Unique Algorithm to Optimize Chemical Dosing to Tertiary Filters in Order to Meet Ultra-Low Effluent Phosphorus Requirements

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ABSTRACT

Municipalities in the United States are facing very tight limits of phosphorus. In order to meet these stringent limits, advanced treatment including enhanced biological phosphorus removal (EBPR) and chemical addition with tertiary filtration is typically used. It is common practice for operators to use trial and error techniques for chemical addition. In these cases, operators typically elect to err to the safe side by adding excess chemical. This study demonstrated the importance of automated and continuous monitoring and control of chemical dosing systems to achieve ultra-low phosphorus limits while improving reliability and conserving chemical consumption.

KEYWORDS: Phosphorus Removal, Ultra-Low Phosphorus, Intelligent Controls, Chemical Savings, Coagulant, Metal-Salt, Polymer, Tertiary Filtration, Cloth Media Filtration, Nutrient Removal.

INTRODUCTION:

Excessive nutrients continue to be a leading cause of impairment of lakes, rivers and coastal waters in the United States (U.S. EPA, 2015). In response, wastewater discharge permits are getting more stringent in the US, with plants around the country facing unprecedented requirements to attain ultra-low total phosphorus (TP) effluent concentrations. It has been demonstrated that tertiary filtration with proper chemical addition and flocculation can meet requirements as low as 0.075 mg/l (Hughes, M. 2015). In these cases, even an optimized biological system designed for enhanced biological phosphorus removal (EBPR) and chemical addition will necessitate further treatment with a tertiary filtration system in order to attain the necessary system reliability.

Despite such stringent requirements, operators quite often use trial and error techniques to calibrate chemical dosing to produce the desired system performance with a fixed-dosed strategy. It is common for the operator to adjust the coagulant feed system to account for the variation of flows and TP loads throughout the day, continually balancing system reliability with the practical costs associated with chemical consumption. With effluent permit compliance ranking as highest priority, plant staff are obliged to select the highest dosage required in order to meet the phosphorus limit at all times and under all conditions. Controls and instrumentation can play a role in many plants, but typically provides the operator with a simple flow-paced program to dose coagulant based on the influent flow to the plant. While this method saves chemical over

a fixed dose strategy, it still does not address the variation in phosphorus concentrations which are often uncorrelated with changes in flow.

The two key challenges faced by design engineers and operators are the reliability of meeting the effluent objective and the cost of adding chemical. Mean levels of non-reactive, soluble phosphorus (sNRP) after filtration are reported to be 0.011 mg/l (WERF 2014), but will be site-specific. In order to meet ultra-low effluent TP numeric limits, even slight variations in the relationship between coagulants and TP can results in discharge violations leaving little margin of error in reducing all forms of phosphorus. While overdosing chemical seems to be an option to precipitate soluble reactive phosphorus (sRP), the high cost of coagulant makes it impractical for municipalities to adopt this method to consistently meet the effluent phosphorus requirements. Further, unnecessarily high chemical dosages will increase the solids loading to the filter resulting in higher backwash flows that can impact solids handling, digestion and return flows to the EBPR system.

An advanced secondary treatment process designed for EBPR, can reliably achieve phosphorus levels of 0.5 mg/l (Sedlak, R. 1991; Jeyanayagam, Samuel 2015), and in certain cases 0.1 – 0.3 mg/l (WERF 2014). To complement the capacity of this system and to reliably meet level of phosphorus below these concentrations, a tertiary filter with chemical addition will be necessary to remove particulate phosphorus. It has been demonstrated that a tertiary filter with coagulant and polymer addition can meet effluent TP levels as low as 0.075 mg/l (Hughes, M. 2015).

This paper demonstrates a control system that is equipped with a unique algorithm that uses on-line instrumentation in a feed-forward and feed-back analysis and control that is designed to enhance effluent phosphorus reliability and continually optimize the chemical addition.

METHODOLOGY:

The study was performed at the Rock River Water Reclamation District (RRWRD) in Rockford, IL. Secondary clarified effluent (SCE) was delivered at a rate of 10.3 m^3/hour (0.065 MGD) to a cloth media filter that was retrofitted with smart controls with unique algorithms for control of chemical addition for phosphorus removal. The cloth media filter is an Aqua MiniDisk® filter and the smart controls the Filter IntelliPro®, manufactured by Aqua-Aerobic Systems, Inc, Loves Park, Illinois.

