**WATER FILTRATION RESEARCH
PART III. THE EFFECTS OF
POLYELECTROLYTE FILTER CONDITIONERS
ON FILTER BED EXPANSION
DURING BACKWASHING**

BY

D. E. OLESEN, B. L. CARLILE,
R. L. SCHMIDT, AND C. J. TOUHILL

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ABSTRACT

The Water Filtration Research program has shown that as a filter conditioner, polyelectrolyte concentrations, in excess of those employed at the Douglas United Nuclear water treatment plants, are necessary before bed expansion is affected. Graphical data is presented to show the effect of various polyelectrolyte concentrations on filter bed expansion. Theoretical clean bed expansion during backwashing is considered for the laboratory filters and a filter at the 100 D water treatment plant.

TABLE OF CONTENTS

ABSTRACT.....	iii
LIST OF TABLES.....	vi
INTRODUCTION.....	1
SUMMARY AND CONCLUSIONS.....	2
DISCUSSION.....	2
Theory and Practice.....	2
Filter Backwashing.....	2
Polyelectrolytes.....	4
Experimental Methods.....	5
Water Filtration Pilot Plant.....	5
Operation.....	5
Backwashing.....	5
Filter Media.....	6
Results.....	6
REFERENCES.....	17
DISTRIBUTION.....	Distr-1

LIST OF TABLES

I	Pilot Plant Filter Media	5
II	Computations for Stratified Anthracite Bed Expansion, Filter No. 1	7
III	Computations for Stratified Sand Bed Expansion, Filter No. 1	7
IV	Computation for Bed Expansion, Filter No. 1	8
V	Computations for Stratified Anthracite Bed Expansion, Filter No. 2	8
VI	Computations for Stratified Sand Bed Expansion, Filter No. 2	9
VII	Computation for Bed Expansion, Filter No. 2	9
VIII	Computations for Stratified Anthracite Bed Expansion, 100 D Filter	10
IX	Computations for Stratified Sand Bed Expansion, 100 D Filter	10
X	Computations for Expansion, 100 D Filter	11

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INTRODUCTION

Cooling water for the Hanford production reactors is produced by a series of physical-chemical treatment operations, the last of which is gravity filtration. The filters are of the dual media type, a layer of anthracite over a layer of sand. During operation, chemically coagulated water is passed through the filters which trap the suspended matter leaving an effluent with very low turbidity. The configuration and operation of the filters are a direct result of the work of Conley and Pitman.⁽¹⁻⁴⁾ Even though filtration is widely used in water treatment and has been the object of much research, it is not a well understood phenomenon. Camp⁽⁵⁾ states: "The development and improvements of filtration has proceeded slowly, by trial-and-error innovations, without the benefit of an adequate understanding of the mechanisms of filtration." This is particularly true of the backwashing phase of filter operation. During backwashing, filtered water is passed upward through the filter at a rate sufficient to wash out the material trapped in the bed. Washing continues until the bed appears to be clean and then the filtering operation is resumed. In order to insure an optimum backwashing procedure, additional research is required. In particular, each variable must be evaluated for its importance as well as for its interaction with other system variables. This research is concerned with one such variable, the effect of polyelectrolytes as filter bed conditioners on filter bed expansion during backwashing.

SUMMARY AND CONCLUSIONS

This research was undertaken to determine the effects of polyelectrolyte filter conditioners on filter bed expansion during backwashing. Experimental results showed that increased bed expansion during backwashing is caused by polyelectrolyte filter bed conditioners in concentrations in excess of 0.1 ppm. However, bed expansion is not significantly affected by polyelectrolyte concentrations below 0.05 ppm. The low concentrations of polyelectrolytes used at the Douglas United Nuclear water treatment plants should not affect filter bed expansion during backwashing.

Theoretical equations were employed to accurately predict clean bed expansion during backwashing of laboratory pilot plant filters.

It is recommended as part of the Water Filtration Research program that all filter beds at the Douglas United Nuclear water treatment plants be cored, and that filter media size distributions be determined to evaluate the condition of the beds. Experimentation has shown that additional research is required to define a method for establishing an optimum backwashing procedure.

