Multi-parameter based coagulant dosing control

L. Manamperuma, L. Wei and H. Ratnaweera

ABSTRACT

The required coagulant dosage is strongly related to the quality of raw water or wastewater. Online sensors for most quality parameters are now readily available to treatment facilities, yet remain rarely used in treatment process control. This paper presents the evaluation of an advanced coagulant dosing control system based on online measurements in full-scale processes. The popular multivariate analytical method, partial least square regression, was used to build up the relationship between the coagulant dose and wastewater quality. The system was tested in two wastewater treatment plants (WWTPs) in Norway. Coagulant savings up to 30% in Norwegian plants were observed with feed forward calibrations. The considerable savings reduce sludge production, leading to further cost saving on sludge treatment. This paper presents the method, function and experiences of the full-scale implementation of the system in different WWTPs.

Key words | coagulant, dosing control system, online parameters

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INTRODUCTION

The coagulation process is one of the most common, robust and practical methods for removing colloids, particulate matters, from water. It is especially used in removing natural organic matter in drinking water treatment (DWT) and converting phosphates (P) into particulate form for removal in wastewater treatment. The coagulation process consists of destabilising colloids and particulate matter, aggregating and binding the destabilised matters into flocculates. The resulting flocs can finally be removed by either settling, flotation or filtration. During this process, several chemicals have been conventionally used as coagulants and a system to dose coagulants into influent water.

Capital costs of a chemical wastewater treatment plant (WWTP) are generally much lower than that of a biological WWTP (Rathnaweera 2010) for removing P. Nevertheless, the operational costs of chemical treatment plants could be high, where chemical costs alone may represent up to 20% of the total operational costs of an average chemical treatment plant (Hangouet *et al.* 2007). This percentage could vary from plant to plant with the influent quality, required treatment efficiency and the management of WWTP. Optimal coagulant dosage and coagulant are the main important factors to reduce these operational costs.

Figure 1 illustrates the variations of flow, turbidity, and colour in Vansjø DWTP and flow, turbidity and Ortho-P, Total-P and suspended solids (SSI) in SRA WWTP over 12 consecutive days, respectively. It confirms that none of the parameters are proportional to each other. Subsequently, the optimal coagulant dosage is not possible to predict based on one or two of these parameters. This is because the optimal coagulant dosage is dependent on several parameters such as flow, particles, colour/phosphates and pH (DOSCON AS 2011). However, the usage of two or more parameters in coagulant dosage control is yet to be seen in full-scale applications as a common strategy.

The recent developments of the online water quality sensors have brought about the practical possibilities to use them in treatment plants. Many successful investigations of mathematical model-based coagulant dosage prediction control systems have been documented, with more stable effluent water quality and more cost effective than the manual/traditional dosing control systems (Chu *et al.* 2004; AlGhazzawi & Lennox 2009; Maier *et al.* 2010; Liu & Ratnaweera 2016). Initially, Lu (2003) developed a single model with multiple parameter inputs for predicting optimal coagulant dosage. Furthermore, a multiple model based advanced coagulant dosage control concept (ADCS) has been developed by DOSCON AS of Norway. The ADCS was tested, elaborated in full-scale WWTP with 30% of the coagulant savings in coagulates at a WWTP by Rathnaweera (2010). Liu *et al.* (2013) extended the ADCS concept to a full-scale DWT plant

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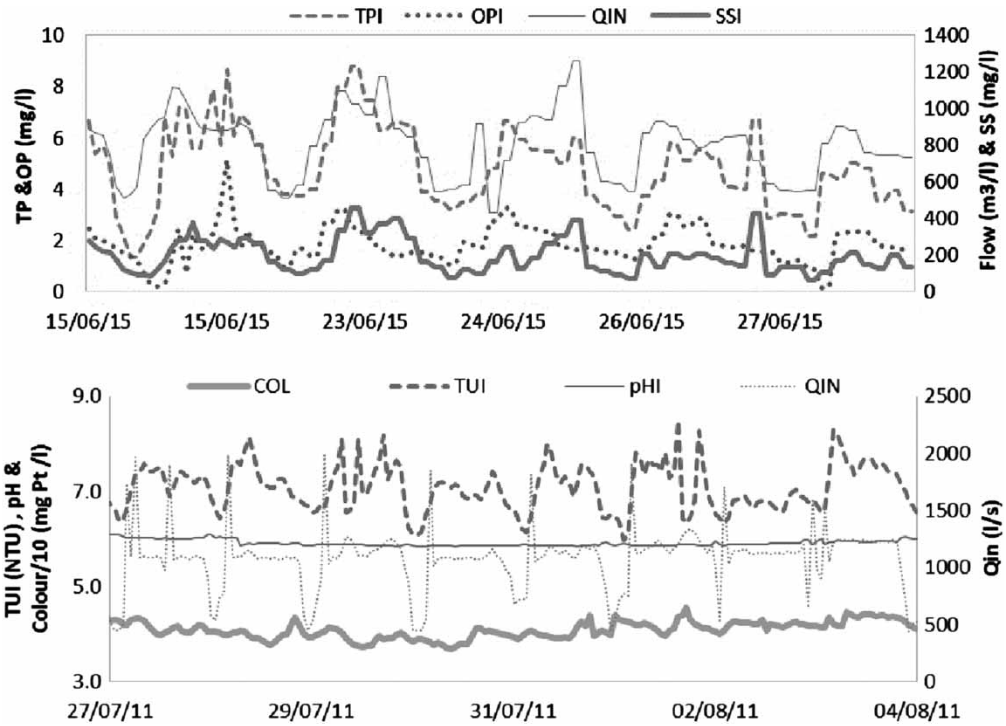

