CITY OF HOUSTON, TEXAS:
A CASE STUDY

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Can a utility afford to operate without on-line TOC analyzers considering the requirements of the D/DBP Rule? On-line vs. Grab Samples: What are the advantages and disadvantages?

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<u>Abstract</u>

The City of Houston, Texas has been aware of the implications that current and pending regulatory standards would have on the operation of their four surface water treatment facilities. In particular, the City has closely monitored changes in regulations related to enhanced coagulation, total organic carbon (TOC) removal, and disinfection by-products (DBP) reduction. The City has, and continues, to conduct extensive bench, pilot, and plant scale tests to determine how these regulatory changes would impact the operation of their surface water facilities.

The TOC content of the source and finished water is the common attribute that significantly impacts each of the regulations of interest. TOC is perhaps the one water quality parameter that could impact the financial bottom line of a utility most. In most cases, a fully automated surface treatment facility still measures TOC by collecting periodic grab samples for laboratory analysis. Making treatment decisions based on periodic TOC grab samples is comparable to flying a commercial airliner without instrumentation.

In a collaborative effort between the Water Quality Laboratory and the Operations Group at the City's East Water Purification Complex (EWPC), an evaluation of on-line TOC equipment has been completed. After nearly a year of plant scale evaluation, the recommendation is being made that on-line TOC analyzers be purchased to enhance facility operations. During the trial, the instrument was used to monitor plant performance and to evaluate alternate coagulants and coagulant aids. The most interesting results of the study related to how poorly the operators responded to changing raw water parameters when given daily grab sample results and how much better they were able to respond when allowed to utilize the on-line analyzer. The on-line TOC analyzer allowed the operators to track real time water quality changes and therefore respond much quicker than would be possible if grab samples were being used. Because the City of Houston has two raw water sources that are dramatically different (alkalinity, pH, turbidity, TOC concentration, and TOC composition), blends of the two raw water sources present special treatment challenges, especially related to coagulation efficiency and TOC removal.

This paper will discuss the results of a variety of tests and it will examine the advantages and disadvantages of implementing continuous on-line TOC monitoring. When considering the economic implication of applying enhanced coagulation measures, it becomes clear that the closer the operator is able to maintain the required TOC removal percentage without overfeeding, the lower the operation cost to the utility. Operating without the proper instrumentation costs money and results in a lower quality water for the utility customers.

INTRODUCTION

The City of Houston's Water Quality Group has been collecting data for several years on all phases of its water, from its watersheds through distribution. The data is extremely useful, but grab samples can not always provide data that can be used to track small fluctuations in water quality. For instance, chlorine, fluoride, turbidity, pH, and temperature are water quality parameters that are currently tracked throughout the treatment process continuously by on-line monitoring equipment. The financial implications of operating in an enhanced coagulation mode to comply with the requirements of the D/DBP Rule makes it more prudent to track the TOC concentration throughout the treatment process. Management, Operations, and the Water Quality Group recognized that TOC removal would be a problem to contend with, but implementation of an on-line TOC monitoring program would require a financial commitment on the part of the City. In order to justify the purchase of on-line TOC monitoring equipment, the benefits of on-line TOC monitoring would have to be weighed against the cost, and in order to do this a plant scale test would be needed.

The first step in conducting a plant scale project is to determine a course of study that is acceptable to all the parties, management, operations, and the technical staff conducting the trial. It could be argued that many times the research staff, state and federal regulatory agencies are not on the same page in the play book as the people responsible for operating the production facility. The primary responsibility of the facility staff, including the technical staff, is to provide an adequate supply of potable, properly disinfected water, at an adequate pressure, while at the same time keeping costs to a minimum. Cost is the aspect of water treatment that most managers and operators would argue that the technical staff has forgotten to factor in. In general, higher quality water must come at a higher operating cost, but when operations and the technical staff work together the additional cost can be minimized, and in some cases a cost savings can be realized. Two questions remains, "Is there a cost benefit to monitoring TOC on-line?" and "Can an on-line analyzer be used to help achieve the required TOC removal percentage?"

TREATMENT HISTORY AND WATERSHED BACKGROUND

The City of Houston has two raw water sources, the Trinity River and the San Jacinto River. The raw water supplied by the two watersheds has uniquely different water quality characteristics that often require quite different treatment techniques. The Trinity River watershed is a larger and more stable raw water source. Its alkalinity averages 98 mg/L as $CaCO_3$, with a range of 71 and 114 mg/L as $CaCO_3$. The Trinity River's TOC level averages 6.0 mg/L, and ranges between 4.2 and 8.6 mg/L.

The San Jacinto watershed is a much smaller watershed and is subject to wide ranging seasonal fluctuations in water quality. Its alkalinity averages 50 mg/L as $CaCO_3$, with an average TOC level of 8.7 mg/L. Compared to Trinity River water, the San Jacinto is generally more expensive and difficult to treat because of its low alkalinity and higher organic load.

