WATER REUSE TECHNOLOGY DEMONSTRATION PROJECT

Demonstration Facility Pilot Study
Ballasted Flocculation (Actiflo)
Primary Treatment Application
Final Draft Report

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By

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BLACK & VEATCH

King County

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Technology Assessment Program

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Executive Summary

The King County Department of Natural Resources conducted a nine-month pilot-testing program to assess the performance of emerging wastewater treatment technologies. The Actiflo process (ballasted flocculation) was tested to determine its utility for primary treatment. This report presents the findings of that testing.

Demonstration Facility and Testing Goals and Objectives

A 50-ft-long Actiflo demonstration unit was brought on-site for a total of six weeks for the pilot test. The unit arrived as a complete packaged system consisting of a rotary drum, fine screen, tanks for injection, flocculation, maturation, and settling, chemical feed equipment, and a SCADA system.

A testing plan was prepared prior to the pilot study and updated throughout the test. The target performance goals were:

- Total Suspended Solids (TSS) removal efficiency > 80 %
- Chemical Oxygen Demand (COD) removal efficiency > 60 %
- Total phosphorus removal efficiency > 80 %
- Sand recovery > 95 %

Testing was conducted to:

- Determine optimum polymer and coagulant types and doses.
- Collect long-term performance data at optimum and sub-optimum chemical doses.
- Evaluate the impact of wet and dry start-ups and loss of chemical feed.
- Collect data pertaining to metals removal.

Results and Conclusions

Following is a summary of the results derived from the pilot testing data:

- Target Performance Goals
  - TSS removal efficiency - The Actiflo process consistently achieved removal efficiencies of 93 and 94 %, achieving the performance goal of greater than 80 %.
  - COD removal efficiency – Removal efficiencies were between 67 and 71 %, achieving the performance goal of greater than 60 %.
  - Total phosphorus removal efficiency – Poly aluminum chloride and ferric chloride achieved 92 and 91 % removal efficiencies, respectively. Both of these values are above the performance goal of greater than 80 %. Aluminum sulfate was less

effective and was determine to remove only 75 % of the total phosphorus, which is below the 80 % goal. The reason for the lower removal efficiency is unclear.

- Comparison of coagulants – With the exception of aluminum sulfate for phosphorus removal, all three coagulants achieved the target performance goals. However, poly aluminum chloride was found to provide the highest overall removal.

- Comparison to Convention Primary Treatment
  - Pilot testing results demonstrated that the Actiflo process performed better than conventional primary clarification in terms of measured COD and TSS removal efficiencies.
  - While the Actiflo process was shown to achieve good removal for BOD_5, TSS, and total phosphorus, it is considerably more expensive to operate than a conventional primary treatment because large volumes of chemicals are required, there is mechanical equipment to operate and maintain, and the process produces more sludge.
  - The Actiflo process requires much less space than primary clarifiers. However, this does not result in lower capital costs. Capital costs associated with the Actiflo process were estimated to be between 10 and 25 % higher than for conventional primary clarifiers, based on a treatment capacity of 1 mgd.
  - To accurately compare Actiflo and a conventional primary treatment, all of the differences and their impacts on the whole treatment plant must be examined. For example, are the extra chemical costs for the Actiflo process offset by reduced energy costs or smaller basins in the subsequent activated sludge treatment process?
- Issues Not Resolved by Pilot Tests
  - Due to the limited length of time for the pilot study, sand recovery and the potential for long-term sand fouling could not be investigated. If this technology is selected for implementation, it may be appropriate to contact staff at the full-scale installations listed in this report to determine whether sand fouling and recovery have been an issue.

Introduction

The King County Department of Natural Resources (King County) conducted a nine-month demonstration pilot-testing project to assess the performance of emerging wastewater treatment technologies. The focus of this project was to assess technologies that had the potential to minimize the footprint, impacts, and costs of producing reclaimed water (Class A or better) at small satellite facilities. The particular unit process assessed in this report (Actiflo) would have to be used in conjunction with a secondary treatment process to produce reclaimed water.

The objective of this unit process report is to present a summary of the findings of the ballasted flocculation (Actiflo) pilot tests. The Actiflo demonstration facility was configured to receive primary influent since the focus of these particular pilot tests was to evaluate the Actiflo process as a primary treatment system.

Description of the Technology

Actiflo is a compact clarification process using micro-sand enhanced flocculation and settling. A coagulant is added to the raw water in a separate coagulation tank, as shown in Figure 1. The coagulated water is conveyed to an injection tank where micro-sand (NSF approved inert pure silica sand) and polymer are added. The micro-sand provides a large contact area and acts as particle ballast, thereby accelerating the settling rate of particle flocs. Polymer bridging binds destabilized suspended solids to the micro-sand particles. In the maturation tank, the particles agglomerate and grow into high-density flocs, which settle to the bottom of the settling tank. Lamella tubes are used in the settling tank.

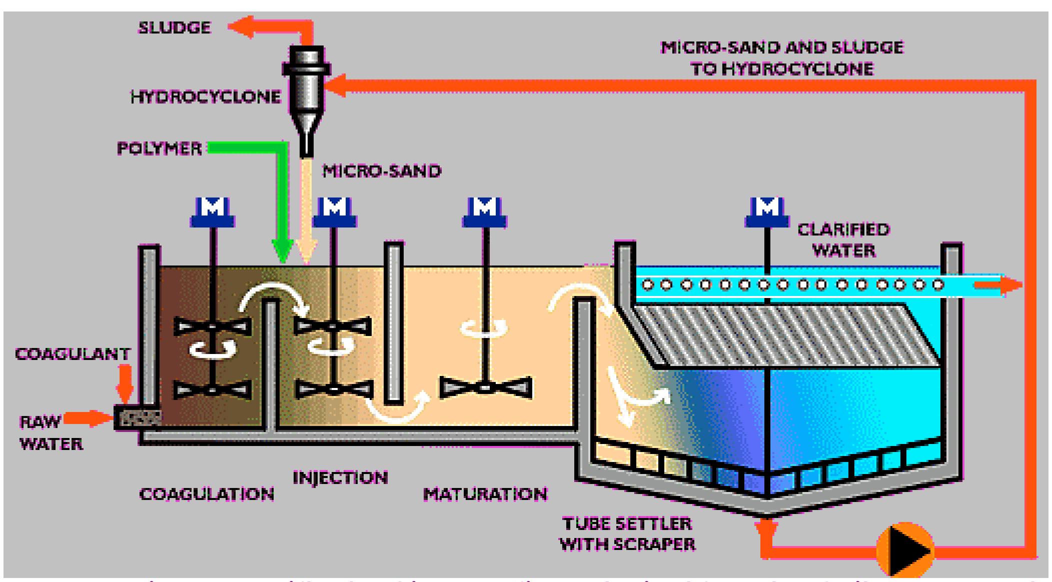

Figure 1. Actiflo Flow Diagram. (figure obtained from the US Filter/Kruger website).

The particle/micro-sand mixture collected at the bottom of the clarifier is pumped to hydrocyclones where the particles are separated from the micro-sand by centrifugal force. The recovered clean micro-sand is recycled back to the injection tank, and the separated solids are continuously discharged to solids-handling facilities.

The following is a summary of the benefits of this physical/chemical process as described in the manufacturer's literature:

- The process offers a high degree of flexibility since it has a short start-up time and reaches steady-state performance quickly.
- The high concentration of micro-sand and injection tank mixing intensity allows the process to handle sudden variations in flow and water quality (such as turbidity or temperature) without compromising effluent quality.
- Chemical (coagulant and polymer) feed can be adjusted to accommodate variations in feed water quality.

Comparison of Actiflo and Conventional Treatment

Compared to conventional primary treatment, the benefits of the Actiflo process are:

- **Smaller Footprint and Basin Requirements:** Surface overflow rates of the Actiflo process are approximately 10 times greater than for conventional primary clarification. The higher loading rates significantly decrease basin volume and surface area requirements.
- **Better Pollutant Removal Efficiencies:** Bench scale tests have demonstrated that the Actiflo process can remove more pollutants compared to a conventional or enhanced primary treatment.[1]
- **Ability to Compensate for Influent Variability:** Due to the high concentration of micro-sand relative to influent particulates, the Actiflo process has the ability to accommodate variations in flow and influent quality without compromising effluent quality.

North American Actiflo Installations

Currently there are no North American facilities that employ the Actiflo process for primary treatment of wastewater. However, there are several facilities that utilize this technology for other purposes. The following is a summary of locations utilizing the Actiflo process and the year in which they were installed:

- **Raw Water Settling (Water Treatment Applications)**
  - Ecole Vaudreuil, Canada - 0.3 mgd (2000)
  - Placer County Water Agency - Auburn, CA - 40 mgd (2002)

[1] Comparison results based on the bench scale tests conducted at the Russian River Wastewater Treatment Facility (HDR Engineering, June 2000).

- **Treatment of Combined or Sanitary Sewer Overflows (CSO or SSO)**
  - St. Bernard, Louisiana - 10 mgd (2001)
  - Lawrence, Kansas - 40 mgd (2002)
  - Bremerton, Washington - 10 mgd (2002)
  - Ft. Smith, Arizona – 31 mgd (2003)
- **Secondary Effluent Polishing Prior to Discharge or Filtration (Wastewater Treatment Application)**
  - Lindsay, Canada - 8 mgd (1999)
  - Deseronto, Canada - 1.3 mgd (2000)
  - Antioch California - Calpine / Delta Diablo Sanitation District - 14 mgd (2000)
  - Strathroy, Canada - 6.2 mgd (2000)
  - Boisbriand, Canada - 4 mgd (2000)
  - West Palm Beach, Florida - 10 mgd (2002)
  - Pampa, Texas - 10 mgd (2002)
  - Onondaga, New York - 126 mgd (2003)
- **Side Stream Treatment (Wastewater Treatment Application)**
  - Burlington, Canada - 5.8 mgd (2001)
  - Santa Fe, California - 4 mgd (2002)

Pilot Testing

Goals and Objectives

The goal of the pilot study was to evaluate the Actiflo process and determine its utility for primary treatment. The pilot study was designed to:

- Evaluate system performance when receiving primary influent by assessing Actiflo's ability to remove 5-day Biochemical Oxygen Demand (BOD_5), COD, TSS, and total phosphorus.
- Determine the optimum combination of polymer and coagulant doses for conventional and advanced (phosphorus removal) primary treatment.
- Quantify process performance during dry start, wet start, and chemical-feed failure conditions.
- Evaluate the process based on operational and maintenance considerations such as labor, chemical and energy requirements, and ease and duration of startup.