The RRWRD NPDES permit presently does not require the facility to remove phosphorus. The plant operates a conventional activated sludge system which does not include enhanced biological phosphorus removal or chemical addition. Therefore, phosphorus removal relied strictly on chemical control in order to meet the goal of this study.

An automated chemical injection skid capable of dosing coagulant and polymer coupled with a flocculation basin that provided a nominal 5 minute hydraulic retention time (HRT) was used prior to the cloth media filter. The coagulant used was Aluminum Sulfate at 48.5%, 1.34 SG, and the polymer was Clarifloc®-6320 from Polydyne Inc.

The system was equipped with an influent flow meter, influent and effluent online turbidimeters (Hach Ultraturb sc), online ortho-phosphate analyzers (ASA Analytics, ChemScan® mini oP), and level sensors in the filter basin. Online data was compiled using the smart control system, where data is interpreted and the decision support tool makes the necessary adjustment.

The phosphorus analyzer was programmed to measure influent and effluent phosphorus by alternating the sample source (influent and effluent sampling pumps – Figure 1) with a cleaning period in between samples.
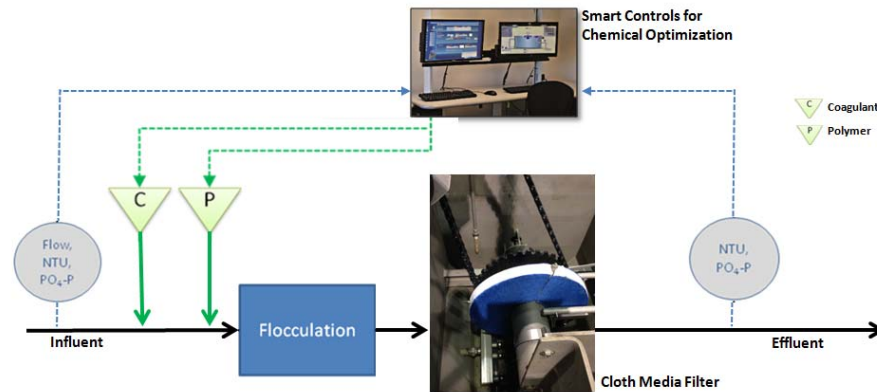
Figure 1. Flow Diagram

Coagulant and polymer addition was controlled by automatically responding to changes in the influent phosphorus mass loading, but monitored the effluent total reactive phosphorus (TrP) concentration to prompt secondary adjustment in the chemical dosing. In essence, the algorithm ensures that the effluent phosphorus target is met with the minimal amount of chemical requirement. The system continuously adjusted the chemical dosage in response to relational parameters such as flow, influent phosphorus, effluent phosphorus and turbidity.

The phosphorus analyzer measured inlet and outlet TrP concentrations (Figure 2) while an influent flow-meter and a PLC supporting the algorithm was used to track the influent phosphorus loading applied to the filter.

Figure 2. System Components

The mass-based control strategy allows for the different response times of the flow meter as compared to the phosphorus analyzer. For example, changes in flow may be sensed every 5 – 10 seconds whereas effluent phosphorus readings may be generated every 5 – 20 minutes, depending on the operator configurable settings. Historical data is recorded and used for establishing initial set points, including the effluent quality changes in response to the molar ratio of metal ion to influent reactive phosphorus.

Testing was performed on RRWRD's secondary clarified effluent which contained total phosphorus concentrations between 2.8 and 3.2 mg/l. The initial target for effluent total reactive phosphorus (as PO_4-P) was set at 0.2 mg/l which allowed for a total non-reactive phosphorus of 0.05 mg/l in order to meet a 0.25 mg/L effluent TP. Figure 3 illustrates typical operator adjustable settings that guide the internal algorithms.

