In-Line Real-Time Measurement of Polymer Concentration in Centrate and Filtrate of Full-Scale Dewatering Facilities

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ABSTRACT

Polymer consumption associated with sludge dewatering operations is typically a significant fraction of operating costs for wastewater treatment plants (WWTPs). Although efforts have been made to generate real-time signals which can be used for optimizing polymer dose, many of these have not proven to be robust or reliable. A UV-vis analyzer configured for 191 nm wavelength, which had been previously validated for quantitation of polymer residual at bench-scale, was tested at full-scale dewatering operations on both centrate and filtrate. The resulting data showed that UV-191 absorbance measurements exhibited the expected parabolic shaped curve, where the minimum absorbance value corresponded to the optimum polymer dose. The UV-191 analyzer can be used for in-line and real-time monitoring of polymer residual at full scale dewatering operations and auto-adjustment of polymer dose.

KEYWORDS: Centrate, filtrate, dewatering, polymer residual, absorbance, cake solids

INTRODUCTION

Most wastewater treatment plants that dewater sludge have made bench scale efforts to identify the optimal dewatering polymer type, molecular weight and charge density that meets the specific goals of final cake dry solids (% DS), solids capture, and annual operating cost. Polymer candidate screening can be achieved and dose optimization can be approximated via jar testing; however, at many plants the feed sludge characteristics can vary from day to day and this can result in a polymer dose that is no longer optimal (WERF Guidance Manual-1993). This is especially true of plants that have little or no volumetric storage of the excess biological sludge directly upstream of the final dewatering operation. With this in mind, a better solution would be one where the target optimum polymer dose is periodically checked, and if necessary, re-established based on one or more feedback signals. For these case studies, a global objective was to progress from bench-scale to full-scale and demonstrate that the UV absorbance value at
191 nm is an excellent candidate for this feedback signal. This optimization method is based on identifying the optimum polymer dose (or narrow dose range) which correlates to the minimum absorbance determined from a polymer dose response curve.

**Background**

Following the successful bench-scale validation of the UV-Vis spectrophotometric method for quantitation of polyacrylamide-based polymer residual concentration in a centrate matrix (see Figure 1 (Gibbons and Ormeci, 2013; Al Moman and Ormeci, 2014), it was decided to continue the evaluation phase by performing demonstration tests at full-scale dewatering facilities. These field study evaluations consisted of monitoring real time signals using a prototype in-line single wavelength UV-Vis analyzer and an in-line dilution system on both centrate and filtrate streams.

![Absorbance spectra of Zetag polymer (0-10 mg/L) in centrate after 1:10 dilution](Gibbons and Ormeci, 2013)

**Figure 1. Absorbance spectra of Zetag polymer (0-10 mg/L) in centrate after 1:10 dilution (Gibbons and Ormeci, 2013)**

The principle objectives of the field study were: i) test the robustness of the prototype analyzer coupled to an automated sampling/dilution system, ii) validate that this method, configured as an
in-line analyzer, could produce accurate field measurements in real time, on centrate and filtrate, ii) demonstrate that the analyzer could produce absorbance signal trends with adequate resolution, within a controlled polymer dose response exercise, such that a dose optimization curve could be generated similar to lab scale trends as reported by Al Momani and Ormeci, 2013 (see Figure 2). The field test results demonstrated that this analyzer and the method can be used to identify an optimum polymer dose over a narrow range.

Figure 2: Relationship between the CST, filtration volume, and filtration absorbance at 191.5 nm in the under dose, optimum dose and over dose ranges for polymer CA 475. (Al Momani and Ormeci, 2014)

METHODOLOGY

The analyzer system consisted of the single wavelength (191 nm) UV-vis spectrophotometer [Real Tech, Inc., Ontario, Canada] with an auto sampling/conditioning/dilution system. This wavelength is considered in the near ultraviolet range. During these test studies, a full spectrum UV-vis spectrophotometer with deuterium light source [Real Tech, Inc., model Real Spectrum Gold Series] was coupled in series with the single wavelength UV-191 analyzer.