- Evaluate the potential for long-term sand fouling.
- Target the following performance goals:
  - TSS removal efficiency > 80 %
  - COD removal efficiency > 60 %
  - Total phosphorus removal efficiency > 80 %
  - Sand Recovery > 95 %

Demonstration Setup and Operation

The US Filter/Kruger Actiflo demonstration facility arrived at the West Point Wastewater Treatment Plant on August 27, 2001. The unit was on-site for a total of six weeks and was shipped back to the manufacturer on October 5, 2001. Two full-time US Filter/Kruger operators operated the unit five days per week eight hours per day, collected data and laboratory samples, and prepared reports summarizing pilot study results.

The demonstration pilot, which has a nominal capacity of 350 gpm, was brought on-site in a 50-foot-long trailer that was parked outside of the testing facility as shown in Figure 2. The unit arrived on-site as a complete packaged system, consisting of: a rotary drum fine screen; tanks for injection, flocculation, maturation, and settling; chemical feed equipment; and a SCADA system. A description of the physical attributes of the pilot unit is presented in Table 1.

Figure 2. Trailer Mounted Actiflo Pilot Unit.

Table 1. Summary of Physical Parameters

Parameter	Unit	Value [a]
Injection Tank		
Length	inches	36.5
Height (total)	inches	62
Width	inches	36
Volume	gallon	343.0
Mixer	HP	1.5
Maturation Tank		
Length	inches	68
Height (total)	inches	62
Width	inches	60
Volume	gallon	1,060.9
Mixer	HP	1.5
Settling Tank	square feet	5.8
Hydrocyclone		
Influent Flow	gpm	22
Sludge Flow	gpm	17.6
Underflow	gpm	4.4
Power Requirement	HP	6.2

[a] Information provided by Daniel Austria Jr. (US Filter/Kruger pilot study engineer).

Instrument Calibration

Instruments used for process monitoring were calibrated in accordance with the manufacturer's recommendations. Instruments were calibrated prior to initiating the pilot test as described in the US Filter/Kruger Pilot Testing Report (US Filter/Kruger Products, 2002).

The chemical feed pumps were calibrated using a draw down method to measure flow rates. Draw downs were performed using graduated cylinders and a stop watch. The flow accuracy of the feed pumps was checked later in the pilot test as described in the US Filter/Kruger Pilot Testing Report (US Filter/Kruger Products, 2002).

Daily Startup and Shutdown Procedure

A description of the daily startup and shutdown procedures is presented in the US Filter/Kruger Pilot Testing Report (US Filter/Kruger Products, 2002). In general, daily startups consisted of manually starting process equipment and instruments and verifying the metering accuracy of the chemical feed pumps.

Shutdown consisted of reversing the startup procedure and allowing the sand pump to run for a period of ten minutes after all the equipment had been shutdown to remove sand from the settling tank hopper.

Testing Plan

A testing plan was prepared prior to the pilot study and updated throughout the pilot test. A copy of the final testing plan is contained in Appendix A. Following is a summary of key information presented in the testing plan:

- The pilot test consisted of two testing stages. Note that each testing stage was run three times to accommodate the three polymer/coagulant combinations:
  - **Stage 1 – Coagulant and Polymer Optimization Trials.** This testing stage was conducted to select a single polymer for all subsequent tests and to determine optimum polymer and coagulant doses.
    1. Three different polymer solutions were tested during the Stage 1 tests. From these results, a single polymer was selected for all subsequent tests.
    2. The second phase of the Stage 1 tests consisted of evaluating different polymer- and coagulant-dose combinations. Selection of optimum chemical doses was based on a review of measured COD, TSS, and turbidity removal efficiencies. For each chemical-dose combination tested, the samples were collected after the pilot unit was operated for at least two hydraulic residence times, which should be sufficient to reach steady-state.
  - **Stage 2 – Continuous Run Trials.** This testing stage was conducted to collect long-term performance data at optimum and sub-optimal polymer and coagulant doses. Stage 2 tests were conducted using the selected polymer and the following three coagulants: alum, ferric chloride, and polyaluminum chloride (PACL). Stage 2 consists of six sub-stages as shown below:
    1. An eight-hour trial run at the optimum polymer and coagulant dose **(Stage 2A).**
    2. A four-hour trial run at the optimum polymer dose and a low coagulant dose to determine the impact of a low coagulant dose on effluent quality **(Stage 2B).**
    3. A four-hour trial run at a low polymer dose and the optimum coagulant dose to determine the impact of a low polymer dose on effluent quality **(Stage 2C).**
    4. A four-hour trial run at a low polymer and a low coagulant doses. Following this period, the chemical doses were returned to optimum levels. Once the process achieved steady-state performance, hourly samples were collected for a minimum of three hours. Data collected during these tests were used to determine (1) effluent quality during low chemical dose periods, and (2) how much time was required for the process to achieve steady-state performance. **(Stage 2D).**

5. Evaluate the impact of wet and dry start-ups and loss of chemical feed conditions. **(Stage 2E)**
6. Samples for metals analysis **(Stage 2F)** were collected and analyzed.

Information collected during Stages 2A through 2D could be used in the future to optimize the Actiflo process with regard to coagulant costs and performance implications.

Sample Collection and Analyses

As described earlier, all samples were collected by the US Filter/Kruger operators throughout the pilot test and analyzed in accordance with Standard Methods. Sample analyses were conducted in the following locations:

- US Filter/Kruger Operators - pH and turbidity (field measurements).
- King County Environmental Laboratory - Stage 2F metal analyses.
- West Point Treatment Plant Process Laboratory – All remaining sample analyses.

Chemical Doses

The coagulants evaluated in the Stage 1 and 2 tests were:

Alum – 46% active and specific gravity of 1.3

Ferric Chloride – 40% active and specific gravity of 1.42

PACL – 100% active, specific gravity of 1.37, and 17.1% Al_2O_3

Alum and ferric chloride doses discussed in this report were calculated using their activity and specific gravity; therefore these doses are based on the dry weight of each chemical (reported as alum or as ferric chloride).

PACL doses discussed in this report were calculated based on the Al_2O_3 activity and specific gravity. Therefore, PACL doses described in this report are based on the dry weight of Al_2O_3 (reported as Al_2O_3). This is different than the approach used in the pilot testing report produced by US Filter/Kruger. Doses described in the US Filter Report are based on the wet weight of the PACL product.

Results

Following is a summary of the results for the testing trials. A summary of the testing data is contained in Appendix B.

Stage 1 – Coagulant and Polymer Optimization Trials

Pilot testing trials were conducted on September 5, 6, 7, and 10, 2001, to determine the optimum polymer type and the optimum chemical doses for the selected polymer and the three coagulant combinations. Pilot-scale trial tests (as opposed to jar testing) were performed to determine these parameters since the Actiflo process responds quickly to chemical dose changes (i.e. it has a short hydraulic detention time). Summaries of operating conditions are shown in Table 2. All Stage 1 optimization trials were conducted at a flow rate of 310 gpm.

Table 2. Stage 1 Operating Conditions.

Operating Condition	Units	Value
Flow Rate	gpm	310
Polymer Dose		
M155	mg/L	0.85
E700	mg/L	0.85
AE1125	mg/L	5.20
Coagulant Dose		
Alum	mg/L	60 – 160
Ferric Chloride	mg/L	60 – 140
PACL	mg/L	10 – 45
Hydraulic Residence Time		
Injection Tank	minutes	1.1
Maturation Tank	minutes	3.4
Surface Overflow Rate	gpm/sf	53.4

Optimization trial results were reviewed during a conference call on September 11, 2001. The purpose of the conference call was to discuss and select the optimal polymer and coagulant doses based on Stage 1 testing results. A copy of the tables and figures that summarize Stage 1 testing results is presented in Appendix B. Below is a summary of the testing and discussion results.

- **Optimum Polymer Type:** Figure 3 shows the turbidity removal efficiencies of the three polymer types evaluated for this study at the same alum dose of 60 mg/L. The two dry polymers evaluated were M155 (anionic-product of CIBA Specialty Chemicals) and E700 (cationic product of Polydyne). The liquid polymer evaluated was Polyfloc AE1125 (anionic product of BetzDearborn). A polymer dose of 0.85 mg/L was used for M155 and E700, and a polymer dose of 5.20 mg/L was used for AE1125. Anionic polymer type M155 was selected as the optimum polymer type due to its higher removal efficiency coupled with lower polymer dose. This polymer type was used in all subsequent pilot tests.
- **Selection Criteria for Optimum Chemical Doses:** Selection of optimum polymer and coagulant doses was based on a review and discussion of measured COD, TSS, and turbidity removal efficiencies. A total of five sample sets, consisting of influent and effluent samples at a constant polymer dose and a varying coagulant dose, were

collected for each polymer/coagulant combination. Optimum chemical doses were selected based on the "best" performance (as opposed to achieving a desired removal efficiency) obtained from various coagulant doses coupled with a constant polymer dose of 0.85 mg/L.

- **Selection Criteria for Low Chemical Doses:** The selections of the "low" polymer and coagulant doses were based on reviews of TSS and turbidity removal efficiency data. The low chemical doses were selected based on the minimum coagulant dose (coupled with a polymer dose of 0.85 mg/L) that would achieve a TSS removal efficiency of 80% or better.
- **Optimum and Low Chemical Doses:** Following is a summary of optimum and low chemical doses:
  - The optimum and low polymer doses were selected to be 0.95[2] and 0.75 mg/L, respectively.
  - Selected coagulant doses are presented in Table 3.

Figure 3. Stage 1 Performance - Comparison of Polymer Types.

Table 3. Selected Coagulant Doses

Coagulant	Units	Optimum Dose	Low Dose
Ferric Chloride	mg/L	110	60
PACL	mg/L	34	17
Alum	mg/L	110	60

Stage 2A – Continuous Run Trials – Optimum Polymer and Coagulant Doses

Stage 2A pilot testing trials were conducted on September 12, 17, and 19, 2001, for each of the three optimum coagulant- and polymer-dose combinations. Table 4 summarizes the operating conditions during this testing stage. All tests were conducted at a flow rate of 350 gpm. Table 5 summarizes the influent and effluent performance data for the various coagulants.

Table 4. Stage 2A Operating Conditions

Operating Condition	Units	Value
Flow Rate	gpm	350

[2] The optimum polymer dose was increased from 0.85 to 0.95 mg/L based on performance testing conducted after the September 11th conference call.

Operating Condition	Units	Value
Polymer Type	--	M155
Polymer Dose	mg/L	0.95
Coagulant Dose		
Alum	mg/L	110
PACL	mg/L	34
Ferric Chloride	mg/L	110
Hydraulic Residence Time		
Injection Tank	minutes	1.0
Maturation Tank	minutes	3.0
Surface Overflow Rate	gpm/sf	60.3

Stage 2B – Continuous Run Trials – Optimum Polymer and Low Coagulant Doses

Stage 2B pilot testing trials were conducted on September 13, 18, and 21, 2001, for each of the three low-coagulant and optimum-polymer dose combinations

Table 6 summarizes the operating conditions during this testing stage. All tests were conducted at a flow rate of 350 gpm. Table 7 summarizes the influent and effluent performance data for the various coagulants.

