Sand Ballasted High Rate Clarification Process for Treatment of Process Water

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ABSTRACT

This paper will focus on the use of a Sand-Ballasted high rate settling technology, known as the ACTIFLO® Process for the treatment of surface water prior to use by industries for industrial supply water, particularly as an effective pretreatment system prior to membrane systems used to produce high purity water. Sand-ballasted settling is a high-rate coagulation/flocculation/sedimentation process that utilizes 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 very fast, allowing for compact clarifier designs with high overflow rates and short detention times. These designs results in system footprints between 5 and 30 times smaller than conventional clarification systems of similar capacity. The use of microsand also permits the unit to perform well, even when the inlet flow rate and influent water quality dramatically change either separately or in tandem, while still producing high quality treated effluent. The paper will discuss a number of case studies which highlight the performance of the ACTIFLO® process for the treatment of surface waters.

ACTIFLO® PROCESS DESCRIPTION

Raw untreated water is pumped into the coagulation tank of the sand-ballasted system (See Figure 1) where a coagulant, such as alum, ferric chloride, ferric sulfate or poly-aluminum chloride 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 flocculent and microsand are added to initiate floc formation. These serve as a "seed" for floc formation and development in the next process step. A hydraulic retention time of about two minutes is maintained in this tank also. Treatment continues as the water passes through the underflow passage from the injection tank 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 between six and eight minutes. From this tank, the fully formed ballasted floc enters a settling tank equipped with inclined lamella plates or tube settlers depending on the application, which provides the rapid and effective removal of the "microsand/sludge" floc. The clarified water is collected and exits the unit via a series of weirs and collection troughs.

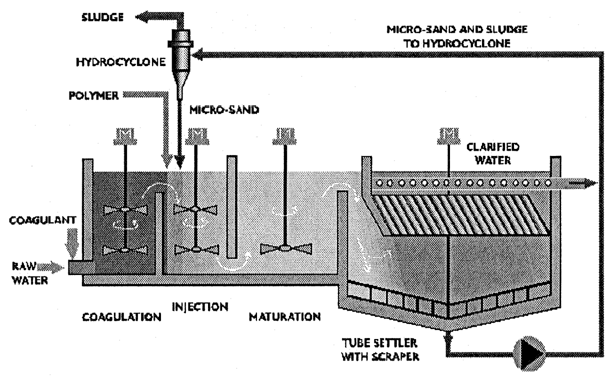

Figure 1
Schematic diagram of the ACTIFLO® process.

The combined mircosand-sludge floc settles to the bottom of the clarifier and is moved to the center of the unit using a sludge scraper mechanism for removal from the unit. The sludge scraper mechanism provides positive sludge removal and is capable of removing high volumes of sludge,

The microsand-sludge stream is pumped to a hydrocyclone. The microsand-sludge is sheared as it passes through the pump. The hydrocyclone separates the floc from the microsand stream. The much 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 to the sludge handling equipment, where it can be thickened and dewatered prior to disposal. The sludge produced from the ACTIFLO® Process is robust and has good settling characteristics, so it is amenable to removal and thickening in a sludge thickener unit. Likewise, the sludge from the thickener shows

This patented processed is used with great success at the Wilsonville, OR water treatment plant. See discussion in this article; data in Figure 4.

good dewatering characteristics, without additional conditioning.

ACTIFLO® OPERATING PRINCIPLE

Fundamentally, the ACTIFLO® process is very similar to conventional (coagulation, flocculation, and sedimentation) water treatment technology. Both processes utilize chemical conditioning using coagulant for destabilization and flocculant aid polymer for the aggregation of suspended (insoluble) materials to enhance the settling velocity. These materials then subsequently settle and are removed from the untreated water stream.

The primary advance made in the ACTIFLO® process is the addition of microsand, typically 100 to 150 microns with a specific gravity of 2.65, as a "seed" or "ballast" to induce and promote the formation of high density robust floc with very high settling velocities. The resulting floc has a relatively high density microsand nucleus that settles rapidly. With these factors in mind, a brief overview of the physiochemical processes involved in conventional water treatment is beneficial in developing and comparing the features and advantages of the ACTIFLO® process.