A majority of the City's surface water is treated at the East Water Purification Complex (EWPC). The complex houses three treatment facilities that supply water to two distribution entry points. The facilities treat a blend of the two raw water sources, generally a ratio of 90% Trinity River and 10% or less of San Jacinto water. Plants 1 and 2 get a majority of the San Jacinto water giving it a higher raw TOC, and subsequently a higher TOC removal percentage. The higher raw TOC level does not equate to a much higher distribution TOC level. Percentage wise, Plants 1 and 2 achieve a higher TOC removal percentage than Plant 3, 34.8% vs. 31.3%, respectively.

AVERAGE ANNUAL TOC (mg/L) 1994 - 2000			
	Maximum	Minimum	Average
San Jacinto River	13.4	5.0	8.7
Trinity River	8.6	4.2	6.0
Plant 1 2 Raw	9.6	4.6	6.6
Plant 3 Raw	10.4	4.4	6.4
Distribution 1	6.0	3.2	4.3
Distribution 3	7.0	3.2	4.4
AVERAGE ANNUAL ALKALINITY 1994 - 2000			
	Maximum	Minimum	Average
San Jacinto River	67	32	50
Trinity River	114	71	98
Plant 1& 2 Raw	108	49	85
Plant 3 Raw	111	58	93

The organic makeup of the raw and distribution waters has been studied extensively by the City's Water Quality Research Group. The group conducted organic fractionation studies that were initiated in part, to answer questions that arose during the ICR data collection process. The group was interested in seeing which molecular weight compounds contributed most to the formation of DBPs. Because the City had access to more than one type of TOC analyzer, raw and distribution water samples were measured using several analyzers, both High Temperature Combustion and UV Persulfate.

The analyzers were calibrated using the same standards, and when validation samples were run each of the instruments produced similar TOC values. However, raw water samples with complex matrixes produced inconsistent results when the dispersion of natural organic material (NOM) was comprised mainly of small organic compounds (fulvic and amino acids). The High Temperature Combustion instruments often produced values higher than those obtained using the UV Persulfate instruments. In particular, there seemed to be a greater difference in the measured TOC levels in Trinity River samples collected during dry weather conditions. Fractionation studies proved that Trinity River water had a higher concentration of small NOM, organics that are more difficult to oxidize. The problem associated with the UV Persulfate analyzer was that incomplete oxidation of the non-purgable organics resulted in lower, inconsistent, and inaccurate measurements. With proper sample preparation, extending UV exposure time, and the use of a stronger oxidant, the problems associated with the UV Persulfate instrument were corrected. Being able to recognize and correct the problems associated with the UV Persulfate analyzer makes it best choice for most laboratories. The UV Persulfate analyzer is much simpler to operate, easier to maintain, and more trouble free than the High Temperature Combustion analyzer.

Based on the alkalinity and raw water TOC concentration, the City of Houston would be required to achieve a TOC removal percentage that ranges between 30 and 50 percent. This depends greatly on the raw water blend and seasonal water quality conditions. Achieving the required TOC removal percentage is much easier during wet weather (winter) conditions. Both raw water sources require higher coagulant dosages during wet weather conditions to achieve adequate turbidity removal. The higher coagulant dose combined with an increased organic load of large humic substances, due to runoff into the watershed, make it much easier to achieve the required TOC removal percentage.

RAW TOC, mg/L	RAW ALKALINITY, mg/L as $CaCO_3$		
	0-60	>60 - 120	>120
>2 - 4	40	30	20
>4 - 8	45	35	25
>8	50	40	30

The greatest unknown for management and operations staff has been whether the required TOC removal percentage could be achieved during dry weather operating conditions, and if so, how could it be achieved, and at what cost. During dry periods, water quality conditions in both watersheds change significantly. Turbidity in the raw water drops, making it easier to achieve the target finished water turbidity, but at the same time the TOC levels drop making it more difficult to achieve the required TOC removal percentage. This is why achieving the required TOC removal percentage during dry weather conditions will be the most difficult challenge facing the water production staff at the City of Houston.

INSTRUMENTATION

A Hach 1950 Plus On-line TOC analyzer was used during this study. The 1950 Plus utilizes the UV/Persulfate analysis method. The City of Houston's decision to purchase this instrument was based on several parameters, including its ability to analyze multiple streams, the relative ease of operation, easy access for maintenance, separation of wetted area from electronics, and the ability to automatically perform validations and calibrations at prescribed time intervals. The most important consideration however, was the analyzer's ability to detect organics that oxidize more slowly. This is achieved through the addition of multiple UV chambers. The more slowly oxidized organics are given the chance to completely oxidize by increasing the UV exposure, thus increasing the accuracy of reported TOC values. For the City of Houston, the addition of a second UV chamber was required to adequately to meet the oxidation requirements. In raw water sources that have a relatively low TOC value, incomplete oxidation could result in the under estimation of the raw water TOC, thus significantly reducing the reported TOC removal value. Anyone considering the purchase of an on-line or laboratory TOC analyzer should determine the organic makeup of their source water prior to purchasing an instrument.

