IMPROVEMENTS IN WATER TREATMENT FOR ONCE-THROUGH REACTOR COOLING

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INTRODUCTION

Nearly all nuclear reactors being designed and built today - whether for research, power, or production of fissionable materials - use recirculating fluids for cooling. However, a number of production reactors are still operating with single-pass cooling by treated natural water. The Hanford Atomic Products Operation of the General Electric Company presently operates production reactors for the AEC at Richland, Washington. The first reactors were built during World War II, and utilized a standard water treatment which was designed to provide large quantities of settled, filtered Columbia River water for once-through cooling.

Since the end of World War II, these reactors have been operated with increased capacities and continued improvement in production efficiency, economy, and safety. These improvements have, of course, included substantial improvements in operation of the water treatment plants. Increased capacities of the reactors provides continual need for increased quantities of cooling water, while maximum reactor efficiency requires that the cooling water supply be of very high quality with respect to suspended solids content. Great incentive also exists for reduction of treatment costs to an absolute minimum.

This paper describes a newly-developed process, using some of the new organic polymers, which has been important in reduction of treatment cost while maintaining high water quality during production of increased quantities of reactor cooling water.
Treatment of natural water (specifically, Columbia River water) which has been partly coagulated and settled, with minute quantities of any of several new high-molecular weight organic polymers permits increased flow through modified rapid sand filters. Polymer materials which have received full plant usage or pilot plant development testing include acrylamides, polysaccharides, carboxymethylcellulose derivatives, alginates, carrageenan, etc. The amounts of these materials needed for effective conditioning of the filters are extremely small. Dosages of the filter conditioner most used at Hanford at the present time range from 0.002 to 0.0010 parts per million parts of water (this is 0.0001 to 0.0005 grains per gallon). The point of addition of these chemicals is important but not critical. Maximum efficiency is ordinarily obtained by addition of these chemicals to the filter influent flume or directly to the filter gullet.

The type of filter system which benefits most from use of conditioning polymers is a modification of that type known as a rapid sand filter. A filter bed composed of 12 inches of gravel, 3 to 6 inches of sand, and 24 to 27 inches of anthracite filter material, has given maximum efficiency at Hanford. Sensitive instrumentation is important in determining the required chemical dosages and in maintaining the water quality required for efficient operation of the nuclear reactors. Measurement of minute turbidity concentrations is necessary to control film formation in the reactor. A light scattering microphotometer has been adapted at Hanford to routinely measure turbidities in the range 0.001 to 0.010 ppm in the treated water.

Increases in water plant capacity and savings in cost have been significant at Hanford with the use of filter conditioning. Total flows through the filters can be 200 percent greater with filter conditioning than with more conventional treatment methods previously used. A capital cost savings of $250,000 was realized at the time the new treatment was started, and annual cost savings of over $200,000 result from the use of this filter conditioning treatment. Quality of the water produced by this treatment is fully as good as that obtained with previous treatments, and control of water quality is more flexible with filter conditioning.

Many industrial and municipal water plants should be able to use a filter conditioning treatment method, with substantial increases in plant throughput above present capacities. Greater flexibility in water quality control will also be helpful to these plants. Modification of the filter beds will be desirable for many plants, to take full advantage of this treatment method. Designs of new facilities, which will use rapid sand filtration, should provide for filter conditioning treatment. In terms of treatment capacity and control flexibility, this design will increase the value of every new filter unit built.

HANFORD WATER TREATMENT FACILITIES

The raw water to be treated for use in cooling the Hanford production reactors is obtained from the Columbia River. This raw water contains moderate amounts of dissolved and suspended materials. Figure 3 shows the maximum, average, and minimum concentrations of various materials in Columbia River water. Shown in Figure 3 are total solids content, calcium, sulfate, silica, magnesium, sodium, chloride, iron, phosphate, manganese, and copper. Also shown are the concentration of suspended solid materials ("turbidity"), and the methyl orange alkalinity and pH.
The original Hanford water treatment system was designed as a conventional rapid sand filtration system. This design, shown in Figure 1, consists of a chemical addition system, flash mixers and flocculators, settling basins, the filters, and a clearwell for storage of treated water. The filters, shown to larger scale in Figure 2, originally contained 10 inches of gravel, 10 inches of sand, and 20 inches of anthracite (anthracite coal, carefully sized). Ferric sulfate or aluminum sulfate was added to raw water near the flash mixers to coagulate suspended solids. During part of each year (i.e., late winter and spring) relatively high turbidity concentrations or low water temperatures required supplemental treatment with activated silica to aid coagulation and achieve the necessary process water quality. Optimum process water pH was believed to be about 7.65 to provide minimum film formation and maximum radiation stability. Raw water pH varies from 7.9 to 8.5 as shown in Figure 3 and aluminum sulfate addition reduces this pH. Therefore, occasional addition of lime was necessary to provide a process water pH of 7.65. All of these chemicals (aluminum or ferric sulfate, activated silica, and lime) were added to the raw water in the inlet flumes leading to the flash mixers. Figure 1 shows this chemical addition point in relation to the other parts of the system. This original system was designed for a maximum flow rate of three gallons per minute per square foot of filter surface.

