

Technical Publication

Title: Using Online Analyzer for Optimizing Chemical Phosphorus
Removal Process in Municipal Wastewater Treatment

ASA Publication #211

Presented at:
WEAO Technical Conference
Ottawa, Ontario
April 22-24, 2012

Published by:
Applied Spectrometry Associates, Inc.
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Waukesha, WI 53186

**USING ONLINE ANALYZER FOR OPTIMIZING
CHEMICAL PHOSPHORUS REMOVAL PROCESS
IN MUNICIPAL WASTEWATER TREATMENT
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OVERVIEW AND SUMMARY

Phosphorus has long been a target nutrient in Ontario. A 1976 Ontario Ministry of the Environment (MOE) report entitled, 'Summary Report on the Phosphorus Removal Program' presented the results of a six year phosphorus study. The six year study called for 'policies requiring the installation of municipal and industrial phosphorus removal facilities not only in the Lower Great Lakes system but also in the Ottawa River system, parts of the Upper Great Lakes system and throughout the inland recreational areas.' (Archer, 1976). More recently, a phosphorus removal review of the performance of wastewater treatment plants discharging into Lake Simcoe was performed and reported to the Water Environment Association of Ontario (XCG Consultants, 2010). One focus of the XCG study was to estimate the cost (in order of magnitude) to achieve enhanced phosphorus removal levels at the 14 sewage treatment plants discharging into the Lake Simcoe watershed. Both the 1976 study and the 2010 study emphasize the MOE's environmental initiatives and the individual treatment plant's required management responses. Current total phosphorus discharge limitations for many of these WWTPs are between 0.1 mg/l and 0.5 mg/l.

In Ontario and many other locations, total phosphorus removal is the primary concern in nutrient removal. The Great Lakes Water Quality Agreement 1978 between US and Canada prioritized the limitation of nutrient discharge to the Great Lakes basin from both sides of the border. It has been the driving force for phosphorus restrictions to the municipalities discharging into the Great Lakes basin. A biological or a chemical method or a combination of both, phosphorus removal processes is employed to achieve this goal. This paper reviews treatment fundamentals from an operational cost perspective. The primary focus is on the role online nutrient analyzers play for achieving optimal cost savings and enhanced process performance.

STATEMENT OF PROBLEM

Traditional design, bid, build, engineered solutions to address regulatory phosphorus removal requirements are not always practical, timely, or affordable for municipalities. An existing treatment plant designed to meet solids and BOD removal requirements may struggle to implement various methods of nutrient removal. Meeting permit limits sometimes necessitates practices that are not optimized. One common practice used to meet enhanced phosphorus effluent limits specifies chemical addition instead of biological optimization. This practice may use a constant feed of precipitant chemicals during times of day when no chemical may be required. The phosphorus precipitation chemical is added to meet the worse-case scenario of flow and concentration which leads to chemical over-feeding. Another common practice is pacing the chemical feed based upon influent flow-rate only. This practice ignores the varying phosphorus concentrations which may lead to over-feeding of chemical. In both cases, lab analysis may

support additional chemical additional dosing, but lab work is time consuming and essential quantitative data may take days for collection, preservation, analysis and reporting.

These common practices, while successful in assisting a treatment plant meet permit requirements, do not help the treatment plant effectively manage chemical costs, and may negatively affect sludge management. Two questions remain, 'What is the right amount of chemical dosing?' and 'How can we acquire accurate, timely, data to optimize treatment processes and reduce costs?'

A PROPOSED SOLUTION

Online nutrient analyzers have been available for monitoring wastewater for over 30 years, however reliable analysis of phosphate in wastewater from analytical and mechanical stand points is a comparatively new development. Specifically, online nutrient analyzers have become important treatment tools as technology has improved their reliability and accuracy. Cost of ownership, like the "common practices" that lead to chemical over-feeding, have too often been overlooked. They are now considered critical components in the design of an economical phosphorous removal system. Following, is a brief summary of biological and chemical phosphorus removal techniques. Additionally case histories of several online analyzers will be reviewed.

