods were investigated. From the data gathered in this research a more comprehensive theory concerning the mechanisms and timing of events occuring in the initial period of degradation has been developed.

The following generalizations concerning the results can be made:

1. The backwash coagulant yielding the best results was generally the same as the primary coagulant system.

2. The optimum time of injection of this coagulant into the backwash water corresponded to the time required to completely displace the backwash water into the filter unit.

3. The backwashing volume required to minimize the initial degradation period is that required to displace the retained particles of filtration out of the filter unit.

4. Variation of the remnant volume above the media does not affect the magnitude of the initial period of degradation, only the timing at which events occur. In systems utilizing backwash coagulants, increasing this volume can enhance the effects of the backwash coagulants.

5. Incremental opening of a filter unit can substantially reduce the magnitude of the initial period of degradation when compared to an instantaneously opened filter.

CHAPTER 1

INTRODUCTION

Operators of municipal water filtration plants have long recognized a brief period of increased effluent turbidity immediately following backwashing of the filter units. Research has indicated that the period of initial effluent degradation is a function of the remnant water remaining in the filter at the end of backwash [3] and/or a function of the influent [7]. The subsequent period of effluent quality improvement, or "filter ripening" has been related to the accumulation of influent particles within the pores of the media resulting in increased capture of further particles [10, 12]. Additional research has also suggested that an increased transport of potentially pathogenic microorganisms through the filter unit [9] may be associated with the initial period of effluent degradation. The initial period of effluent quality degradation and subsequent improvement is to be termed in the current research as the "filter ripening sequence".

Several methods have been suggested and researched to reduce or remove the period of poor quality effluent from filter effluent. The most important methods considered have been the addition of polyelectrolytes (polymers) to the backwash water and "filtering to waste" of the poorest quality effluent. The addition of polymers to the backwash water has been suggested as a means of "preconditioning" the filter by adsorption of the polymer to the filter media [5, 8, 15]. The adsorbed polymers have been shown to significantly reduce the effluent turbidity in the initial stages of filtration [5, 8, 15]. The use of a "filter to waste" period at the beginning of a filter run can also be effective in restricting the initial period of poor quality effluent. However, due to the significant length of the filter ripening sequence, sometimes two hours or more [4], the "filter to waste" period may induce an excess consumption of raw water. Therefore research conducted to reduce or remove the filter ripening sequence should be developed in a manner minimizing the consumption of raw water.

A literature review revealed that the use of backwash coagulants other than polymers, or the variation of several physical parameters of backwashing, to reduce the magnitude and duration of the filter ripening sequence, has not been extensively researched. The current experimental work for this thesis was conducted to fill some of the gaps in present knowledge.

As a result of the experimental work conducted in the current research project, and from a review of previous theories, a more encompassing hypothesis has been developed on the mechanisms of the filter ripening sequence. Data has also been developed concerning the variation of physical and chemical parameters of backwashing to determine their importance in affecting this phenomenon. From this data, some methods have been determined for the optimized reduction of the initial period of effluent degradation.

CHAPTER 2

RESEARCH OBJECTIVES

The overall objective of this research project is to further describe the physical and chemical phenomena which affect the filter ripening sequence of a deep-bed, dual media, in-line filtration unit. A better understanding of this phenomena will allow development of methods to reduce the magnitude and duration of the filter ripening sequence.

The individual research objectives are as follows:

1. Develop a more encompassing hypothesis to describe the physical and chemical phenomena which define the magnitude and duration of the filter ripening sequence.
2. Determine the most effective backwash coagulant to reduce the magnitude and duration of the filter ripening sequence for each of the three primary coagulant systems used; polymer, aluminum sulfate, and aluminum sulfate/polymer combination. The optimum dosages of each coagulant will be determined for each system using the Bozeman, Montana tap water. The seasonal variations of the optimum dosages of backwash polymer will be described.
3. Determine the optimum time for the injection of coagulant into the backwash water with respect to completion

of the backwashing phase.