There is a high likelihood that centrate and filtrate will be relatively high in suspended solids concentration (TSS) and large particles can be present. Sample filtration to remove TSS would increase the complexity of a real-time monitoring system. Bench-scale testing proved it is
sufficient to simply dilute the sample with suspended solids free water without any filtration step. In addition, in order to settle out the larger and heavier suspended solids to avoid internal analyzer tube clogging, a small stilling well (with approximately 1-3 minute HRT) was employed upstream of the dilution stream. The centrate or filtrate sample is pumped via mini peristaltic pump to the stilling well. A second mini peristaltic pump continuously conveys supernatant from the stilling well into and through the analyzers. A third mini-peristaltic pump provides dilution by pulling deionized (DI) water from a reservoir at a preset dilution rate. The DI water is continuously mixed with the sample via in-line static mixer. The diluted sample then flows through the sample cell in the UV191 analyzer and finally through the full spectrum analyzer to a drain. The proper dilution ratio (water:sample) is predetermined via a screening exercise where a range of dilution factors are tested over a polymer dose range and the resulting absorbance values are recorded at each polymer dose. Both the magnitude of the absorbance values and the dynamic range of absorbance values over the polymer dose range are a function of the dilution ratio. The optimum dilution ratio is matrix specific and therefore site specific. An example of how the dilution ratio can affect the sensitivity of the absorbance measurement is more obvious in the lab-scale belt filtration test data presented in Figure 3. In this case there is a clear increase in sensitivity of absorbance signal as the dilution ratio was decreased from 140:1 to 40:1 as deionized water:sample. (This data is from bench tests performed at the S. Durham WRF. Preliminary experiments such as this were used to screen for typical dilution ratio ranges and make final determinations on whether dilution is required.

Fig. 3- Effect of Sample Dilution on Absorbance Signal Amplitude at 191 nm.
The automated sampling/dilution system is a key component and was field verified by performing drawdowns using graduated cylinders. In order to investigate the potential signal influences of auto dilution, the following procedure was performed using two different dilution ratios: grab centrate samples were collected and immediately refrigerated; the centrate samples were run through the auto dilution system and UV 191 analyzer and the absorbance values were recorded. This absorbance data was compared to absorbance results measured on manually diluted centrate samples at each dilution ratio. The absorbance values differed by less than 10% on a relative scale.

**Centrifuge Field Demonstration Test**

The South Cary WRF (SCWRF) is a 12.8 MGD advanced activated sludge treatment system designed for nutrient removal. The current flow averages 5.3 MGD. There is no primary treatment system; therefore, only waste activated sludge (WAS) is generated. The SCWRF WAS is blended with WAS imported from two other facilities and aerobically digested in a 1.8 MGal aerobic sludge holding basin. Following aerobic stabilization, the sludge is dewatered, via centrifuge, and thermally dried. The plant uses Clarifloc (R) SE-757 a high molecular weight cationic polyacrylamide. The facility typically doses polymer between 20 to 30 lbs/DT, producing cake solids between 18 to 20% and consumes approximately 175,000 lbs of dewatering polymer annually.

Initial tests were run to see if potable tap water could be used in lieu of DI water (i.e. would use of tap water produce signal interference or bias?). The absorbance results using potable water were compared to those using DI water and it was determined that the DI water was not required. Both optical units and the auto dilution system are shown in Figure 4.

![Figure 4 - UV-Vis 191 analyzer setup](image)

**Centrifuge Test Results**

Full scale testing at the SCWRF began in January 2014 and continued over a period of 2 months. After establishing the required dilution ratio (77:1) the sampling frequency was set to 1 minute intervals. Centrate sampling and UV absorbance analysis was performed continuously while the full scale dewatering polymer dose was manually decreased in 4% increments by varying the
polymer feed pump speed (e.g. from 36% to 32%) and then increased above the original set point dose likewise in 4% increments. At a time point approximately 45 minutes after each polymer dose change, representative samples of cake were collected and the resulting dry solids concentration was measured (EPA Method 160.3). Table 1 below is a summary of the field data. Results showed that the minimum absorbance of 191 analyzer (and centrate turbidity) occur at a dose of 23.5 lb/DT. The lowest absorbance measurement on the full spectrum analyzer was at a dose of 25.5 lb/DT. This bias is expected as the single wavelength analyzer has better sensitivity and its response time is faster.

Table 1: Analysis of cake solids, turbidity and real-time measurement of UV absorbance (191 nm) in centrate when polymer dose was incrementally increased during full-scale testing.

<table>
<thead>
<tr>
<th>Dilution Ratio (DI-Centrates):</th>
<th>77:1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Polymer Pump</strong></td>
<td><strong>Polymer Pump Feed Rate</strong></td>
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<tr>
<td>Percent (%)</td>
<td>(gpm)</td>
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<td>9.49</td>
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<td>44</td>
<td>15.49</td>
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<tr>
<td>48</td>
<td>16.49</td>
</tr>
</tbody>
</table>