Conventional water clarification processes primarily involve the destabilization, flocculation and subsequent removal of suspended solid materials. Unfortunately, the floc formed by chemical conditioning is fragile and not readily removed by gravity settling. The source of these suspended materials can be natural, synthetic organic, inorganic compounds, microorganisms, and/or viruses that typically range in size from 0.001 to 1 micron. In most natural systems, the stability of colloidal suspended materials is attributed to a net negative surface charge that causes individual particles to repel each other and remain in suspension. To counteract these repulsive forces, a chemical coagulant such as alum ($Al_2(SO4)_3$), ferric chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), poly-aluminum chloride (PAC), lime (CaO or $Ca(OH)_2$) or any other highly charged ionic chemical species is added to reduce the repulsive force between the suspended materials. This chemical conditioning process results in the destabilization and/or attraction of the suspended solids to form a floc.

Although destabilized, the floc may not settle and will not be removed if the settling velocity is lower than the water velocity exiting the unit, due to its extremely low mass. Removal of these particles is most easily achieved by aggregating the smaller particles together into larger more settleable floc. Floc formation is typically accomplished by forming inter-particle polyelectrolyte bridges using a polymeric flocculant. This process produces a larger, more settleable floc with a higher settling velocity, which can now be removed with gravity separation techniques.

ACTIFLO® differs from conventional clarification in that it uses microsand as a "ballasting" agent, in the flocculation (i.e. maturation) process step. The microsand serves several important roles in the ACTIFLO® process:

- The high-specific surface area to volume ratio of the microsand particles serves as a "seed" for floc formation.
- The microsand and polymeric flocculant "seed" promotes the enmeshment of suspended materials and results in the formation of large stable floc.
- The relatively high specific gravity of the microsand (~2.65) serves as ballast for the formation of high-density floc.
- The high microsand concentration within the ACTIFLO® process effectively dampens the effects of changes in the raw water quality.
- The chemically inert microsand does not react with the process chemistry, allowing it to be effectively removed from chemical sludge and reused in the process.
- The resulting settling velocity is increased significantly and the process can be operated in the range of 20 to 80 gpm/sqft.

Together, these factors provide a unit process that is extremely efficient in the treatment of "difficult-to-treat" waters, providing reliable and consistent performance, while being easy to operate and maintain.

Overall, the use of microsand results in the development of a robust floc that is significantly denser compared to the floc formed using a conventional clarification process. This microsand-floc has a considerably higher settling velocity; so higher clarifier overflow rates are achieved. Higher overflow rates achieved by ACTIFLO® technology translates into smaller tank volume requirements and reduced equipment footprints providing end-users with lower total installed costs compared to other treatment alternatives. The system consistency and reliability also provides better treated water quality.

The detailed process description is presented in several of our earlier publications (Banerjee and Blumenschein, 2001; Blumenschein and

Banerjee, 2002; Blumenschein and Banerjee, 2003 [a], Banerjee and Blumenschein, 2003 [b]).
The ACTIFLO® technology has been used for the treatment of surface water, municipal and industrial wastewater, and groundwater. Pilot and full-scale installation results confirm and demonstrate the capability of the technology to remove total suspended solids including small particles, organic as well as inorganic colloids, turbidity, heavy metals, dissolved and colloidal silica, phosphorus and algae. The objective of this paper is to present and discuss the results pertaining to the performance of sand ballasted settling process for the treatment of industrial process water taken from various sources. A brief discussion covering the specific water quality parameters of concern is provided below.

REMOVAL OF TURBIDITY, COLOR, COLLOIDS, AND SMALL PARTICLES

Negatively charged colloidal particles are removed by adsorption onto the surface of iron oxy-hydroxide or aluminum hydroxide, which eventually form floc by aggregation of the smaller particles. In presence of polyelectrolyte, these flocs form quicker and can be adsorbed onto the surface of microsand. Once this occurs, slow settling particles become fast settling flocs.
Over the years, several ACTIFLO® systems have been installed for treatment of surface waters.
CASE STUDY – RAPPAHANNOCK RIVER, VIRGINIA – An ACTIFLO® plant was designed and constructed to treat 12 MGD of river water for this site. The treatment chemicals include alum addition, anionic polymer and caustic soda to maintain proper pH. The water is further processed with downstream filtration.
During the pilot studies for this project, testing was done to establish a relationship between polymer dosage and turbidity removal. This type of testing, either at batch or at continuous mode, is conducted on all applications to confirm the proper polymer and the associated dosage requirements for proper operation of the system. In this case, the polymer dosage ranged between 0.2 and 0.5 mg/L. The raw sample that was collected on a particular day had a turbidity of about 10 NTU. As Figure 2 illustrates, at a specified alum dosage of 14 mg/L, increasing polymer dosage increased the turbidity removal efficiency of the unit.