STUDY PLAN

Over several years, the laboratory staff at the City of Houston has conducted hundreds of jar tests and numerous pilot studies. These tests have provided insight as to how the required TOC removal percentage might be achieved. Unfortunately, jar tests and pilot studies can only provide an indication of what might be expected in the full-scale production facility. Therefore, a plant scale study was conducted at the City of Houston's East Water Purification Complex during dry weather operating conditions. The study also provided an opportunity to evaluate how effectively the operating staff could achieve and maintain the required TOC removal percentage through the use of an on-line TOC monitoring device.

The study plan was relatively simple. First, determine if the target removal percentage can be attained. Second, explain to the operators how the target removal percentage can be achieved. Third, evaluate the operator's performance to see if they can achieve and maintain the target removal percentage without the aid of the on-line TOC analyzer. Fourth, allow the operator to use the on-line analyzer and see if their performance improves. And finally, determine the benefits of using an on-line analyzer.

This trial was started in mid summer after an extended period of dry weather, raw water turbidity and TOC levels had dropped significantly, thus requiring lower chemical dosages to achieve the target finished water turbidity. The study was conducted on a single treatment train at the East Water Purification Complex. At the time of the study a blend of 90% Trinity River water and 10% San Jacinto River water was being treated at the facility. The flow rate through the treatment train was held constant at 40 mgd (a 0.6 gal/min/ft^2 surface overflow rate). In addition to monitoring the TOC on-line, pH, total chlorine, turbidity, lime feed rate, streaming current, and coagulant (alum) dose were monitored on-line. An alkalinity grab sample was collected on the raw water each shift by the operations staff.

PRELIMINARY TREATMENT EVALUATION

STAGE 1: ALUM ADJUSTMENT WITH LIME AND POLYMER ADDITION

A preliminary treatment evaluation was conducted to determine if the required TOC removal percentage could be achieved on a plant scale. The first step was to establish a normal operating range, based primarily on finished water turbidity and production cost. Under this treatment scheme aluminum sulfate (alum), cationic polymer, and lime were added to achieve the highest turbidity removal at the lowest operating cost. Three treatment options for TOC removal were evaluated: alum adjustment with lime and polymer addition (current treatment scheme), alum adjustment with polymer and no lime addition, and alum adjustment with no lime or polymer addition.

After the baseline treatment scheme was established, the alum dose was increased in 5 mg/L increments (dry basis) without changing the cationic polymer dose (0.7 mg/L of Stockhausen K187). The lime dosage was adjusted as needed to maintain a settled water pH in an operating range of 7.3 to 7.5. The initial alum dose was set at 30 mg/L and was allowed to stabilize 6 hours before the next alum adjustment. Every 6 hours the alum dosage was increased 5 mg/L until one of the following termination criteria was met. The criteria for terminating the run were: settled water turbidity adversely affects filter performance; additional alum no longer effectively reduces TOC, attainment of the target TOC removal percentage, treatment cost becomes too high, or when the coagulant dosage reaches the point-of-diminishing return, approximately 85 mg/L.

Of the three methods tested, this treatment scheme was the least effective method for reducing the TOC level. The TOC removal percentage ranged from 19% to 29.5%. It became apparent after the alum dosage had been increased to 55 mg/L (dry basis) that it would be cost prohibitive to achieve the required removal percentage using this treatment scheme. Therefore, no further alum additions were made after the dosage had been increased to 55 mg/L. Although the plan was to keep the pH range between 7.3 to 7.5, the lime feed was lost due to mechanical problems after the alum dose had been increased to 55 mg/L (See graph: Preliminary Treatment Evaluation). Up to that point the TOC removal percentage had only increased to 27.5%, but with no lime being fed the pH dropped to below 6.9 which provided a better environment for coagulation. During that time the removal percentage increased to nearly 38%. After the lime feed was reestablished the TOC removal percentage dropped back to 29.5%. Because of the problems associated with the lime feed pumps, increasing rising treatment costs, and the fact that very little increase in TOC removal was being realized by the addition more alum, the decision was made to proceed with the next stage of the study.

STAGE 2: ALUM ADJUSTMENT WITH POLYMER AND NO LIME

During stage 2, the lime addition was discontinued and the system was allowed to stabilize before decreasing the alum dosage. This was a continuation of the previous stage, therefore the initial alum dosage began at 55 mg/L (dry basis). A decrease of 5 mg/L in the alum dosage was made every 6 hours. The cationic polymer dosage, 0.7

mg/L of Stockhausen K187, remained constant throughout the duration of this run. The rapid mix pH was allowed to fluctuate as the alum dosage was changed, the range was 6.8 to 7.3. pH adjustments were made after the water had reached the clearwell. The criteria for terminating the run were: settled water turbidity adversely affecting filter performance; or when the TOC removal percentage dropped below 20%.

