Comparison of the Ability of Three Coagulants to Enhance Filter Performance

Abstract

In the operation of both rapid and slow sand filters an initial ripening interval is often observed in which particle removal is less than desired. Alum, ferric chloride, and polyaluminum chloride are commonly used in drinking and wastewater treatment to modify the surface properties of the particles being filtered. In the research described in this paper, these three coagulants were utilized to artificially ripen a sand media before challenging the filter media with an otherwise untreated kaolin suspension. After modification of the filter medium, high particle removal efficiencies were achieved using a short (7.5 cm) sand column with relatively large grained sand (1 mm in diameter). The best observed particle removal (96 %) using alum and PAC occurred at the surface loading of 550 mmol Al/m2, but the filter performance deteriorated at higher surface loadings. In comparison, the untreated sand achieved a baseline particle removal of 60%. Fractional colloid removal increased with increased ferric chloride surface loading over the entire range of dosages tested (up to 97.5 % at 2200 mmol Fe/m2). The experimental results suggest that pretreatment of filter medium by coating with Fe or Al hydroxides can eliminate the poor performance otherwise experienced when a ripening period is needed.

Keywords: Filter ripening, enhanced filtration, coagulants

Introduction

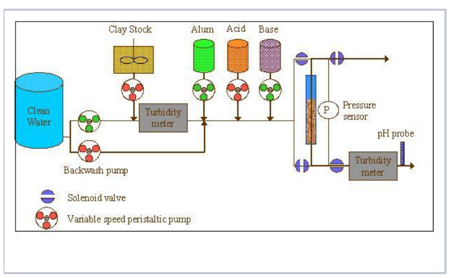
Deep bed filtration through particulate media is a commonly used method for removal of solids present in surface waters, precipitated hardness from lime-softened water, and precipitated iron and manganese present in many well water supplies (Weber 1972). The removal of suspended particles within a filter is considered to involve at least two sequential steps: transport and attachment. In the first step, the particles are transported from the bulk fluid to the immediate vicinity of solid-liquid interface presented by the filter (i.e., to a grain of the media or to another particle previously retained in the filter bed). The transport of particles to the filter medium may occur through three mechanisms: Brownian diffusion (molecular effects), interception (contact as a result of fluid flow near the surface of the porous medium), and sedimentation (gravity effects). Particle attachment to the media surface is dominated by electrical and chemical interactions such as electrostatic attraction or repulsion within the electrical double layer and van der Waals attractive forces that act between particles and surfaces at short distances (O'Melia 1980, Yao 1971, Elimelech 1990).

Sand media is a key, if not the sole, component of most filters. However, sand media may not be efficient in the removal of fine or sub-micron particles including colloids, bacteria, and viruses because of electrostatic repulsion arising from the fact that both the particles and sand media are negatively charged at circumneutral pH values. Fe and Al are commonly added as coagulants to modify colloid surfaces (Weber 1972, Tchobanoglous 2003) and improve particle removal. Polyaluminum chloride (PAC) has recently been reported to be superior to alum in removal of particles with advantages of reduced alkalinity consumption, less sludge production, decreased temperature and pH dependence, and reduction of cost (Hu 2006). In some cases iron and aluminum hydroxides have also been used to modify filtration media to improve the particle removal efficiency. (Edwards 1989, Lukasik 1999, Ahammed 2006). In these studies Fe and Al surface modification was achieved by soaking the sand media in aluminum chloride or ferric chloride solutions and followed by treatment with an ammonium hydroxide solution.

In the research described in this paper, three common coagulants, alum, ferric chloride ($FeCl_3$), and PAC were chosen to modify sand medium prior to challenging the filter media with a colloidal suspension of kaolin. A novel process was used for modification of the sand medium in which the sand media in the filter was "pretreated" in situ before challenging the filter. The resulting particle removal efficiencies are compared as a function of Al and Fe surface loading. Head loss was also monitored during pretreatment and during the challenge to the filter.

Materials and Methods

Apparatus. An automated filtration test apparatus described by Weber-Shirk (Weber-Shirk 2008) was used to conduct parametric tests of the use of alum, ferric chloride (Fisher Scientific), and polyaluminum chloride, PAC (Holland Company Inc.) to modify (artificially ripen) the media in a sand filter. A schematic of the apparatus is shown in Figure 1.



In all tests 22°C Cornell University tap water was used as the raw water source. Kaolin clay was added to the tap water to achieve an influent turbidity of 55~60 NTU. The concentration of the stock solutions, clay suspension and the alum doses used are given in Table 1. The filter column was 2.5 cm in diameter and contained 7.5 cm of 0.8 to 1 mm in diameter filter sand (U.S. Filter, New Jersey).