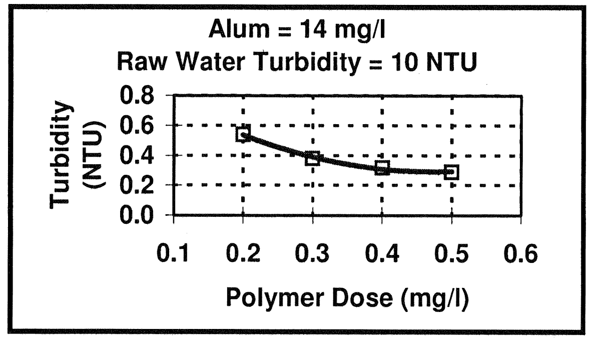

Figure 2
Polymer Dosage Evaluation

After completion of construction, the plant has been operating within design conditions. The designed over flow rate of the sand ballasted settling system was approximately 20 gpm/sqft. Table 1 presents a summary of the over all performance of the treatment system:

Table 1

Raw Water Turbidity:	20 to 40 NTU
Clarified Water Turbidity:	0.5 NTU
Filtered Water Turbidity:	<0.1 NTU
Alum:	20 mg/l,
Anionic polymer:	0.3-0.5 mg/L
pH	7.05

Figure 3 shows the turbidity data for the influent, clarified water and final filtered water over a three day test period.

