Evaluation of an “Off the Shelf” automated chemical phosphorus removal system

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Abstract

In order to reduce ferric chloride consumption and maintain effluent compliance, the wastewater plan in Beaver Dam, Wisconsin installed an ‘off the shelf’ phosphorus control system manufactured by Hach Lange Company. In this installation, the phosphorus control system measures effluent orthophosphate and flow, using that information in the algorithms to control ferric chloride feed in real time before the final clarifiers. After 160 days of operation, the phosphorus control system reduced the ferric chloride feed by 56% (26,688 gallons) which equates to approximately $30,691 saved in chemical costs alone. Based upon these figures, return on investment of the installed cost of the phosphorus control system was 6.8 months.

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1. Introduction

Recently an “off the shelf” control system was developed for wastewater plants that perform chemical phosphorus removal. The system is called the “RTC101 Phosphorus Control System” manufactured by Hach (Loveland, CO) and consists of a phosphate analyzer and a pre-programmed control module which can be connected to a PLC, collecting flow and phosphate information to calculate the actual phosphorus load and output.
the appropriate chemical dose needed to meet the orthophosphate set point. The intended benefits of the system include a reduction in chemical consumption, a reduction in chemical sludge, and assurance that the effluent phosphorus limit is in compliance. The phosphorus control system was evaluated (and remains in operation) at the wastewater plant in Beaver Dam, Wisconsin, a 5 MGD extended aeration activated sludge plant that uses ferric chloride to precipitate phosphate in order to meet their 1.0 mg/L monthly average total phosphorus limit. Beaver Dam uses a simultaneous precipitation process, adding ferric chloride into the combined mixed liquor channel before distribution to the final clarifiers. The phosphate rich precipitant is settled in the final clarifiers, where some is wasted to their solids handling process, but most is recycled in the return activated sludge. After final clarification the wastewater is disinfected with sodium hypochlorite, dechlorinated with sodium bisulfite, and then discharged.

2. Materials and Methods

The entire system was installed on November 3, 2011, including an orthophosphate analyzer, transmitter for the analyzer, the phosphorus control system, and all cables and plumbing in order to make the system operational. The system at Beaver Dam is a feedback (closed loop) control system: measuring phosphate after final clarification and controlling the chemical feed upstream of the clarifiers. The phosphate analyzer is installed in a tunnel underneath the wastewater plant, measuring the effluent after disinfection. The phosphorus controller uses advanced algorithms to calculate the phosphorus load, beta value, stoichiometric relationships, and resulting feed required to precipitate the current phosphorus load. The algorithm calculations are then tuned using a PID loop based on input values from the phosphorus analyzer. The phosphorus controller is installed in a PLC cabinet on a DIN rail. Plant effluent flow measurement was output from the PLC to the phosphorus control system, and the precipitant dose was output from the phosphorus control system to the PLC where the existing pump control logic employed the suggested dose. The phosphorus control system required programming the following items, which were entered through the sc1000 controller:

- 4-20mA scale for chemical feed pumps, effluent flow meter, and orthophosphate concentration
- Concentration and molecular weight of the precipitant used
- Effluent orthophosphate set point
- Proportional gain and Integration time of the loop
- The minimum dose rate of the chemical feed system

Figure 1: Phosphate analyzer & Sampling equipment
Once installation and programming was complete, chemical control was switched from a static dose of 12.5 gallons per hour (gph) to the dose suggested by the real time controller. The initial proportional gain was set at 3.0 and an integration time of 10 minutes was set for the PID loop tuning of the algorithm used to calculate the appropriate dose of precipitant. Data was collected and analyzed between November 3, 2011 and April 11, 2012; for a total of 160 days of operation.

All of the components of the phosphorus controller are supplied by Hach (Loveland, CO). The phosphate analyzer used at this location is the PHOSPHAXsc, connected to a sc1000 controller. Ultrafiltered sample is supplied by the FILTERPROBEsc. Maintenance of the PHOSPHAXsc includes changing the reagent bottles (one bottle of reagent and one bottle of cleaning solution) every three months, and periodically inspecting the tubing and fittings to determine if any replacement is necessary. The FILTERPROBEsc has two self-cleaning ultrafiltration membranes and internal diaphragm pumps, which is immersed in a sample sink that contains plant effluent, as shown in Figure 1. Maintenance of the FILTERPROBEsc in this application includes wiping the membranes with a sponge every three weeks, and replacing the membranes when they are completely fouled. After 160 days of operation, the original membranes are still in operation, and it is expected that the membranes will provide at least two years of operation in this application. The sc1000 and phosphorus controller require no maintenance aside from periodic inspection to verify wires are still connected and the system is functional.

