Feed-forward coagulant control using online UV/Vis monitoring
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ABSTRACT

Water quality from the Murray River, Australia, can vary considerably and is expected to become more challenging to treat due to recent drought followed by widespread flooding and future climate change impacts. Better tools are required to help plant operators maintain water quality. Morgan water treatment plant (WTP) operates overnight to take advantage of off-peak electricity, however the stop/start practices add an additional complication to accurate coagulant dosing. Online monitoring and feed forward prediction is ideal in these situations as it can provide information while there is still a chance to make adjustments, unlike the feedback (post-dosing) control achieved with many other methods. Using a multiport sampling arrangement, water quality was monitored at Morgan WTP for a 6 month period. Data were validated against other online parameters and laboratory measured samples. In a comparison of predicted versus actual plant dose, results showed that treatment was optimised when the plant dose was changed in response to product water quality deterioration and eventually matched the prediction, even though this was not known to the operators at the time. The software prediction demonstrated faster reaction to inlet water quality changes and can produce more stable treated water quality. The predicted dose was added to the operator’s Supervisory Control and Data Acquisition (SCADA) system for several months as a real-time display to provide an additional tool to aid decision making and instill confidence in the resulting water quality.

Key words | coagulation, feed-forward control, spectroscopy

INTRODUCTION

In 2009, many eastern Australian water sources were suffering from the effects of extended drought. Towards late 2010, the input of considerable volumes of floodwaters produced source water qualities unseen for decades, with considerable impact on treatment plant operations. The Murray River is the main water source for South Australia. The water quality can vary considerably and like many surface water sources, quality is generally subject to seasonal trends and short term variability. With greater public expectation and tightening of drinking water guidelines, better tools are required to help assist plant operators maintain high quality drinking water. The Morgan water treatment plant (WTP), located 140 km from Adelaide, South Australia, operates predominantly overnight to take advantage of lower off-peak electricity charges; however the stop/start practices add an additional complication to accurate coagulant dosing. While the plant has historically produced consistent water quality, the source variation has required plant operators to develop appropriate response strategies built upon years of experience. Coagulant doses were set in response to changes in settled water turbidity. This form of dose control was reactive and if the settled water turbidity started to increase it would take hours to recover performance. The use of feed forward coagulant dose prediction would change the control strategy from reactive to proactive, with the aim of avoiding any settled water turbidity increases.

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The application of feed-forward control has another advantage in supporting the operation of the Morgan WTP. When the plant was built in the mid-1980s it was accepted practice to return any water that was below specification to the river, and the infrastructure of the plant was arranged accordingly. As this is no longer practiced due to environmental concerns, if an incorrect coagulant dose causes unacceptable settled water quality (detected after the event) the only choice is to circulate the water through the plant pre-filters while adding more coagulant, until the settled water meets the required standard. This can take up to 12 hours and has a significant impact on human resources and operational expenditures.

It is well established that the concentration and character of natural organic matter (NOM) has considerable impact on coagulant dose and coagulation efficiency. Several characterisation techniques have been developed to enable a better understanding of the impact of organic matter on treatment processes. NOM is more commonly represented by the measurement of total (TOC) or dissolved organic carbon (DOC) concentration due to the high cost of quantification of the separate components. Generally, TOC and DOC are determined using an organic carbon analyser. Though most of the commercially available organic carbon analysers are automated units, the principle of organic carbon measurement requires multiple analytical steps to be performed in sequence and are therefore not true online instruments. Simple analytical techniques, such as single wavelength UV absorbance measurements (UV254) or colour (absorbance at 456 nm) have been used as surrogate parameters to monitor the concentration of NOM and they are widely accepted by water treatment operators as parameters to assess treatment plant performance. Measurement of single wavelength UV absorbance is one of the simplest organic matter qualitative characterisation methods and spectrophotometers of both laboratory and field instruments are widely available, however single wavelength measurements capture only a fraction of the available information in the absorbance spectrum of organics in a water source. Full UV/Vis absorption spectra can be used to obtain much more analytical data and better capture chemical changes in a water source that may affect its interaction with treatment and disinfection processes (Li et al. 2000; Nikolaou & Lekkas 2001; Korshin et al. 2007).

The use of online instrumentation for the monitoring of water quality parameters is not a new concept, with many WTPs acquiring real-time data as a matter of normal operation. However, advancement of both hardware and scientific evaluation of the data is creating new possibilities for prediction and control in treatment plant operations. Online, full spectrum (multi-wavelength) UV-visible analysers offer reagent-free operation and calculated equivalents for many water quality parameters (Storey et al. 2011). One example, the Spectro::lyser (s::can Messtechnik GmbH, Austria) is a self-contained unit with an adaptable software suite enabling multiple parameters to be monitored simultaneously (Langergraber et al. 2003; Rieger et al. 2004; Sutherland-Stacey et al. 2008; van den Broeke et al. 2008; Libovic et al. 2009). Coagulant dose prediction can be achieved through Com::pass, an add-on software package using inlet water quality parameters and advanced algorithms to give feed-forward control. While this technology has already been successfully applied to actively control coagulant dosing, it was unclear if the particular water quality of the Murray River water would be amenable to this means of coagulant dosing prediction. The aim of this investigation was to determine the feasibility of using an online analyser to provide feed-forward coagulant dosing advice at the Morgan WTP and compare the performance and efficiency to traditional control methodologies.