FUNDAMENTALS OF PHOSPHORUS REMOVAL

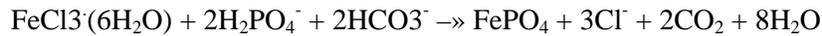
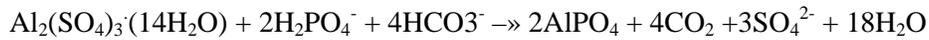
Biological and chemical phosphorus removal are widely used in municipal wastewater treatment processes. Process selection between biological and chemical phosphorus removal configurations is based on the treatment goal and operational cost considerations. A general rule is to select a biological phosphorus removal process when total phosphorus discharge limits are greater than 1.0 mg/l and select a chemical or combination of biological and chemical processes when total phosphorus discharge limits are less than 1.0 mg/l. Understanding the characteristics of each process assists in optimizing existing plants or selecting a treatment process for a new plant.

Biological Phosphorus Removal

Biological phosphorus removal is not the focus of this paper. What follows is a rather a brief review. The biological phosphorus removal process is well developed and based on the theory of phosphorus luxury uptake and release under different biological environments. In the anaerobic condition, phosphorus removing micro-organisms take-up and store volatile fatty acids while simultaneously releasing phosphorus. In the aerobic condition, phosphorus removing microorganisms produce energy by oxidizing the stored organics while taking up the dissolved form of phosphorus (intracellular phosphate). Various anaerobic/aerobic sequence processes have been developed based on this principle. Process configurations include Bardenpho process, modified Bardenpho process, University of Capetown (UTC) process, oxidation ditches with anaerobic zones and sequencing batch reactor (SBR), etc.

Chemical Phosphorus Removal

Chemical phosphorus removal is the focus of this paper and is essentially a chemical precipitation process, in which aluminum or iron salts are used for removal of phosphorus. The most common chemicals are aluminum sulfate (alum), ferrous sulfate, ferric chloride and ferrous chloride. The chemical equations for the reactions are as follows:



The US EPA publication State of Technology Report on Nutrient Control Design Manual (January 2009) provides estimates of the required molar ratios for chemical phosphorus removal:

Alum to phosphorus ratio,	1.38 : 1 for 75% removal
	1.72 : 1 for 85% removal
	2.3 : 1 for 95% removal
Iron to phosphorus ratio,	1 : 1 is required with a supplemental amount of 10 mg/l iron added to satisfy the formation of hydroxide.

‘COMMON PRACTICES’ OF MAKING CHEMICAL PHOSPHORUS REMOVAL

Many municipal wastewater treatment plants add chemical by (1) a pre-set constant chemical dosage or (2) a flow-pace match of chemical dosage based on the raw influent flow rate. The main disadvantage of these two practices is the potential for costly overfeeding of the chemical. A common practice to optimize chemical dosing is chemical mass based dosage through on of the following manners:

- Jar Testing or Bench Testing – using a simple method to determine wastewater characteristics and real metal to phosphorus ratios required at different chemical injection locations;
- Historical Trending – if historical data is sufficient to demonstrate hourly, daily or monthly phosphorus loading patterns, the varying chemical dosing levels can be configured via with the plant’s SCADA system using these trends;
- Third party laboratory analysis – data used for reporting purposes. This data can also be used to fine-tune chemical dosage, but the long wait times are a problem for “real time” control. Increasing analysis costs are another concern if multiple sample locations are monitored.
- Plant’s lab analysis – chemical dosage is adjusted based on the data collected and analyzed in laboratory by the plant staff. This is a labor consuming process and difficult for the “real time” process adjustments.

A PROPOSED SOLUTION – ONLINE PHOSPHATE ANALYZER

The on-line phosphate analyzer is a solution for real time chemical dosing control. It introduces direct SCADA-linked measurements for automatic dosing control based on the desired phosphorus level at one or more locations. It can also provide direct feed forward or feed back to the SCADA system on appropriate chemical to ortho-phosphate ratios. Continuous final effluent monitoring is important for plant quality control.