4. Determine the effect on the magnitude and duration of the filter ripening sequence of changing the volume above the filter media into which the remnant water is displaced during backwash.

5. Determine the effect on the magnitude and duration of the filter ripening sequence of changing the total volume of backwash water used to backwash the filter at a given rate.

6. Link the results of the laboratory pilot plant study to the Bozeman, Montana Water Treatment Plant in terms of the reduction of the magnitude and duration of the filter ripening sequence. The pilot plant will be transported to the BWTP so it may utilize the same raw influent derived directly from the plant's flocculation units.

CHAPTER 3

FILTER RIPENING: A LITERATURE REVIEW

Backwash

During the operation of a deep-bed filter unit, a point is reached in which either the water head above the filter media has built up to an excessive level, or an increase in the effluent turbidity occurs. At this time, the filter is taken off line and backwashed. The backwash is conducted by reversing the flow of water through the filter in order to remove the particulate material and chemical coagulant flocs held within the filter media. This backwash process has been shown by Amirtharajah [1] to be most efficient for removal of attached particles from the media when the media bed is fluidized from 30 to 50%. The fluidization occurs when the drag force of the water against the media is sufficient to suspend the media grains in a particular position of expansion. The drag forces which fluidize the bed have been empirically explained by Fair et al [6] as a function of the velocity of the fluid through the bed and the expanded porosity of the bed.

$$\frac{Le}{L} = \frac{1 - f}{1 - \left(\frac{Ve}{Vs}\right)^{q}} \qquad (1)$$

Where: V_e = wash rate as superficial velocity

V_s = bed grain settling velocity

q = 0.2 to 0.3, depending on the shape of the media grains and the flow regime.

f = porosity of the packed bed

L_e = expanded bed depth

L = packed bed depth

Studies by Amirtharajah [1] have shown that during backwash, particle collisions are insignificant in terms of removing attached particles from the media grains. The major mechanism of cleaning has been determined to be the hydrodynamic shear that occurs around the particle while it is in the backwash flowstream. This maximum shear occurs within a size graded media at bed expansions of 30 to 50%. In general, backwashing alone is fairly effective in removing particles and flocs from within the pores of the filter media. Studies by Regan [13], however, indicate that the use of air scour in addition to a water backwash provides better removal of particles attached to the media grains. Air scour is generally not used in the United States, though a surface wash is frequently used to break up mud balls and caked mud which occur on top of the filter media during filtration.

Filter Ripening Theory

Work conducted by Amirtharajah and Wetstein [3] showed that the initial effluent quality from a filter used over several filtration runs could be divided into three periods; the lag period, the rising limb culminating in two turbidity peaks, and a long receding limb (Figure 1). Amirtharajah and Wetstein [3] proposed that the lag period was due to the clear backwash water in the underdrains up to the bottom of the media, the rising limb was due to particles derived during collisions of the settling media at the end of backwash, and the receding limb was due to the dispersion of the media derived particles from the filter and the accumulation of particles in the media pores.

Recent work by Francois and Van Haute [7] has somewhat altered Amirtharajah and Wetstein's [3] description of the filter ripening sequence. They concluded that the peak turbidity is more related to the influent water (they say 95%) than to the remnant water as Amirtharajah and Wetstein had proposed. Francois and Van Haute go further to explain that the ripening period of the filter coincides with a change in pore structure of the filter bed. They relate the initial turbidity breakthrough to the breakdown of the initially placed weak hydroxide flocs within the pores of the media due to the rapid increase of velocity gradients