After the effects of discontinuing the lime feed had taken place the TOC removal percentage rose dramatically. This was a repeat of the pattern observed during the previous test run when the lime feed was lost. At the beginning of the run the pH was approximately 7.3 and the TOC removal percentage was 29.5%. After the system had stabilized the pH dropped to near 6.9 and the TOC removal percentage increased to nearly 40%. The TOC removal percentage remained above the target level of 35% until the dosage was dropped to 40 mg/L. After the alum dosage was dropped to below 35 mg/L the removal percentage quickly dropped to as low as 18%, at a dosage of 20 mg/L (See graph: Preliminary Treatment Evaluation).

STAGE 3: ALUM ADJUSTMENT WITH NO LIME AND NO POLYMER

The combination of a low coagulant dose and no cationic polymer generally causes the filters to perform poorly; therefore the alum dosage was increased to 30 mg/L to start the run. After stabilization the filters were still performing poorly so the second incremental increase was 10 mg/L to 40 mg/L, from 40 mg/L to 60 mg/L dosage the alum was increased in 5 mg/L increments. The alum dosage changes were made every 6 hours. The pH was allowed to float (7.1 to 6.7) and no pH adjustments were made until after the water had reached the clearwell. The criteria for terminating the run were: settled water turbidity adversely affecting filter performance, additional alum no longer effectively reduces the TOC level, the target TOC removal percentage is attained, when the pH dropped below 6.3, or when the coagulant dosage reached the point-of-diminishing return, approximately 85 mg/L.

At an alum dosage of 30 mg/L the removal percentage was approximately 20.5% and at the upper limit of the run (55 mg/L above) the removal percentage reached 40% and higher. The target removal percentage of 35% was meet at a dosage of 50 mg/L. During this run, filter performance became a problem. Without lime or cationic polymer addition the required TOC removal percentage was achieved, but the higher removal percentage came at the expense of higher finished water turbidity. During stage 2 the filters performed better at the lower coagulant dosages than they had at the higher dosages. This condition often occurs when raw water turbidity drops to relatively low levels. Without raw turbidity to remove, the higher coagulant dosage produced settled water that was too “clean” to effectively be filtered. Although TOC removal was a treatment goal, filter performance and low turbidity finished water were still key aspects to water treatment.

OPERATOR'S PERFORMANCE TEST

With an understanding of what was expected of them, the operators were asked to make treatment decisions based on the results of the preliminary treatment evaluation. The operator's goal was to maintain a TOC removal percentage as close as possible to the target TOC removal percentage without compromising established water quality parameters. Each stage of the operator performance test was tracked for a minimum of 5 days. The operators were allowed to use all information gained from the preliminary treatment evaluation to make treatment decisions.

An assessment of the preliminary treatment tests was made by the operators and a treatment strategy developed for the operator's performance test. Alum adjustment with lime and polymer addition, was ruled out because it was not certain if the target removal percentage could be achieved, and if it could it would have been the most expensive of the three treatment schemes tested. Alum with no polymer or lime addition worked, but poor filter performance and the increased cost associated with feeding more alum and more caustic to offset the lower pH also made this option impractical. Alum with the addition of polymer and no lime was by far the most practical means of attaining the desired TOC removal percentage.

STAGE 4: OPERATOR PERFORMANCE WITHOUT THE AID OF ON-LINE TOC ANALYZER

The treatment train was returned to the operating conditions that were being used in the remainder of the plant at the time of the trial. After the system was stable the operator was given the results of a grab sample analysis so that chemical changes could be made. Every six hours the operator was given the results of another TOC grab sample so that additional chemical adjustments could be made. Six hours after the initial coagulant dosage change tracking of the operator's performance was begun. At the beginning of the tracking period the removal percentage was as low as 12.5%, and after slightly more than one day the operators were able to reach a TOC removal percentage near the target removal percentage. The highest TOC removal percentage reached during the run was 40.4%.

The target TOC removal percentage was 35%, and the goal for the operators was to stay within 5 percent (33.3% to 36.8%) of the target removal percentage. During this run the operators were able to stay within 5% of the target 19.7% of the time and within 10% (31.5% to 38.5%) of the target 48.6% of the time. Several factors seemed to impact the operator's performance: changing raw water blend ratios; raw water pump changes; under or overestimating the required coagulant dose; and daily fluctuation in the raw water TOC levels. **Since the installation of the on-line analyzer, daily fluctuations in the raw water TOC have been noted. The TOC fluctuation (increase) occurs at nearly the same time each day. At this time there is not a good explanation for this strange occurrence. The Water Quality Group is currently investigating this water quality condition.* Although all of these factors play a role in the operator's ability to maintain a target TOC removal percentage, the simple fact remains that periodic grab samples do not afford an adequate means of tracking and reacting to changing TOC conditions.