The majority of online phosphate analysis is based on spectrometry using wet chemistry. Ortho phosphate reacts with ammonium Molybdate under acid condition with the presence of other chemical reagents to form yellow Vanadomolybdophosphoric acid. The intensity of the yellow color is proportional to the phosphate concentration. An online spectrophotometer can be used to determine color

intensity. This is also called the “Yellow Method”. Using an ammonium molybdenum reagent to form a blue coloration is called the “Blue Method”.

In general, phosphate analyzers are the complex integrations of chemical, electrical and mechanical technologies. Labor saving, speed of data acquisition, and consistency, reliability and accuracy of the data have been driving forces behind analyzer development. But saving labor and acquiring data are not justified if the online analyzer only adds a maintenance burden or if the analyzer is not reliable. The quality of online phosphate analyzer has been improved significantly in the past 10 years. There are online phosphate analyzers with user-friendly designs that are easy to maintain and feature auto-zeroing and auto-cleaning. It is important to know how to determine the analyzer’s qualifications before installation. The evaluation of online analyzers should include the following:

- i. Check References. This should be the first step of an evaluation. Compare information from a vendor’s product specifications, opinions from existing customers can be valuable information regarding to accuracy, reliability and maintenance requirements.
- ii. Reliability and Accuracy. Evaluation of existing installations data: Regression analysis or chart comparison using laboratory data against analyzer data can be used to determine reliability and accuracy.
- iii. Interference compensation. Online phosphate analyzers should be capable of compensating for typical sample background interferences.
- iv. Self-cleaning and self-zeroing. Some analyzers feature automated chemical cleaning to reduce maintenance due to fouling of the optical cell. Automatic zeroing allows the analyzer to restore a new background after cleaning. This feature is typically configured to run on a daily basis although alternative sequences can be programmed. Self-clean and self-zeroing features ensure reliable and consistent analysis results.
- v. Sample Handling. High turbidity in raw wastewater caused by suspended solids, colloidal matters and other microscopic organisms creates analytical interferences and must be filtered before analysis. Mixed liquor samples directly taken from aeration basins must be filtered before analysis. A good sample handling system is reliable with minimal downtime and requires low maintenance. Modern sample filtration systems have self-cleaning ability to dramatically reduce maintenance.
- vi. Maintenance Requirement. Daily, monthly and annual requirements.
- vii. Overall cost of ownership analysis. Overall cost of ownership should include “Initial Cost” and “Operational Cost”. Initial cost include: analyzer, sample handling system and spare parts. Operational costs include the costs of chemical reagents, service contracts, replacement parts, etc. Overall cost of ownership is the most important evaluation tool and should encompass all of the preceding topics.

INSTALLATIONS AND CASE HISTORIES

Online phosphorus analyzers have been installed in municipal wastewater treatment facilities for monitoring purpose since late 1970’s. There have been more installations since 1990 not only for process control - to meet increasingly stringent nutrient limits - but also for operational cost savings. For example; the City of Johannesburg, South Africa, saved an estimated \$1 million USD in phosphorus precipitation chemicals utilizing data from an online phosphate analyzer.

Chemical feed locations for chemical phosphorus removal include the following locations:

- Pre-precipitation – when chemicals are added to raw wastewater and use primary clarifier to precipitate phosphorus;
- Co-Precipitation – when chemicals are added to aeration basin and phosphorus precipitation is removed with sludge wasting;
- Post-Precipitation – when chemicals are added after secondary sedimentation and phosphorus precipitation is removed in a tertiary treatment process.

