**WATER FILTRATION RESEARCH PART I.
THE WATER FILTRATION PILOT PLANT**

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

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1. Page 12, Paragraph 3, Line 8 should read, "Between the perforated steel plate and the bottom lucite plate, the side of the column has a 1 in. NPT outlet port. The bottom section of each column has twelve, 1/4 in. NPT ports..."
2. Page 18, Paragraph 2, Line 10 should read, "The feed rate of the polyelectrolyte filter conditioner is measured by Manostat Predictability Flowmeters, Model 36-541-08."
3. Page 19, last line should read, "platinum-iridium electrodes."
4. Page 22, Paragraph 3, Line 22 should read, "The chemical mix tank and flocculators are drained with the mixers running..."

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ABSTRACT

The water filtration pilot plant, employed in water treatment research programs at Hanford, is described. This pilot plant consists of three unit operations (chemical addition and mixing, flocculation, and filtration) and has extremely flexible capabilities for investigating those parameters which affect water treatment efficiency. Configurations and employment of pilot plant equipment is fully described along with many of the operational procedures.

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INTRODUCTION

The history of water treatment practice at the Hanford process reactors is marked by several significant innovations in water treatment technology and process control. Multimedia filter beds, polyelectrolyte filter conditioning, and the application of light-scattering microphotometry for turbidity measurement⁽¹⁻⁴⁾ are recognized as major advances toward reduced water treatment costs and higher quality water. An effective measure of the significance of these developments is their adoption into the design of most modern water treatment facilities. These innovations resulted from research, by Conley and Pitman, employing a water filtration pilot plant for evaluating the factors which affect water filtration.

Hanford water treatment practices were evaluated by C. J. Touhill in 1964, and an extensive water treatment research program was proposed.⁽⁵⁾ The optimization of reactor process water treatment by simulation techniques is the ultimate goal of the proposed research program. The parametric controls and experience factors necessary for the development of the optimization techniques will be determined. Short term research projects will also be undertaken, including requested technical assistance to reactor management to aid in the solution of immediate water treatment problems and the evaluation of new products and techniques for water treatment. To accomplish the proposed research goals, a water filtration pilot plant having flexible capabilities for measuring, and controlling the parameters that affect filtration was designed and installed in the Battelle-Northwest Water and Waste Management laboratory. This report describes the pilot plant and its operation.

DESCRIPTION OF THE PILOT PLANT

The Water Filtration Pilot Plant consists of three unit operations:

- 1) Chemical addition and mixing
- 2) Flocculation
- 3) Filtration.

Incoming raw water is mixed with a flocculating agent and the pH adjusted in a small elevated mix tank. The water then passes through a series of flocculation reactors which promote the growth of particles to such size that maximum removal will occur during filtration. After flocculation, polyelectrolyte filter conditioner is added, and the water is filtered through multi-media beds contained in lucite columns. A schematic diagram of the pilot plant is shown in Figure 1.

CHEMICAL ADDITION AND MIXING

The raw water supplied to the water filtration pilot plant is imported from a reservoir located near the Columbia River in the 100B reactor area. The quality of this water is identical to Columbia River water supplied to the reactor water treatment plants except for turbidity. The turbidity of the Columbia River ranges as high as 125 Jackson Turbidity Units (JTU) during spring runoff; the turbidity of water from the 100B reservoir varies from 1 to 3 JTU. The flow rate of the raw water to the chemical mix tank is monitored by a rotameter and is closely controlled to maintain proper coagulant dosage.

Reagent grade aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O}$ (formula weight 666), is generally employed as the coagulating agent. The stock alum solution contains 200 g/liter aluminum sulfate (16.2 g/liter Al^{+3}) and is metered to the mix tank with an infusion-withdrawal pump. This pump, Harvard Model 600-950,*

* *Harvard Apparatus Co., Inc., Dover, Massachusetts.*

FIGURE 1. *Layout of Water Filtration Pilot Plant*

employs two hypodermic syringes which alternately fill and empty. Positive flow direction is maintained by solenoid-operated pinch clamps. An automatic limit switch activates the valves and controls the rotational direction of the syringe driver to provide continuous flow. The pump has a 12 speed transmission and can be fitted with 6 different syringes to provide 72 pumping rates ranging from 0.0079 to 38.2 ml/min. The coagulant concentration can be varied by adjusting the stock alum dilution, the alum pumping rate, and the raw water flow rate.