DISCUSSION

THEORY AND PRACTICE

Filter Backwashing

Filter beds are backwashed to remove the material which was deposited in the beds during the filtering operation. By passing filtered water upflow through the filter, the media is expanded and agitated to free the trapped material so it can be carried away with the backwash water. The degree of bed expansion obtained during backwashing is important for several reasons. First, if the expansion is too little, the particulate matter cannot be freed from the bed. Second, if

the expansion is too great, intermedia contact or scrubbing will not function to dislodge particles attached to the media. The backwash rate employed should be that which will produce rapid bed cleansing due to the shearing action of the water and the intermedia contact within the bed. There is, at present, no method for determining this optimum wash rate for a particular filter. This situation exists because of a lack of understanding of the interrelationships of such variables as: characteristics of the suspension being filtered, filter media, temperature of backwash water, and the duration and rate of backwashing. However, if a clean filter bed is considered, a theoretical treatment of backwashing is possible. For a given backwashing rate, filter media grain size distribution and temperature of backwash water, the corresponding bed expansion can be calculated with the following equations. (6)

$$1. \quad L_e = L (1 - e) \int \frac{x}{1 - e_e}$$

where:

L_e = relative bed expansion

L = depth of filter

e = porosity of settled bed

e_e = expanded bed porosity

x = fraction by weight of particles having the expanded porosity e_e

$$2. \quad \frac{e_e^3}{1 - e_e} = \frac{k}{g} \frac{\mu}{(Sg - 1)\rho} v \left(\frac{\psi}{d} \right)^2$$

where:

k = hydraulic constant: $k = 5$ for settled bed

$k = 4$ for expanded bed

g = gravitational constant

Sg = specific gravity of filter media
 ρ = mass density of backwash water
 μ = absolute viscosity of backwash water
V = velocity of backwash water
 Ψ = media shape factor: $\Psi = 6.1$ sand, $\Psi = 8.2$ anthracite
d = geometric mean diameter of particle, ft

Calculations which are based on the above equations can be applied to verify laboratory experimentation; however, in the theoretical situation the filter bed is assumed to be clean while in practice the bed contains some particulate matter after backwashing. Thus, complete agreement between theory and practice should not be expected.

Polyelectrolytes

Separan* and Magnifloc 990** are the polyelectrolytes which are used routinely at the Douglas United Nuclear water treatment plants as filter bed conditioners. Both are nonionic high-molecular-weight polyacrylamides. They are fed continuously to the chemically coagulated water immediately before filtration. The polyelectrolytes were adopted for use only after they were demonstrated to significantly reduce turbidity breakthrough at high alum concentrations and high filtration rates.⁽⁴⁾ Pitman and Wells,⁽⁷⁾ in testing various polyelectrolytes, have demonstrated the importance of their use. Robeck, Dostal, and Woodward⁽⁸⁾ found polyelectrolytes of value as filter bed conditioners in preventing turbidity breakthrough at high filtration rates. Increased rates of head loss have been noted with the use of polyelectrolytes, but practical operating experience at Hanford has demonstrated that this is more than offset by the ability to operate at high filtration rates.

* Separan is a product of the Dow Chemical Company, Midland, Michigan.

** Magnifloc 990 is a product of the American Cyanamid Company, Wayne, New Jersey.

EXPERIMENTAL METHODS

Water Filtration Pilot Plant

A complete description of the laboratory facility employed in this study can be found in the report: "Water Filtration Research Part I: The Water Filtration Pilot Plant," (in preparation). Table I contains data on the filter media used in the Water Filtration Pilot Plant during this study.

TABLE I. *Pilot Plant Filter Media*

<u>Anthracite</u>	<u>Mesh Size Range</u>	<u>Effective Size, mm</u>	<u>Uniformity Coefficient</u>
Filter No. 1	7-45	0.82	1.93
Filter No. 2	7-45	0.74	1.76
<u>Sand</u>			
Filters No. 1 & 2	18-40	0.38	1.79

Operation

Alum and polyelectrolyte were added to the raw water in a rapid mix tank. pH of the water was held at 6.6 by the addition of caustic soda (NaOH). Alum was fed at 7.1 ppm as aluminum in all tests. Following contact in the rapid mix tank the water flowed by gravity to the filters which were operated at 8 gpm/ft². Filter runs were terminated when the headloss across the filters reached 8 ft of water.