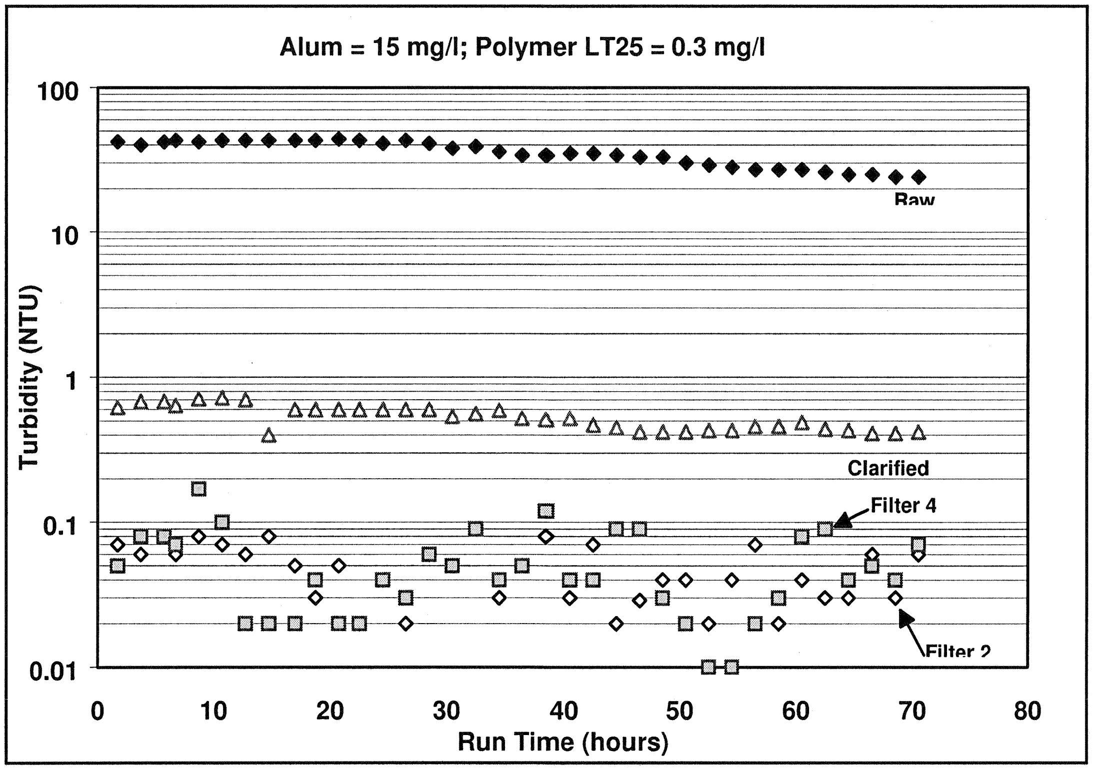

Figure 3
Turbidity Data

As can be seen from Figure 3, the ACTIFLO® clarified water reduced the turbidity to less than 1 NTU. The turbidity after the filters is below 0.1 NTU.

Particle Count measurements were undertaken to determine the overall performance of the ACTIFLO® process. Table 2 below summarizes the data collected on the raw and ACTIFLO® clarified water.

Table 2

	2-3 µm	3-5 µm	5-15 µm	15-200 µm
Raw	1548	1522	841	2
Clarified	114	98	92	2

Color Removal data were collected to determine the impact of the ACTIFLO® Process on overall color removal. Below is a summary of that data.

Raw Water:	23 TCU
Clarified Water:	2 TCU
Filtered Water:	<1 TCU

CASE STUDY – WILLAMETTE RIVER, OREGON - At this site in Oregon, a 15 MGD ACTIFLO® Plant was designed and constructed to treat river water. This plant was designed based on 20 gpm/sqft. The treatment chemicals include alum, cationic polymer and caustic soda to maintain proper pH. The water is further processed with ozone and GAC filtration.

Figure 4 below presents long term operating data for the treatment facility. Shown on the figure are the turbidity measurements for the influent, clarified water and filtered water. Also shown, is the alum dosage, note that the alum dosage is linked to the influent turbidity measurements as part of the overall control system.