The chemical dosing location also affects precipitation chemical to phosphorus ratio and the end result. The primary sedimentation injection point requires a higher chemical dosage because of the competitive reactions caused by higher biological concentrations, existing competing chemicals and variations in coagulant demand. Biological treatment processes convert most polyphosphates and organically bound phosphorus into simple form ortho-phosphates. Therefore, compared to primary injection only, adding chemical after biological treatment not only reduces chemical dosage, but also increase overall wastewater treatment plant phosphorus removal rate (EPA Nutrient Control Design Manual 2009). Online phosphorus analyzers can be categorized as a *Single Sample Channel Analyzers* or a *Multiple Sample Channel Analyzers*. Depending on the monitoring strategy adapted, different types of analyzers can be selected and installed.

Single Analysis Point installations can be found in “Pre-precipitation” or “Co-precipitation” applications, where online data can be used to set up appropriate chemical feed ratio via SCADA or for manually fine tuning the chemical feed pump settings. Either a feed-forward or a feed-back control loop is used.

- Primary Clarifier Effluent data is used to determine Pre-precipitation chemical dosage.
- Secondary Clarifier Effluent data is used to determine Co-precipitation chemical dosage.

Case Histories of single analysis point installations: Various methods of feed-back control are discussed below.

Kiel, Wisconsin The Kiel, WI WWTP is an activated sludge process with grit removal, screening and primary clarifiers followed by secondary clarification and sand filtration. The design flow is 3.4 million liters per day. The phosphorus permit limit is 1.0 mg/l. A cheese making facility in the community is a major contributor of phosphorus. Biological phosphorus reduction was not feasible. Ferrous Sulfate is added to chemically precipitate phosphorus at the secondary clarify splitter box. An online ortho-phosphate analyzer is installed at the secondary effluent location. The analyzer data is collected by the plant’s SCADA which varies the ferrous sulfate feed rate in feed-back control. Chemical expenses have been reduced by 20% since the installation of the single channel online ortho-phosphate analyzer.

New London, Wisconsin The New London, WI WWTP is an activated sludge process with grit removal and screening followed by secondary clarification. The design flow is 7.57 million liter per day. The phosphorus permit limit is 1.0 mg/l. A cheese making facility in the community is a major contributor of phosphorus. Ferric Chloride is added to chemically precipitate phosphorus. An online

ortho-phosphate analyzer is installed at the secondary effluent location. The single channel analyzer data is collected by the plant's SCADA which varies the Ferric Chloride feed rate through feed-back control. Chemical expenses have been reduced since the installation of the online ortho-phosphate analyzer saving New London over \$900/month in chemical costs.

Sheboygan, Wisconsin Sheboygan, WI has an advanced WWTP servicing a population of 50,000 with many local industries and septage hauling companies. The current phosphorus effluent limit is 1.0 mg/l, but the Wisconsin Department of Natural Resources (DNR) has recommended lowering the plant's effluent phosphorus permit limit to 0.05 mg/l. The plant uses Ferric Chloride and spent more than \$160,000 for Ferric Chloride in 2009. In anticipation of the lower phosphorus effluent limit and in an effort to save chemical costs, one single channel online ortho-phosphate analyzer was purchased in 2010. The first online analyzer performed so well, a second online analyzer was purchased for the parallel process train. Output from the online analyzer is collected by the plant's SCADA and uses feed-back logic for chemical addition. The online analyzer investment was recouped in eleven months based on reduced chemical costs.



Figure 1. Online Phosphate Analyzer Installation

Hite Creek, Kentucky Hite Creek WWTP is one of Louisville Sewer District's thirteen plants. It is a typical secondary activated sludge treatment process with UV disinfection. The plant receives unpredicted phosphorus load from a nearby industrial source. Alum solution is added at the influent stream (combined with return activated sludge flow) to the aeration basin. An ortho-phosphate analyzer is installed at the secondary effluent location. With the analyzer installed, the plant has much better understanding of the phosphorus load. As a result, the plant has been able to set up improved alum feed rate for different days of the week in order to match the expected phosphorus load based on the analyzer's data over several months. As a result, the daily alum feed rate has been cut from 750 liter/day to current 380 liter/day approximately. Operator is still able to fine-tune the feed rate based upon the analyzer's current data.