Table 5. Stage 2A Performance - Optimum Polymer and Coagulant Doses

Constituent	Units	Coagulant (average of composite and continuous online samples)[a]		
		Alum	PACL	Ferric Chloride
Run Duration	hours	8.0	8.0	8.0
pH				
Influent	su	7.0	7.0	7.0
Effluent	su	6.6	6.6	6.2
Turbidity				
Influent	NTU	123	166	148
Effluent	NTU	3.7	2.7	4.9
Removal Efficiency	%	97	98	97
TSS				
Influent	mg/L	197	249	264
Effluent	mg/L	11	11	15
Removal Efficiency	%	94	96	94
COD				
Influent	mg/L	894	648	838
Effluent	mg/L	262	180	260
Removal Efficiency	%	71	72	69
Total BOD				
Influent	mg/L	174	136	217
Effluent	mg/L	45	51	48
Removal Efficiency	%	74	63	78
Insoluble (Particulate) BOD				
Influent	mg/L	102	66	139
Effluent	mg/L	7	9	6
Removal Efficiency	%	93	86	96
Total Phosphorus				
Influent	mg-P/L	2.94	2.58	2.64
Effluent	mg-P/L	0.24	0.09	0.25
Removal Efficiency	%	92	97	91

[a] Turbidity measurements were the only continuous on-line measurement. Composite samples were generated from grab samples collected every 30 minutes.

Table 6. Stage 2B Operating Conditions.

Operating Condition	Units	Value
Flow Rate	gpm	350
Polymer Type	--	M155
Polymer Dose	mg/L	0.95
Coagulant Dose		
Alum	mg/L	60
PACL	mg/L	17
Ferric Chloride	mg/L	60
Hydraulic Residence Time		
Injection Tank	minutes	1.0
Maturation Tank	minutes	3.0
Surface Overflow Rate	gpm/sf	60.3

Table 7. Stage 2B Performance- Optimum Polymer and Low Coagulant Doses

Constituent	Units	Coagulant (average of composite and continuous online samples)		
		Alum	PACL	Ferric Chloride
Run Duration	hours	4.0	4.0	4.0
pH				
Influent	su	7.0	7.1	7.0
Effluent	su	6.8	6.9	6.6
Turbidity				
Influent	NTU	147	142	107
Effluent	NTU	13.1	4.3	9.6
Removal Efficiency	%	91	97	91
TSS				
Influent	mg/L	446	251	180
Effluent	mg/L	28	15	29
Removal Efficiency	%	94	94	84
COD				
Influent	mg/L	1,252	604	460
Effluent	mg/L	1,035	156	280
Removal Efficiency	%	17	74	39
Total Phosphorus				
Influent	mg-P/L	3.86	2.61	2.08
Effluent	mg-P/L	1.40	0.63	1.53
Removal Efficiency	%	64	76	26

Stage 2C – Continuous Run Trials – Low Polymer and Optimum Coagulant Doses

Stage 2C pilot testing trials were conducted on September 13 and 18, 2001 and October 3, 2001, for each of the three optimum-coagulant and low-polymer dose combinations. Table 8 summarizes the operating conditions during this testing stage. All tests were conducted at a flow rate of 350 gpm.

Table 9 summarizes the influent and effluent performance data for the various coagulants.

Table 8. Stage 2C Operating Conditions

Operating Condition	Units	Value
Flow Rate	gpm	350
Polymer Type	--	M155
Polymer Dose	mg/L	0.75
Coagulant Dose		
Alum	mg/L	100
PACL	mg/L	34
Ferric Chloride	mg/L	110
Hydraulic Residence Time		
Injection Tank	minutes	1.0
Maturation Tank	minutes	3.0
Surface Overflow Rate	gpm/sf	60.3

Table 9. Stage 2C Performance- Low Polymer and Optimum Coagulant Doses

Constituent	Units	Coagulant (average of composite and continuous online samples)		
		Alum	PACL	Ferric Chloride
Run Duration	hours	4.0	4.0	4.0
pH				
Influent	su	7.0	7.0	6.9
Effluent	su	6.6	6.7	6.3
Turbidity				
Influent	NTU	146	161	143
Effluent	NTU	7.7	26.5	31.6
Removal Efficiency	%	95	84	78
TSS				
Influent	mg/L	227	270	249
Effluent	mg/L	28	86	107
Removal Efficiency	%	88	68	57
COD				
Influent	mg/L	640	557	428
Effluent	mg/L	248	261	472
Removal Efficiency	%	61	53	-10
Total Phosphorus				
Influent	mg-P/L	3.02	3.33	2.18
Effluent	mg-P/L	0.46	0.58	1.35
Removal Efficiency	%	85	83	38

Stage 2D – Continuous Run Trials – Low Polymer and Low Coagulant Doses

Stage 2D pilot testing trials were conducted on September 14 and 25, 2001, for low-polymer and low-coagulant dose combinations for alum and PACL. There was no trial run using ferric chloride as a coagulant. As previously described, this testing stage consisted of a four-hour trial run at low-polymer and low-coagulant doses followed by an increase in chemical doses to optimum levels. Hourly samples were collected during the low chemical dose period and were combined to produce a single, hand composite for subsequent analysis. Once the process achieved steady-state performance, hourly samples were collected for a minimum of three hours and combined to produce a single, hand composite sample at optimum chemical doses for subsequent analysis. Turbidity and pH were continuously monitored throughout the test on a 30-minute time interval. Table 10 summarizes the operating conditions during this testing stage. All tests were conducted at a flow rate of 350 gpm.

Table 10. Stage 2D Operating Conditions

Operating Condition	Units	Value
Flow Rate	gpm	350
Polymer Type	--	M155
Low Chemical Dose Interval		
Polymer Dose	mg/L	0.75
Coagulant Dose		
Alum	mg/L	60
PACL	mg/L	17
Optimum Chemical Dose Interval		
Polymer Dose	mg/L	0.95
Coagulant Dose		
Alum	mg/L	110
PACL	mg/L	34
Hydraulic Residence Time		
Injection Tank	minutes	1.0
Maturation Tank	minutes	3.0
Surface Overflow Rate	gpm/sf	60.3

Figure 4 and Figure 5 present raw influent and effluent turbidities. As shown, the change in chemical doses appears to have a more dramatic impact when alum is used as a coagulant compared to PACL. Table 11 summarizes the influent and effluent performance data for the various components.

Figure 4. Stage 2D Low Alum Doses Followed By Optimum Alum Doses – Polymer Dose 0.95 mg/L.

Figure 5. Stage 2D - Low PACL Doses Followed By Optimum PACL Doses - Polymer Dose 0.95 mg/L.

Table 11. Stage 2D Performance - Low Polymer and Low Coagulant Doses Followed by Optimum Doses

Constituent	Units	Low Chemical Dose Period[a]		Optimum Chemical Dose Period[a]	
		Alum	PACL	Alum	PACL
pH					
Influent	su	7.0	7.1	7.0	7.0
Effluent	su	6.8	6.9	6.6	6.7

Constituent	Units	Low Chemical Dose Period[a]		Optimum Chemical Dose Period[a]	
		Alum	PACL	Alum	PACL
Turbidity					
Influent	NTU	112	119	142	155
Effluent	NTU	12.8	4.4	4.7	3.6
Removal Efficiency	%	89	96	97	98
TSS					
Influent	mg/L	185	229	252	262
Effluent	mg/L	26	11	21	15
Removal Efficiency	%	86	95	92	94
COD					
Influent	mg/L	610	579	633	666
Effluent	mg/L	190	221	233	173
Removal Efficiency	%	69	62	63	74
Total BOD					
Influent	mg/L	181	203	na	264
Effluent	mg/L	56	39	na	51
Removal Efficiency	%	69	81	---	81
Insoluble (Particulate) BOD					
Influent	mg/L	na	129	na	176
Effluent	mg/L	na	8	na	11
Removal Efficiency	%	--	84	--	94
Total Phosphorus					
Influent	mg-P/L	3.04	3.36	2.32	2.81
Effluent	mg-P/L	1.74	0.77	0.52	0.16
Removal Efficiency	%	43	77	78	94

[a] Average of composite and continuous online samples.

na = data not collected.

Stage 2E – Continuous Run Trials – Wet and Dry Startups and Loss of Chemical Feed

The Stage 2E pilot testing trial was conducted on October 1, 2001, using polymer and PACL. The intent of this trial was to determine the responsiveness of the Actiflo process to wet and dry startups and loss of chemical feed. The trial duration was approximately seven hours and consisted of the following components:

- Dry Startup. This test consisting of bringing the pilot unit on-line with all process tanks empty (i.e. pilot unit is shutdown, drained, then restarted).
- Loss of Chemical Feed. Both polymer and coagulant addition was stopped.
- Chemical Feed Re-initiated. Both polymer and coagulant addition was restarted.
- Loss of Polymer Feed. Polymer addition was stopped.
- Polymer Feed Re-initiated – polymer addition was started.
- Loss of Coagulant (PACL) Feed. PACL addition was stopped.
- Process Shutdown.
- Wet Startup. This test consists of bringing the pilot unit on-line with all process tanks full (i.e. pilot unit was shutdown but not drained; then restarted, and both polymer and coagulant addition was started).

Figure 6 shows the raw wastewater and effluent turbidities along with the various operating modifications made throughout the testing trial.

Figure 6. Stage 2E Continuous Run Dry Start, Coagulant Loss and Recovery, and Wet Start Trial.

The following is a summary of key information derived from the turbidity trends shown in Figure 6.

- **1.0 Dry Startup:** The Actiflo process took approximately 15 minutes to reach steady-state performance once a dry startup was initiated. This interval is equal to approximately twice the hydraulic detention time of the Actiflo process.[3]
- **2.0 Loss of Chemical Feed:** The first sample was collected ten minutes after the chemical feed was stopped. This sample showed a dramatic decrease in the turbidity removal efficiency (measured removal efficiency of 14 %). The next sample, which was

[3] This detention time is based on the combined volume of the injection, maturation, and settling tanks.

collected 20 minutes after the chemical feed was stopped, showed essentially no turbidity removal (measured removal efficiency of 1 %). Although this sampling interval is not sufficient to provide a detailed characterization of how performance deteriorates with loss of chemical feed, it does indicate that performance will deteriorate quickly and within a time period equivalent to one hydraulic detention time.