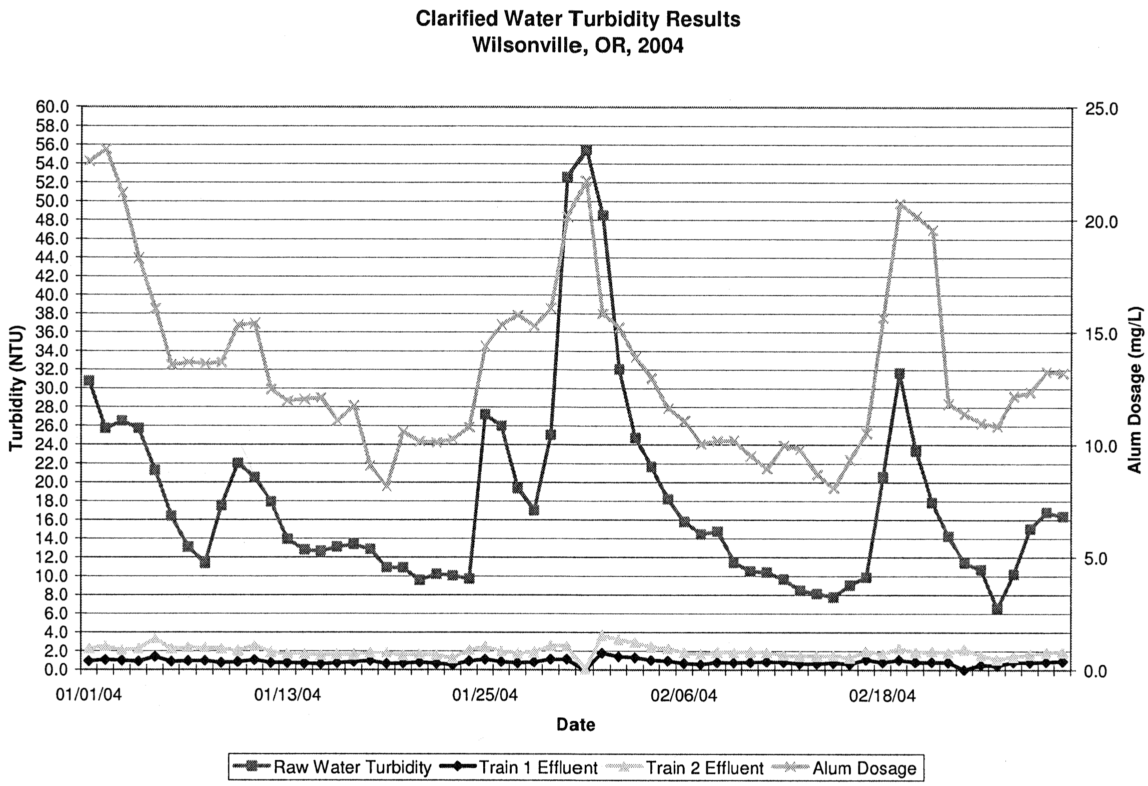

Figure 4

As can be seen, even with significant fluctuations in the influent turbidity conditions, the ACTIFLO® Process produces a consistent effluent quality.

At another location in California, surface water was treated with ACTIFLO® to determine the ability of the process to remove discrete particle sizes ranging from 2 to 15 microns. A pilot study was conducted over a one week period to determine the overall performance of the system to remove particles from 2 to 15 microns in size. The average feed water turbidity during the study was 26.3 NTU, The clarified effluent turbidity was 0.42 NTU. Table 3 below presents the results from this study.

TABLE 3
Particle Count Reduction Evaluation

Particle Size	Counts per ml	
	Raw Water	Clarified Water
2 to 5 Microns	78,122	378
5 to 15 Microns	11,255	107
Total <15 Microns	89,377	485

During the study, a storm event occurred and a substantial amount of silt was present in the raw water. The turbidity spiked to >600 NTU as a result of the storm event and the clarified effluent turbidity was maintained below 1 NTU. Table 4 below presents the results during the storm event.

TABLE 4
Storm Event - Particle Count Reduction Evaluation

Particle Size	Counts per ml	
	Raw Water	Clarified Water
2 to 5 Microns	1,109,200	2,190
5 to 15 Microns	376,350	913
Total <15 Microns	1,485,550	3,103

COMPARISON TO OTHER TECHNOLOGIES

Studies have been conducted to compare ACTIFLO® to other treatment technologies; (conventional clarifiers, sludge blanket clarifiers and dissolved air floatation units) for the removal of Turbidity, particle count reduction and specific UV-absorbance (SUVA)

In a study at a surface water treatment plant in Kentucky, ACTIFLO® was used as a pretreatment step and was compared to the existing clarification system for turbidity and particle size removal. The treatment system was operated with ferric sulfate and a cationic polymer. During this study the ACTIFLO® was operated at a rise rate of 16 gpm/sqft and the conventional clarifier was operated at 0.5 gpm/sqft. Table 5 below presents a comparison the results.

TABLE 5
Comparison of Actiflo to Conventional Clarifiers

Process	Turbidity (NTU)	Particle Counts (counts/ml)	
		3 – 5 µm	7 -15 µm
Raw Water	90	87,750	28,000
ACTIFLO®	<0.5	157	108
Clarifier	3.2	1,237	813

Below is a summary of data collected from a full scale study on water from Lake Washington, located in Florida. The existing conventional clarifier was operated with alum and polymer. This unit served as the base line and was compared to ACTIFLO®, a sludge blanket clarifier and a dissolved air floatation (DAF) unit. These three processes were operated with ferric sulfate and polymer. Dosages to each system were similar.

Table 6 compares the operating hydraulic flow rates for each unit.

Table 6
Hydraulic Overflow Rates

Process	Hydraulic Flow Rate (gpm/sqft)
ACTIFLO®	25
Sludge Blanket Clarifier	1.0*
DAF	3.0
Conventional Clarifier	0.5

*(typical conditions)

Table 7 presents the results of the total particles great than 2 µm in the effluent from each treatment process.

TABLE 7
Particle Data – Clarified Water
(Total Particles per ml >2 µm)

Process	Max	Min	Ave	Std Dev
ACTIFLO®	97	14	43	21
Sludge Blanket Clarifier	11,257	125	1,595	2,209
DAF	5,934	212	2,467	1,880
Conventional Clarifier	4,685	171	680	1,213

Turbidity data on the clarified water is presented in Table 8.

