Innovative municipal water softening using high-rate sand-ballasted technology

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Sand-ballasted settling is a high-rate coagulation/flocculation/sedimentation process that uses microsand as a seed for floc formation. The microsand provides a surface area that enhances flocculation and acts as a ballast or weight. The resulting floc settles quickly, allowing for compact clarifier designs with high overflow rates and short detention times.

These designs result in system footprints between five and 30 times smaller than conventional clarification systems of similar capacity. The use of microsand also permits the unit to perform well under dramatically changing flow rates without affecting final effluent quality.

Raw water is pumped into the coagulation tank of the sand-ballasted system (Figure 1) where a coagulant, such as alum, ferric chloride or ferric sulphate, is added to destabilize the suspended solids and colloidal matter in the influent stream. Typically, hydraulic retention time in this tank is approximately two minutes.

The water then flows into the injection tank where polymeric flocculant and microsand are added to initiate floc formation. These serve as a "seed" for floc formation and development in the next step of the process. A hydraulic retention time of about two minutes is maintained in this tank as well.

Treatment continues as the water passes to the maturation tank. In this tank, relatively gentle mixing provides ideal conditions for bridging between the microsand and the destabilized suspended solids. Typical hydraulic retention time in the maturation tank is approximately six minutes.

From this tank, the fully-formed ballasted floc enters a settling tank equipped with a lamella, which provides the rapid and effective removal of the microsand/sludge floc. The clarified water exits the system via a series of collection troughs or weirs.

The sand-sludge mixture that settles to the bottom of the clarifier is then pumped to a hydrocyclone for separation. After separation, the higher-density microsand is discharged from the bottom of the hydrocyclone and re-injected into the process for re-use. The lighter-density sludge is discharged from the top of the hydrocyclone, then thickened and dewatered prior to off-site disposal.

Figure 1. Schematic diagram of the ACTIFLO® process.

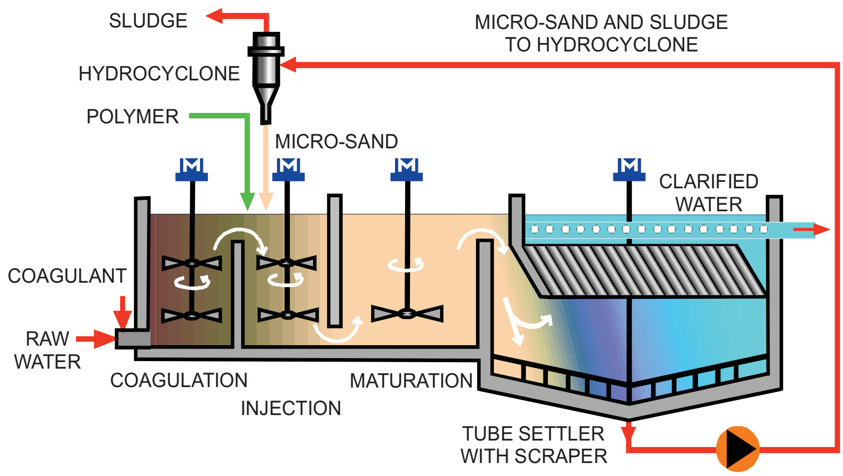
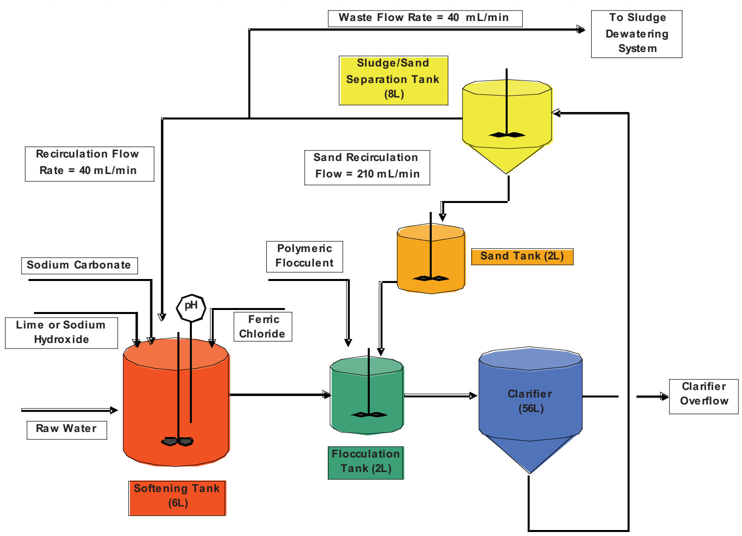


Figure 2. Process flow diagram for the softening testing.