Figure 3. Coagulant Setup Screen

For those plants facing ultra-low phosphorus limits, polymer addition may be necessary to reduce colloidal or particulate–associated phosphorus that is not rejected by the filter. Common practice is to conduct a series of jar-tests in the lab to evaluate the best type of polymer and the optimal dosage. While such testing is vital, the drawback to this approach is the time necessary to conduct the testing and the question of scalability to the full-sized installation. The process algorithm uses the existing, full-scale system to effectively conduct an on-demand jar test to determine the optimal dose of polymer necessary to achieve the lowest effluent turbidity reading. In the testing at RRWRD, the operator set the number and length of each test, the concentration of polymer and the start time of the test. The system assesses the turbidity reduction at each polymer dose and records the comparative results. These results are displayed in a table, highlighting the best possible scenario of polymer dose in response to the percentage of turbidity removed during each incremental test.
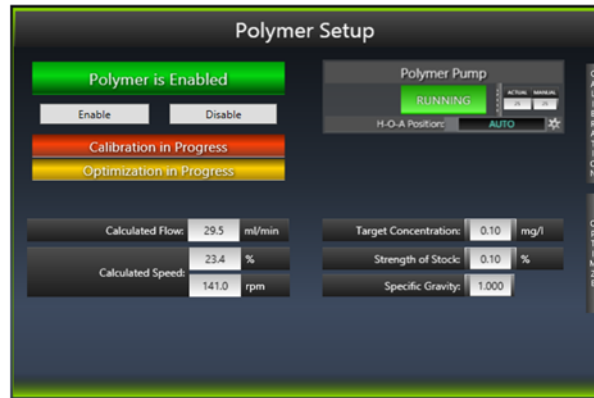
Figure 4. Polymer Setup Screen

Once the best polymer concentration was identified, the system automatically adjusted the polymer dosing to match this optimal dose point with the influent flow. As the effluent turbidity varied, the control system adjusted the concentration of polymer in response to the effluent quality. As an example, if the filter performance continually improves, the polymer optimization scheme will continue to reduce the polymer dosage resulting in on-demand delivery. Conversely, operator-selected upper limits prevent unintended escalation of chemical dosing should the water quality characteristics become recalcitrant to chemical addition.

To validate the algorithm, a main test was performed over a 24-hour period with coagulant addition testing to observe the performance of this piece of the smart system. A second test was performed for an additional 24-hour duration in order to determine chemical savings based on influent phosphorus concentration variation.

RESULTS:

The data shown in this study illustrates variations in the influent phosphorus loading based on the influent volumetric flow and phosphorus concentration. A diurnal flow pattern was programmed and can be seen in Figure 5.
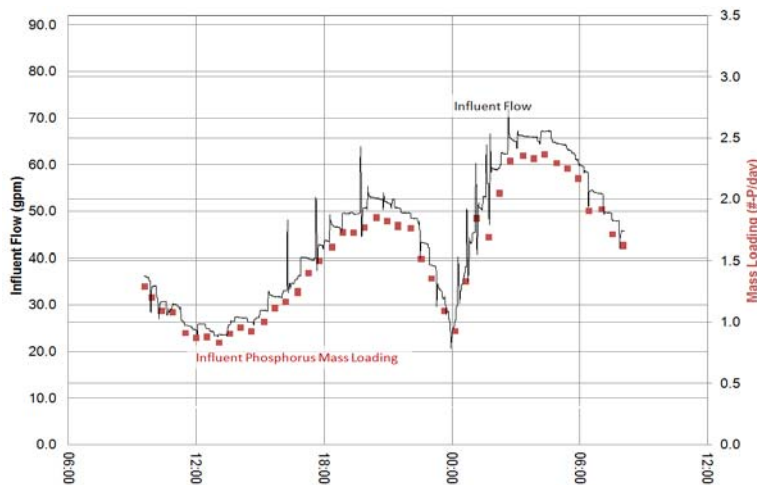

Figure 5. Influent Flow and Phosphate Mass Loading

Coagulant Control
Overlaying the coagulant dosage using the smart control system demonstrates that the chemical addition followed the general pattern but took into account the variation of loading. The initial dosage is set based on the Al:P molar ratio of 3:1 based on empirical data and experience on other plants. From there, the smart control system adjusted the dosage based on the actual influent loading variation. A small adjustment period can be observed. Then, the dosage automatically adjusted to the loading and slight correction is detected due to the effluent phosphate feedback (figure 6). This resulted on an Al:P ratio of approximately 1.8:1.
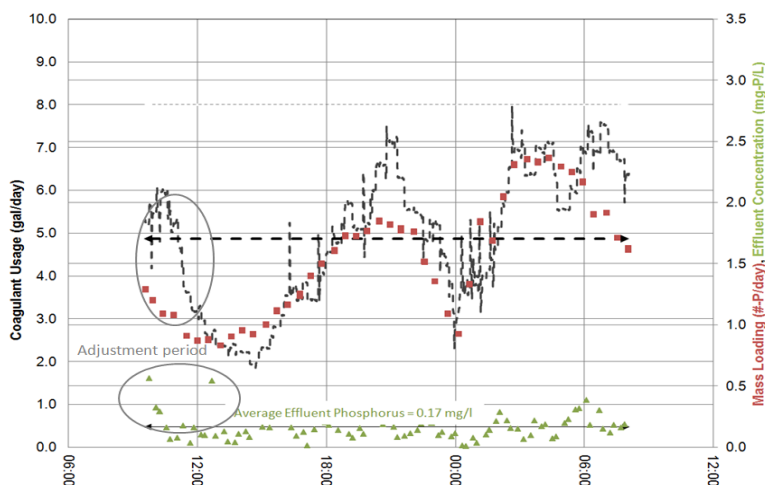