Except for minor piping changes, the physical plant remains the same today as when it was built. Yet, this system can now produce more than twice the water which it was designed to produce. A substantial part of this flow increase is due to rearrangement of the filter media and use of the filter conditioning treatment method. Process water pH is now adjusted to 7.0 by addition of sulfuric acid instead of lime, in order to minimize corrosion of aluminum reactor components. But this pH adjustment does not provide any flow increase. Flow through a rapid sand filter is quite dependent upon the composition of the filter bed. High flow rates are presently achieved in the Hanford filters using a bed with relatively large average particle size. Present filter beds at Hanford, shown in cross-section in Figure 4, contain a bottom layer of 10 inches of gravel, maximum size 1 inch, an intermediate layer of 3 to 6 inches of sand, effective size 0.3 to 0.4 millimeters, and a top layer of 24 to 27 inches of anthracite filter media, effective size 0.7 to 0.8 millimeters. Compare this bed with the portion of original filter bed shown on the right side of the filter in Figure 4. Breakthrough of turbidity from these filter beds is effectively controlled by simple adjustments in the feed of coagulant and filter conditioning chemicals. These adjustments are described in detail later.

WATER QUALITY MEASUREMENT REQUIREMENTS

Improvement in Hanford water quality measurement methods was necessary to obtain maximum benefit from filter conditioning with the modified filters. The water quality characteristic which is of immediate concern in reactor operation is suspended solids content (turbidity). Even minute amounts of fine solids in the cooling water will cause film formation (nowadays, popularly called "crud" deposition) on heated surfaces within the reactor. Collection of these solids on a cotton plug inserted in a filter effluent sample line has been used successfully for measurement of total solids content. The cotton plugs are removed at specified intervals and carefully burned. The collected turbidity remains as the primary constituent of the burned residue. Another method of determining water quality is to measure the iron content
of filtered water. Iron concentrations in Hanford process water have been found to correlate reasonably well with total suspended solids content and, therefore, provide a measure of the film forming tendencies of the water. Iron compounds constitute a substantial portion of the suspended solids. However, the necessary measurement sensitivity requires concentration of the iron in the sample by boiling away a large volume of water. The major difficulty with either the cotton plug measurement or the boil-down iron measurement is the long sampling and/or analysis time required to obtain the necessary measurement sensitivity. The minimum sampling time for the cotton plug measurement is of the order of three days and boiling down sufficient water to measure the iron content requires about three hours. So, even if only a single measurement is used to indicate the need for treatment changes, the nuclear reactor must still operate for three hours with the poor quality water.

Film formation in reactor flow channels, produced by poor quality water, reduces the rate of heat transfer from fuel elements to the reactor coolant. Film also restricts flow through the reactor and increases the pressure drop along the reactor flow channels. This latter effect of film formation is critical to reactor operation; because, a constant flow of coolant, and accurate measurement of this flow, are important for safe and efficient operation of the reactor. Certain types of poor quality water can cause significant film formation within a few hours, requiring recalibration of several hundred pressure gauges. Furthermore, this flow loss remains until steps can be taken to remove the film from the reactor flow surfaces. This removal often requires shutdown of the reactor.

Measurements of treated water turbidity are now obtained at Hanford in less than five minutes, using a modified microphotometer. In this instrument, recently described in detail in AWWA Journal, Vol. 49 #1 January 1957, a beam of light is directed through a small sample of the water being tested, and light reflected and refracted from the solid particles in the water is detected and measured. The angle at which the incident light beam enters the water, in relation to the detection system, is important in obtaining maximum detection efficiency. Sample containers must be scrupulously clean. The sensitive standards required for calibration of the microphotometer are not difficult to prepare, and use of a commercial spectrophotometer as an auxiliary instrument simplifies calibration of the microphotometer. Suspended solids contents in the range 0.001 to 0.010 parts per million are routinely measured by the Hanford microphotometers. With the short sampling and measurement times required with this instrument, control of reactor flow channel film formation is swift and certain, with the filter conditioning treatment.

DESCRIPTION OF TREATMENT METHOD

Filter conditioning consists of continuous preparation of the filter bed to adsorb and retain fine solid particles carried in the influent water. The filter bed is not pretreated. No precoating, nor visible coating of any kind, is put on the filter bed. Rather, the filter conditioning chemical is added to the settled water just as it enters the filter. The filter conditioning chemical is combining with the suspended turbidity particles at the same time that it is being adsorbed on the grains of filter bed media.
Filter conditioning is a finish treatment to produce water with very low turbidity content. Initial raw water treatment is coagulation and settling of the larger suspended particles by addition of a coagulant such as aluminum sulphate, with subsequent settling of the coagulated solids. Settled water is then treated with the filter conditioning chemical and immediately filtered. Length of coagulating and settling time is not critical. Filter conditioning treatment may increase filter head loss at a greater rate than partially settled water but with completely settled water, but considerable variation of settling time is possible without markedly changing the rate of filter head loss buildup.