Multi Point refers to multiple location chemical feed applications. Compared to single location chemical feed, multiple location feed uses less chemicals and demonstrates better phosphorus removal. Case studies are listed below.

Waupun, Wisconsin A case study conducted by Steven Arant of Donohue Associates (now AECOM) in 2005 at Waupun, Wisconsin, investigated overall sludge production and chemical consumption between single and multiple point chemical feed. The result shows less sludge production and less precipitation chemical consumption when chemicals are feed at multiple locations. As mentioned earlier, primary clarifier feed requires a higher dosage because of the competition reactions caused by higher biological concentrations, existing competing chemicals and variation in coagulant demand. The case study is summarized in the two diagrams in below.

In addition to chemical savings, overdosing in pre-precipitation (primary clarifier) should be avoided because it may result in the loss of alkalinity and nutrient deficiency to the subsequent biological process.

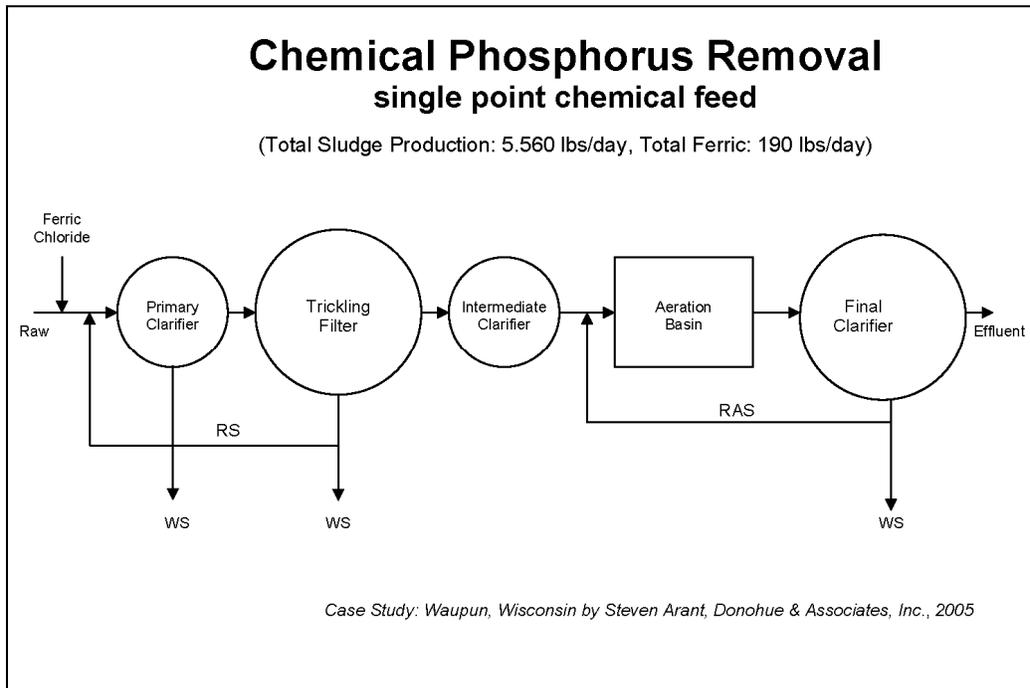


Figure 2. Single Point Chemical Feed

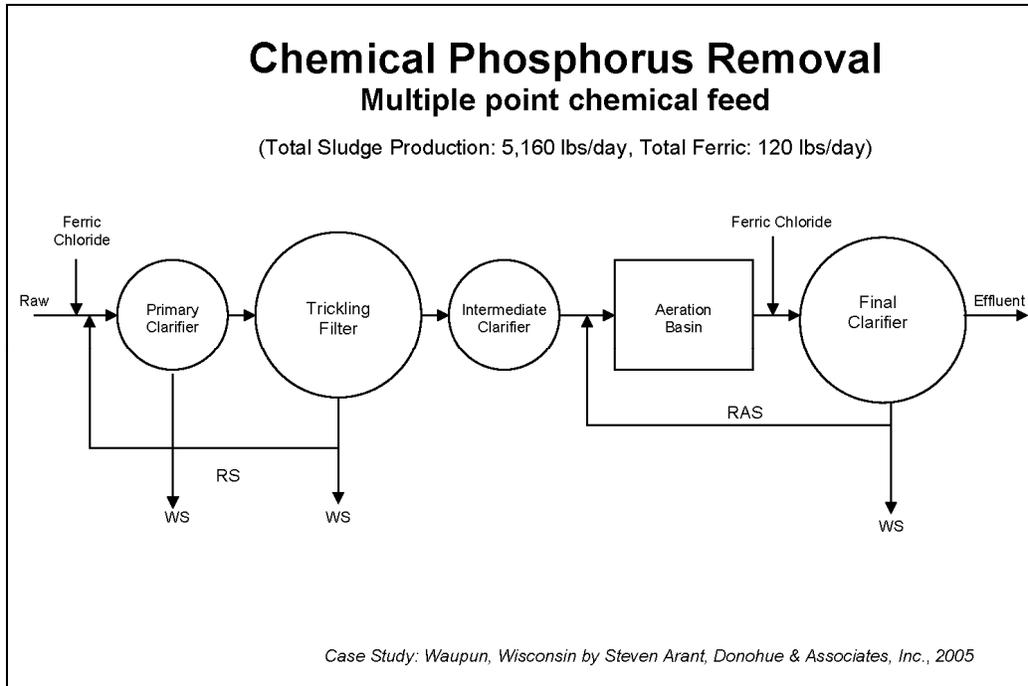


Figure 3. Multiple Point Chemical Feed

Hagerstown, Maryland Hagerstown, Maryland on-site demonstration project was funded by the State of Maryland. The existing secondary treatment utilizes pure oxygen. The nutrient discharge limits are total phosphorus of 0.3 mg/l and total nitrogen of 3.0 mg/l. The purpose was to demonstrate that a tertiary Denitrification filter with ferric chloride feed can achieve the discharge limit. Methanol and ferric chloride are mixed with secondary effluent and then fed to tertiary filter. Both chemicals need to have a precise control. The challenge for ferric control is to ensure sufficient quantity to precipitate phosphorus while not over dosing causing phosphorus deficiency to the biological filter. One centralized analyzer is installed. The analyzer has two sample channels. At each sample location, the analyzer monitors four parameters: ortho-phosphate, nitrite, nitrate and ammonia. Eight data signals in total are sent to the tertiary filter's PLC which controls methanol and ferric metering pumps accordingly. The demonstration yielded successful results. A full size tertiary denitrification filter and a multiple parameter, a multiple channel analyzer has been installed and operating since 2010.