Figure 1 | Variations of influent water quality of SRA WWTP (above) and Vansjø DWTP (below): colour inlet (mg Pt/L), influent flow (L/s), turbidity (NTU), influent pH, influent Ortho-P (mg P/L), influent Total-P (mg P/L) and suspended solids (mg/L).

and documented 10% coagulant savings compared with flow proportional dosing control.

WWTPs have limited treatment capacity and are not able to treat all wastewater that enters the plant (i.e. heavy rain and water from rapid snow melting). Therefore, bypassing exceeding portions without treatment is a common practice during extremely high inflows. On the other hand, authorities in Norway have started to require total pollution discharge documentations, and discharge permits related to the total wastewater volumes received or discharged, rather than only for the portion that goes through the WWTP. Manamperuma *et al.* (2013) reported successful results on how recalibration of the ADCS can increase the treatment efficiencies while also rapidly increasing the flow rates and bypass lines.

Due to the long retention time in separation stages, the ADCS was based on feed-forward concept only. Liu & Ratnaweera (2016) improved the ADCS with feed-back concepts. Later, they presented an outlet software sensor that enables the feedforward-feedback model to be used in systems with traditional separation stages with hours of retention times. The successful test results from DWT plants and WWTP demonstrate the more stable effluent water quality.

An efficient coagulant dosing control system and treatment of municipal and industrial wastewater and drinking water are crucial to sustaining community health and a clean, safe environment. Previous test results highlight that the application of the ADCS for coagulant dosing shows a positive impact on the operations, maintenance, process development and savings for DWTPs and WWTPs. This paper describes case studies on further applications of the ADCS in treatment plants, aiming to improve and stabilise effluent treatment quality while reducing the coagulant consumption.

MATERIALS AND METHODS

The ADCS developed by DOSCON AS is installed at the Nedre Romerike (NRA) WWTP in Norway, serving about 130,000 pe or 50,000 m^3/day. It is located in Lillestrøm, Norway and built inside a tunnel of rock, which serves the population of the four municipalities Nittedal, Lørenskog, Rælingen and Skedsmo. The ADCS receives online signals of water quality from the WWTP's supervisory control and data acquisition (SCADA) system, and an embedded PC with a set of algorithms enables the estimation of the optimal dosage for any given influent quality. Then, the estimated dosage value is sent to the WWTP's SCADA system to control the dosing pump. The treatment process of NRA WWTP consists of the pre-treatment process; biological process with a series of moving bed biofilm reactors; chemical coagulation process; and sludge treatment.

Vansjø DWTP is located in Moss, Norway. The DWTP serves around 63,000 people. At present, Vansjø DWTP supplies the municipality of Sarpsborg. The water source is Vansjø lake. The treatment scheme consists of coagulation, flocculation, flotation, filtration and disinfection. After flotation the water is filtered in three-layer media filters. The layers consist of gravel, sand and anthracite coal. The media filters are followed by charcoal filters. Chlorine is used as disinfectant. Additionally, UV radiation was installed in 2010. The hydraulic retention time for disinfection is approximately 8 h. Vansjø DWTP uses the SCADA system for process control.

Solumstrand WWTP (SRA) was built in 1991 with a capacity of 72,000 m^3 /day. Demands for adaptation to secondary treatment and increased capacity to prepare for the potential closure of Muusøya WWTP resulted in a comprehensive rehabilitation and expansion of the plant in 2011. The new capacity is 96,000 m^3/day with the secondary treatment. The first treatment steps of Solumstrand WWTP include grit and sand removal and primary mechanical treatment. Afterwards follows a biological treatment with an intermediate sedimentation tank, and chemical treatment with post Actiflow® separation.

Data collection for ADCS

When the ADCS is applied in WWTPs, inlet water parameters such as influent flow (Qin), turbidity (TUI), conductivity (CNI), pH (PHI), temperature (TMP), pH after coagulation (PHO) and outlet turbidity (TUO) need to be measured online. Meanwhile, in DWTPs, influent colour (COL) is measured by online sensors. The inlet water parameters are recorded at 15 min intervals.