- **3.0 Chemical Feed Re-Initiated:** The Actiflo process took approximately ten minutes to reach steady-state performance once the chemical feed was re-initiated. This is equal to approximately 1.5 times the hydraulic detention time of the Actiflo process.
- **4.0 Loss of Polymer Feed:** Loss of polymer had a dramatic impact on performance. As shown in Figure 6, effluent turbidities were actually higher than influent values. The first sample, collected 15 minutes after polymer feed was stopped, showed negative removal efficiency. As in the loss-of-chemical event, this sampling interval was not sufficient to provide a detailed characterization of how performance deteriorates with loss of polymer feed. However, this data does indicate that performance will deteriorate quickly and within a time period equivalent to two hydraulic detention times.
- **5.0 Polymer Feed Re-Initiated:** The first sample, which was collected five minutes after polymer feed was re-initiated, showed a dramatic improvement in turbidity removal. Although the removal efficiency was high (measured removal efficiency of 91 %), it was slightly lower than the values achieved under steady-state conditions (measured removal efficiencies in the range of 97 to 98 %). These data indicate that the Actiflo process responds very quickly when polymer feed is re-initiated. Overall, the Actiflo process took approximately ten minutes to reach steady-state performance once the polymer feed was re-initiated. This interval is equal to approximately 1.5 times the hydraulic detention time of the Actiflo process.
- **6.0 Loss of Coagulant:** As with the loss of polymer feed, the loss of coagulant feed had a dramatic impact on performance, although, negative removal efficiencies were not encountered. As shown in Figure 6, effluent turbidities were approximately equal to influent turbidities (no removal) within ten minutes after the coagulant feed was stopped. As with to the loss of chemical event, the sampling interval was not sufficient to provide a detailed characterization of how performance deteriorates with loss of coagulant feed. However, this data does indicate that performance will deteriorate quickly and within a time period equal to 1.5 times the hydraulic detention time of the Actiflo process.
- **7.0 Shutdown:** Influent flow was discontinued and process tanks were maintained full for ten minutes.
- **8.0 Wet Startup:** The Actiflo process took approximately ten minutes to reach steady-state performance once a wet startup was initiated. This interval is equal to approximately 1.5 times the hydraulic detention time of the Actiflo process, which is slightly less than the interval required for a dry startup.

In addition to turbidity measurements, samples were collected for TSS and COD analyses throughout the continuous trial runs. Samples were also collected for total and insoluble BOD analyses near the beginning of a change and sometime after the process had achieved steady-state performance (typically about 10 minutes). A copy of the detailed laboratory analyses results is contained in Appendix B. A review of these results indicates that TSS and COD removal efficiencies require the same amount of time to achieve steady-state performance as those shown in Figure 6.

Stage 2F – Continuous Run Trials – Metals Removal Assessment

The Stage 2F pilot testing trial was conducted on September 19 and 26, 2001. The intent of these trials was to evaluate the potential of the Actiflo process to remove various metal constituents. All three trials were operated at optimum coagulant and polymer dose combinations and a constant flow rate of 350 gpm. Table 12 summarizes the results that were developed from this testing trial along with the method detection limits (MDL) for each constituent.

Table 12. Stage 2F Performance - Metals Analysis Results

Parameter / Constituent	Units	Coagulant		
		Alum	PACL	Ferric Chloride
Operating Parameters				
Flow Rate	gpm	350	350	350
Polymer Type	-	M155	M155	M155
Polymer Dose	mg/L	0.95	0.95	0.95
Coagulant Dose	mg/L	110	34	110
Performance Results				
Turbidity				
Influent	NTU	105	123	144
Effluent	NTU	2.4	3.6	4.89
Removal Efficiency	%	98	97	97
Aluminum (MDL = 0.01 mg/L)				
Influent	mg/L	1.45	1.96	1.32
Effluent	mg/L	0.19	0.511	0.04
Removal Efficiency	%	87	74	97
Antimony (MDL = 0.0025 mg/L)				
Influent	mg/L	0.0011	0.0011	0.00061
Effluent	mg/L	0.00063	0.00063	0.0005
Removal Efficiency	%	43	43	18
Arsenic (MDL = 0.0025 mg/L)				
Influent	mg/L	0.00356	0.00563	0.0024
Effluent	mg/L	0.0013	0.0018	0.00097
Removal	%	63	68	60

Parameter / Constituent	Units	Coagulant		
		Alum	PACL	Ferric Chloride
Efficiency				
Barium (MDL = 0.001 mg/L)				
Influent	mg/L	0.0417	0.0461	0.0366
Effluent	mg/L	0.00562	0.00945	0.00657
Removal Efficiency	%	87	80	82
Beryllium (MDL = 0.001 mg/L)				
Influent	mg/L	0.0002	0.0002	0.0002
Effluent	mg/L	0.0002	0.0002	0.0002
Removal Efficiency	%	0	0	0
Cadmium (MDL = 0.0005 mg/L)				
Influent	mg/L	0.00034	0.00046	0.00026
Effluent	mg/L	0.0001	0.0001	0.0001
Removal Efficiency	%	71	78	62
Chromium (MDL = 0.002 mg/L)				
Influent	mg/L	0.0177	0.00672	0.0064
Effluent	mg/L	0.00059	0.00084	0.00096
Removal Efficiency	%	97	88	85
Cobalt (MDL = 0.001 mg/L)				
Influent	mg/L	0.0008	0.00134	0.00078
Effluent	mg/L	0.00025	0.00041	0.00147
Removal Efficiency	%	69	69	0
Copper (MDL = 0.002 mg/L)				
Influent	mg/L	0.0735	0.0701	0.075
Effluent	mg/L	0.00322	0.00747	0.0107
Removal Efficiency	%	96	89	86
Iron (MDL = 0.05 mg/L)				
Influent	mg/L	1.94	2.69	1.78
Effluent	mg/L	0.15	0.19	2.45
Removal Efficiency	%	92	93	(38)
Lead (MDL = 0.001 mg/L)				
Influent	mg/L	0.0229	0.0302	0.0179
Effluent	mg/L	0.00119	0.00314	0.00064
Removal Efficiency	%	95	90	96
Mercury (MDL = 0.00015 mg/L)				
Influent	mg/L	0.000152	0.00029	0.000495
Effluent	mg/L	0.00005	0.00005	0.00005
Removal	%	67	83	90

Parameter / Constituent	Units	Coagulant		
		Alum	PACL	Ferric Chloride
Efficiency				
Molybdenum (MDL = 0.0025 mg/L)				
Influent	mg/L	0.0129	0.00964	0.0371
Effluent	mg/L	0.0105	0.00788	0.0224
Removal Efficiency	%	19	18	40
Nickel (MDL = 0.0015 mg/L)				
Influent	mg/L	0.00596	0.00695	0.007
Effluent	mg/L	0.00263	0.00299	0.0091
Removal Efficiency	%	56	57	(3))
Selenium (MDL = 0.0075 mg/L)				
Influent	mg/L	0.0015	0.0015	0.0015
Effluent	mg/L	0.0015	0.0015	0.0015
Removal Efficiency	%	0	0	0
Silver (MDL = 0.001 mg/L)				
Influent	mg/L	0.00363	0.00429	0.00924
Effluent	mg/L	0.0002	0.0003	0.00051
Removal Efficiency	%	94	93	94
Thallium (MDL = 0.001 mg/L)				
Influent	mg/L	0.0002	0.0002	0.0002
Effluent	mg/L	0.0002	0.0002	0.0002
Removal Efficiency	%	0	0	0
Vanadium (MDL = 0.0015 mg/L)				
Influent	mg/L	0.00369	0.00537	0.00315
Effluent	mg/L	0.0014	0.0015	0.0003
Removal Efficiency	%	62	72	90
Zinc (MDL = 0.0025 mg/L)				
Influent	mg/L	0.175	0.193	0.135
Effluent	mg/L	0.025	0.0406	0.0222
Removal Efficiency	%	86	79	84

Note values shown in () represents negative removals.

Evaluation of Pilot Results

Table 13 contains a comparison of conventional primary clarification and the Actiflo process with regard to operating (design) parameters and performance. As shown in Table 13, the Actiflo process performed significantly better than conventional primary clarification. Overall this process was determined to out-perform conventional treatment with regard to average removal efficiencies and performance variability. This finding is based on a comparison of

Actiflo pilot results and King County primary clarification performance data obtained for October 2001.

Table 13. Comparison of Conventional Primary Clarification and Actiflo Operation and Performance.

Operation / Performance Parameter	Units	Conventional Primary Treatment			Ballasted Flocculation (Actiflo)		
		Average	Peak	Range	Average	Peak	Range
Overflow Rate[a]	Gpm/sf	0.7[b]	1.7	--	40	60	--
Hydraulic Retention Time[c]	minutes	120	--	--	9	6	--
COD Removal[d]	%	36	--	25 – 47	70	--	63 – 74
TSS Removal[d]	%	78	--	71 – 86	93	--	90 – 96

[a] Overflow rate based on primary clarifier surface area and Actiflo settling tank surface area. Primary clarifier overflow rate is based on typical criteria for process design.

[b] Actual 2001 average overflow rate for King County was 0.80 gpm/sf (1,150 gpd/sf).

[c] Hydraulic retention time based on primary clarifier volume and the total combined volume of all Actiflo process tanks. Primary clarifier hydraulic retention time is based on typical criteria for process design.

[d] Average performance values and ranges are based on October 2001 King County primary clarifier performance data and optimum chemical dose trials.

Effectiveness of Technology to Achieve Performance Goals

Table 14 summarizes target performance goals and continuous run trial results at optimum chemical doses. Values shown in Table 14 are based on an average of all continuous trials performed at optimum chemical doses. BOD_5 (both total and particulate), COD, and turbidity performance measurements were included in the table for comparison purposes.

Table 14. Effectiveness of Process to Achieve Performance Goals

Goal Description	Target	Measured Performance		
		Alum[a]	PACL[b]	Ferric Chloride[c]
	(%)	(%)	(%)	(%)
BOD_5 Removal	NE	74	75	78
Particulate BOD_5 Removal	NE	93	87	96
COD Removal	> 60	70	71	67
TSS Removal	> 80	93	93	94
Turbidity Removal	NE	97	97	97
Total Phosphorus Removal	> 80	75	92	91

NE = Performance goal was not established.

[a] Average of trial tests conducted on September 17, 25, and 26 at optimum polymer and coagulant doses.

[b] Average of trial tests conducted on September 12, 14, 26, and 28 at optimum polymer and coagulant doses.

[a] Average of trial tests conducted on September 19 and 20 at optimum polymer and coagulant doses.