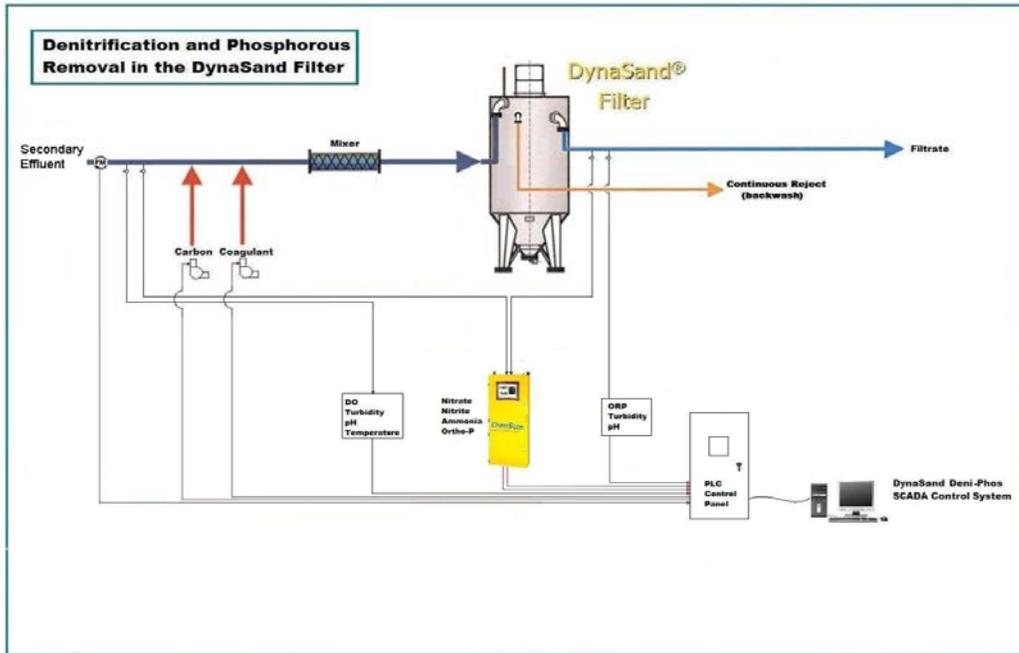


Figure 4. Hagerstown, MD ENR Demo Process Diagram

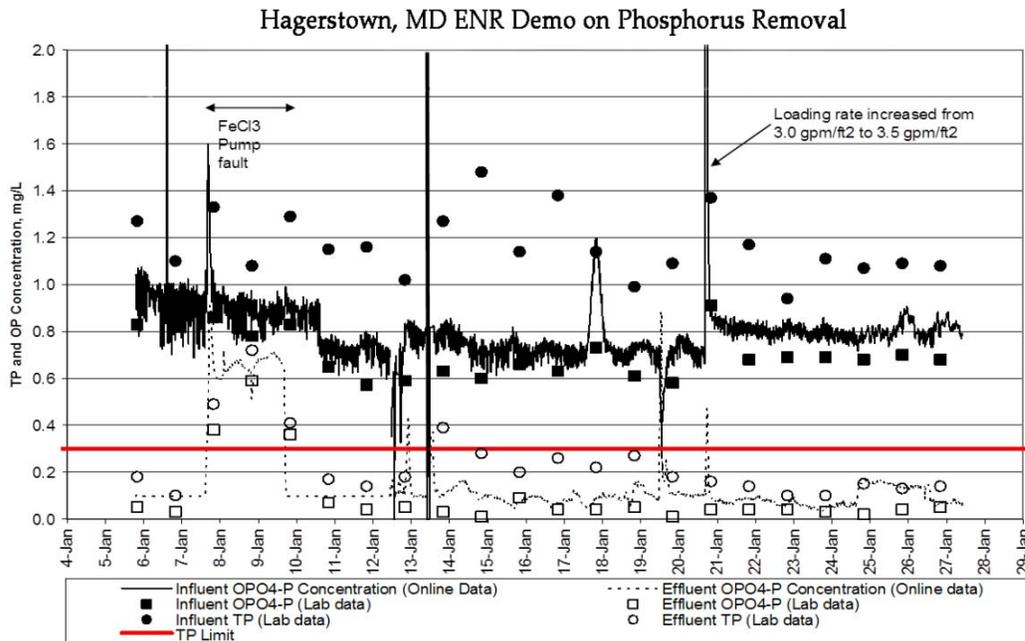


Figure 5. Chemical Phosphorus Removal Data



Figure 6. Online Analyzer with Multiple Sample Channel and Multiple Parameters

CONCLUSION

Ever tightening nutrient regulations, reductions in operating budgets, increasing utility and chemical costs all demand ongoing process improvements. Online ortho-phosphate analyzers have been used successfully in many wastewater treatment plants to gather timely, accurate and reliable data to ensure enhanced effluent limits are met, chemical costs are reduced and the treatment process is optimized. This has been achieved without burdensome maintenance requirements on plant staff.

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