All plants have SCADA systems with a real-time flow proportional dosing system. All the ADCS-related sensors connect to the SCADA system. A programmable logic controller (PLC) is the main hardware of the ADCS, which enables it to run with software. The PLC communicates with the SCADA system to get data and information. After calculation, a dosage prediction signal is sent back to the SCADA, which is used to control the dosing pump. Data are logged in the main hard disk of the ADCS and can be downloaded via web-SCADA.

The data set is divided into two subsets, a calibration set and a test set. The calibration set is used to compute the model components. The test set is only used for validation. Since the test set has no influence on model calibration, external validation is the most 'objective' validation method. Predicted Y-values are compared with the observed values. The prediction residuals can be used to compute validation residual variance or root mean square error (RMSE) predictions.

Statistical analysis

The variables chosen for modelling are Qin, TUI, CNI, PHI, TMP, PHO, COL, TUO and coagulant dosage. The prediction of optimal coagulant dosage process with ADCS includes the following steps:

(1) The data set is edited by removing identifiable error data (i.e. measurements during the calibration and maintenance work).
(2) Determination of the parameter range levels for the process and possible interaction between the selected parameters.
(3) Selection of the best-fit samples with required treatment range.
(4) The regression models are developed by Unscrambler® V 10.3.
(5) The coefficient of determination (R^2) is used to demonstrate how well the model explains calibration vs validation data set.
(6) The RMSE of real value and the predicted value from the model are used to study the accuracy of prediction.

RESULTS AND DISCUSSION

The collected data are used to develop models using the algorithms and equations. The sample selection criteria are varied in each selection due to available effluent measurements, demanding effluent water quality, treatment needs and duration of investigation. TUO is the common online water parameter used in all the studies. Two model calibrations are conducted in each test to find a robust system with optimal dosage calibrations. Calibration set 1 is conducted using historical data and the plants' traditional dosage. Calibration set 2 is conducted with the data collected from ADCS logs.

The models run in the plant without active control of the dosage in order to observe the real-time behavior of predictions. These observations are conducted for 4 months at SRA and for 45 days in NRA. Figure 2 shows the comparison of traditional flow proportional dosing method with dosage predictions by the ADCS predictions. The

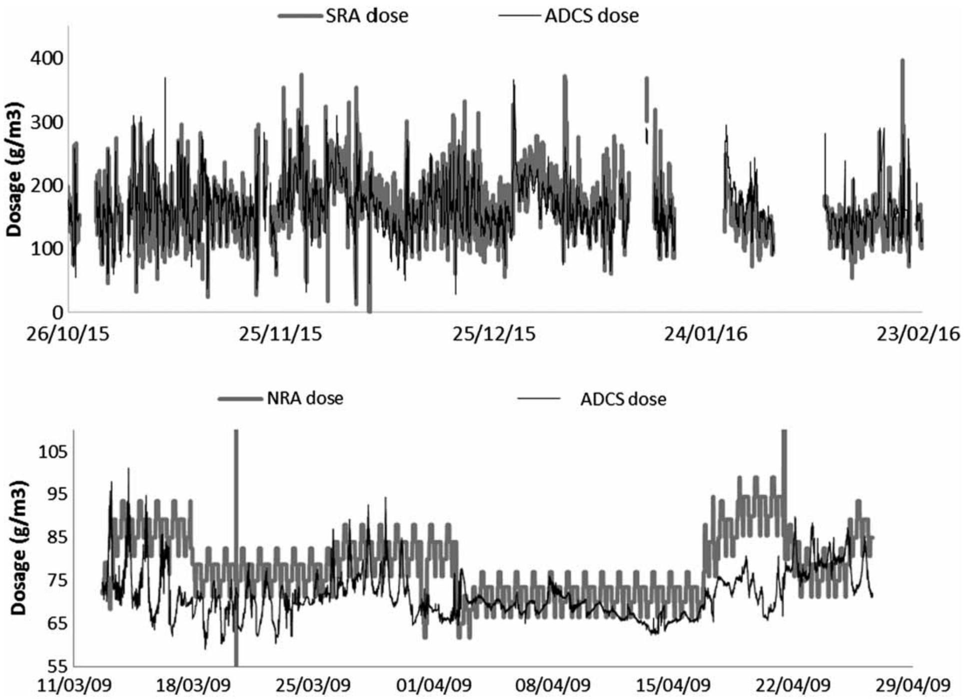

Figure 2 | Traditional flow proportional WW dosing methods at SRA (above) and NRA (below) compared with the ADCS predictions, a comparison during the testing period without active dosing.

observations show that the predicting power of the ADCS satisfactorily follows the pattern of the dosage prediction in the plant with a higher sensitivity.