Chemicals used for filter conditioning are principally organic. Materials which have been used successfully in the full scale plant or in the pilot plant include polysaccharides, polyacrylamides, carbomxmethylation and several others. It is clear that the ability to condition a filter is not limited to any specific chemical formula. Filter conditioners are most efficient when added immediately upstream of the filter bed itself. Good addition points are the inlet to the filter gullet or the outlet weir to the settling basin. Addition equipment is not complex. Addition equipment may consist of a tank with an efficient mixer, a good screen or strainer, a small pump, and some method of flow control. Good mixing in the tank is important because some of the materials are only slightly soluble in water and when dissolved tend to form rather viscous solutions. A small rotameter may be used for flow control but often a length of plastic tubing with a pinch clamp used in gravity or friction control is all that is necessary for flow control. Carbon steel or galvanized iron pipe are usually adequate for the piping system for the filter conditioners.

An important reason for the value of the filter conditioning method is the small quantity of the conditioner needed. Continuous dosage rates of only 0.005 to 0.02 parts per million have been completely successful in providing top quality water for the Hanford plants. It is important to note that filter conditioners are "assisting" chemicals, in that they are used with a standard alum coagulant treatment and during certain seasons of the year, when the raw water quality is particularly good, filter conditioning may not be needed with the alum coagulant.

**TYPICAL RESULTS**

With filter conditioning and alum coagulation the Hanford plant filters can be operated with flow rates of six to ten gallons per minute per square foot of filter bed media. This is twice, or more than twice, as much flow as the filters were originally designed for, and is more than twice the flow that is normally expected of this type of filter in industrial and municipal use. The quality of water for the Hanford plants is more important than for many municipal and other industrial plants. Of prime importance to the reactor operation is water with extremely low content of dissolved solids or turbidity. Turbidity concentrations of 0.003 to 0.005 are continuously and routinely obtained with the filter conditioning treatment and alum coagulation. Cost of the filter conditioning treatment is low in comparison with many of the other industrial and municipal treatments. The treatment used at Hanford prior to filter conditioning also involved alum coagulation but required activated silica addition with the alum during certain seasons of the year to provide top quality treated water. Approximately $200,000 has been saved each year since filter conditioning was started at Hanford from the cost that would have been incurred had activated silica addition been continued with the alum coagulation.
The filter conditioning method should be applicable either directly or with minor modifications to nearly any plant which uses rapid sand filtration. The Hanford water plants are completely standard design such as is used in many industrial and municipal plants. Many plants now using the alum activated silica coagulation or ferric coagulation may be able to use filter conditioning with alum coagulation and obtain more than twice as much flow as traditionally has been expected of these plants and at the same time reduce chemical addition costs.

CONCLUSION

A filter conditioning method has been developed which will assist alum or other coagulation methods in producing large quantities of extremely high quality cooling water for nuclear reactors. This same treatment can be used to provide high quality water in large quantities for other industrial or municipal requirements. The three important features of this treatment method are: first, a modification of the conventional rapid sand filter bed to provide a low pressure loss through the filter bed at high filter flow rates; second, use of a modified light-scattering microphotometer to obtain accurate and rapid measurements of suspended solids content in the treated water; and last, the addition of minute quantities of certain organic polymers to condition the filter bed and improve filtration of coagulated and settled water.

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Coilant Systems Development Operation
Reactor & Fuels Research & Development Operation
HANFORD LABORATORIES OPERATION

UNCLASSIFIED
FROM RIVER HEAD HOUSE MIXER FLOCCULATORS SETTLING BASINS SETTLED WATER FILTERS FILTERED WATER FLUME FLUME CLEARWELL TO REACTOR

1 COAGULANT ADDITION POINT, & COAG. AID. ADD. PT.
2 ACID ADDITION POINT

FIGURE 1 TYPICAL HANFORD WATER PLANT
FIGURE 2
TYPICAL HANFORD FILTER
NOTE:
(DATA FROM WEEKLY SAMPLES TAKEN AT HANFORD DURING A SIX TO ELEVEN YEAR PERIOD).

CONCENTRATIONS IN ppm (EXCEPT pH).

- MAXIMUM
- AVERAGE
- MINIMUM

TOTAL SOLIDS
METHYL ORANGE
ALKALINITY, AS CaCO₃
CALCIUM
SULFATE
pH
SILICA, AS SiO₂
MAGNESIUM
SODIUM
CHLORIDE
IRON
PHOSPHATE
MANGANESE
COPPER
TURBIDITY

FIGURE-3
COLUMBIA RIVER WATER COMPOSITION
FIGURE 4
COMPARISON OF FILTER BED ARRANGEMENTS
NEW ARRANGEMENT
ORIGINAL DESIGN
ANTHRACITE
SAND
GRAVEL
TO REACTOR

1. COAGULANT ADDITION POINT, & COAG. AID. ADD. PT.
2. ACID ADDITION POINT
3. FILTER CONDITIONER - OPTIMUM ADDITION POINTS

FIGURE 5
TYPICAL HANFORD WATER PLANT