TABLE 8
Turbidity – Clarified Water, NTU

Process	Max	Min	Ave	Std Dev
ACTIFLO®	4.1	0.22	0.42	0.46
Sludge Blanket Clarifier	4.8	0.31	1.28	0.93
DAF	2.8	0.27	1.11	0.57
Conventional Clarifier	1.8	0.09	0.69	0.30

As shown above, ACTIFLO® achieves the highest particle removal results, compared to conventional or enhanced clarification or dissolved air flotation. Removal rates for particles in the size range of 2 -15 µm were measured to be in range from 1.0 and 3.0 logs.

IMPACT ON FILTER PERFORMANCE

As a result of the ability of ACTIFLO® to reduce small particles and produce low turbidity water quality, studies have shown an improvement on downstream filter performance. Again referring to a study mentioned earlier on water treated from Lake Washington, the effluent from the ACTIFLO®, sludge blanket clarifier and DAF were each evaluated for filter performance and filter effluent quality. The filters in this evaluation were gravity fed dual media filters with 30" of anthracite and 10" of sand. The design filtration rate for the filters was 4 gpm/sqft. The evaluation was conducted by monitoring filter run time, headloss accumulation, unit filter run volumes (UFRV) and particle and turbidity levels in the filtered water. Table 9 summarizes the filtration data.

TABLE 9
Summary of Filtration Data

Process	Filtration Rate (gpm/sqft)	Run Time (hrs)	UFRV (gal/sqft)	Particle Count (#/ml)
ACTIFLO®	4	48	11,520	<20
Sludge Blanket Clarifier	4	37	8,880	>20
DAF	4	36	8,640	>20

As a result of the long filter run times observed with the ACTIFLO® Process, additional testing was conducted at a higher filtration rate, 6 gpm/sqft, to evaluate the performance of the filters. TABLE 10 presents the results of this evaluation

TABLE 10
Summary of Higher Rate Filtration

Process	Filtration Rate (gpm/sqft)	Run Time (hrs)	UFRV (gal/sqft)	Particle Count (#/ml)
ACTIFLO®				
Run 3	6	40	14,400	<20
Run 4	6	30	10,800	<20

Even at the higher flow rate ACTIFLO® was able to maintain almost the same UFRV and produced a satisfactory water quality with low particle counts. The data also shows that the effluent from the ACTIFLO® allowed the filters to operate for longer time periods and permitted more flow to be treated between backwash cycles.

SILT DENSITY INDEX – SDI

The ACTIFLO® Process is currently being used as pretreatment in reverse osmosis membrane systems. Typically, after the ACTIFLO® the water is further treated with Multimedia and cartridge filters prior to the membrane systems. Studies have been conducted to determine the performance of ACTIFLO® with and without filters to evaluate impact on the SDI values.

In one case for a seawater reverse osmosis system, ACTIFLO® was used as the first pretreatment step to remove suspended solids and turbidity. The raw water turbidity was in the range of 2.2 – 4.0 NTU. The treatment chemistry included 3 – 4 mg/L Ferric Chloride and 0.3 – 0.5 mg/L of Cationic polymer. The average Turbidity after the ACTIFLO® was <0.5 NTU and the average SDI was less than 3.

In another case, for treatment of river water through a reverse osmosis system, ACTIFLO® was again used as the pretreatment step. The water was treated using a poly-aluminum chloride and an anionic polymer. Then the water was further treated with multimedia filters. The raw water turbidity ranged from 10 to 50 NTU. After ACTIFLO® the treated water turbidity was in the range of <1.5 – 2.0 NTU. After filtration the turbidity was reduced to 0.05 – 0.06 NTU with a SDI of 2.0 to 3.2.

REMOVAL OF ALGAE

The algae removal mechanism of the ACTIFLO® system is the same as that for suspended solids. The ACTIFLO® systems were consistently able to achieve 90% to 98% removal of Green algae and 70% to 95% removal of Blue-Green algae .. When the ACTIFLO® treated effluent streams were treated further by a mixed media filter, over 98% removal efficiency was achieved. However, the studies were able to achieve these results without any “pre-chlorination”. When the ACTIFLO® treated effluent streams were treated further using mixed media filtration, removal rates of 98% were achieved.

Table 11 summarizes data collected from a project on the Shenago River in Pennsylvania.