Backwashing

Immediately after filtration was terminated the columns were backwashed. Backwashing proceeded as follows: the backwash valve was opened slowly and after 0.4 min the flow was set at 5.9 gpm/ft²; after 2.0 min the flow was increased to 15.8 gpm/ft²; this flow was maintained for an additional 13 min. Sanitary water was employed for backwashing since it is similar in quality to the filtered water of the pilot plant. During backwashing, bed expansion was measured and plotted against time.

Filter Media

After completion of the laboratory filter runs, a 2 in. core of the anthracite-sand media was removed from each of the filter columns. Anthracite and sand were separated with a hydraulic sand washer and dried. Grain size distributions for the two filter beds were then determined by mechanical sieving (Table I). Porosity of each filter media was determined by allowing the media to stand in a column of water for several days to become completely saturated with water. The water level in the column was then lowered to the level of the media and a vacuum was attached to the bottom of the column to extract the remaining water until the upper layers of the media began to show drying. Volume of the water removed under vacuum was taken as the void space of the media and was used for the porosity.

RESULTS

Tables II through IX contain the results of the filter bed corings and the associated calculations for bed expansion of the laboratory pilot plant filters. Under the test conditions of temperature and backwash rates, filters 1 and 2 have theoretical expansions of 6.95 in. and 7.8 in. respectively. Similar calculations are shown in Tables VIII through X for a filter at the Douglas United Nuclear 100 D water treatment plant. The theoretical expansion was 5.2 in. The anthracite of the 100 D filter had a uniformity coefficient of 1.6 and an effective size of 1.06 mm, as opposed to 2.0 and 0.7 mm in the original configuration.⁽⁵⁾ Loss of fine material from the filter bed during backwashing is probably the cause of the change. This single coring suggests the need for coring all of the filters at the reactor water treatment plants to evaluate the extent of change and the need for replacement.

Figures 1 through 4 contain the data on the filter bed expansion studies at various polyelectrolyte concentrations. Two filtration runs were made at each set of operating

TABLE II. Computations for Stratified Anthracite
Bed Expansion, Filter No. 1: Temperature =
15.5 °C, Wash Rate = 15.8 gpm/ft²

Sieve No.	Percentage of Anthracite Retained x 100	Geometric Mean Size (d) ft x 10 ³	$\frac{e_e^3}{1 - e_e}$	e_e	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
7-8	0.369	8.51	0.08640	0.377	1.6051	0.0059
8-10	7.371	7.23	0.12243	0.415	1.7094	0.1307
10-12	21.376	6.01	0.17324	0.455	1.8349	0.3922
12-14	20.025	5.05	0.24546	0.498	1.9920	0.3989
14-16	19.287	4.25	0.34679	0.542	2.1834	0.4211
16-18	13.268	3.57	0.48953	0.587	2.4213	0.3213
18-20	10.074	3.01	0.69172	0.633	2.7248	0.2745
20-25	2.826	2.54	0.97375	0.679	3.1153	0.0880
25-30	3.071	2.14	1.36424	0.723	3.6101	0.1109
30-35	1.116	1.80	1.93822	0.767	4.2918	0.0475
35-40	0.983	1.50	2.76688	0.809	5.2356	0.0515
40-45	0.246	1.25	3.94581	0.846	6.4935	0.0160

$$\sum = 2.2585$$

TABLE III. Computations for Stratified Sand Bed Expansion,
Filter No. 1: Temperature = 15.5 °C, Wash Rate =
15.8 gpm/ft²

Sieve No.	Percentage of Sand Retained x 100	Geometric Mean Size (d) ft x 10 ³	$\frac{e_e^3}{1 - e_e}$	e_e	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
40-45	10.020	1.25	0.765	0.6465	2.83	0.2840
35-40	10.421	1.50	0.531	0.597	2.48	0.2585
30-35	9.218	1.80	0.369	0.5485	2.21	0.2035
25-30	25.451	2.14	0.261	0.505	2.02	0.5140
20-25	36.272	2.54	0.185	0.4632	1.86	0.6740
18-20	8.617	3.01	0.132	0.424	1.735	0.1495

$$\sum = 2.0835$$

TABLE IV. Computation for Bed Expansion, Filter No. 1

$$L_e = L (1 - e) \sum \frac{x}{1 - e_e}$$

e of sand = 0.40

e of anthracite = 0.455

L of anthracite = 27 in.

