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WATER FILTRATION RESEARCH PART II.**THE EFFECTS
OF BACKWASH WATER TEMPERATURE
ON FILTER BED EXPANSION**

C. J. TOUHILL, R. L. SCHMIDT

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By

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Water and Wastewater Research
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ABSTRACT

The Water Filtration Research program has shown that the bed expansion of Hanford-type filters is influenced by the temperature of backwash water. Empirical equations were derived to relate temperature and bed expansion for various flow rates. A nomograph is included to assist operational personnel in determining optimum backwash rates.

TABLE OF CONTENTS

ABSTRACT.	iii
LIST OF FIGURES.	v
INTRODUCTION	1
SUMMARY AND CONCLUSIONS	2
DISCUSSION	2
Theory and Practice	2
Filter Backwashing	2
Temperature.	4
Experimental Methods	5
Water Filtration Pilot Plant	5
Backwashing--Temperature Study.	5
Results.	7
REFERENCES.	16
DISTRIBUTION	17

LIST OF FIGURES

1	Water Filtration Pilot Plant	6
2	Bed Expansion for Pilot Plant Filters--12.0 °C	8
3	Bed Expansion for Pilot Plant Filters--15.7 °C	8
4	Bed Expansion for Pilot Plant Filters--19.7 °C	9
5	Bed Expansion for Pilot Plant Filters--21.9 °C	9
6	Bed Expansion--Backwash Flow Relationship	10
7	Bed Expansion for 30 in. Bed Versus Flow	10
8	Bed Expansion--Backwash Flow Versus Temperature	11
9	Effect of Backwash Temperature on Bed Expansion for 0.74 mm Anthracite	12
10	Nomograph for Calculating Backwash Flow Rate for Known Temperature and Bed Expansion	15

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INTRODUCTION

Many of the significant innovations in water treatment technology are the result of a vigorous filtration research program at the Hanford Project. The extensive use of such developments as microphotometers for monitoring water turbidity, polyelectrolytes for enhanced particulate removal and filter conditioning, and dual-media filters for increased water throughput are the direct result of experimental research conducted by Conley and Pitman at Hanford.⁽¹⁻⁴⁾ So successful are these techniques in increasing the capacity of existing facilities and in producing high quality water that they have been adopted in numerous water treatment plants throughout the country.

The continuing efforts in water treatment research at Hanford have been directed toward 1) the production of high quality water and 2) the reduction of water treatment costs. High quality water is essential because impurities may be activated to radioactive species as the water passes through the reactors for cooling. Even though the radionuclides discharged to the Columbia River are not detrimental to the public, continuing efforts at Hanford have striven to reduce this discharge to the lowest possible amount. Experience has shown that reductions in the amount of radionuclides discharged have been directly related to improvements in the production of high quality water. The research reported in this paper is part of this continuing program.

SUMMARY AND CONCLUSIONS

This research was undertaken to determine the effects of backwash temperature on filter bed expansion. Experimental results showed that increases in temperature necessitate increased backwash flow rates for constant percent bed expansions. The influence of backwash temperature on bed expansion can be represented by empirical equations.

A nomograph (Figure 10) can be used to provide operational personnel with a more definitive means for determining the proper backwash rate based on backwash water temperature. In conjunction with the nomograph, a bed expansion of 30% is recommended on a test basis prior to the experimental identification of the optimum rate and duration of backwash.

DISCUSSION

THEORY AND PRACTICE

Filter Backwashing

The backwashing process is critical in preparing a filter bed for reuse. Its function is to "scrub" the filter media so that enmeshed floc and particulate material (turbidity) can be discarded to waste. The backwash rate is especially important in providing the most effective "scrubbing" or cleaning of the filter bed. At low backwash rates the media is not lifted or expanded sufficiently to provide the intermedia contact and agitation necessary for floc and particulate removal. At high backwash rates the filter bed is expanded too much so that there is very little intermedia contact and interparticulate agitation. Ideally, optimum cleaning occurs when the media is expanded to that point where intermedia contact is just maintained and when agitation is sufficient to remove floc and particulate matter adhering to the media surfaces.