The data presented in Table 14 show the following:

- **BOD_5 Removal.** BOD removal in the Actiflo was excellent, ranging from 74 to 78 % for the three coagulants tested. Comparison of particulate and total BOD_5 influent concentrations obtained throughout the trials tests shows that the particulate BOD fraction is consistently between 60 and 67 % of total BOD_5 concentrations in the influent stream. A comparison of removal efficiencies and particulate BOD fractions shows that some “soluble” BOD was removed in the Actiflo process. Most likely, this "soluble" BOD removal was associated with small colloidal particles that were slightly smaller than the pore size of the membrane used for suspended solids analysis.

- **COD Removal.** As evident by the high TSS removal efficiencies, the Actiflo process is highly effective at removing particulates/solids from raw wastewater. However, since it is a physical/chemical process and relies on particle-to-sand (or particle-to-particle) interaction for removal, it lacks the ability to remove soluble organic constituents. Some colloidal particles can be coagulated and removed as evidenced by the BOD removal. COD removal efficiency is between 67 and 71 % for the three coagulants tested, achieving the 60 % removal target for the Actiflo.
- **TSS and Turbidity Removal.** The Actiflo process consistently achieved excellent TSS removal of 93 and 94 %, achieving the goal of 80 %. Turbidity removal averages 97% for the coagulants tested. This process is highly effective for removal of suspended solids and turbidity.
- **Total Phosphorus Removal.** PACL and ferric chloride achieved 92 and 91 % phosphorus removal, achieving the goal of 80 % removal. Surprisingly, alum addition was less effective for phosphorus removal. The reason for lower phosphorus removal is not clear. Phosphorus removal efficiency is proportional to TSS removal. In other words, reduction in suspended solids removal is expected to cause a reduction in phosphorus removal. Pilot testing results appear to following this relationship. However, changes in influent pH, temperature, and wastewater composition could affect the aluminum-phosphate reaction. It is possible that for this particular wastewater, alum reactions are less favorable to precipitate phosphate and particulate coagulation.
- **Comparison of Coagulants.** With the exception of alum for phosphorus removal, all three coagulants were found to achieve the target performance goals. However, PACL was found to provide the highest overall removal based on a comparison of COD, TSS, and phosphorus removal efficiencies.

Sand Recovery

Initially, approximately 800 pounds of micro-sand was added to the pilot unit during startup. On fifteen occasions between September 20 and October 3, 2001, 50 pounds of micro-sand was added for a total of 750 pounds. The total combined effluent production throughout the testing was approximately 3,070,000 gallons. Based on these values, the estimated sand loss is about 250 pounds per million gallons produced.

According to the pilot facility operators, sand was added as needed and was not monitored; therefore the pilot testing was not operated to minimize sand loss. Typically the initial sand charge during full-scale startup is in the range of 800 pounds per mgd of treatment capacity; additional sand is added thereafter to compensate for dead zones within the process tanks. Under typical optimal conditions sand loss would be expected to be in the range of 8 to 12 pounds per MG of water treated.

Residual Characteristics

Sludge concentrations ranged between 3,900 and 8,020 mg/L. The overall average sludge concentration for all testing stages was 6,000 mg/L. This concentration is considered to be dilute compared to conventional primary sludge, which is typically in the range of 20,000 to 40,000 mg/L (2 to 4 %).

Reliability Considerations and Comparison of Coagulation Chemicals

Figure 7 and Table 15 show the results of statistical analyses of Actiflo effluent data for the three chemical combinations. All of the data collected for the optimum chemical dose continuous run trials were utilized for these analyses. Effluent turbidity values were used as a surrogate to measure effluent stability since it offered the largest number of available data.

Although PACL provided the highest effluent quality with regard to effluent turbidities, the difference between the three coagulants represents less than 1 % in terms of turbidity removals. Considering this result, all three coagulants appear equal in terms of turbidity removal. However, coagulation through alum addition appears to provide the most consistent effluent since this chemical had the lowest overall coefficient of variance.

Figure 7. Process Reliability and Coagulant Comparison.

Table 15. Comparison of Chemical Coagulants Effluent Turbidity Statistics.

Value	Units	Actiflo Effluent Turbidity		
		Alum	PACL	Ferric Chloride
Average (50-percentile Value)	NTU	3.64	3.22	4.03
10th percentile value	NTU	2.60	2.11	2.76
90th percentile value	NTU	5.10	4.91	5.88
Standard Deviation	NTU	1.09	1.26	1.38
Coefficient of Variance	%	30.0	39.0	34.3

In addition to removal efficiencies, alkalinity consumption and sludge production should also be considered when selecting the best chemical for this application. Table 16 contains a summary of the optimum coagulant doses and estimated sludge production and alkalinity consumptions based on stoichiometry and a flow rate of 1 mgd. For reference, the additional sludge production attributed to alum and ferric chloride addition represents an increased of approximately 20 % in the overall primary sludge production on a dry weight basis.[4]

Table 16. Comparison of Alkalinity and Sludge Production

Coagulant	Optimum Coagulant Dose (mg/L)	Estimated Sludge Production[a] (lb TSS / mgd)	Estimated Alkalinity Consumption (lb Alkalinity / mgd)	Estimated Alkalinity Consumption mg/L
Alum	110	240	470	55
PACL	34	460	1,700	205
Ferric Chloride	110	285	845	100

[a] Dry weight basis.

Table 17 contains a summary of chemical dose requirements and estimated chemical costs obtained from a local vendor. Chemical costs (both unit and daily chemical costs) are expressed in terms of the weight basis previously described. Daily chemical costs are based on a flow rate of 1.0 mgd.

Table 17. Comparison of Coagulant Costs

Coagulant	Optimum Coagulant Dose (mg/L)	Unit Cost ($/pound)[a]	Daily Chemical Costs ($/day)
Alum	110	0.146	135
PACL	34	1.75	495
Ferric Chloride	110	0.15	140

[a] Unit costs are reports based on a dry weight basis for alum and ferric chloride and on a dry weight of Al_2O_3 basis for PACL.

As shown, the costs associated with PACL are significantly higher than those associated with alum and ferric chloride. Overall ferric chloride and alum are approximately equal with regard to cost. Ferric chloride is a considered to be more corrosive than alum due to its low pH and ability to stain surfaces. In addition, ferric produces more sludge and requires more alkalinity

[4] This value is based on an assumed influent TSS concentration of 175 mg/L and a 95 % removal efficiency. Both of these assumed values are equal to the average of values reported for the Stage 2A trials.

addition compared to alum. Based on these findings, the most favorable coagulant for this application appears to be alum.

Metals Removal

Primary, secondary, and tertiary treatment processes have been shown to have the potential for significantly reducing pollutant metal concentrations.[5] During primary treatment, metals removal occurs by sedimentation of particle-associated metals. However, when chemicals such as iron salts or alum are added, interactions may occur between the added chemicals and metal complexes that enhance the overall removal of these pollutants. Removal of both particle-associated and dissolved metals can occur in the activated sludge process through the incorporation of particle-associated metals in flocs and dissolved metal uptake or adsorption.

Table 18 contains a summary of metals removal data for copper and zinc obtained from the City of Lansing, MI.[6] This facility consists of primary, secondary, and tertiary filtration processes. These data correspond to the average of 12 months of daily monitoring data. Information derived from average influent and effluent copper and zinc data for the Actiflo pilot unit are presented in Table 18 for comparison purposes.

Table 18. Comparison of Pilot Results and Conventional Treatment Process for Copper and Zinc Removal

Constituent	Lansing, MI Facility		Actiflo Pilot	
	Average Concentration (μg/L)	Overall Removal Efficiency (%)	Average Concentration (μg/L)	Overall Removal Efficiency (%)
Copper				
Influent	47.2	--	72.9	--
Primary Effluent	24.3	48.5	7.1	97.4
Secondary Effluent	6.1	87.1	--	--
Final (Filtered) Effluent	2.8	94.1	--	--
Zinc				
Influent	121.2	--	167.7	--
Primary Effluent	56.9	53.1	29.3	82.5
Secondary Effluent	25.0	79.4	--	--
Final (Filtered) Effluent	20.0	83.5	--	--

The results presented in Table 18 demonstrate that the performance of the Actiflo process is comparable to the combined performance of the primary, secondary, and tertiary treatment processes at the City of Lansing wastewater treatment facility with regard to copper and zinc removal efficiencies. These results are impressive considering that the Actiflo process was

[5] Water Environment Research Federation (2000).
[6] Data obtained from Water Environment Research Federation (2000).

functioning as a primary treatment process and does not have the ability for metals removal via biological uptake or adsorption.

Implementation

Design Criteria

The following is a summary of the recommended design criteria for this application.

- Injection tank detention time = 1 minute (Lawrence, Kansas - 1 minute)
- Maturation tank detention time = 3 minutes (Lawrence, Kansas - 3 minutes)
- Settling tank overflow rate = 60 gpm/sf (Lawrence, Kansas – 60 gpm/sf at maximum design flow)

These criteria were developed based on the pilot study testing results. It is anticipated that these criteria will be applicable for primary treatment applications that have similar raw water characteristics as those measured throughout the pilot test. Because there are no full-scale Actiflo primary treatment applications, a comparison of recommended and full-scale design criteria cannot be made at this time. However, the criteria used for the design of the Lawrence, Kansas facility is presented above for comparison purposes. Criteria for the Kansas facility was selected for comparison purposes because this facility is one of the latest full-scale Actiflo installations and represents the most similar type of application (treatment of sanitary sewer overflows). As shown above, these criteria are identical to the recommended criteria. The only difference between the two sets of criteria is that the full-scale application has a coagulation chamber immediately upstream of the injection tank. This chamber is designed to provide a hydraulic detention time of 48 seconds at the maximum design flow. However, based on the excellent results of the pilot test, it appears that this coagulation chamber is not required to maximize the impact of chemical addition.

Full-Scale Considerations

The following is a summary of items that should be considered prior to the design of a full-scale Actiflo process.

- Pilot testing results demonstrate that the Actiflo process performed better than conventional primary clarification in terms of measured COD and TSS removal efficiencies. However, this assessment was based on pilot testing results and may not be indicative of full-scale performance due to the following considerations:
  - **Wall Effects:** Small-scale pilot tests do not perform as well as full-scale applications due to wall effects which impact particulate settling.
  - **Constant Flow Rate:** The pilot test was operated at a constant flow rate. This is considered to be a significant advantage compared to full-scale applications, which must compensate for diurnal variations.

- While the Actiflo process was shown to achieve good removal for BOD_5, TSS, and total phosphorus, it is considerably more expensive to operate than conventional primary treatment because it requires large volumes of chemicals, there is more mechanical equipment to operate and maintain, and it produces more sludge.
- The Actiflo process requires much less space than primary clarifiers. However, this does not result in lower capital costs. Capital costs associated with the Actiflo process were estimated to be between 10 and 25 % higher than conventional primary clarifiers, based on a treatment capacity of 1.0 mgd.
- To accurately compare Actiflo and conventional primary treatment, all of the differences and their impacts on the whole treatment plant must be examined. For example, are the extra chemical costs for the Actiflo process offset by reduced energy costs or smaller basins in the subsequent activated sludge treatment process.