Stage 5: Operator Performance with the Aid of the On-line TOC Analyzer:

Prior to starting the trial the test treatment train was returned to the operating conditions that were being used in the remainder of the plant at the time of the trial. When the test began the operator was allowed to use the on-line TOC analyzer to make their first coagulant change. After the system had stabilized for six hours the test comparison began. The operators were able to reach the required removal percentage very quickly after the tracking period began. A few hours after the data logging period began the operators were within 95% of the target removal percentage. The operators were within 5% of the target removal percentage 68.6% of the time, and within 10% of the target removal percentage 94.3% of the time.

The TOC removal percentage ranged from 29.9% and 37.2%, much better than was achieved without the aid of the on-line analyzer (see graph: Operator Removal Performance). Many of the same treatment factors were encountered during this stage of the operator's performance evaluation, but unlike the previous stage, the operators were able to use the on-line TOC analyzer. The operator's performance was greatly enhanced during this stage because they were able to react quickly to fluctuations in the raw water TOC.

Conclusions and Recommendations

This study answered many questions concerning the how the City of Houston might achieve the required TOC removal percentage. Finding of the preliminary treatment evaluation provided insight as to which treatment scenario provided the highest TOC removal at the lowest operating cost. The study also answered questions concerning how an on-line TOC analyzer could be used to enhance the operator's ability to achieve a target removal percentage. From the results the study it is apparent that the operators could achieve a target removal percentage if given grab samples. However, they were unable to quickly respond to fluctuations in raw water TOC, meaning the operators often under or overfed coagulants in an effort to achieve the target removal percentage. If there is uncertainty concerning whether the required TOC removal percentage has been achieved, the natural tendency would be to overfed the coagulant to insure that the removal percentage was met. It is also not practical, or cost effective, to run grab samples as often (every 6 hours) as they were during this trial. The time involved in sample collection, sample preparation, calibration, and instrument maintenance would quickly approach the cost associated with the initial purchase of the on-line instrument. The conclusion of the study group is that on-line monitoring is beneficial and essential from both a water quality and operations stand point. With upcoming regulatory changes the use of an on-line TOC analyzer will aid the operator in producing the highest quality water, while at the same time keeping costs to a minimum.