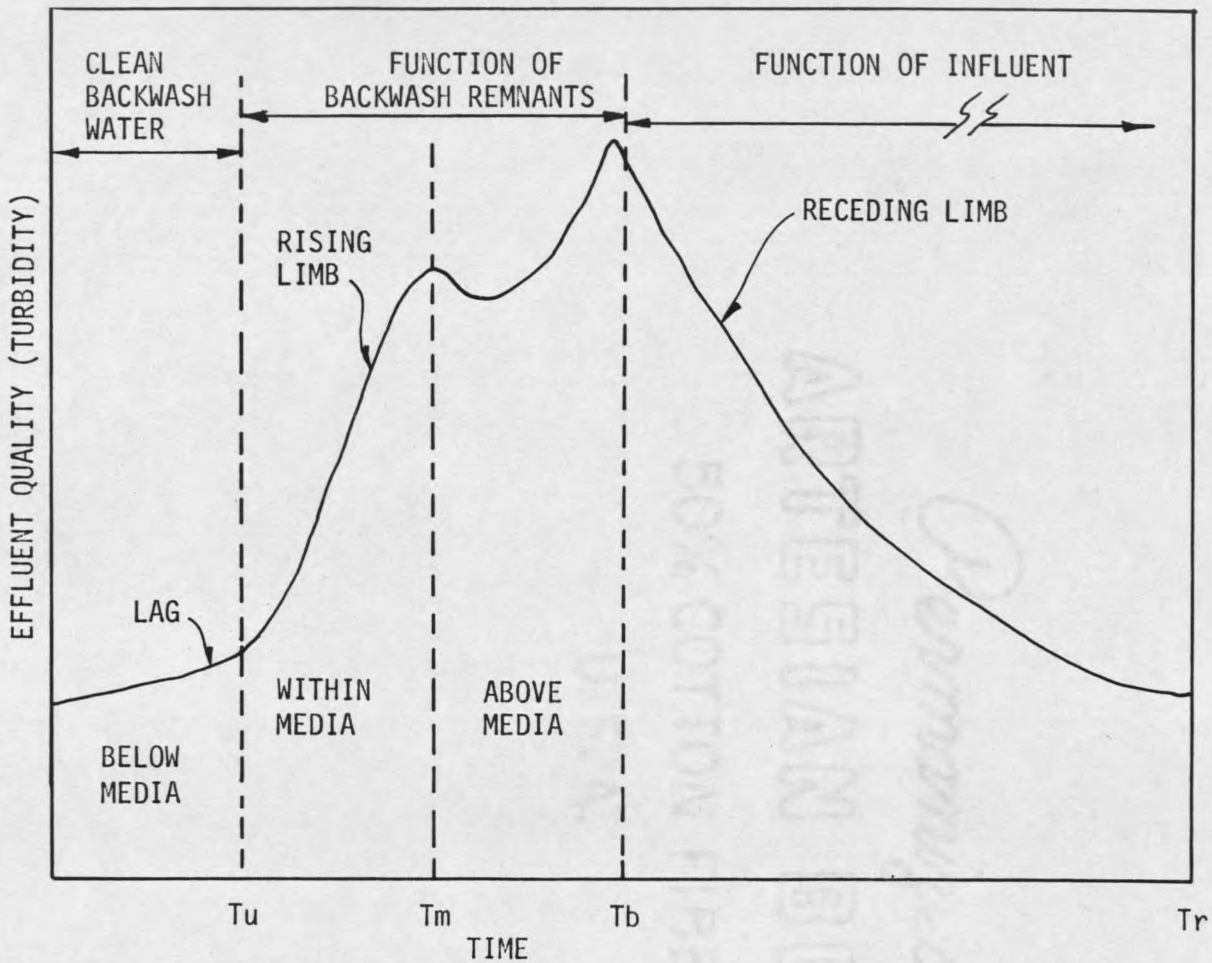


Figure 1. Characteristics of Initial Effluent Quality.

as particles begin to accumulate. The loosely deposited flocs are scoured back into suspension in considerable amounts. Francois and Van Haute also discovered that overdosing the primary coagulant at the beginning of a filter run will decrease the ripening peak and shorten the time for it to occur. They attribute this to an increased blocking rate of the pores and dead zones. The primary peak of degradation is thus assumed to be due to a lack of filter efficiency because of an inadequate pore structure and passage of the initial weak flocs through the filter media. The rate of pore blocking is suggested to be strongly influenced by the chemical treatment of the raw water.