To maintain the desired pH, usually pH 6.6, sulfuric acid (2M) is added to the chemical mix tank with a peristaltic pump, Sigmamotor Model T-8.* This type of pump employs cam-operated fingers that press sequentially against flexible tubing to impart positive flow through the tube. Since the acid does not directly contact the pump, no contamination or corrosion results. A stepless, variable-speed drive coupled to the pump allows rapid adjustment of the pumping rate to control the pH at the desired level.

The stainless steel mix tank is 7 3/4 by 7 3/4 by 24 in. high and is fitted with a 1 in. overflow line 2 in. from the top and a 1 in. drain line at the bottom (Figure 2). The chemicals are mixed with raw water by a variable-speed stirrer, Eastern Model 8,** having a 30 in. shaft and a 5 in. propeller. The speed is controlled by a rheostat and can be varied from 100 to 900 rpm. The alum and acid solutions enter the mix tank at the same elevation as the propeller and are rapidly and turbulently mixed with the raw water. Figure 3 is a diagram of the mix tank and piping.

* Sigmamotor, Inc., Middleport, New York.

** Eastern Industries, Hamden, Connecticut.

FIGURE 2. Chemical Mix Tank

FIGURE 3. *Diagram of Chemical Mix Tank*

FLOCCULATION

The chemically treated water is flocculated in four cylindrical containers connected in series (Figure 4). Each flocculator is subdivided internally to provide a total of eight identical reactors. The flocculators, adapted from a design by Harris, Kaufman, and Krone,⁽⁶⁾ are stainless steel cylinders, 14 in. in diameter and 50 in. high. Figure 5 is a cut-away view showing the baffles and paddles. A schematic diagram of the flocculators, piping, and valves is shown in Figure 6. When four flocculators are used, the water flows down through Flocculator 4, up through Flocculator 3, down through Flocculator 2, and up through Flocculator 1. The flow may also be directed through Flocculators 1 and 2 or 3 and 4 only.

Two stainless steel, H-shaped stirring paddles are mounted on a vertical steel shaft that is coaxial with the flocculator cylinder. The paddles are driven by a variable-speed, 1/15 hp, shuntwound dc motor, General Electric Co. Model 5BN68MA60. Motor speed is controlled by a Variac motor speed control, Type 1701-AKW.* A right-angle drive, worm-gear speed reducer (Boston Gear Model T109-20:1)** with 20:1 speed reduction is installed between the motor and the paddle drive shaft (Figure 7) to allow horizontal motor mounting and to reduce the torque load against the motor.

The torque on the paddle shaft is measured by a Series 783 Torqmeter.[†] This torque measuring device employs a pair of counterwound coil springs that couples the input and output shafts. A calibrated circular dial is rigidly attached to one of the shafts; a pointer is connected to the other. Dynamic torque is read directly as the displacement of the pointer on the dial. At speeds over 300 rpm, a built-in magnetic pulse generator synchronizes a stroboscope to view torque readings.

* General Radio Company, West Concord, Massachusetts.

** Boston Gear Company, Quincy, Massachusetts.

† Power Instruments, Inc., Skokie, Illinois.

FIGURE 4. *Flocculators*

FIGURE 5. Cutaway View of Flocculator

FIGURE 6. Flow Through Flocculators

FIGURE 7. *Flocculator Power Unit and Torquemeter*

The speed of the motor shaft is measured by a photocell sensor connected to an electronic tachometer, Model 832 Tachlite.* The speed of the paddle shaft is twenty times less than the motor speed but can be read directly on the tachometer by adjusting the meter range selector switch to the correct setting. The motor speed controls and tachometer are shown mounted in an instrument rack in Figure 4.