Design Features

Control, monitoring, special

The following features should be included in a full-scale Actiflo application for primary treatment:

- **Chemical Addition Facilities.** As shown in Figure 6, the Actiflo process is highly dependant on both polymer and coagulant addition for pollutant removal. When feed of either of these chemicals was stopped, effluent turbidities were found to be essentially equal to influent turbidities (i.e. no turbidity removal was achieved). Providing redundant feed pumps, chemical feed and turbidity monitoring equipment, and automatic switchover capability for changing feed pumps should be considered for full-scale applications. These attributes should minimize the potential for process upsets due to loss of chemical feed.
- **Monitoring and Process Control.** Turbidity is used as the primary instrument for monitoring and controlling the Actiflo process. At a minimum, turbidimeters should be installed to monitor the influent and effluent Actiflo streams. Streaming current detectors could be considered for optimizing chemical addition.

Pretreatment requirements

- **Fine Screen.** Providing fine screening prior to the Actiflo process will lessen the potential of clogging or damaging process equipment. In addition, it will minimize the amount of fine particles being recycled and accumulated within the process. The manufacturer recommends that a three- to ten-mm fine screen be provided upstream of the Actiflo process in primary treatment applications. The selected screen opening size is dependant on the diameter of the hydrocyclone apex tip, which in turn, is dependent on the capacity of the Actiflo process. The recommended minimum screen opening for a single, 1 mgd Actiflo unit is 3 millimeters.

- **Grit Removal.** The manufacturer recommends grit removal for primary treatment applications to minimize solids accumulation in the process tanks and the amount of particles being recycled within the process. The removal system should be designed to remove all particles larger than 100 microns.

Residual treatment

Due to the higher TSS removal efficiency, the Actiflo process will generate more sludge than the conventional primary treatment process. Moreover, the Actiflo sludge stream has a significantly lower solids concentration. Typically, the sludge concentration from conventional primary clarifiers ranges between 10,000 and 40,000 mg solids/L. As previously described, Actiflo sludge stream concentrations ranged between 4,000 and 8,000 mg/L during the pilot study. Based on the average sludge concentration of 6,000 mg/L, Actiflo sludge flow rates are estimated to be in the range of 330 and 660 % greater than those of conventional primary clarification if the two systems achieve equal removal efficiencies.

In a conventional wastewater treatment plant, where solids stabilization is performed on-site, an intermediate thickening process would be required between the Actiflo and sludge digestion processes. However, King County is considering the Actiflo process for a satellite treatment plant where the solids stream would be routed to back into the collection system for subsequent treatment and disposal at a different wastewater treatment plant. In this scenario, a more dilute solids stream is not detrimental because a higher flow rate would provide more carrier water to minimize solids deposition within the collection system. The biological and chemical sludges produced by the Actiflo process are not expected to have any detrimental effects on the collection system.

The generation and handling of chemical sludge is another factor that should be considered when determining if the Actiflo process is a viable alternative to conventional primary treatment. As previously described, alum and ferric chloride addition can increase the overall sludge production by approximately 20 %, on a dry weight basis, when used in primary treatment applications.

Issues Not Resolved By Pilot Test Program

Due to the limited time of the Actiflo pilot study, sand recovery and the potential for long-term sand fouling (inability to completely clean sand) were not investigated during the study.

References

US Filter/Kruger Products (2002) *ACTIFLO Pilot Study for King County, WA at West Point WWTP Seattle, WA.*

Water Environmental Research Federation (2000) *Assessing Methods of Removing Metals from Wastewater: A Review of Data and Methodologies*. WERF Project 97-CTS-4 Final Report.

Appendix A - Test Plan

Appendix B - Testing Data

Appendix C - Pilot Unit Photos

Actiflo Testing Protocol (Version 2)

The USFilter ACTIFO pilot unit arrived at the West Point WWTP on August 27. It will be on-site for a total of six weeks and is scheduled to leave the site on October 5. This unit will be operated 5 days per week, 8 hours per day by two full-time USFilter operators. The unit is being tested as one of 8 treatment process for the Demonstration Project. The demonstration testing facilities are configured to convey West Point WWTP primary influent to the ACTIFLO unit. The focus of the testing will be to evaluate this ballasted sedimentation process as a primary treatment plant. If possible, the primary influent feed source will be diluted with West Point secondary effluent to simulate a Combined Sewer Overflow (CSO) event. This version of the test plan addresses the testing for the next several weeks for the primary treatment application. A revision to this plan will be released in the near future to address the CSO application testing.

Primary Treatment Application Test Goals

Under constant flow conditions evaluate one polymer and three coagulants with the following performance goals:

- TSS removal: >80%
- COD removal: >60%
- BOD removal under optimum dose conditions
- Phosphorus removal: > 80%
- Metals removal under one optimum dose condition

BOD sampling is limited due to the current workload for the West Point Process lab. The intent is to use COD and TSS removal as the primary evaluation parameters for evaluating this technology for primary treatment. Under optimal conditions, BOD analysis will be conducted.

Metals analysis will be limited to one test condition to minimize the county laboratory's workload.

Once a range of coagulant and polymer doses are tested, selected chemical feeds will be used to assess the following:

- How long it takes the unit to achieve effective treatment during a dry startup
- How long it takes the unit to achieve effective treatment during a wet startup
- The impacts on treatment performance due to loss of chemical feed
- The impacts on treatment performance under peak flow conditions
- The impacts of peak solids loading on treatment performance in a rain event

With the exception of the peak flow test, all of the testing will be conducted at a constant feed flow rate. Initially the maximum flow rate was 310 gpm (equivalent to a hydraulic loading rate of 53 gpm/sf). The County replaced the feed pump impeller to increase its capacity. This modification was made on September 11, 2001 and resulted in an increase in pumping capacity from 310 to 370 gpm (equivalent to a hydraulic loading rate of 60 gpm/sf). A throttling valve will be used to adjust the feed flow to the desired level of 350 gpm during a portion of the tests.

Test Stages

There will be two stages in the primary treatment evaluation. Both are defined below.

Stage 1 – Optimization/Coagulant & Polymer Trials (*Conducted on September 5, 6, 7, and 10, 2001*)

Optimization will be used to quickly determine an optimal polymer and coagulant dose. We also refer to this as the polymer and coagulant trials phase. Each test condition is expected to last only one to two hours in order to evaluate a wide range of coagulant and polymer doses in a brief period. This is possible with this test unit because the hydraulic residence time is under 30 minutes. Typically, the unit is operated under one test condition for only two hydraulic residence times before taking a sample that is representative of that test condition.

The data collected will be used to develop U-shaped curves for dose-versus-effluent turbidity, COD and TSS. BOD will not be measured because of the long turn-around time for the analysis and impacts to the West Point Process lab workload.

Optimization test results[1] were reviewed and discussed during a conference call on September 11, 2001. The purpose of the discussion was to determine the optimal polymer and coagulant doses for the various chemicals. Below is a list of the testing results:

- The selection of the optimum coagulant doses was based on a review and discussion of measured COD, TSS, and turbidity removal efficiencies. Optimum chemical doses were selected based on the “best” (as opposed to achieving desired removal efficiencies) performance obtained from various coagulant doses coupled with a constant polymer dose of 0.85mg/L.
- The selections of “low” coagulant doses were based on reviews of TSS and turbidity removal efficiency data. The overall goal of the selection process was to determine the minimum coagulant dose (coupled with a polymer dose of 0.85 mg/L) that would achieve 80 percent TSS removal efficiencies.
- Polymer doses for subsequent testing phases: The optimal polymer dose was determined to be 0.95 mg/L. Polymer doses will be reduced to 0.75 mg/L during the reduced coagulant tests.[2]

[1] See Preliminary Actiflo performance data and figures developed by US Filter operators (data collected September 5, 6, 7, and 10).

- Coagulant doses for subsequent testing phases:

1. Alum: The optimal alum dose was determined to be 110 mg/L. Alum doses will be reduced to 60 mg/L during the reduced coagulant tests.
2. Ferric Chloride: The optimal ferric dose was determined to be 110 mg/L. Ferric doses will be reduced to 60 mg/L during the reduced coagulant tests.
3. Poly Aluminum Chloride: The optimal poly aluminum chloride dose was determined to be 30 mg/L. Poly aluminum chloride doses will be reduced to 15 mg/L during the reduced coagulant tests.

Stage 2 – Continuous Run

This stage will be used to confirm the optimal coagulant and polymer doses for COD, TSS and BOD removal. A sustained (up to eight-hour run) for the optimal test conditions will be conducted. Also, the impacts of reducing the coagulant and polymer will be evaluated. Wet and dry startup, loss of chemical feed, peak flow and peak solids testing will also occur in this stage.

Test Conditions and Sampling

The test conditions and number of samples/analyses for the Optimization and Continuous Run stages are listed in Table 1 along with the number of samples. The sample locations and type are listed below. All sample locations are within the ACTIFLO trailer and will be collected by the USFilter operators.

[2] Originally the optimum and low polymer doses were selected to be 0.85 and 0.65 mg/L, respectively. The value was later changed to 0.95 and 0.75 mg/L, respectively based on discussion with Bob Bucher.

SAMPLING

Table 1 describes the sample designation and types for the various testing phases. Table 1 contains a description of the anticipated duration for each testing phase and conditions.

Table 1. Sample Designation and Types

Sample Description	Sample Designation	Sampling Make-up / Methodology	
		Optimization Phase	**Continuous Run Phase**
Influent	Sample# S1BF	Single grab sample	Hand composite of hourly grab samples
Actiflo Effluent	Sample# S5	Single grab sample	Hand composite of hourly grab samples
Hydrocyclone Sludge	none required	--	Hand grab sample
Sand	none required	--	Hand grab sample[a]

[a] Analyses shall be performed by US Filter operators during the Continuous Run testing phase. Data shall be provided to King County so it can be put into the County's data management system.

TEST CONDITIONS

Stage 1 – Optimization: Coagulant and Polymer Trials

Operate unit at constant flow rate of 310 gpm.

Test two polymers at various dose rates with alum at a constant dose.

USFilter operators will develop U-shaped curves for polymer dose versus turbidity, COD and TSS. Select the polymer and its dose for subsequent coagulant trials.

Test alum, poly aluminum chloride (PaCl), and ferric chloride at varying doses to achieve a target clarifier effluent turbidity of <5 NTU and the target percent removals for TSS and COD of 80% and 60%, respectively. Use selected polymer and a constant dose as described above.