Studies by Payatakes et al [12] and O'Melia and Ali [11] have shown that the improving phase of filter ripening is due to the accumulation of particles within the media flow channels. Payatakes [12] used visual data to show that the main mechanism causing alteration of the geometry of the flow channels within the filter media was throat clogging. This throat clogging resulted in an increase of local capture efficiency explaining the improving phase of filter ripening. The study by O'Melia and Ali [11] using a polymer coagulant system, mathematically related the improving phase of filtration to the accumulation of particles and the formation of dendrites and particle chains within the media pores. The constantly accumulating particles within the media are thought to continually improve the effluent quality by the improved capture of influent particles by the dendrites.

From this work O'Melia and Ali [11] developed an extension of the particle capture theory to model the improving phase of filter ripening. The equation not only includes the collector efficiency of the original filter grain, but it also displays the collector efficiency of the filter grain and its associated particles collected during filtration.

$$nr = (A \times n) + (N \times Ap \times np) \times \left(\frac{dp}{dc}\right)^2 \qquad (2)$$

Where:
- np = Collection efficiency of a retained particle.
- nr = Single collector efficiency of a particle and its retained particles.
- Ap = Collector efficiency factor of retained particle.
- dp = Diameter of suspended particle.
- N = Number of particles that act as collectors.
- A = Collision efficiency factor.
- dc = Diameter of collector.
- n = Single collector efficiency

A further equation was developed based on a mass balance about a differential volume element of the filter in which the retained particles act as collectors so that removal varies with time. This equation is modified by simplifying assumptions and numerically integrated as a step function. Experimental data was used to estimate the coefficients and for calibration of the model. Though the resulting equation is somewhat emperical, it does correspond well with data collected on experiments during their study.

$$\ln \frac{ni}{no} = -\frac{3}{2} \times n \times A \times (1-f) \times \left(\frac{L}{dc}\right)\left[1 + np \times Ap \times B \times vo \times dp^2 \times \left(\frac{\pi}{4}\right) \times \left[\sum no \times \Delta te^{-\left(\frac{3}{2} \times (1-f) \times nr_{i-1} \times \left(\frac{L}{dc}\right)\right)}\right]\right] \quad (3)$$

Where: ni = Particle concentration in the depth L at time i.

(nr i-1) = Single collector removal efficiency for for the (i-1) time step.

B = Particle retention fraction on media.

te = Time

L = Depth in media.

no = Initial particle concentration.

f = Bed porosity.

vo = Fluid velocity.

A rational approach to interpreting the studies by Payatakes and O'Melia would be to assume that in actual plant operation, the methods of accumulation they described, dendrites versus pore clogging, will act synergistically in varying degrees of importance to provide increased effluent quality during the improving stages of the filter ripening sequence. It would be difficult to realistically assume that a system utilizing alum and a system utilizing a polymer as primary coagulants would act exactly the same in respect to formation of dendrites or pore clogging due to the varying nature of the chemicals.

Filter Media Preconditioning During Backwash

Beginning with the study by Harris [8] in 1970, several researchers have looked into the use of coagulants, primarily polymers, added into the backwash water in order to reduce the magnitude and duration of the filter ripening sequence. These studies have assumed that at least a portion of the beneficial effects of adding a polymer into the backwash water would be the adsorption of the polymer onto the grains of the filter media. The adsorbed polymer would subsequently improve the capability of the filter to remove the particles initially passing through the filter, quickly clogging the pores, thus reducing the transport of particles through the filter.