FILTRATION

Prior to filtration, a polyelectrolyte filter conditioner is added to the flocculated water. The influent line of each filter column is equipped with a polyelectrolyte feed tube. A solution containing 1 to 5 g/liter of dry polyelectrolyte is gravity-fed from an elevated bottle. The polyelectrolyte flow rate is controlled by a compression clamp drip regulator.

The flocculated water is filtered through mixed media beds of anthracite and sand contained in three lucite columns 5 1/2 in. in diameter and 8 ft high (Figure 8). A filter column consists of two, 4-ft sections of lucite tube held together by bolted flanges. The top plate is drilled and tapped in the center for 1 in. NPT. The bottom of the lower section of each column is fitted with three lucite blocks (1 x 2 x 6 in.) that support a perforated steel plate. Between the perforated steel plate and the bottom lucite plate, the side of the column has a twelve, 1/4 in. NPT ports equipped with petcocks for sampling the filter media or the filtered water. Manometers can also be connected to these ports for pressure drop measurements. A similar port near the top of the upper section of each column is used for sampling backwash effluent and for pressure drop measurements.

* Power Instruments, Inc., Skokie, Illinois.

FIGURE 8. Filter Columns

Each column is supported at the bottom by an L-shaped steel base which is bolted to the wall. Metal straps screwed to wooden supports hold the column vertically. The columns are mounted above a 1 by 1 by 8 ft stainless steel tank which serves as a gutter.

The inlet and outlet lines of the filter columns are connected to the piping with flexible plastic tubing to avoid exerting excessive strain and vibration on the lucite tubes. The upper section of each column may be easily removed for replacing the filter media. The media is removed as a slurry with a "slurp" tube and aspirator system.

A diagram of a filter column and piping is shown in Figure 9. The "syphon breaker" at the top of the column is open to the atmosphere to prevent syphoning of the column during backwashing. The piping and valves at the bottom are arranged to allow the use of one flowmeter for both filtering and backwashing.

The filters are backwashed with sanitary water that is similar in quality to the clear well water used for backwashing at the reactor water treatment plants. Cold and hot sanitary water are supplied so that the temperature of the backwash water may be adjusted.

The filter bed configuration which was used for the initial experiments at the Water Filtration Pilot Plant is shown in Table I. The effective size is defined as the 10 percentile size: 10% of the media by weight is less than this size. The uniformity coefficient is the ratio of the 60 percentile size to the 10 percentile size.⁽⁷⁾ The gravel in the bed acts as a support for the sand and as a dispersing medium for the backwash water.

Valve	Filtering	Backwashing
1	Open	Shut
2	Shut	Open
3	Open	Shut
4	Shut	Open
5	Open	Shut
6 (a) (b)	Shut	Open

FIGURE 9. Diagram of Filter Column and Piping

TABLE I. *Filter Bed Configuration for the Water Filtration Pilot Plant*

<u>Media</u>	<u>Size (a)</u>	<u>Depth, in.</u>
Anthracite	e = 0.7 mm U = 2.00	27
Sand	e = 0.45 mm U = 1.50	3
Gravel	1/16 to 1/8 in.	2
	1/8 to 1/4 in.	2
	1/4 to 1/2 in.	3
	1/2 to 3/4 in.	3

(a) *e* = effective size
U = uniformity coefficient

INSTRUMENTATION

pH

The pH of the chemically treated water is measured continuously in a small flow cell by a laboratory pH meter having an expanded scale.* The flow cell consists of a 400 ml glass beaker fitted with an inlet tube at the bottom and a drain tube near the top. The sample line to the cell is connected to the effluent line from the mix tank. The flow rate through the cell is about 0.2 gpm.