**METHODOLOGY**

**s::can Spectro::lyser**

The on-line UV/Vis spectrophotometer chosen for this investigation is the s::can Spectro::lyser™ (s::can Messtechnik GmbH, Austria). The s::can hardware comprises a submersible double beam full spectrum UV/Vis-spectrometer (200–750 nm) with optical path lengths in a selectable range between 0.05 and 10 cm. The instrument is designed on the principle of the photodiode array (PDA) emitter, having no moving parts. The rapid full spectrum UV absorbance measurement provides concentration information for a number of parameters and calculated equivalents for others such as TOC, DOC, trihalomethane formation potential, nitrate, nitrite, turbidity, total suspended solids and particle
size. It has been shown to be a useful tool to provide warning of any sudden changes of water quality (Perfler et al. 2002; Langergraber et al. 2004). Consequently the Spectro::lyser™ has many diverse applications, from drinking water to waste water quality assessment as well as monitoring of industrial fluids (Langergraber et al. 2002). For this study, a 3.5 cm path length unit was selected for combined raw and treated water monitoring. Com::pass (h2opec, NZ) is an add-on software package that uses the UV/Vis data from the Spectro::lyser™ along with on-line turbidity measurement to determine the coagulant dose required to achieve treatment aims. Com::pass uses a NOM characterisation parameter similar to SUVA (Korshin et al. 1997; Weishaar et al. 2003), derived directly from the solids compensated UV/Vis spectra, to determine what weighting to give to component algorithms for turbidity removal and NOM removal. Com::pass is available with global calibration settings developed from work on a large number of different plants (Laidlow 2007; Colton & Laidlow 2009). The global calibration settings can also be fine-tuned for a specific site by training the software on real-time plant data. The predicted coagulant dose can be input into the plant control system to automatically control the coagulant dose in response to on-line measurement of raw water quality or it can be used in the plant supervisory control and data acquisition (SCADA) system in an advisory mode to aid the operator decision making.

Morgan WTP program

The investigation was conducted in three phases. Firstly, using a multiport sampling arrangement, water quality was monitored at the Morgan WTP at the inlet and four other points throughout the treatment process for a 6 month period to evaluate the applicability of Com::pass in an off-line mode. Data collected was validated against other online parameters and laboratory measured samples. Secondly (Phase 2), monitoring was restricted to the plant inlet water stream (location 1, Figure 1) and coagulant demand prediction was applied in a blind test reported on a monthly basis. Similarly, a streaming current monitor (SCM) (SC5200, Milton Roy, Australia) was installed towards the end of the 6 month period for comparison with the Com::pass predictions.

Finally, the demand prediction was made available to plant operators via a live SCADA output at the control panel to allow it to guide dosing strategies until the completion of the project.

RESULTS AND DISCUSSION

Treatment plant operations

The parameter that drives coagulant dosing strategy at the Morgan WTP is the settled water turbidity. Typically, dosing is adjusted to maintain this parameter below a defined set-point. For this reason, accurate determination of turbidity is one of the more important considerations in sustaining plant performance. Comparison of data from online monitors, regular plant samples and laboratory analysed data shows good agreement between the trend of scan spectroscopically derived turbidity and plant online turbidity meters; however the samples transported for laboratory analysis showed evidence of transport effects.
resulting in lower turbidity values than measured onsite (Figure 2). In addition, towards the latter half of the month, plant lab samples showed a number of uncharacteristically high results demonstrating the potential risks of grab sampling practices which occur routinely at the same phase of plant operation, such as shortly after start-up.

In the second phase of the investigation, Com::pass predicted alum doses were compared with actual plant doses. It was observed that treatment was optimised when the plant dose set by the operators in response to product water quality deterioration eventually matched the Com::pass prediction, which had not yet been made available to the operators (Figure 3). Actual plant alum dose changes were made over a 5 d period (5th to 10th January) in response to a perceived water quality change, in this case a settled water turbidity increase (Figure 4).

Through observation of the filtered water turbidity (Figure 5), it can be seen that the changes made to the alum dose required 48 hours at the existing plant flow conditions to produce the required reduction to product water turbidity. This highlights the need for rapid reaction to inlet water quality changes to maintain consistent product water quality. Evaluation of the data showed Com::pass had been predicting a requirement for a 45 mg/L alum dose since late December 2008. In contrast, the period from 19th to 27th January illustrates an area where Com::pass predicted some coagulant dose reduction could be made without compromising treated water quality (Figure 3). Although the variation to inlet water quality over the investigated period was only moderate, Com::pass demonstrated rapid and appropriate reaction to water quality changes that would be expected to produce more stable water quality. The results indicate that the coagulant prediction based on characteristic UV/visible absorbance was similarly
effective in this water source as other coagulant models based on input water quality parameters used in published studies (Edwards 1997; van Leeuwen et al. 1999).