ACKNOWLEDGEMENTS

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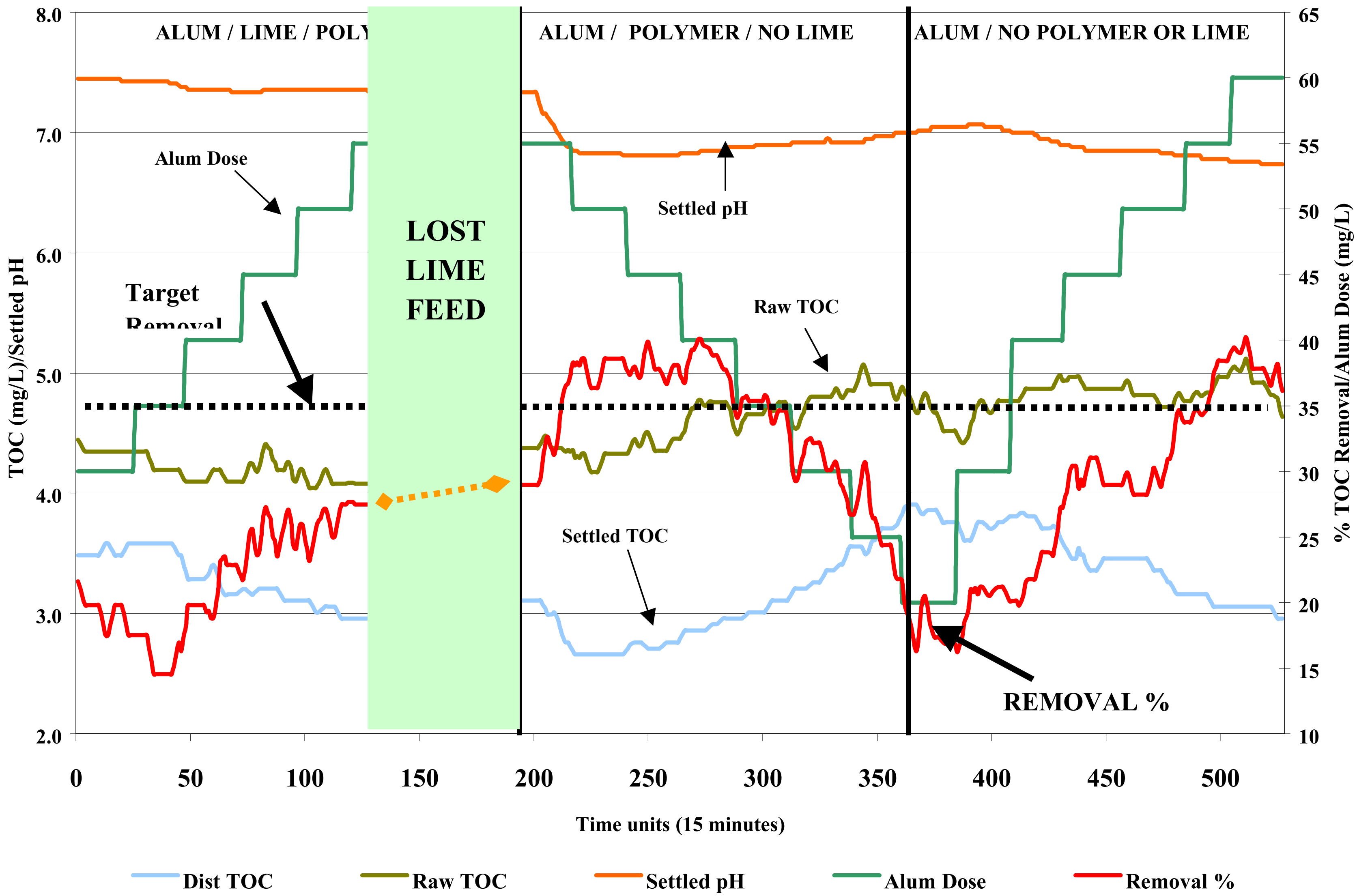