Temperature

A thermistor thermometer consisting of several stainless steel thermistor probes connected to an electronic meter is used to measure the temperature of the water at several points on the Water Filtration Pilot Plant. The probes, Yellow Springs Model 410,** are stainless steel tubes, 4 1/2 in. long, with a thermistor sealed into one end. Each probe is equipped with a 1/8 in. NPT fitting and a 10 ft vinyl covered, shielded lead with a phone

* Corning Model 10 Expanded-Scale pH Meter.

Corning Scientific Instruments, Corning, New York.

** Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio.

plug connector. The thermometer, Yellow Springs Model 44TD,* measures temperature directly by sensing the unbalance of a Wheatstone bridge circuit. The bridge becomes unbalanced as the probe resistance varies due to changes in temperature. This instrument has a temperature range of 0 to 50 °C, an accuracy of ± 0.5 °C, and a readability to 0.2 °C. It is equipped with a 12-point switch, each point connected to a probe channel. The temperature of the water at various points on the pilot plant may be read by switching from channel to channel.

Turbidity

The turbidity of the filtered water is measured with a continuous flow nephelometer, Hach CR Low Range Turbidimeter, Model 1720.** This instrument consists of a flow chamber, electric lamp, photocell assembly, power supply, and read-out meter. A portion of the filtered water is passed through the flow chamber where a very intense beam of light is directed downward through the sample. Two hermetically sealed photoconductivity cells are submerged in the sample. The light scattered by the presence of turbidity is received by the photocells. The amount of light striking the photocells is in direct proportion to the amount of turbidity present. The photocells convert the light energy into an electrical signal which is measured by the indicating meter. A strip chart recorder has been connected to the meter for continuous recording of turbidity. This instrument is standardized using a standard reflectance rod of frosted glass that reflects a definite and constant amount of light. The reflectance rod is inserted through a rubber entrance seal into the light beam in front of the photocells. The standardization control is then adjusted to the correct reading. This instrument has four ranges: 0 to 0.2, 0 to 1.0, 0 to 3.0, and 0 to 30 JTU.

* Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio.

** Hach Chemical Company, Ames, Iowa.

A Hach Laboratory Turbidimeter Model 1860* is used for measuring raw water turbidity, backwash water turbidity, etc. This unit, like the continuous flow turbidimeter, measures the light scattered by suspended particulate matter. It consists of a sample cell holder, photocells, lamp, power supply, and indicating meter. A strong beam of light is directed upward through a tube containing the sample. The photocells, sensing the light reflected by the particles, produce an electrical signal which is measured by the meter. This meter has five ranges: 0 to 0.2, 0 to 1, 0 to 10, 0 to 100, and 0 to 1000 JTU. A smaller cell and cell holder are used for measurements in the 0 to 1000 JTU range. This instrument is standardized with a polyacrylic rod which has a special turbidity material cast into it. The rod reflects an amount of light equal to a given number of Jackson Turbidity Units.

Flow Rate

The flow rate of raw water to the chemical mix tank is measured with a Model 10A2735 Flowrator Meter** equipped with a FP-1"-35-G-10 tube and a 1"-GNSVT-65 float. This unit is a glass tube variable-area flowmeter providing visual indication of flow rate. The maximum flow rate of this meter is 10 gpm. The filter columns are equipped with Model 10A1735 Flowrator Meters⁺ fitted with B6-35-10 tubes and BSVT-64 floats. These flow meters, which have a maximum capacity of 6.6 gpm, are used to measure the flow rate of the filtered water and the sanitary backwash water. The feed rate of the polyelectrolyte filter conditioner measured by Manostat Predictability Flowmeters, Model 36-541-08.⁺⁺ These meters consist of tapered glass tubes and spherical floats and are capable of measuring flow rates from 0.043 to 10.30 ml/min.

* Hach Chemical Company, Ames, Iowa.

** Fischer and Porter Company, Hatboro, Pennsylvania.

⁺ Manostat Corporation, New York, N. Y.

⁺⁺ The Meriam Instrument Co., Cleveland, Ohio.