In August 2009, the predicted dose was added to the operator’s SCADA system as a real-time display to provide an additional tool to aid decision making in coagulant dose selection. In the test period from January to November 2009, it was shown that the plant performance was optimised when the alum dose applied matched more closely with the Com::pass prediction. An example of this is shown in Figure 6. Following a period of stable treated water quality where the plant alum dose and predicted doses were closely aligned, the Com::pass prediction began to decrease as a result of detection of an inlet water quality change. The plant alum dose remained steady, however filtered water turbidity began to increase slightly due to overdosing. This was noted by the plant operators and the alum dose was appropriately reduced, more closely matching the predicted dose. Subsequently, the filtered water turbidity regained optimised levels.

Other on-line instrumentations

In the latter part of the investigation, a SCM was installed to investigate the comparative performance of a more affordable and established technology for optimisation of coagulation performance. The strategy for successful operation of a SCM is to determine operating conditions that produce optimal water quality and record the output value of the SCM. From this point, the aim is to maintain this value through manipulation of the dosing, thereby producing consistent product water. If inlet water quality changes dramatically, this optimum ‘set-point’ can shift and will need to be revised accordingly. In Figure 7, the output of the SCM is shown between August and December 2009.

The monitor appeared to operate on 75 min cycles, requiring significant time within each cycle to stabilise and was therefore not well suited to the start/stop operational mode employed at Morgan WTP. This resulted in difficulty achieving SCM setpoint values at any time during plant operation (Figure 8). In addition, the trend of the values did not always appear to follow the water quality changes that prompted either the independent plant dose used by the operators, or the Com::pass prediction (Figure 7).

Economic evaluation

An economic evaluation was undertaken to determine any potential cost savings that would result from operating the
Table 1 | Economic evaluation of coagulant control modes at Morgan WTP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 average daily plant flow</td>
<td>ML/d</td>
<td>58</td>
</tr>
<tr>
<td>2009 average plant alum dose</td>
<td>mg/L as Al$^{3+}$</td>
<td>50</td>
</tr>
<tr>
<td>2009 average Com::pass alum dose</td>
<td>mg/L as Al$^{3+}$</td>
<td>47</td>
</tr>
<tr>
<td>% coagulant reduction</td>
<td>%</td>
<td>6</td>
</tr>
<tr>
<td>Actual coagulant used per annum</td>
<td>Tonnes/yr</td>
<td>1,059</td>
</tr>
<tr>
<td>Predicted coagulant used per annum</td>
<td>Tonnes/yr</td>
<td>995</td>
</tr>
<tr>
<td>Reduction per annum</td>
<td>Tonnes/yr</td>
<td>64</td>
</tr>
<tr>
<td>Alum chemical supply cost</td>
<td>A$/Tonne</td>
<td>200</td>
</tr>
<tr>
<td>Cost saving</td>
<td>A$/yr</td>
<td>12,800</td>
</tr>
<tr>
<td>s::can Spectro::lyser capital expenditure</td>
<td>A$</td>
<td>46,800</td>
</tr>
<tr>
<td>Morgan WTP break-even duration</td>
<td>yr</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Notes: *The plant actually runs at 116 ML/d for approx 12 hours a day. 
*With similar source quality variation.

plant on the Com::pass predicted dose compared with the actual dose used. The basis for the economic evaluation is summarised in Table 1. Given the capital cost of the instrumentation and annual variation consistent with the monitored 2009 calendar year, it was projected that it would require 3.7 yr to recoup the capital cost in coagulant savings. If source water quality was of greater (non-drought) variability, a shorter break-even duration could be expected.

CONCLUSION

While there have been clear benefits to the application of Com::pass coagulant dosing control in treatment plants with variable inlet water quality, it was necessary to investigate whether the improvement in performance at a well managed WTP outweighed the relatively high capital cost of such online instrumentation and the need for rigorous cleaning schedules.

In addressing the aims of the investigation, evidence for the benefits of feed-forward dose prediction was obtained using real plant data at the Morgan WTP where daily start/stop operation created challenges. Specifically:

- Online coagulant dosing prediction appeared effective with faster and more appropriate response to water quality changes than evaluation of post-treated (settled) water performance indicators;
- Com::pass dose prediction was more stable and easily interpreted than output from a streaming current detector on the same water source; and
- Capital costs of the instrumentation could be recovered in 3.7 yr based on coagulant dose savings calculated for Morgan WTP during the term of the investigation.

Overall, even without direct dosing control, coagulant demand prediction tools can offer guidance and boost operator confidence in times of source water quality uncertainty.

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