Figure 5 is a dose response curve at a fixed dilution ratio of 77:1 water:centrate depicting absorbance measured at 191 nm, with single-wavelength and full-spectrum UV analyzers and the centrate turbidity. Absorbance and turbidity (measured with a bench turbidimeter) were recorded approximately 20 minutes after each polymer dose change. The absorbance curve followed a parabolic shaped trend with an absolute minimum at a polymer dose of 23.5 lbs/DT. The plants operational dose for this day was 35 lb/DT. If operating at the optimal dose as determined by UV-191, the plant could potentially see a 30% reduction in polymer consumption while still maintaining similar final cake solids concentration as cake solids showed minimal changes (approximately 1% increase throughout the entire dose range of this test). The parabola based curve is a result of two conditions: underdosing and overdosing. On the underdosing side of the curve (where the slope is negative) the absorbance signal increases at the lower doses due to underfloculated particles that are carried over in the centrate, thus increasing the absorbance signal. Around the optimum polymer dose the absorbance is at a minimum due to the removal of the particles and lack of excess polymer in the centrate. On the overdosing side of the curve, the absorbance signal again increases due to the increasing excess polymer in the centrate.
Further experimentation was performed with collected samples to test the validity and effect of the stilling well on the absorbance. Concerns arose around the residual polymers effect over time and the retention time of the stilling well. Samples from this previous real-time experiment were collected and refrigerated for a day or more. The settled samples were then pumped through the analyzers at the same dilution rate. Absorbance values showed a similar curve shape; however, with a broader minimum, see Figure 6. This could be due to latent polymer reactions with wastewater constituents, settling out of the particles and possibly due to polymer hydrolysis/decay. Further experimentation included testing real-time centrate without the stilling well in place. Results showed increased signal fluctuations and a much less defined minimum absorbance signal. These experiments proved that the simple stilling well adequately removed larger particles while providing a stable representative sample for the UV-191 analyzer. This was beneficial because it shows no additional processes (spinning, filtering etc.) were needed for pretreatment of the centrate sample. The stilling well(conditioning system proved to be a suitable simple solution for pre-treatment.

Figure 5: Absorbance trend-Centrifuge Demonstration Testing
The data presented in Figures 5 and 6 and Table 1 support the theory that the absorbance signal measured on centrate will be at its minimum when the polymer residual in the sample is at its lowest concentration. The turbidity data trends correlate well to absorbance trends, as the clarity of the centrate is the best at the optimum polymer dose.

**Belt Filter Press Field Demonstration Test**

The Danbury, CT Water Pollution Control Plant is operated by Veolia Water. The treatment system consists of primary settlers, trickling filters and activated sludge. The excess sludge is anaerobically digested (mesophilic). The typical PS:WAS ratio is approximately 70:30. The dewatering equipment consists of two 2.5-meter Roediger Pittsburgh BFPs. The plant uses a Mannich polymer (Polydyne Clarifloc C-321) at doses of 11 to 16 lbs/DT producing cake at 16 to 19 % DS.
Fig. 7 Typical Filtrate Quality – Danbury, CT

Fig 8: Roediger Belt Filter Presses -Danbury, CT Water Pollution Control Plant
BFP Test Results

Belt filter press testing began in September 2014 and continued for several weeks. Initial testing consisted of making slight adjustments on the polymer speed pump. The speed of the pump was recorded and then verified with draw-downs for an accuracy check on polymer dose measurement. Initial tests showed that the UV191 analyzer was recording a similar curve trend to that of centrifugation. This particular trend is ideal in that a distinct minimum can be detected and an optimal dose can be selected. Data collected during the first week of testing is presented in Figure 9 below.

![Figure 9: Absorbance, Turbidity and Cake Solids trends - Belt Filter Press Demonstration testing](image)

The dilution ratio was preset to 25:1 and a 5 point curve was run. The UV191 analyzer detected a minimum absorbance at a dose of 12.5 lb/DT, approximately 10% higher than the plant’s target applied dose of 11.4 lbs/DT. The filtrate turbidity trend followed a similar shape but with a minimum at a polymer dose of 17 lbs/DT. In reviewing the overall range of absorbance values it was noted that the dilution rate was likely not optimized, because the dynamic range of absorbance was very narrow (spanning only 0.07 absorbance units). Samples were then collected and refrigerated and analyzed at various dilutions to further target the optimal dilution rate, see Figure 10. In this particular case the lowest dilution ratio showed the largest changes in absorbance. The dilution ratio was then set to 14:1 and testing continued.
Further investigation was conducted by testing the absorbance signals taken at various sample locations on the press. Modern BFPs typically consist of 2 belts in a 3-zone configuration. The three main zones, include: a gravity zone, a low pressure zone, and a high pressure zone. This particular press employed a rotating flocculation drum as the gravity zone. Filtrate samples from the low and high pressure zone are typically very high in turbidity (>1000 NTU) and usually contain a high solids concentration in the filtrate. Both turbidity and absorbance were measured on samples collected in the gravity zone (drum filtrate) and the low pressure zone. Different dilutions were also tested for absorbance measurements. This data is summarized in Table 2 below:

![Absorbance vs. Dilution Rates](image)

**Table 2: Belt Filter Demonstration testing data**

Results showed the absorbance trends for samples collected from the gravity zone/drum filtrate were similar to those collected in the low pressure zone. Fewer disturbances and fluctuations were noted on the gravity zone filtrate compared to the low pressure zone filtrate. The gravity zone had essentially no wash water which minimized the potential for interference. Sample points downstream (pressure zones) have large amounts of washdown water and significantly
higher suspended solids so these locations were eliminated as non-ideal. Following this investigation, all filtrate samples were collected from the flocculation drum/gravity zone drain port.