Some of the adverse effects of overexpansion or underexpansion of filter beds during backwash are as follows:

- Initial turbidity purges immediately following backwashing
- Premature filter breakthrough
- Shortened filter runs and high initial head loss
- Anthracite losses.

For these adverse effects to be minimized, some optimum backwash rate must be selected. This backwash rate and the corresponding bed expansion for stratified beds can be determined using the following two equations. ⁽⁵⁾

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

where

Le = relative bed expansion

L = depth of filter

e = porosity of settled bed

e_e = expanded porosity

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

The porosity ratio of the expanded media is determined from the following relationship:

$$\frac{e_e^3}{1 - e_e} = \frac{k}{g} \frac{\mu}{(S_g - 1)\rho} v (\psi/d)^2$$

where

k = a hydraulic constant; k = 5 for settled bed; k = 4 for expanded bed

g = gravitational constant

S_g = specific gravity of filter media

ρ = mass density of backwash water

μ = absolute viscosity of backwash water

v = velocity of backwash, ft/sec

ψ = shape factor; $\psi = 6.1$ for sand; $\psi = 8.2$ for anthracite

d = geometric mean diameter of particle, ft.

Theoretical calculations which are based on the above equations will be employed only as approximations to verify the results of laboratory and pilot plant experimentation. Theoretically the filter bed is assumed to be clean, but practically it contains flocculant material; therefore, some discrepancy should be expected between theory and practice.

Because the mass density and viscosity of water varies inversely with temperature (above 4 °C), increased backwash rates are required to expand the filter beds for increasing water temperatures. Thus, if a given bed expansion is deemed optimum for filter renovation, the most suitable backwash rate required to achieve this expansion will vary according to the temperature of the backwash water. This procedure is not compatible with existing water treatment practice at Hanford, or at most other installations throughout the country.

These pilot plant experiments have been conducted to determine the magnitude of temperature influences on backwashing with the intent of providing operational guidelines for backwash rates. Research to determine an optimum procedure for backwashing is part of the continuing program of additional pilot plant experiments performed in conjunction with the Douglas United Nuclear in-plant testing program.

Temperature

Seasonal temperature differences of about 14 °C have been observed for the Columbia River. The average monthly Columbia River temperatures for 1960-64 ranged from 4.2 °C in February to 17.8 °C in August.⁽⁶⁾ It is very likely, therefore, that seasonal temperature variations in backwash water will be in the 10 to 12 °C range.

The temperature range for these experiments was 9.9 °C. The temperature of sanitary water at the Water and Wastewater Research Laboratory was 12.0 °C in April 1966 (minimum for the research period, April through November, 1966), and 21.9 °C in August 1966. These differences were sufficient to require increased backwash flow rates during the summer and decreased rates during the winter to maintain a constant bed expansion. ⁽⁷⁾

EXPERIMENTAL METHODS

Water Filtration Pilot Plant

The experiments were conducted at the Water Filtration Pilot Plant in 222-U building, 200 West Area. The pilot plant (Figure 1) consists of three lucite filter columns (5 1/2 in. diam by 8 ft long), a chemical mix tank, chemical feed pumps, flow rate controllers, variable speed flocculators; instrumentation includes a recording pH meter, recording turbidimeter, rotameters, and manometers. The filter bed configuration for this study was 30.4 in. of anthracite (8-30 mesh, effective size = 0.7 mm), 3 in. of sand (20-40 mesh, effective size = 0.45 mm), and 10 in. of gravel supported by a perforated steel plate. * This bed configuration represents a typical filter bed at the Hanford reactor water treatment plants.