TABLE 11
Algae Removal Data

Green Algae (units/ml)	Raw Water	ACTIFLO® Settled	Filter Effluent
	11,000	532	220
	3,900	360	110
	5,400	186	60
	9,360	252	190
	5,600	150	150
Blue Green Algae (units/ml)	18,000	3,220	260
	9,000	680	660
	6,600	320	192
	4,500	1,360	260
	6,000	1,360	560

REMOVAL OF SILICA & COLLOIDAL SILICA

Reactive silica is removed by adsorption onto the surface of iron, aluminum, or magnesium hydroxide. The optimum pH for adsorption onto iron and aluminum hydroxide is between 6.5 and 7.5. If magnesium hydroxide is used the optimum pH is higher, nearer to 11.0. Using the ACTIFLO® technology, the silica is adsorbed onto the inner surface of the hydrous metal oxide/oxy-hydroxide floc. Once the silica is adsorbed, flocs are separated from water by ballasting to the microsand, which again creates a rapidly settling particle. Silica removal results are presented in Figure 5. As the figure illustrates, Data obtained from silica removal studies indicate the ACTIFLO® system is capable of reducing silica from an initial concentration of 85 mg/L to less than 10 mg/L Detailed results on silica removal are presented in our earlier publication (Banerjee and Blumenschein, 2003[b]).

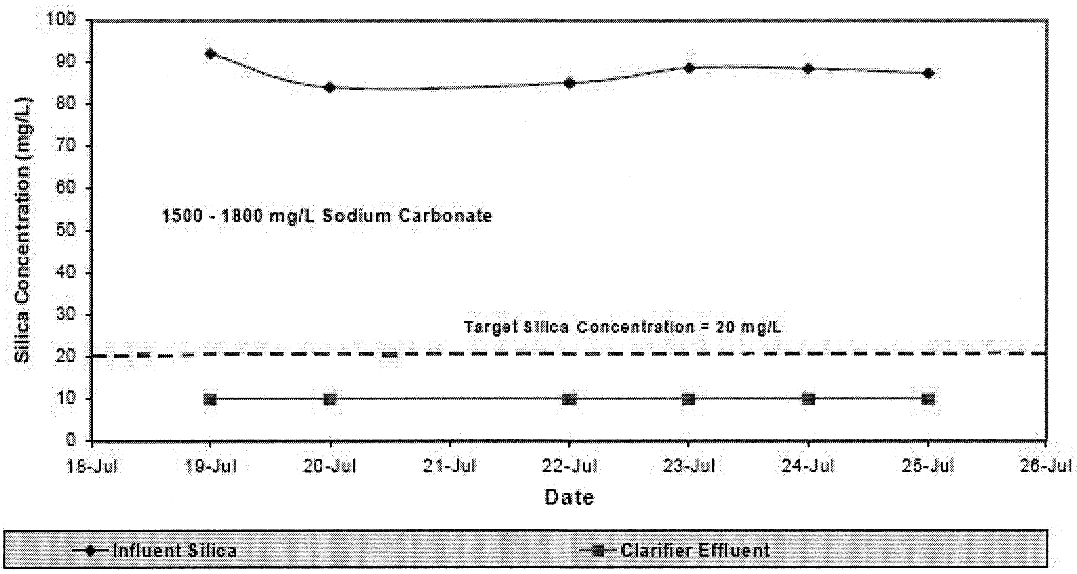

Figure 5

Removal of colloidal silica by ACTIFLO® follows the same principal, described above for reactive silica. However, after adsorption of the colloidal particulate, which on average has a larger particle diameter, then to occupy the surface of the adsorbent. Because of this surface effect, higher levels of adsorbent must be maintained to achieve high levels of colloidal silica removal. The amount of microsand used in the ACTIFLO process helps provide sufficient amounts of adsorbent sites to ensure the removal of colloidal silica, while not adversely impacting treated water quality.

SUMMARY

The sand ballasted high rate clarification process provides a unique and effective means to rapidly reduce turbidity, small particles, color, silica, and algae from surface waters. The ability of the system to operate at very high settling rates permits the system to be installed in a small foot print saving land area. In cases of cold weather climates the system can be installed in a small building. The overall performance of the system provides a benefit to downstream filtration systems allowing these systems to run longer, thus reducing backwashing while producing a high quality effluent.

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