L of sand = 3 in.

$$\begin{aligned} L_e &= (27)(1 - 0.455)(2.2585) + 3(1 - 0.40)(2.0835) \\ &= (27)(0.545)(2.2585) + 3(0.60)(2.0835) \\ &= 33.2 + 3.75 \\ &= 36.95 \text{ in.} \end{aligned}$$

$$\text{Expansion} = 36.95 - 30.0 = 6.95 \text{ in.}$$

TABLE V. Computations for Stratified Anthracite Bed Expansion, Filter No. 2: Temperature = 16 °C, Wash Rate = 15.8 gpm/ft²

Sieve No.	Percentage of Anthracite Retained x 100	Geometric Mean Size (d) ft x 10 ³	$\frac{e_e^3}{1 - e_e}$	e_e	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
7-8	0.247	8.51	0.08518	0.376	1.60256	0.0045
8-10	3.832	7.23	0.12108	0.414	1.70648	0.0703
10-12	13.350	6.01	0.17139	0.454	1.83345	0.2450
12-14	15.451	5.05	0.24212	0.496	1.98412	0.3066
14-16	18.789	4.25	0.34230	0.540	2.17391	0.4085
16-18	17.058	3.57	0.48241	0.585	2.40963	0.4110
18-20	16.811	3.01	0.68087	0.631	2.71002	0.4556
20-25	6.181	2.54	0.96065	0.677	3.09597	0.1914
25-30	6.181	2.14	1.34337	0.721	3.58422	0.2215
30-35	1.236	1.80	1.90769	0.766	4.27350	0.0528
35-40	0.742	1.50	2.72311	0.807	5.18134	0.0384
40-45	0.124	1.25	3.89258	0.845	6.45161	0.0080

$$\sum = 2.4136$$

TABLE VI. *Computations for Stratified Sand
Bed Expansion, Filter No. 2:
Temperature = 16 °C, Wash Rate =
15.8 gpm/ft²*

Sieve No.	Percentage of Sand Retained x 100	Geometric Mean Size (d) ft x 10 ³	$\frac{e_e^3}{1 - e_e}$	e_e	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
40-45	10.020	1.25	0.757	0.645	2.815	0.2825
35-40	10.421	1.50	0.526	0.596	2.475	0.2585
30-35	9.218	1.80	0.365	0.548	2.21	0.2035
25-30	25.451	2.14	0.258	0.504	2.02	0.5140
20-25	36.272	2.54	0.183	0.463	1.86	0.6740
18-20	8.617	3.01	0.131	0.4235	1.735	0.1495
						$\Sigma = 2.0820$

TABLE VII. *Computation for Bed Expansion, Filter No. 2*

$$L_e = L(1 - e) \sum \frac{x}{1 - e_e}$$

e for anthracite = 0.477

e for sand = 0.40

L for anthracite = 27 in.

L for sand = 3 in.

$$\begin{aligned} L_e &= 27(1 - 0.477)(2.4136) + 3(1 - 0.40)(2.082) \\ &= (27)(0.523)(2.4136) + 3(0.60)(2.082) \\ &= 34.1 + 3.75 = 37.85 \text{ in.} \end{aligned}$$

$$\text{Expansion} = 37.8 - 30.0 = 7.8 \text{ in.}$$

TABLE VIII. Computations for Stratified Anthracite
Bed Expansion, 100 D Filter: Temperature =
4 °C, Wash Rate = 15 gpm/ft²