**Fig. 11** – Absorbance and Turbidity measurements at 14:1 dilution on samples collected in Gravity Zone

**Fig. 12** – Absorbance and Turbidity measurements at 30:1 dilution on samples collected in Gravity Zone
The data presented in Table 3 is a summary of six individual test runs and it shows that the minimum UV absorbance signal corresponds to a significantly different polymer dose from week to week over a three week period, indicating that the sludge quality is potentially changing from one week to the next. Cake solids were for the most part very similar using the operator selected dose compared to the analyzer-determined optimal dose, but previous tests also showed that final cake solids did not respond to even large changes in polymer dose (see Figure 9) likely due to the characteristics of this polymer. It should be noted that this was a well managed dewatering operation already operating in the optimal polymer dose range. Final results indicated the analyzer-determined optimal dose was, on average, within 10% of the operational target dose. The results in Table 3 also show that, even at well-operated facilities, there is room for improvement in the dewatering operations due to the daily changes in sludge characteristics.

<table>
<thead>
<tr>
<th>Date</th>
<th>Plant Operation Dose</th>
<th>Minimum Absorbance Signal</th>
</tr>
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<tbody>
<tr>
<td>17-Sep</td>
<td>11.73 % 17.50 lb/DT</td>
<td>13.35 % 19.30 lb/DT</td>
</tr>
<tr>
<td>18-Sep</td>
<td>11.50 % 18.10 lb/DT</td>
<td>11.89 % 18.18 lb/DT</td>
</tr>
<tr>
<td>23-Sep</td>
<td>11.80 % 16.99 lb/DT</td>
<td>11.94 % 16.90 lb/DT</td>
</tr>
<tr>
<td>26-Sep</td>
<td>14.76 % 16.80 lb/DT</td>
<td>16.88 % 17.70 lb/DT</td>
</tr>
<tr>
<td>30-Sep</td>
<td>13.30 % 18.10 lb/DT</td>
<td>15.06 % 18.54 lb/DT</td>
</tr>
<tr>
<td>7-Oct</td>
<td>15.79 % 18.50 lb/DT</td>
<td>17.51 % 17.92 lb/DT</td>
</tr>
</tbody>
</table>

**Table 3: Belt Filter Demonstration Testing Summary**

**CONCLUSIONS**

Full-scale dewatering testing was carried out at two WWTPs. The first plant uses high speed centrifuges and the second plant uses BFPs. The polymer dose incrementally increased to cover the under-dose, optimum dose and over-dose polymer ranges, and centrate/filtrate absorbance at 191 nm, turbidity and cake solids were measured.

Centrate/filtrate UV absorbance was measured with an in-line and real-time UV analyzer that is also equipped with an auto dilution system. The results showed that absorbance measurements exhibited a parabolic shaped curve where the minimum point corresponded to the optimum polymer dose. On the underdosing side of the curve (where the slope is negative) the absorbance signal increased at the lower polymer doses due to the underflocculated particles. At the optimum polymer dose, the absorbance was at a minimum due to the removal of the particles and not having excess polymer in centrate. On the overdosing side of the curve, the absorbance signal again increased due to the presence of excess polymer and the UV-191 analyzer’s ability to measure this residual polymer concentration.

The full-scale tests confirmed the lab scale results that were previously reported by Ormeci and co-workers (Al Momani and Ormeci, 2014; Aghamir-Baha and Ormeci, 2014) and proved this analyzer is suitable for use in full-scale dewatering optimization.

- The unit was operated for several weeks without requiring chemical cleaning of sample lines (including periods where centrate turbidity was as high as 1,000 NTU).
Following the screening protocol for determination of optimum dilution ratio, absorbance signal dynamic range and signal stability was excellent.

Absorbance versus polymer dose trends can be generated and used to determine optimum polymer dose.

The unit can be used for in-line and real-time monitoring and adjustment of polymer dose to account for daily changes in sludge characteristics.

Final implementation and integration of the analyzer configuration will consist of using the UV–191 absorbance signal trend, generated via periodic dose response tests, directly as the feedback signal for setpoint adjustment of polymer dose in a full-scale dewatering operation.

Acknowledgements

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REFERENCES


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