Figure 6. Adjusted coagulant dosage with smart controls

Based on empirical data, the system would have required approximately 8 gallons of Alum based on the 3:1 Al:P ratio, instead of approximately 5 gallons utilized in the testing. The most dramatic savings can be experienced when comparing the adjusted coagulant dosage with chemical requirement as a fixed rate assuming 8 gallons of Alum (Figure 7). Savings of approximately 40% are expected if the operator sets the fixed dosage to maintain adequate treatment during peak hours of the day when the phosphorus level is at its highest.
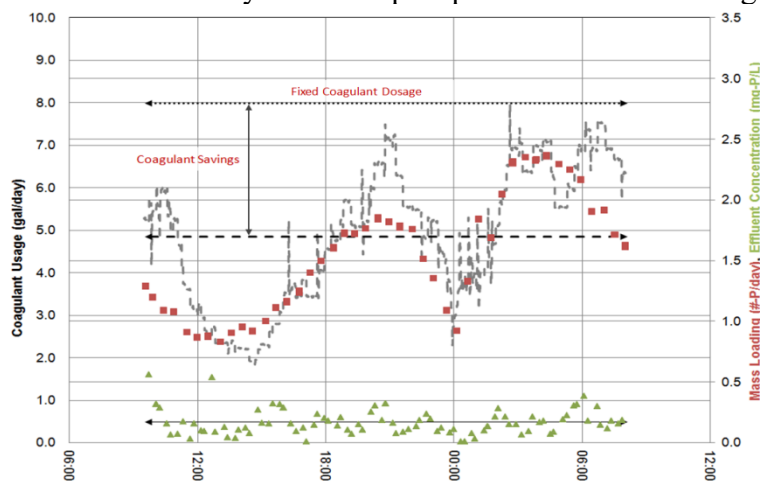

Figure 7. Adjusted Coagulant Addition vs. Fixed Coagulant addition

The mass-based chemical dosing with effluent monitoring translates to annual savings of approximately $60,000 per MGD treated based on commercially available aluminum sulfate priced at $0.30/lb.

In comparison to flow-paced chemical feed systems, the chemical control based on molar ratio and phosphorus loading with this algorithm represents a savings proportional to the phosphorus concentration variation in the influent. Testing at the RRWRD facility yielded conservative estimates due to the low variation of influent TrP concentrations. Facilities which observe significant or rapid fluctuations in flow or influent phosphorus will realize a higher degree of system reliability and cost savings. As shown in Figure 8, the algorithm ensures effluent phosphorus stability despite the changing influent conditions. Systems which use the flow-paced strategy face the potential to under-dose the coagulant during these periods risking compliance with permit objectives.
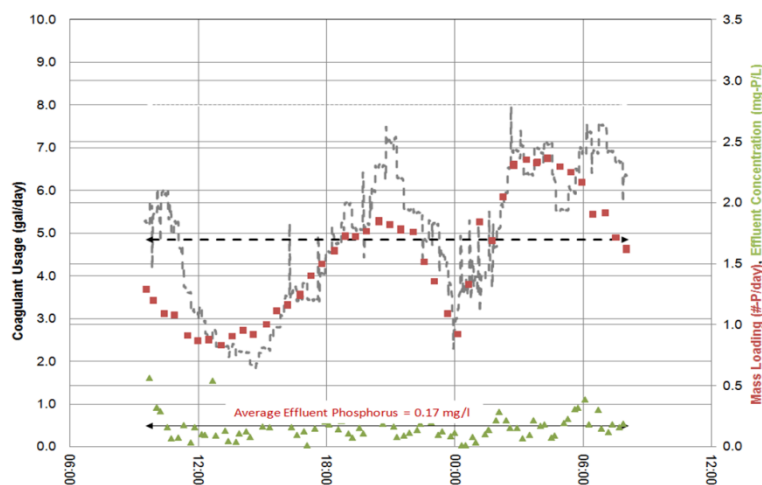
Figure 8. Effluent phosphorus