Table 1.Stock and feed concentrations of the reagents used

Stock	Concentration	Dilution factor	Concentration at filter influent
Kaolin clay	350 (mg/L)	7	50 (mg/L)
Aluminum sulfate	3.4 (mmole/L as Al)	13.6	250 (mole/L as Al)
Polyaluminum Chloride (PAC)	3.4 (mmole/L as Al)	13.6	250 (mole/L as Al)

Ferric Chloride	3.4 (mmole/L as Fe)	13.6	250 (mole/L as Fe)
Sodium carbonate	12 (mmole/L as CO3-2)	40.8	300 (mole/L as CO3-2)
Hydrochloric acid	0.1 (mole/L as H+)	1	0.1 (mole/L as H+)

The coagulants were applied to the top of the filter column to treat the filter media prior to challenging the filter with the clay suspension. As shown below, a high fraction (90% to 95%) of the applied coagulant was retained within the filter media and acted as a filter aid. We report the amount of coagulant applied to the filter as a surface loading with units of mmol/m2 where the area is the cross sectional area of the filter. The total surface loading of coagulant, , is a function of the coagulant flow rate, Q, filter surface area, A, influent concentration, C, and application time, t as described by equation 1.
(1)
Experiments at each surface loading (mmol/m2) were replicated. The filtration rate was 5 m/hr in all experiments. Backwash and an acid wash (0.1M HCl) were used between each experiment to remove residual clay and filter aid. Duplicate control experiments with zero filter aid were conducted at the start of each series of experiments and after the experiment with the highest surface loading to confirm the ability of the filter washing steps to restart the sand to its original (untreated) condition.
The Process Control software for the automated filtration apparatus cycled through states shown in Table 2 for each test. The hydraulic retention time from the clay stock pump to the effluent turbidity meter is 3.8 minutes based on the filtration rate of 5 m/hr. In the filter column, the volume of water above the sand was 35 cm3, and the hydraulic retention time from top of filter to the bottom of filter is 1.2 minutes (porosity = 0.4).

Table 2.Process Controller States

State Name	Purpose	Duration
Backwash filter-1	Clean the filter	4 minutes
Acid wash	Wash out the coagulant	2 minutes
Backwash filter-2	Clean the filter	4 minutes
Wash turbidity meters	Wash the turbidity meters	4 minutes
Pretreatment	Ripen the filter	variable
Downflow	Challenge the filter	20 minutes

The concentration of the applied coagulants was approximately the same during the pretreatment state, but the pretreatment state duration was varied to achieve different surface loadings.
During the particle challenge state filter performance was measured by inline turbidimeters (Figure 1). The turbidimeters were chosen because they have small volume sample cells (30 mL) that make it possible to achieve reasonable response times at the flow rates used in this research. The hydraulic residence time from the inlet of the influent turbidimeter to the outlet of the effluent turbidimeter at a flow rate that corresponds to a filtration velocity of 5 m /hr was 4 min. We do not report the data from the first 1.5 hydraulic residence times (i.e., about 6.5 minutes) at the beginning of each the particle challenge since that data show an artificially high particle removal caused by the clean pore water that is still exiting the filter into the effluent turbidimeter and being displaced from the tubing and turbidimeter sample vial.
Particle capture efficiency is expressed here as pC* where C* is the turbidity of the effluent water normalized by the turbidity of the influent water and p is the -logarithm function (base 10).

Measurement of Al and Fe concentrations in the effluent water during pretreatment. Retention of applied filter aid in the filter media was assessed by measuring aluminum and iron concentrations in the effluent during pretreatment at the highest (2200 mmol/m2) and lowest (70 mmol/m2) surface loading used in experiments.
A colorimetric assay, the modified Eriochrome Cyanine R Method, was selected for Al analysis, in which the volume of reagents and samples were scaled down to fit into 4.5 mL cuvettes. (Standard Methods for the Examination of Water and Wastewater, 1998). The assay can detect aluminum at concentrations above 20 µg/L. All glassware used was first acid washed for 24 hours with 10% nitric acid (Reagent grade) made with distilled deionized (DDI) water followed by a 24 hour wash in 10% nitric acid (Trace metal grade). The glassware was rinsed with DDI water 6 times in between the 24 hour wash steps. Aluminum chloride (AlCl3*6H2O, Fisher Scientific) was used to prepare Al standard curves.
Atomic absorption spectrometry was utilized for the determination of iron in the effluent water during pretreatment (Standard Methods for the Examination of Water and Wastewater, 1998). An air-acetylene flame was used. The assay can detect iron at concentrations above 20 µg/L. All glassware was acid washed as described above. Iron standards were made by dilution of iron stock (1000 mg/L, Fisher Scientific). The measurement was carried out in triplicate.

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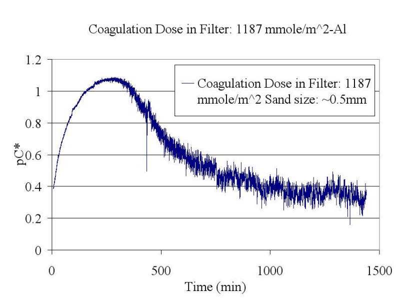
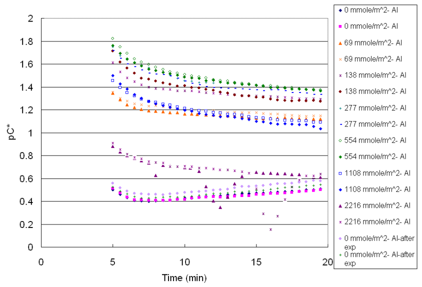


Differential pressure sensor.



pC vs time.

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Differential pressure sensor.

Coagulant Enhanced Rapid Sand Filtration

Procedure

We used process controller to perform these experiments.