Backwashing--Temperature Study

Although filtration experiments had been conducted before the initiation of this study, the filters were essentially clean prior to backwashing. The beds were backwashed with 222-U building sanitary water. Sanitary water was used because its quality is quite similar to the clear well water used for in-plant backwashing. The temperature of the backwash water was measured to the nearest 0.1 °C at the waste outlet of the filters and at a laboratory tap.

* The Water Filtration Pilot Plant will be described in detail in a subsequent report presently in preparation.

Temperatures at these sources agreed consistently. Filters were flushed of the water held in them by backwashing at a low flow rate causing essentially no bed expansion. Bed expansion measurements used for final analysis were made at sanitary water temperatures of 12.0 °C (April 19, 1966), 15.7 °C (June 2, 1966), 19.7 °C (July 15, 1966), and 21.9 °C (August 3, 1966).

FIGURE 1. Water Filtration Pilot Plant

The expansion of two filter beds was measured at backwash flow rates ranging from 4 to 22 gpm/ft² in 2 gpm/ft² increments. The flow rate was held steady for about 1 min at each increment before the bed expansion was measured. Measurements were made from a standard reference mark on each filter column during both increasing and decreasing

increments of flow rate. The measured bed expansion was related to the average settled bed depth to obtain the percent bed expansion. For this study the average settled bed depth was 33.4 in.

RESULTS

The measurements of bed expansion during increasing and decreasing flow rate were averaged for each filter. These data are shown in Figures 2 through 5. When the average percent bed expansion for the two filters is plotted on logarithmic paper, straight lines are obtained (Figure 6). The expression describing this relationship is:

$$\log \text{ percent expansion} = m (\log \text{ flow rate}) + a$$

where m and a are constants. A regression analysis⁽⁸⁾ of the logarithmic data was performed. The regression lines were fitted to the data by the method of least squares. The equations calculated are given in Table I.

TABLE I. Equations Describing Bed Expansion Versus Backwash Flow Rate at Constant Temperature

Temperature, °C	Logarithmic Equation log % expansion =	Exponential Equation % expansion =
12.0	1.86496 (log flow rate) - 0.66859	0.21449 (flow rate) exp(1.86496)
15.7	1.90074 (log flow rate) - 0.76227	0.17288 (flow rate) exp(1.90074)
19.7	1.90577 (log flow rate) - 0.81498	0.15311 (flow rate) exp(1.90577)
21.9	2.03142 (log flow rate) - 0.99003	0.10232 (flow rate) exp(2.03142)

From the equations in Table I, the expansion for a 30 in. bed at the temperatures studied was calculated and is shown in Figure 7. From these same equations, flow rates were calculated for 20, 30, 40, and 50% bed expansions. These data are shown in Figure 8. Regression analysis of the data points at 12.0, 15.7, and 19.7 °C yielded the expressions shown in Table II. The lines shown in Figure 8 represent the equations in Table II.

FIGURE 2. Bed Expansion for Pilot Plant Filters--12.0 °C

FIGURE 3. Bed Expansion for Pilot Plant Filters--15.7 °C

FIGURE 4. Bed Expansion for Pilot Plant Filters--19.7 °C

FIGURE 5. Bed Expansion for Pilot Plant Filters--21.9 °C

FIGURE 6. Bed Expansion--Backwash Flow Relationship

FIGURE 7. Bed Expansion for 30 in. Bed Versus Flow

FIGURE 8. Bed Expansion--Backwash Flow Versus Temperature

TABLE II. Equations of Backwash Flow Rate for Constant Bed Expansion

Bed Expansion, %	Flow Rate
20	$0.1959 (\text{temp}) + 9.05$
30	$0.2346 (\text{temp}) + 11.34$
40	$0.2660 (\text{temp}) + 13.33$
50	$0.2923 (\text{temp}) + 15.10$

To verify these results, and perhaps extend their usefulness, they were compared with results of previous research. Data reported by Powell⁽⁹⁾ are shown in Figure 9. Assuming a backwash flow rate of 15 gpm/ft² at 20 °C, Powell reports a bed expansion of greater than 50% for 0.74 mm anthracite. The work conducted in this research shows that, for similar conditions, the expansion is about half or 25% (Figure 6). The discrepancy between the two sets of data is considerable. However, actual in-plant expansion values at the Douglas United Nuclear reactor water treatment plants tend to corroborate the Battelle-Northwest data.