It was decided to install the analyzer and sampling equipment in a tunnel underneath the wastewater plant due to the proximity to the closest PLC cabinet, and the ease of performing maintenance on the analyzer. While the analyzer is rated for outdoor environments, operators are much more likely to perform maintenance on the equipment if it is easily accessible and not subject to extreme temperatures and weather.

The phosphorus controller is manufactured by Beckhoff (Verl, Germany) and programmed by Hach. End user set points are entered into the phosphorus controller through the user interface of the sc1000 controller. The phosphorus controller consists of a power supply, local power disconnect switch, a CPU module, and input/output modules as shown in Figure 2 below.

Figure 2: Phosphorus Controller Hardware
3. Results

Figure 3 below displays the initial results from the phosphorus control system between November 3rd and November 23, 2011.

Initially the phosphorus control system output the minimum dose of ferric chloride, as defined in the program (0.66 gph). The orthophosphate set point was initially programmed to 0.7 mg/L PO₄-P and due to the accumulation of ferric chloride already present in the system, the analyzer measured between 0.35 and 0.55 mg/L PO₄-P in the effluent and output the minimum dose. At 5:35am on November 4th the phosphate concentration exceeded the set point and the phosphorus controller output an increase in ferric chloride dose, eventually reaching the maximum dose for the feed system of 19.4 gph. The controller immediately requested the maximum possible dosing rate to reduce the PO₄-P down towards the set point. With the PO₄-P concentration reducing, the dosing rate was also reduced to a level to reach the targeted value of 0.7 mg/L PO₄-P. This same trend was observed throughout the study period as spikes of phosphorus came into the plant and required an increase in precipitant.

It was determined that the minimum dose of 0.66 gph was too low for the diaphragm-type chemical feed pumps to function correctly, so in the morning of November 8th the operator reprogrammed the minimum to 1.33 gph, and changed the orthophosphate set point to 0.6 mg/L PO₄-P in order to satisfy the minimum requirements of the chemical feed pumps. It is between this time and November 12th that the phosphorus control system actively responds within the expected range to changes in flow and orthophosphate concentration in order to maintain the targeted orthophosphate set point.
Figure 4 above displays the clarifier effluent orthophosphate concentration against the programmed set point of 0.60 mg/L PO$_4$-P, as well as the ferric chloride dose in gallons per hour compared to the previous dose of 12.5 gallons per hour. On February 14th the phosphorus control system sensed an increased load of phosphate and increased the ferric feed in order to maintain the desired 0.60 mg/L set point. The phosphorus load continued to increase, which the control system sensed and increased the ferric dose until the maximum dosing rate of the system was reached. Once the load decreased below the set point, the control system decreased the ferric dose until another spike of phosphorus entered the plant. This happened several times during the study period, which explains the relatively high original ferric dose of 12.5 gallons per hour. Overfeeding to such a high degree was necessary to meet the desired effluent concentration set point.

Table 1: Summary of the precipitant dosing data

| Ferric Chloride Savings (160 Day Period) | Before          | After          |
|----------------------------------------|-----------------|----------------|
| Dose                                   | 12.5            | 5.55           |
| Gallons Consumed                       | 48,000          | 21,312         |
| Gallons Saved                          |                 | 26,688         |
| % Saved                                |                 | 56%            |

Table 1 highlights the entire study period data, comparing the ferric chloride dose before and after the installation of the phosphorus controller. After 160 days of operation, the average dose was 5.55 gph compared to the previous dose of 12.5 gph. Over the study period this equates to a reduction in chemical feed of 26,688 gallons, or 56%, while maintaining an effluent total phosphorus concentration less than the 1.0 mg/L monthly average limit.

The installed cost of the system was approximately $40,000 which included the orthophosphate analyzer, phosphorus controller, wiring, plumbing, and integration costs.
The average cost of ferric chloride over the study period was $1.15 per gallon. Reducing the ferric dose by 26,688 gallons saved $30,691 in ferric costs alone. It is estimated that a significant reduction in sludge production also occurred along with the reduction of precipitant, but at the time of this writing, the sludge production data was not available. In the future, analysis of the sludge production data would be helpful to understand the complete benefits of the phosphorus controller system.

Based upon this data, the return on investment of the phosphorus control system is 6.8 months (208.5 days).

4. Conclusions

The phosphorus control system at Beaver Dam, Wisconsin has proven that it will perform as expected, and dose ferric chloride in real time in order to meet an effluent set point. The return on investment of the control system is 6.8 months, which may be faster than most wastewater treatment plants due to the relatively high original ferric chloride dose, and the fact that it was a static dose and not a flow proportional dose. Future research on the phosphorus controller should include a complete understanding of the benefits such as sludge production, and a longer study time frame of one to two years to fully understand the costs including a more complete understanding of maintenance requirements.

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