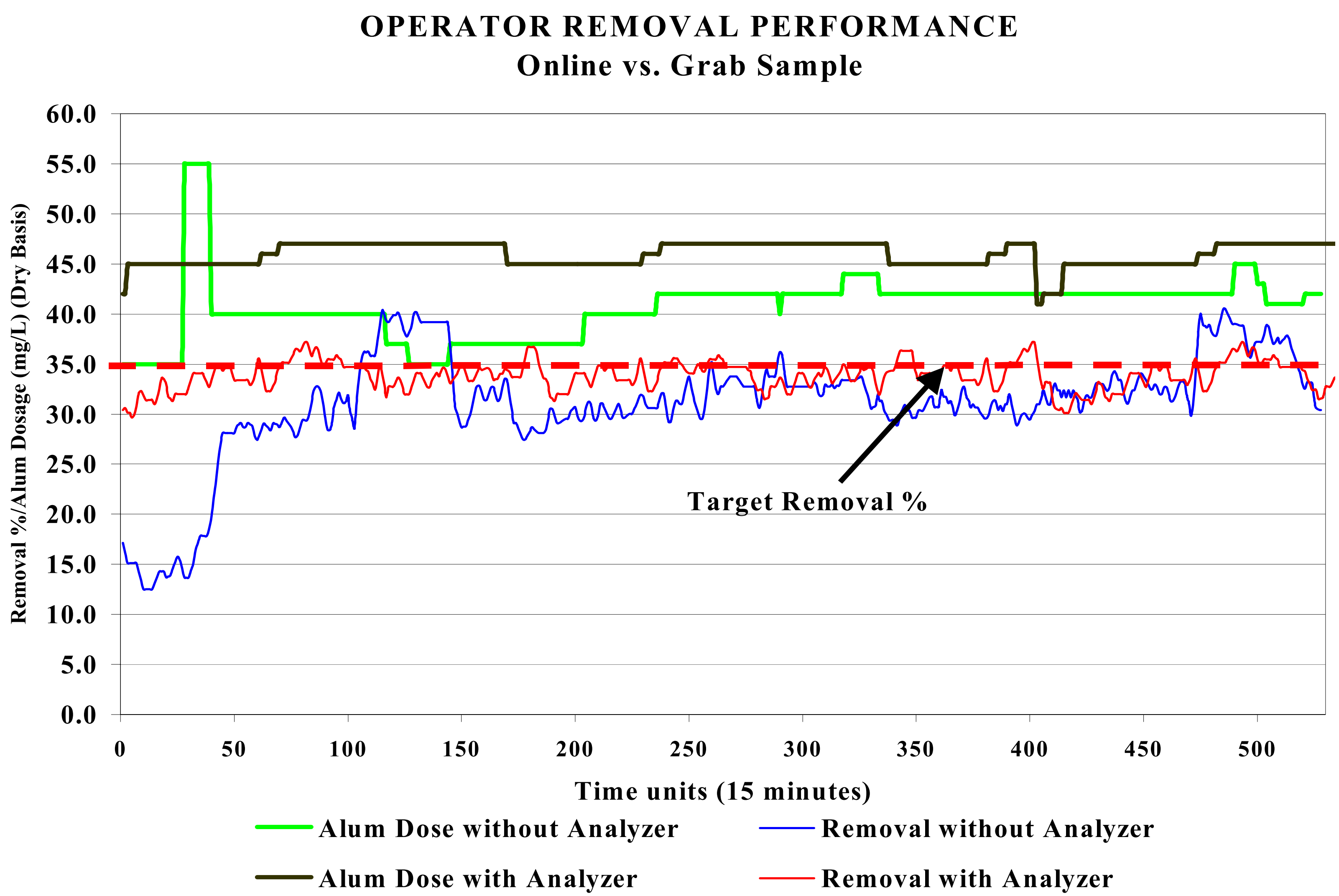
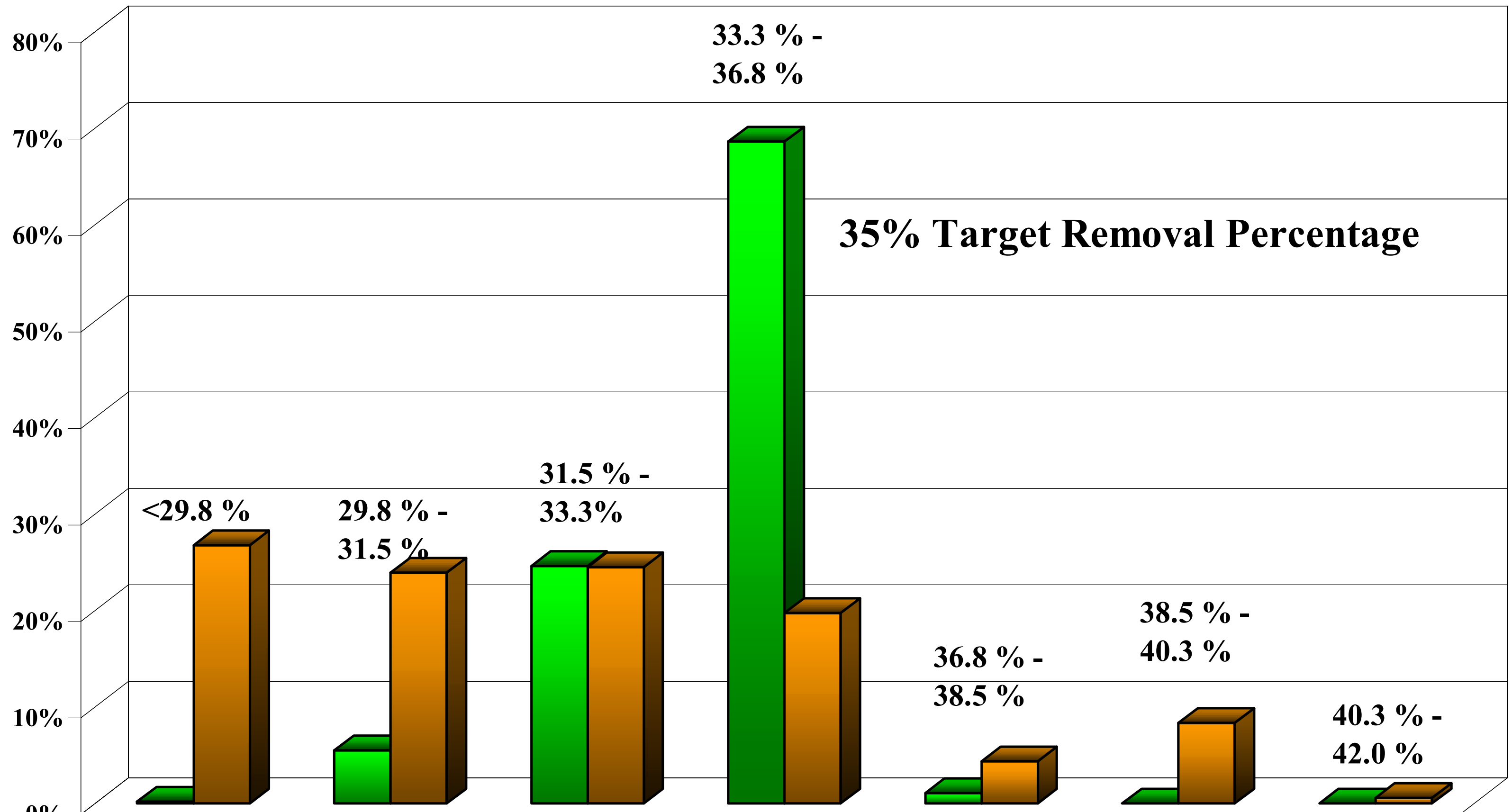
PRELIMINARY TREATMENT EVALUATION