FIGURE 9. Effect of Backwash Temperature on Bed Expansion for 0.74 mm Anthracite (adapted from Water Conditioning for Industry, S. T. Powell, McGraw-Hill Book Co., 1954)

Camp^(10, 11) noted the influences of temperature on backwash flow rates. He states,⁽¹¹⁾ "It is evident . . . that higher wash rates are required for the same bed expansion as temperature increases." Camp also presented theoretical data through which a backwashing number (B) may be calculated. Two aspects of Camp's work limit its usefulness at Hanford. It is based entirely on ideal conditions and would involve laborious calculations to apply to a given example.

Theoretical bed expansions were calculated using Equations (1) and (2). Computations are shown in Tables III and IV. In the theoretical examples, temperature was assumed to be 10 °C, the backwash rate = 15 gpm/ft², and the sand bed porosity = 0.40. The anthracite bed porosity was measured experimentally and was found to be 0.436. For these conditions the calculated expansion of anthracite was 12.2 in. The

measured expansion was about 11.7 in. Agreement between experimental and theoretical values was quite good; however, due to inconsistencies in the actual filter beds, experimental values should be considered more representative of true backwash expansion.

TABLE III. Computation Table for Stratified Anthracite Bed Expansion

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	$\frac{1}{1 - e_e}$	$\frac{x}{1 - e_e}$
30-35	1.980	1.80	2.1308	0.778	4.504	0.0892
25-30	8.316	2.14	1.5075	0.736	3.788	0.3150
20-25	6.534	2.54	1.0701	0.692	3.247	0.2121
18-20	12.673	3.01	0.7620	0.646	2.825	0.3580
12-18	41.186	4.25	0.3822	0.554	2.242	0.9235
10-12	17.821	6.01	0.1911	0.467	1.876	0.3344
8-10	10.891	7.23	0.1321	0.424	1.773	0.1931
7-8	0.594	8.51	0.0953	0.388	1.773	<u>0.0105</u>

$$\Sigma = 2.4358$$

TABLE IV. Computation Table for Stratified Sand Bed Expansion

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	0.8447	0.660	2.941	0.2947
35-40	10.421	1.50	0.5866	0.611	2.571	0.2679
30-35	9.218	1.80	0.4086	0.563	2.288	0.2109
25-30	25.451	2.14	0.2882	0.518	1.930	0.4913
20-25	36.272	2.54	0.2046	0.475	1.905	0.6909
18-20	8.617	3.01	0.1457	0.435	1.770	<u>0.1525</u>

$$\Sigma = 2.0981$$

Based on the work of Cox⁽¹²⁾ and Camp,^(10, 11) it appears that a bed expansion of 25 to 30% should yield best results in backwashing. However, selection of an optimum procedure for filter backwashing is complicated by the relationships between the variables involved, i. e.,

backwash rate, duration of wash, character of suspension being filtered, temperature of the wash water, and the filter media. Bed expansion is often used as an indicator of proper backwash rate; however, bed expansion itself is not a variable of the system, but rather is a result of a given combination of system variables. In this study, bed expansion was used to simply show the importance of temperature on backwash procedure.

The final figure (Figure 10) reduces the pertinent data to nomographic form which is applicable to the filter bed configuration and the grain size distribution used in this study. The nomograph is based on the assumption that 30% bed expansion is desired.

Work is continuing in an effort to establish a workable method of determining the optimum procedure for backwash which would allow the plant operator to employ a nomograph for his routine use to relate duration of wash, temperature of wash water, and backwash rate.

FIGURE 10. Nomograph for Calculating Backwash Flow Rate for Known Temperature and Bed Expansion

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