Sieve No.	Percentage of Anthracite Retained x 100	Geometric Mean Size (d) ft x 10 ³	$\frac{e_e^3}{1 - e_e}$	e_e	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
4-7	5.94	12.04	0.05704	0.336	1.5060	0.0895
7-8	11.54	8.51	0.11418	0.407	1.6863	0.1946
8-10	15.26	7.23	0.15821	0.445	1.8018	0.2750
10-12	23.29	6.01	0.22895	0.489	1.9569	0.4558
12-14	16.82	5.05	0.32427	0.533	2.1413	0.3602
14-16	14.28	4.25	0.45785	0.578	2.3697	0.3384
16-18	8.42	3.57	0.64888	0.625	2.6667	0.2245
18-20	3.51	3.01	0.91279	0.620	3.0303	0.1064
20-25	0.95	2.54	1.28185	0.715	3.5088	0.0333
						$\Sigma = 2.0777$

TABLE IX. Computations for Stratified Sand Bed Expansion,
100 D Filter: Temperature = 4 °C, Wash Rate =
15 gpm/ft²

Sieve No.	Percentage of Sand Retained x 100	Geometric Mean Size (d) ft x 10 ³	$\frac{e_e^3}{1 - e_e}$	e_e	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
18-20	4.644	3.01	0.17450	0.456	1.8382	0.0854
20-25	12.289	2.54	0.24504	0.497	1.9881	0.2443
25-30	42.354	2.14	0.34522	0.541	2.1786	0.9227
30-35	27.213	1.80	0.48935	0.587	2.4213	0.6589
35-40	12.520	1.50	0.70265	0.635	2.7397	0.3430
40-45	0.978	1.25	1.01183	0.684	3.1646	0.0309
						$\Sigma = 2.2852$

TABLE X. *Computations for Expansion, 100 D Filter*

$$L_e = L(1 - e) \sum \frac{x}{1 - e_e}$$

$$L = 30 \text{ in.}$$

$$L \text{ for Anthracite} = 23.9 \text{ in.}$$

$$L \text{ for sand} = 6.1 \text{ in.}$$

$$e \text{ for anthracite} = 0.46$$

$$e \text{ for sand} = 0.40$$

$$\begin{aligned} L_e &= 23.9(1 - 0.46)(2.0777) + 6.1(1 - 0.40)(2.2852) \\ &= 23.9(0.54)(2.0777) + 6.1(0.60)(2.2852) \\ &= 26.8 + 8.37 \\ &= 35.2 \text{ in.} \end{aligned}$$

$$\text{Expansion} = 35.2 - 30.0 = 5.2 \text{ in.}$$

FIGURE 1. Bed Expansion versus Time of Backwash

FIGURE 2. Bed Expansion versus Time of Backwash

FIGURE 3. Bed Expansion versus Time of Backwash

FIGURE 4. Bed Expansion versus Time of Backwash

conditions, but only data from the second run were used. This was a result of an apparent conditioning of the filter beds during each of the first runs. Since Separan and Magnifloc 990 are in routine use at the reactor water treatment plants, both were evaluated in this study. Similar results were obtained with both polyelectrolytes. At polyelectrolyte concentrations above 0.1 ppm, increased bed expansions during backwashing were experienced. From visual inspection of the filters during backwashing, the higher polyelectrolyte concentrations appear to bond the upper portion of the filter media into a single mass. In order to break up this mass and produce a clean bed, longer periods of backwashing are required. Surface sprays to break up the surface layer of the filter during backwashing are important with the use of high polyelectrolyte concentrations. There appears to be a relationship between increasing polyelectrolyte concentration and increasing bed expansion; however, this point was not studied since the polyelectrolyte concentrations involved were well above those of present operating interest.

At polyelectrolyte concentrations below 0.05 ppm there appears to be little influence of bed expansion during backwashing. Results of this study indicate the concentrations of polyelectrolyte employed at the Douglas United Nuclear water treatment plants have no effect on bed expansion or bed cleansing during backwashing.

This research has evaluated the importance of one factor in filter backwashing. Studies are continuing in order to establish a method for defining the optimum backwash rate and duration under any set of operating conditions.

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