Studies by Yapijakis [15], conducted using the pilot plants for the 100 mgd Newark N.J. and for the 300 mgd Croton N.Y. City water treatment plants, showed that the addition of a small amount of polymer (0.15 mg/l) to the backwash water substantially reduced the duration of the filter ripening sequence. The studies by Harris [8] indicated that similar results could be obtained using a polymer dose of 0.10 mg/l. Further study by Yapijakis [11] indicated that when polymer had been added to the backwash water, the settling characteristics of the backwashed flocs displaced to the settling basins was much improved. The study by Francois and Van Haute [7] was conducted on a pilot plant flocculating domestic waste water with alum in conjuction with a non-ionic polymer. During the last 15 minutes of the backwashing cycle, the polymer was added to the backwash water. These studies showed similar results to the previous researchers; both a decrease in the initial degradation peak and a decrease in the duration of the filter ripening period. They attribute this effect to the ability of polymers to form larger flocs than hydroxides, thus filling the pores of the filter media earlier reducing the time required for ripening.

A study by Chen [5] concerning the preconditioning of a filter during backwash, again indicated an improvement in the effluent quality in cases where polymer was added to the backwash water. Another focus of the study was to determine if filter preconditioning during backwash would also reduce the concentration of microorganisms passing through the filter. Klebsiella was added into the influent water and a determination of the quantities passing through the filter during normal filtration and during preconditioning were made. This study did not show a very good correlation in removal efficiency between the microorganisms and the turbidity in the runs where filter bed preconditioning was used.

Logsdon's study [9] concerning the same microorganisms, including Giardia, did show an increase of microbes passing through the filter in the initial stages, decreasing as the filter ripening sequence progressed. It is possible that when preconditioning is used to improve the initial effluent from the filter in terms of turbidity, that a similar improvement will occur with the removal of microbes.

CHAPTER 4

EXPERIMENTAL RESEARCH

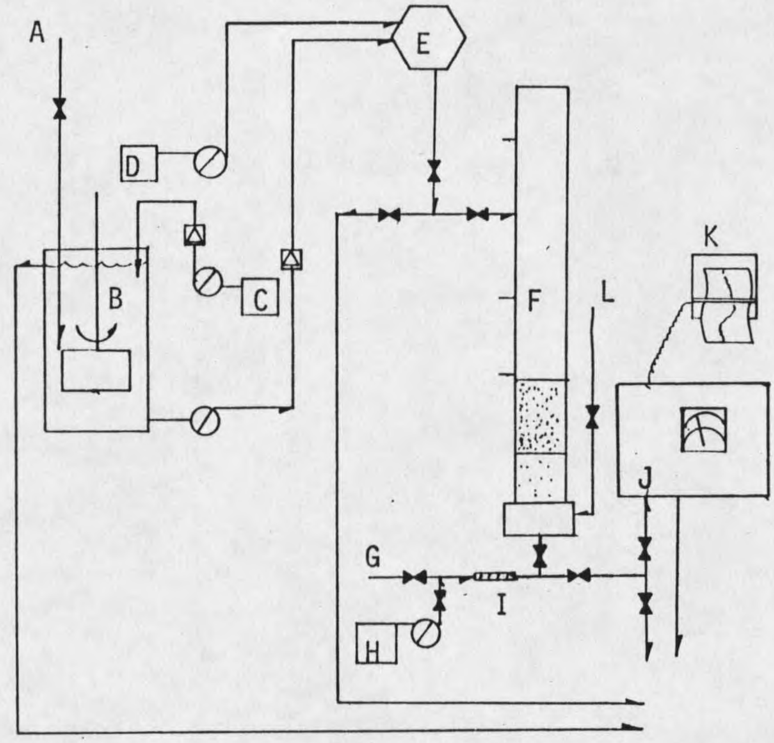
Experimental Methods

The experiments for this study were conducted using the in-line, dual media filtration pilot plant in the Montana State University Environmental Engineering Laboratory. The pilot plant filter (Figure 2) consists of a 6" by 6" plexiglass unit with a media of anthracite coal and sand.

Table 1. Pilot Plant Filter Media Size Distribution [14].