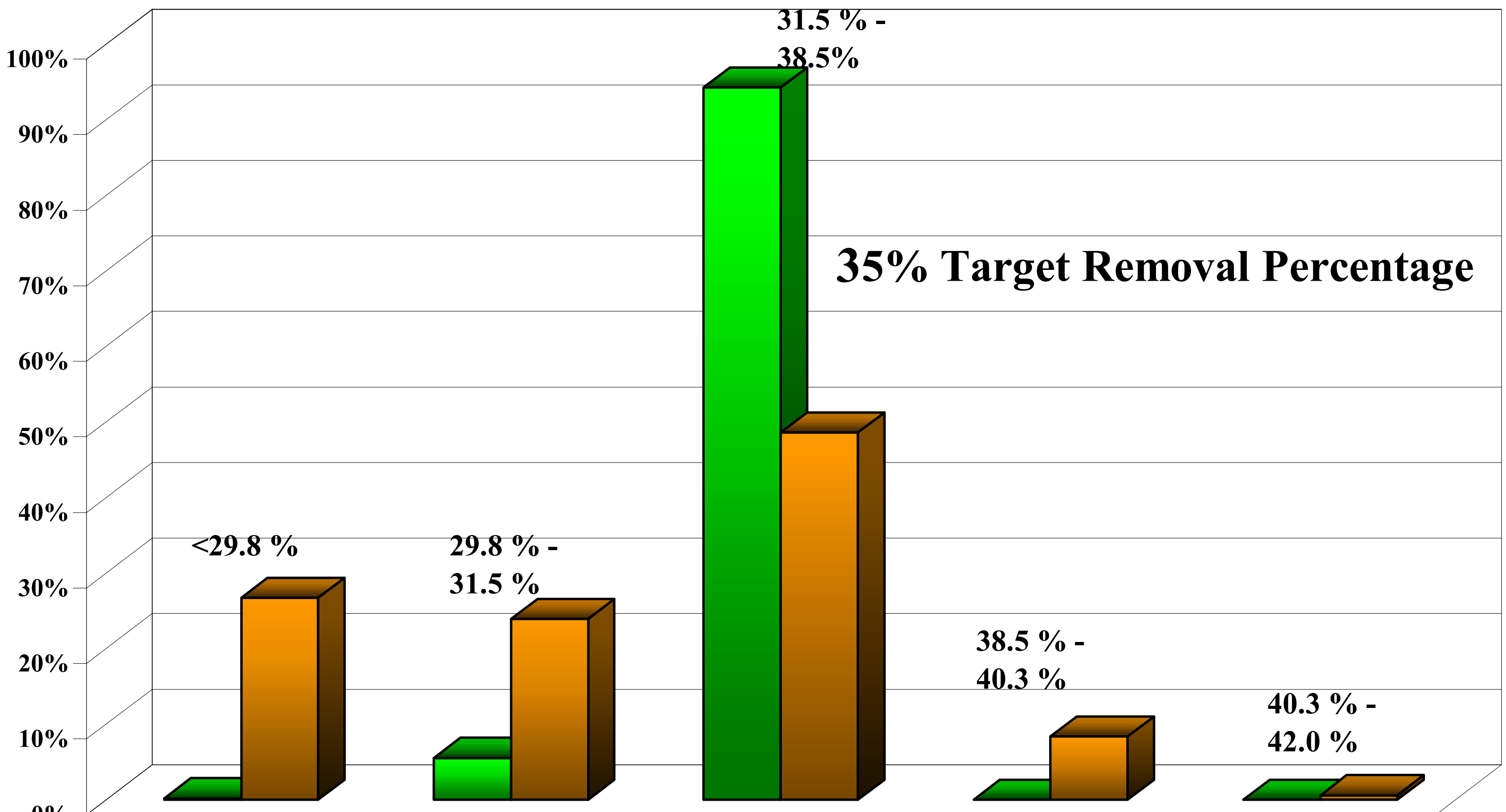

OPERATOR REMOVAL PERFORMANCE
Online vs. Grab Sample
Removal %/Alum Dosage (mg/L) (Dry Basis)
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
50
100
150
200
250
300
350
400
450
500
Time units (15 minutes)
Target Removal %
Alum Dose without Analyzer
Removal without Analyzer
Alum Dose with Analyzer
Removal with Analyzer

OPERATOR PERFORMANCE EVALUATION (5% TOLERANCE): GRAB SAMPLING vs ON-LINE SAMPLING



	<85%	85-90%	90-95%	95-105%	105-110%	110-115%	115-120%
On-line Analyzer	0.2%	5.5%	24.6%	68.6%	1.1%	0.0%	0.0%
Grab Sample	26.8%	23.9%	24.5%	19.7%	4.4%	8.3%	0.6%

OPERATOR PERFORMANCE EVALUATION (10% TOLERANCE): GRAB SAMPLING vs ON-LINE SAMPLING



	<85%	85-90%	90-110%	110-115%	115-120%
On-line Analyzer	0.2%	5.5%	94.3%	0.0%	0.0%
Grab Sample	26.8%	23.9%	48.6%	8.3%	0.6%

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- Astro International Corporation sold Astro Model 1950s to the City of Houston prior to the sale of Astro by the current Star management.

- After Astro was sold to Zellweger Analytics, Zellweger continued with the City of Houston until they sold the Astro Model 1950 to Hach Chemical Company.

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