US Filter operators will develop U shape curves showing dose versus effluent turbidity, COD and TSS. From these curves, select the optimal alum, ferric chloride and PaCl doses for the Continuous Run stage.

Stage 2 – Continuous Run

With the exception of the peak flow test, operate the unit at 350 gpm under the following test conditions:

Alum

- 8 hour run: optimal alum and polymer dose from optimization
- 4 hour run: half the alum dose, optimal polymer dose
- 4 hour run: optimal alum dose, half the polymer dose
- 8 hour run: 4 hour run of half the alum and polymer optimal doses. Following this 4-hour test, alum and polymer additions will be increased to optimum doses. Turbidity measurements to be recorded during all test runs. This data will be used to determine how much time is required for the process to achieve steady-state performance. Once the process has achieved steady-state performance, hourly samples are to be collected for a minimum of three hours to produce a single hand composite sample.

Ferric Chloride

- 8 hour run: optimal alum and polymer dose from optimization
- 4 hour run: half the alum dose, optimal polymer dose
- 4 hour run: optimal alum dose, half the polymer dose
- 8 hour run: 4 hour run of half the ferric chloride and polymer optimal doses. Following this 4-hour test, ferric chloride and polymer additions will be increased to optimum doses. Turbidity measurements to be recorded during all test runs. This data will be used to determine how much time is required for the process to achieve steady-state performance. Once the process has achieved steady-state performance, hourly samples are to be collected for a minimum of 3 hours to produce a single hand composite sample.

Poly Aluminum Chloride

- 8 hour run: optimal alum and polymer dose from optimization
- 4 hour run: half the alum dose, optimal polymer dose
- 4 hour run: optimal alum dose, half the polymer dose
- 8 hour run: four-hour run of half the poly aluminum chloride and polymer optimal doses. Following this four-hour test, poly aluminum chloride and polymer additions will be increased to optimum doses. Turbidity measurements to be recorded during all test runs. This data will be used to determine how much time is required for the process to achieve steady-state performance. Once the process has achieved steady-state performance, hourly samples are to be collected for a minimum of three hours to produce a single hand composite sample.

Further Alum, Ferric Chloride, and Poly Aluminum Chloride Testing

- 4 hour run: (if needed) further reduction of alum dose to assess the impact of chemical dose on COD, TSS, or phosphorus removal efficiencies.
- 4 hour run: (if needed) further reduction of ferric chloride dose to assess the impact of chemical dose on COD, TSS, or phosphorus removal efficiencies.
- 4 hour run: (if needed) further reduction of poly aluminum chloride dose to assess the impact of chemical dose on COD, TSS, or phosphorus removal efficiencies.

Develop curves for effluent COD, TSS and P versus coagulant and polymer dose. Calculate percent removals for the parameters measured. As indicated in Table 1, BOD (total and soluble) will be measured for the two optimal runs, both coagulant and polymer doses, for each of the three coagulants. For one of these coagulants, influent and effluent metals will be measured during a single test condition (i.e., optimal coagulant and polymer doses).

Dry Start

Shut down unit.

Restart with all tanks empty. Operate at 350 gpm. Assume this test will last only four hours.

Use a single coagulant/dose and polymer/dose at optimal treatment conditions from previous testing. Selection of the coagulant will be based on review of the Optimization and Continuous Run data. Based on the on-line effluent turbidity monitoring, collect a minimum of four grab samples once the effluent turbidity is <5 NTU. Combine these grabs into a composite for analysis per Table 1. It is expected that this test will last four hours. USFilter operators will note how long it takes for the effluent turbidity to reach <5NTU.

Wet Start

Shut down unit. Wait for a minimum of one hour. Keep tanks full.

Restart unit. Operate at 350 gpm.

Use the same coagulant/dose and polymer/dose that were used in the Dry Start test. Based on the on-line effluent turbidity monitoring, collect a minimum of four grab samples once the effluent turbidity is <5 NTU. Combine these grabs into a composite for analysis per Table 1. This test is also expected to last four hours. USFilter operators will note how long it takes for the effluent turbidity to reach <5NTU.

Chemical Feed Failure

Shut off coagulant and polymer feed for one hour. Keep operating unit at 350 gpm. In the next hour, collect four grab samples and combine these into a composite for analysis per Table 1. USFilter operators will note how long it takes for the effluent turbidity to exceed 5 NTUs.

Restart chemical feed and operate the unit for one hour at same flow rate. In the next hour, collect four grab samples and combine these into a composite for analysis per Table 1. It is anticipated that this test will last four hours. USFilter operators will note how long it takes, since the chemical feed is restarted, for the clarifier effluent turbidity to drop back down below 5 NTUs.

Peak Flow Stress Test

The County will test maximum flow conditions for the ACTIFLO unit's primary influent feed pump. This will be the maximum flow used in this test. The average flow rate will be 275 gpm or 25 percent lower than the peak flow of 370 gpm to allow enough of a difference in flow rates to evaluate the impacts on the treatment performance.

The unit will be operated at the average flow condition for two hours. Four grab samples will be collected and combined into a composite sample for analysis per Table 1.

The unit will then be operated at the peak flow condition for two hours. Four grab samples will be collected and combined into a composite sample for analysis per Table 1.

Finally, the unit will be operated back at the average flow rate for another two hours. Four grab samples will be collected and combined into a composite sample for analysis per Table 1.

SCHEDULE

The duration of the testing and associated dates are listed in Table 1. It is assumed optimization will start on September 7, 2001. Per the proposed schedule, the primary treatment testing will be finished on October 1, 2001. With the unit leaving the site on October 5, this only leaves three days of testing for CSO treatment. October 5th will be reserved for disassembling and packing up the unit.

CONTACTS

Since this testing is occurring in a very brief period, and many test conditions will be evaluated, it is important to maintain frequent, if not daily communications between the USFilter operators and staff, King County and the consultant team (HDR and Black & Veatch). The following is a list of the project team members.

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It is essential that the project team hold frequent conference calls as needed. Bob Bucher will coordinate the calls. At a minimum, they will include Daniel Austria and/or Chris White from USFilter and JB Neethling and Kevin Kennedy, HDR.

King County Water Reuse Demonstration Project
ACTIFLO Pilot Unit Testing
Primary Treatment Application
Table 1 - Sampling Plan (Version 2)

Test Phase	Anticipated Schedule	Actual Schedule	Duration Hours	Influent: Sample# S1							Clarifier Effluent: Sample # 5g							Hydrocyclone Sludge Grab	Sand Concentration Concentration
				Number of Hourly Grabs for Composite						On Line	Hourly Grabs for Composite						On Line		
				TSS	COD	P	BOD		Metals [6]	Turbidity	TSS	COD	P	BOD		Metals	Turbidity	TSS	Grab [5]
							Total	Soluble						Total	Soluble				
Optimization																			
Polymer Trials [1]	9/7	9/5, 9/6. 9/7, and 9/10	4	10	10	0	0	0	0	Yes [3]	10	10	0	0	0	0	Yes [3]	0	0
Coagulant Trials [2]	9/7 & 9/10		12	15	15	0	0	0	0	Yes [3]	15	15	0	0	0	0	Yes [3]	0	0
Continuous Run [4]																			
ALUM																			
Optimal (1 coag. & poly dose)	9/11	9/12	8	1	1	1	1	1	1	Yes [3]	1	1	1	1	1	1	Yes [3]	1	1
Non Optimal (1/2 coag. dose)	9/12	9/13	4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Non Optimal (1/2 poly dose)	9/12		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Non Optimal (1/2 coag & 1/2 poly dose)	9/13		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Optimal (same coag & poly dose as above)	9/13		4	1	1	1	1	1	0	Yes [3]	1	1	1	1	1	0	Yes [3]	1	1
Optimal Other (any add'l coag or poly dose tests to assess minimum doses for TSS removal or optimum dose for P removal)	9/14		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
FERRIC																			
Swith Coagulant setup	9/14		4																
Optimal (1 coag. & poly dose)	9/17		8	1	1	1	1	1	0	Yes [3]	1	1	1	1	1	0	Yes [3]	1	1
Non Optimal (1/2 coag. dose)	9/18		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Non Optimal (1/2 poly dose)	9/18		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Non Optimal (1/2 coag & 1/2 poly dose)	9/19		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Optimal (same coag & poly dose as above)	9/19		4	1	1	1	1	1	0	Yes [3]	1	1	1	1	1	0	Yes [3]	1	1
Optimal Other (any add'l coag or poly dose tests to assess minimum doses for TSS removal or optimum dose for P removal)	9/20		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
PaCl																			
Swith Coagulant setup	9/20		4																
Optimal (1 coag. & poly dose)	9/21		8	1	1	1	1	1	0	Yes [3]	1	1	1	1	1	0	Yes [3]	1	1
Non Optimal (1/2 coag. dose)	9/24		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Non Optimal (1/2 poly dose)	9/24		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Non Optimal (1/2 coag & 1/2 poly dose)	9/25		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Optimal (same coag & poly dose as above)	9/25		4	1	1	1	1	1	0	Yes [3]	1	1	1	1	1	0	Yes [3]	1	1
Optimal Other (any add'l coag or poly dose tests to assess minimum doses for TSS removal or optimum dose for P removal)	9/26		4	1	1	1	0	0	0	Yes [3]	1	1	1	0	0	0	Yes [3]	1	1
Switch Coagulant setup (optional)	9/26		4																
DRY START (1 coag/1 dose)	9/27		4	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
WET START (1 coag./1 dose)	9/28		4	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
CHEM FEED FAILURE			1																
no chemical feed (1 coag./1 dose)	9/28		2	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
w/chemical feed (1 coag./1 dose)	9/28		2	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
PEAK FLOW (1 coag./1 dose)																			
Average flow condition	10/1		2	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
Peak flow condition (>25% average flow condition)	10/1		2	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
Average flow condition	10/1		2	1	1	1	1	0	0	Yes [3]	1	1	1	1	0	0	Yes [3]	1	1
																		1	1
Total				**50**	**50**	**25**	**13**	**6**	**1**	-	**50**	**50**	**25**	**13**	**6**	**1**	-	**26**	**26**
Notes:																			
(1)	Assume 2 polymers. 5 doses per polymer																		
(2)	3 coagulants. Assume 5 doses per coagulant																		
(3)	Continuous on-line monitoring. Data via Main PLC.																		
(4)	Primary influent feed flow rate a constant 350 gpm, except for peak flow test.																		
(5)	Samples collected and analyzed by USFilter Operators. West Point Lab not required.																		
(6)	Only one influent and effluent sample for the 8 hour optimal run on a single coagulant dose. Table shows Alum, but this could be for feric or PaCl.																		