Pilot and full-scale data reveal that the ballasted microsand process can produce an effluent with very low total suspended solids and turbidity.

Objectives of this study

The primary objective of this work was to determine the results of incorporating water-softening chemistry into the sand-ballasted flocculation system operation to create a single process that would both soften and clarify raw water. The investigation evaluated the process parameters and operational considerations of this marriage of the water-softening and sand-ballasted Actiflo© technologies.

Other objectives were to demonstrate the efficiency of the system for removing organic compounds during the softening process, to explore the solid/liquid separation as well as sand/sludge separation efficiency of the system, to evaluate the solids settling rates in the clarifier, to determine the quality of treated water, and to explore the poten-

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tial for solids build-up on the sand, especially in the presence of high calcium and magnesium concentrations.

Process verification study procedures

As the process flow diagram (Figure 2) illustrates, feed water was pumped continuously into a reactor/softening tank where the required dosages of lime and sodium carbonate were added. The softening reaction was conducted at a pH between 10.5 and 11.2 units. After the softening reaction was complete, the mixture flowed to a flocculation tank. Recycled sand and a selected dosage of polymeric flocculant were added into this tank.

The water was then diverted to a clarifier where the sludge (mixture of sand and sludge) was allowed to settle. After settling, the treated water was discharged. The mixture of sand and sludge, predominantly calcium carbonate and magnesium hydroxide, was then pumped into a sludge/sand separation tank equipped with a mixer where the sand was separated from the sludge.

In the full-scale system, separation of sand from sludge is accomplished with a hydrocyclone; however, this equipment could not be made small enough to be effective in this situation. Because of this, a separation tank equipped with an agitator was used. The speed of the agitator was adjusted to simulate the velocity gradient achieved in the hydrocyclone. The sand was then recycled to the system.

A portion of the sludge, without sand, was recycled to the softening tank as a "seed" for crystal growth. Samples of untreated water, clarified water, overflow and underflow from the sand/sludge separation tank (simulated hydrocyclone), and waste sludge were collected and analyzed for total and dissolved calcium, magnesium, silica, total suspended solids, total dissolved solids, turbidity and percentage of solids in the sludge.

The characteristics of the influent water used in the softening study are summarized in Table 1. The system was operated continuously (24 hours a day, seven days a week) for several months. The average concentration of dissolved calcium was 260 mg/L (as Ca^{2+}); magnesium, 100 mg/L (as Mg^{2+}); and silica, 90 mg/L (as SiO_2). The raw water had a pH of about 8.0.

Parameter	Value
pH, S.U.	8.0
Calcium, mg/L	260
Magnesium, mg/L	100
Silica, mg/L	90
TSS, mg/L	10
TDS, mg/L	12,000

Table 1. Influent water quality for softening study.

Results and discussion

The softening study results revealed that the concentration of total calcium in the treated water was reduced from an initial value of about 260 mg/L (as Ca^{2+}) to less than 10 mg/L and that of magnesium was reduced from 100 mg/L (as Mg^{2+}) to less than 12 mg/L. At magnesium-to-silica ratio of about 1:1, the silica concentration was reduced to less than 10 mg/L.

The results also indicated that the concentrations of calcium and magnesium ions before and after filtration were

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Table 2. Mass balance calculation.

Parameter	Influent	Effluent
Flow Rate (mL/min)	212.2	212.2
Calcium as Ca^{2+} (mg/L)	260	10
Mass of Calcium as Ca^{2+} (mg)	55	2.2
Calcium as $CaCO_3$ (mg)	137.5	5.5
Magnesium as Mg^{2+} (mg/L)	100	12
Mass of Magnesium as Mg^{2+} (mg)	21	2.5
Magnesium as $Mg(OH)_2$ (mg)	51	6.0
Flow of Recycle Stream (mL/min)	42	44
TSS of Recycle Stream (mg/L)	38,900	38,900
Mass of Solids in Recycle Line (mg)	1634	1711
Total Solids (mg)	1823	1723

Table 3. TOC removal during softening study.