A second test was performed with a similar flow pattern programmed. In this testing, the influent phosphorus concentration varied. The impact of the variation in concentration on the chemical usage can be seen in Figure 9. The addition of chemical based on a flow-paced strategy may result on overdosing, particularly if the operator has incorporated any safety factor into the dosage. In this case, the resulting penalty on chemical dosing required approximately 10% more chemical, which translates to approximately $10,000 per MGD per year based on the use of 48.5% aluminum sulfate. More importantly, there were several periods during the day where the flow-paced strategy did not add sufficient coagulant, potentially risking non-compliance.
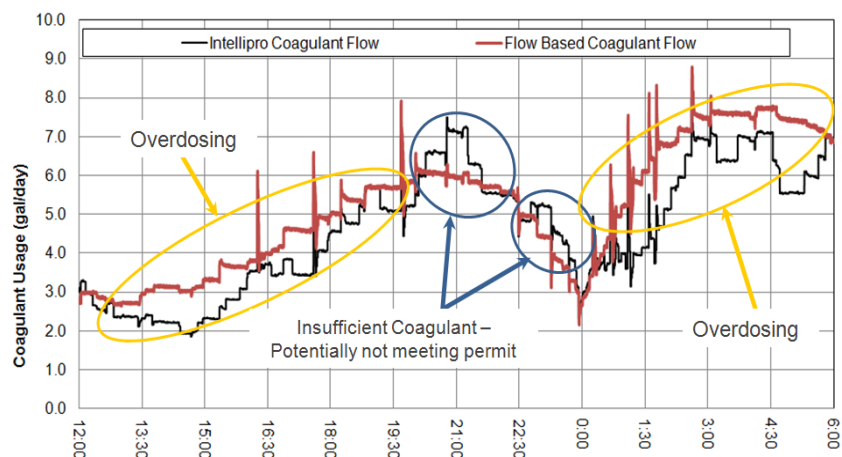
Figure 9. Flow based coagulant addition vs. smart control addition

Polymer control

The influent turbidity at the RRWRD is approximately 2 – 3 NTU under most conditions. The addition of coagulant at the rate required for phosphorus precipitation produces chemical solids primarily due to hydroxide formation. Data shows that the influent turbidity to the filter increase to approximately 10 – 11 NTU, demonstrating that the influent solids due to coagulant addition increased between 7 – 9 NTU. This is consistent with calculated data based on chemistry which shows that the estimated chemical solids production of 17 mg/l TSS.

Dosing of polymer was determined based on an overnight test where an initial concentration of 0.25 mg/l was selected and a total of ten tests were performed incrementing the dosage by 0.05 mg/l each hour. The results indicated that the optimal addition of polymer at the ninth coagulant dosing test at 0.65 mg/l and provided approximately 82.69% removal of turbidity.

Test Point	Dose (mg/l)	Influent T (NTU)	Effluent T (NTU)	Removal %
#1	0.25	10.05	2.04	79.70
#2	0.30	10.79	2.48	77.01
#3	0.35	10.90	2.94	73.03
#4	0.40	10.48	2.83	72.99
#5	0.45	10.70	2.99	72.05
#6	0.50	10.76	3.04	71.74
#7	0.55	10.76	2.79	74.07
#8	0.60	10.79	2.09	80.63
#9	0.65	10.92	1.89	82.69
#10	0.70	10.89	1.92	82.37

Figure 10. Polymer Optimization

Selecting the dosage that gives the best solids removal ensures that the particulate phosphorus was low thorough the test. After the initial dosage was selected, the system continually adjusted the dosage based on the effluent turbidity.

DISCUSSION/CONCLUSIONS:

When faced with ultra-low phosphorus limits, data collection becomes critical to optimize the performance of a system both from reliability and cost perspectives. However, vast data sets can impede operational optimization if continual monitoring and assessment isn't tied to system adjustment. Although instrumentation and controls can generate and record the necessary data, current control methods lack the ability to perform sufficient relational assessment and timely response to changing process conditions. As a result, operators are left with deploying conservative measures rather than risking permit non-compliance. Such efforts to sustain performance reliability are attained at significant costs due to excessive chemical usage and the ensuing solids production that affects various processes in the overall treatment scheme.

It was demonstrated that a unique algorithm evaluated instrument derived data and applied established process control measures to effectively manage polymer and coagulant feed systems. This strategy revealed that an increased level of system reliability could be maintained while optimizing chemical usage. The study showed that by determining the incoming mass of phosphorus in real-time, and monitoring effluent performance the potential for overdosing or underdosing can be managed to a greater extent than commonly used chemical flow-paced strategies.

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