ACTIFLO Pilot Study @ King County, WA
August 27 - October 5, 2001

Final Summary

Date 2001	Time	Flow Rate gpm	Rise Rate gpm/sf	Coagulant Type	Coagulant mg/l	Polymer Type	Polymer mg/l	pH Inf.	pH Eff.	Turbidity NTU Inf.	Turbidity NTU Eff.	Turbidity NTU %Rem.	Comments
2-Oct	8:30	350	60	Alum	60	M155	0.65						
	9:00							6.97	6.70	107	7.20	93	
	9:30							7.01	6.73	105	8.82	92	
	10:00							7.03	6.77	110	7.02	94	
	10:30							7.03	6.76	98	7.15	93	
	11:00							7.03	6.76	98	9.27	91	
	11:30							7.04	6.78	100	9.90	90	
	12:00							7.02	6.78	110	12.10	89	
	12:30							6.94	6.73	115	11.10	90	
	12:45				30								
	13:45							7.13	6.99	140	34.60	75	
	14:15							7.06	6.94	148	45.60	69	
	14:45							6.93	6.88	137	48.80	64	
	15:15							6.94	6.83	150	49.30	67	
	15:45							6.91	6.82	145	64.00	56	
	16:15							6.85	6.76	153	62.60	59	
	16:30							6.88	6.78	140	64.20	54	
													Shutdown
3-Oct	8:15	350	60	Alum	60	M155	0.95						
	8:45							6.91	6.72	90	7.61	92	
	9:15							7.00	6.71	92	7.62	92	
	9:45							7.00	6.75	102	7.24	93	
	10:15							7.05	6.76	98	4.93	95	
	10:45							6.95	6.71	115	6.30	95	
	11:15							7.00	6.69	100	6.05	94	
	11:45							7.02	6.70	111	6.12	94	
	12:15							7.07	6.74	115	5.95	95	
	12:20				100		0.75						
	13:15							6.96	6.56	122	8.61	93	
	13:45							7.05	6.59	150	7.54	95	
	14:15							7.06	6.62	145	7.93	95	
	14:45							7.02	6.59	165	7.56	95	
	15:15							6.94	6.56	150	7.96	95	
	15:45							6.90	6.52	147	7.33	95	
	16:15							6.95	6.52	140	6.99	95	
	16:20				110		0.95						
	16:45							7.06	6.60	140	3.01	98	
													Shutdown
4-Oct	8:30	350	60	$FeCl_3$	110	M155	0.75						
	9:00							6.84	6.14	115	10.80	91	
	9:30							6.90	6.13	106	7.21	93	
	10:00							6.95	6.19	120	9.86	92	
	10:30							6.91	6.17	109	7.16	93	
	11:00							6.92	6.18	99	7.52	92	
	11:30							6.81	6.08	105	12.50	88	
													Shutdown

Actiflo Pilot Unit Photos

Introduction

The following photos of the USFilter/Kruger Actiflo pilot unit were taken during the pilot testing. Each photo includes a caption, and several photos include text boxes to point out key pieces of equipment.

Figure 1. USFilter/Kruger Pilot Unit Located Adjacent to West Point WWTP Technology Assessment Test Facility

Figure 2. USFilter/Kruger Pilot Unit Side View

Figure 3. USFilter/Kruger Pilot Unit, Back End of Trailer – Coagulant and Polymer Feed Equipment

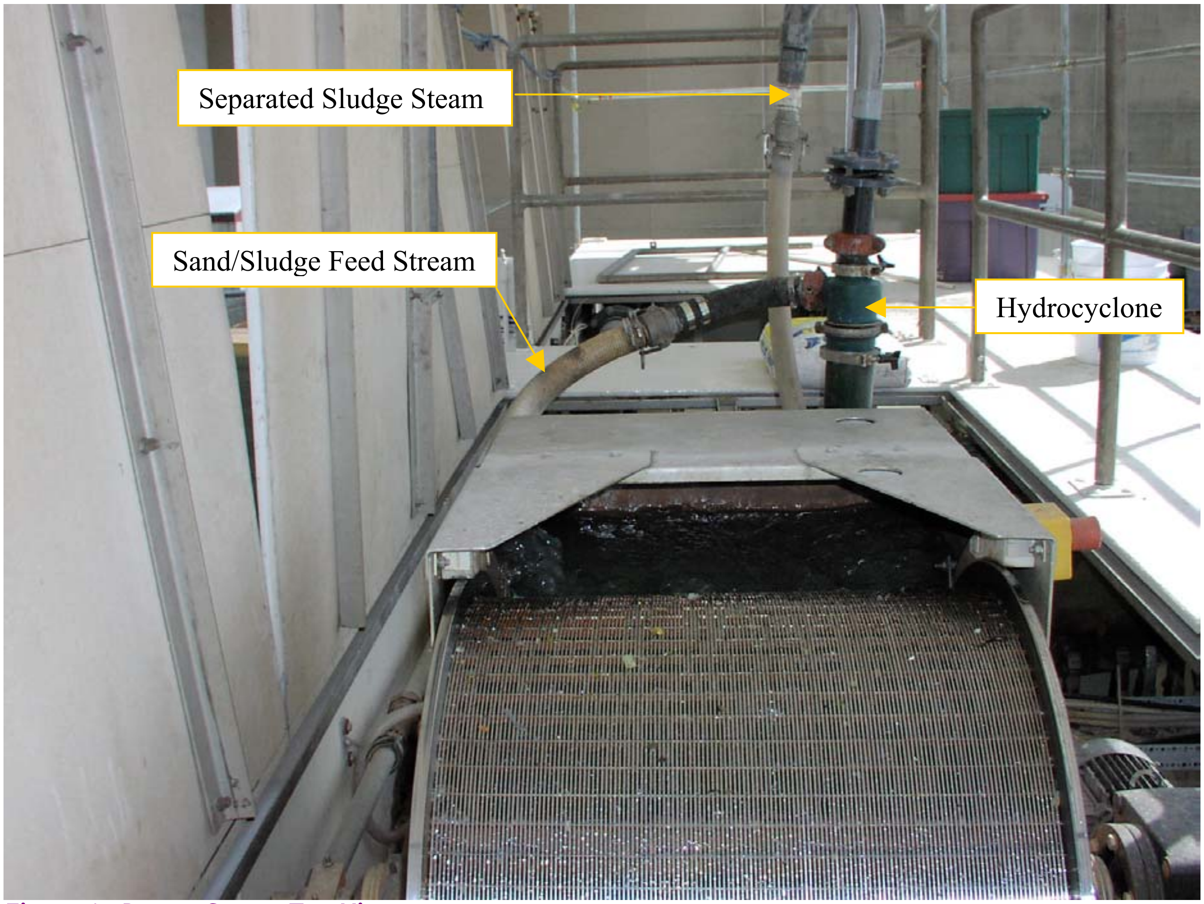

Figure 4. Rotary Screen Top View

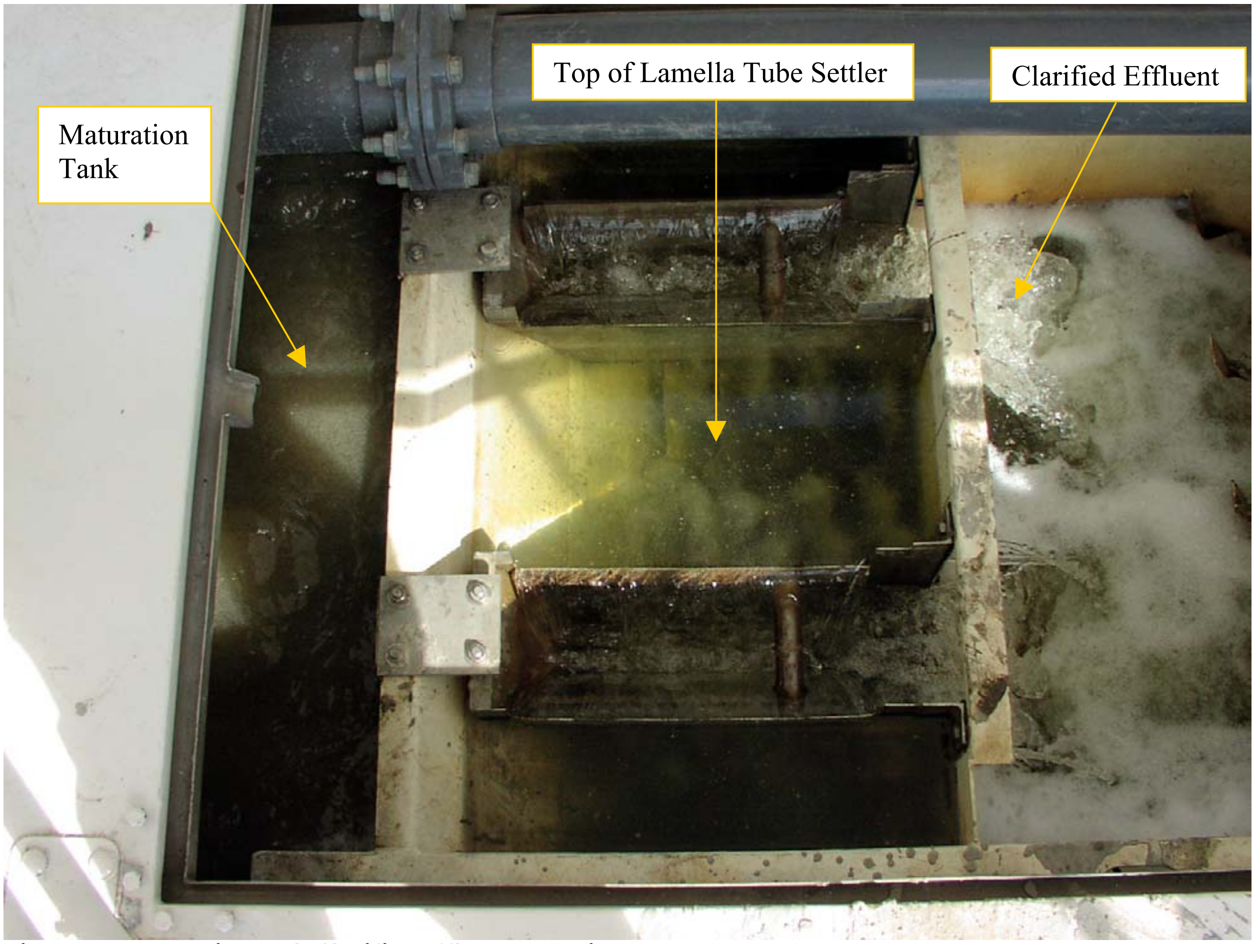

Figure 5. MaturationTank/Clarifier Effluent Top View