Headloss

The headloss across the filter beds is measured with 24 in. Standard Cleanout Manometers* connected as shown in Figure 10. Pressure drop across increments of the filter beds is measured with 15 in. U-type Manometers, Model 10AA25WM.* The depth of each increment and the arrangement of the manometers is shown in Figure 10. The first 15 in. manometer measures the pressure drop across the portion of the bed that extends above the top piezometric tap (usually 1/2 to 1 in. of material). The remaining manometers are connected in series across increments of the bed as shown in the figure.

Microelectrophoresis

Practically all suspended particulate matter is surrounded by an electrokinetic charge. The charge on raw water turbidity, which is usually electronegative, has sufficient strength to cause mutual repulsion of the particles.⁽⁸⁾ The relative strength of this charge, which is called the zeta potential, can be measured by observing the electrophoretic mobility of individual colloidal particles.

Two methods for determining electrophoretic mobility are used in the Water Filtration Pilot Plant. One method employs a Briggs microelectrophoresis cell, a monocular microscope equipped with a dark field condenser and ocular micrometer, and a dc power supply. This technique, a basic research tool in the investigation of the flocs produced in coagulation, is described in detail by Black and Smith.⁽⁹⁾

The second method uses a recently developed, commercial microelectrophoresis apparatus called a Zeta-Meter.** The Zeta-Meter consists of a stereoscopic microscope with ocular micrometer, a dc power supply, and a clear plastic electrophoresis cell equipped with platinum-irridium electrodes.⁽¹⁰⁾

* The Meriam Instrument Co., Cleveland, Ohio.

** Zeta-Meter Inc., New York, N. Y.

FIGURE 10. Manometers for Differential Pressure Drop Measurement

The electrophoretic mobility is determined with either technique by observing microscopically visible particles as they migrate in the electric field. The rate of motion is obtained by timing the migration of a particle across an ocular scale. The electrophoretic mobility, which is expressed in velocity per unit field strength (microns/second per volt/centimeter), is then calculated, in the case of the Briggs cell, or read from a graph furnished with the Zeta-Meter.

OPERATION OF THE PILOT PLANT

START-UP

The pilot plant is not often operated on a continuous 24-hr basis and must be started up and shut down daily. First, the alum pump and the acid pump are started, the mixer is turned on, and the raw water feed valve is adjusted to the desired flow rate. Next, the pH cell is filled, and the pH of the chemically treated water is noted. The flocculator motor controls are then activated, and the speed of the paddles is adjusted. After the pH reaches the required level, the flocculators are filled. When the flocculators are full, the polyelectrolyte flow rate is adjusted.

FILTRATION

Filtered water flows through the flowmeters as the filter column drain valves are opened to the desired flow rate. If the continuous turbidimeter is to be used, the turbidimeter line is connected to one of the filters, and the flow rate is adjusted. Headloss, pH, turbidity, and temperature measurements are recorded periodically. The filtration flow rate, which decreases as the headloss across the filter increases, must be maintained at the desired level by adjustment of the valve opening. When the headloss reaches a certain limit, usually 8 ft of water, the filtration run is terminated.

BACKWASHING

The flow of the flocculated water and polyelectrolyte to the filter column is stopped, and sanitary backwash water flows through the flowmeters into the filter columns. The backwash flow is increased in four equal increments at 30 sec intervals until the required flow is reached.

The columns can be backwashed at a constant temperature by mixing hot water with the sanitary backwash water. In this case, the backwash water is initially sent through a bypass waste line. The cold water flow rate is adjusted to slightly greater than the desired backwash rate, and the hot water valve is opened until the required temperature is reached. The flow is then directed to the filter columns and the rate adjusted by closing the bypass valve.

SHUT-DOWN

After completion of the backwash cycle, the valves at the bottom of the filter columns are closed to avoid draining the bed. The chemical mix tank and flocculators are frained with the mixers running to prevent accumulation of floc in the tanks. The pumps and instruments are turned off or placed in a standby mode and, when the tanks are drained, the mixers are shut off.

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