SIZE CHARACTERISTIC	SAND	COAL
D10 (mm) (effective size)	0.46	0.86
D60 (mm)	0.62	1.25
D90 (mm)	0.70	1.52
Uniformity coefficient	1.35	1.46

The plant was continuously operated at a rate of 4 gpm/sq. ft. using a raw water mixed within the pilot plant unit, composed of tap water with bentonite for the polymer studies and tap water with a silica clay (Min-u-sil 30) as the turbidity source for the alum studies. The primary reason for different turbidity sources was that the polymer



A. INFLUENT WATER (TAP)
B. ARTIFICIAL WATER PREPARATION
C. TURBIDITY FEED
D. PRIMARY COAGULANT FEED
E. RAPID MIX UNIT
F. DUAL MEDIA FILTER UNIT
G. BACKWASH WATER (TAP)
H. BACKWASH COAGULANT FEED
I. KOMAX STATIC MIXER
J. HACH SCATTER 4 TURBIDIMETER
K. HEWLETT-PACKARD STRIP CHART RECORDER
L. AIR SCOUR INJECTION

Figure 2. Laboratory Pilot Filtration Plant Schematic.

could not effectively remove the Min-u-sil and the alum could not effectively remove the bentonite with the given water.

The particle size distribution for the Min-u-sil 30 was determined by Trusler [17] using a standard hydrometer (ASTM D 422) for the weight distribution, and an Omnimet image analyzer for the particle count distribution (Figure 3). The bentonite particle distribution was supplied by Wyo-Ben Inc. and is as follows:

Table 2. Bentonite Particle Size Distribution

Screen size	% passing
# 200 (0.074 mm)	80 %
# 325 (0.045 mm)	50 to 60 %

The blended raw water was pumped from the mixing unit to a rapid mix unit where it was blended with the respective coagulants; 3.5 mg/l Cat Floc TL polymer, 19 mg/l alum, or 16:0.8 mg/l alum/polymer combination. The respective primary coagulant dosages were optimized by varying the dosages administered to the pilot plant under controlled conditions. From the rapid mix unit the water passed into the filter unit. The filtered water then passed through the underdrains and the full flow volume passed through a Hach Scatter 4 turbidimeter where turbidity was