Sample	Influent TOC (mg/L)	Effluent TOC (mg/L)	Percent Removal
1	5.8	4.0	31.0
2	5.7	3.0	47.5
3	5.6	3.0	46.0

comparable, indicating that the system is capable of removing almost all the particulates formed during the softening process. The effluent quality from this process, including TSS and turbidity, is comparable to that of filtered water. This process resulted in a settling rate that varied between 60 to 120 m/h. After 24 hours of settling, TSS in the settled sludge (without microsand) ranged between 20% and 25%. After operating the unit continuously for two months, an insignificant amount of solid build-up was observed on the recycled sand.

Mass balance calculation results for the solids generated in the softening process are presented in Table 2. The calculations were performed based on average concentrations of calcium and magnesium, average flow rate of the influent and effluent streams, average TSS concentration and flow rate of the recycle stream (without sand), and average TSS concentration and flow rate of the waste solids stream.

It was also assumed that the silica was removed by being adsorbed onto the reactive surface of magnesium hydroxide. As the table illustrates, summation of the mass of the TSS in the influent stream and the effluent stream are comparable. The difference is approximately 6%. It is anticipated that the small amount of solids that could not be accounted for may have stuck to the clarifier wall or been carried away during sand recycle.

The effluent total suspended solids was also very low (<15 mg/L) throughout the study.

The total organic carbon removal results obtained from the softening study are summarized in Table 3. As the table illustrates, a 30-48% TOC removal efficiency

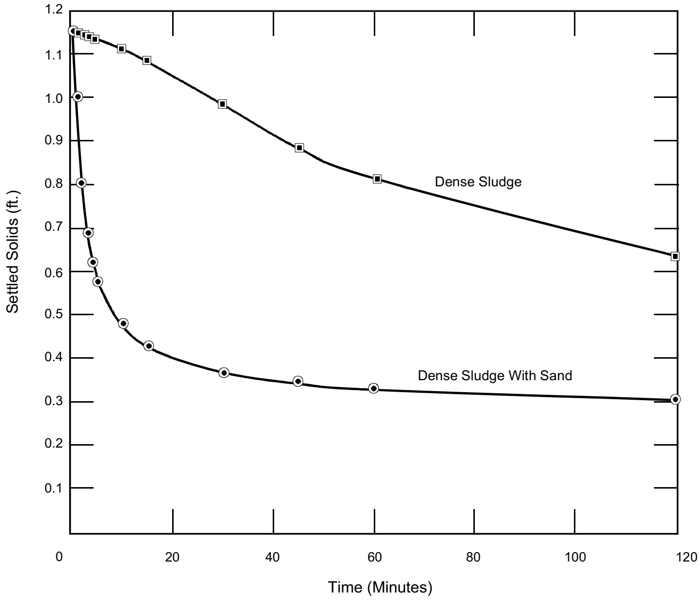

Figure 3. Solids settling curve, comparing sludge alone and sludge with sand.

was achieved; however, the removal efficiency is a function of water quality, pH condition and chemical dosage.

One of the important aspects of this study was to compare the settling rate of the solids with and without the addition of microsand. Figure 3 presents the results of this study. As the figure illustrates, the solids settling rate was improved tenfold with the addition of microsand.

Conclusions

The high-rate ballasted flocculation Actiflo process appears to have excellent potential for use as a high-rate softening technology. This is a cost-effective, innovative technology that is capable of effectively removing a variety of concentrations of calcium, magnesium and silica from raw water. It reduced the calcium concentration to less than 10 mg/L (as Ca^{2+}) and the magnesium concentration to less than 12 mg/L (as Mg^{2+}), while maintaining a clarifier overflow rate of 60 to 120 m/h.

Excellent water quality was achieved at overflow rates as high as 120 m/h. This increased overflow rate results in a system footprint significantly smaller than that of a conventional clarification process with similar capacity, thus making the system economical, especially for treating high flow. Because of the increased overflow rate, the unit is capable of performing well under dramatically changing flow rates without affecting the final effluent quality. Solids/scale build-up on the recycled microsand was insignificant and did not affect the operation of the system.

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