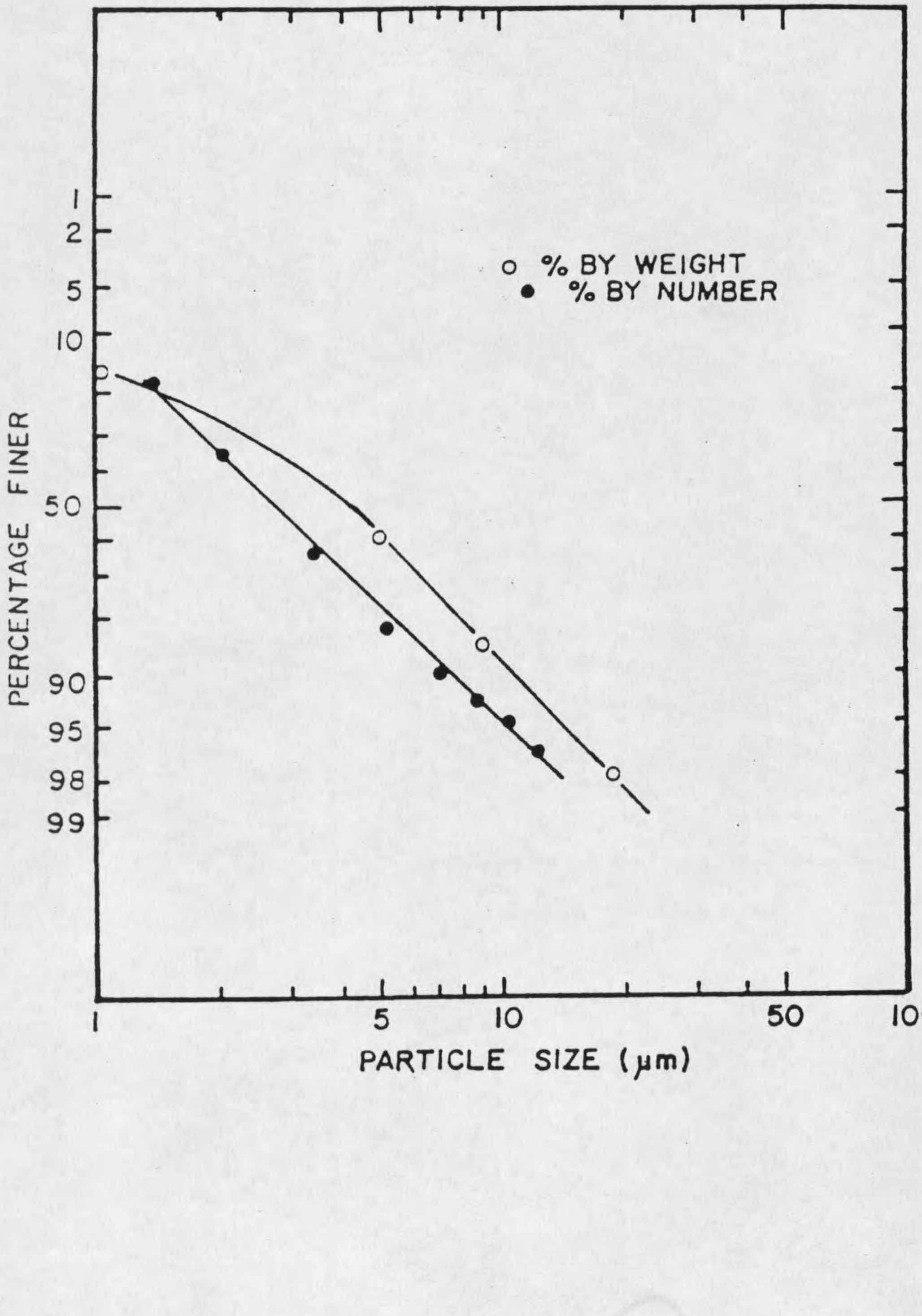


Figure 3. Particle Size Distribution for Min-u-sil 30. (Trusler 14)

continuously monitored and recorded on a Hewlett-Packard strip chart. The flowrate was routinely checked by timed displacement.

Although the maximum recommended flow through the Hach turbidimeter is about 1 liter/min., trial runs indicated that under actual flow conditions of up to 4 liters/min. the turbidity measurements could be made with a good degree of accuracy.

Following a cycle of filtration, which generally was 50 minutes, the filter was backwashed. The backwashes were conducted as follows:

1. The filter media was air-scoured for 1 minute in order to remove a buildup of coagulant balls on top of the media.
2. The backwash water was circulated through the turbidimeter bypassing the filter until the backwash water turbidity stabilized.
3. The filter media was then backwashed for a period of 5 minutes at approximatly 21 gpm/sq. ft. (30% expansion [1]).
4. At the end of backwash, the backwash influent water was again circulated through the turbidimeter and the turbidity monitored until it stabilized.
5. At the same time the backwash water was being monitored, the pilot plant was operated bypassing the

filter in order to stabilize the turbidity and coagulant dosages in the filter unit influent. This generally took about 3 minutes.

6. Upon stabilization of the backwash water and the influent, the valves were switched to bring the filter unit on-line to the turbidimeter. The filter ripening sequence was monitored with the Hewlett-Packard strip chart.

7. During experiments where coagulants were injected into the backwash water, the coagulant was introduced into the backwash water at the base of the media by means of a Sigma finger pump. This water passed through a Komax static mixing unit before it reached the filter.

During the experiments, temperature, flowrates, pH, and influent turbidity were routinely monitored for quality control. All measurements of coagulant dosages were determined by timed displacement into a graduated cylinder. Influent turbidities were determined from grab samples using a Hach 2100A nephelometer.

Following monitoring of the filter ripening sequence with the strip chart, (see Figure 4 for actual chart data for experiment B-2) the values from the strip chart were plotted on standard graph paper, time versus turbidity. The