Figure 3 illustrates the plant's dosage, over or under (outlier TUO) effluent turbidity and the ADCS dosage predictions. The required TUO target is between 2 and 20 NTU. Due to the uncertainty of accuracy of the traditional dosing method, the WWTP uses higher dosages than required (over-dosing) and results in TUO less than 2 NTU, while under-dosing results in TUO higher than 20 NTU. It can be clearly seen that the ADCS is responding well to the outliers of turbidity; when TUO is lower than 2 NTU the ADCS dosage predictions are lower than the plant's traditional dosage, and the opposite with high effluent turbidity.

Figure 4 shows the effluent turbidity with the plant's dosage. About 35% of the effluent turbidity data are outliers (black closed circles), due to inaccurate coagulant dosage. The effluent turbidity varies from 0.1 to 80 NTU, which is a challenge for the next treatment steps that could affect the whole treatment performance, and the required or accepted TUO range is 2–20 NTU. The plant's dosage calculated by flow proportional dosing method is only related to WW flow, instead of inlet water parameters that have

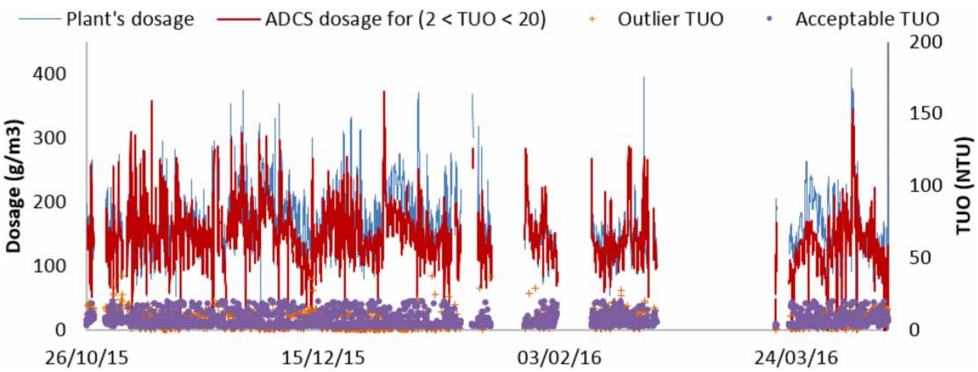

Figure 3 | Comparison between plant's dosage and the ADCS dose predictions to obtain TUO between 2 and 20 NTU. Outlier TUO (crosses) and Acceptable TUO (circles).

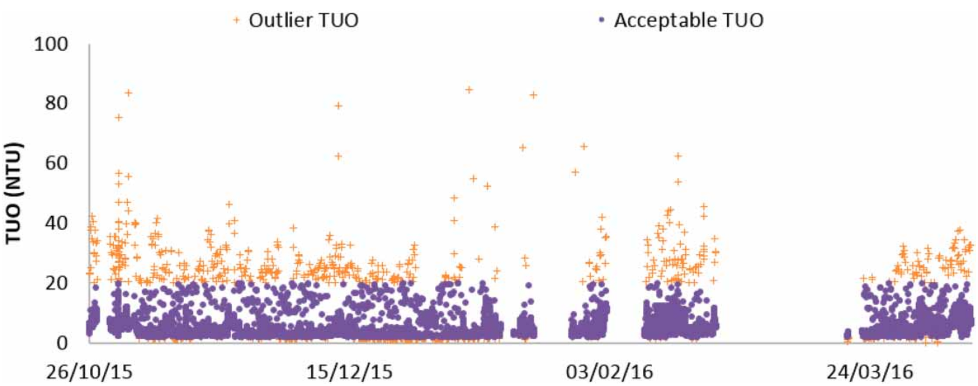

Figure 4 | Turbidity outlet (TUO) by plant dosage at SRA WWTP. Outlier TUO (crosses) and Acceptable TUO (circles).

rapid and amplitude variations. Thus, it is necessary to predict real time dosage considering the related inlet parameters.

Figure 5 compares the TUO before and after the ADCS function in SRA WWTP. The models are well functioning with more stable TUO in the range between 2 and 30 NTU with the first calibration, but the targeted range is 2–20 NTU; when compared with before ADCS, the TUO range is more stable after ADCS. The variation range under the ADCS control is also observed as lower than with traditional dosage. Furthermore, the percentage of low turbidity resulting from over-dosage has lessened. Hence, the test results prove that the ADCS provides better results than the plant's previous dosing control system. At the time of this publication, the system is successfully running up-to-date.

The ADCS saves coagulants and reduces sludge production produced by excess aluminium hydrolysis. In addition, there are more savings such as labour cost for dosage controlling, transportation of reagents and sludge, sludge treatment and environment pollution. These parameters are not quantified in this study, to simplify the calculations.

Estimated annual savings in NRA in the year 2009, compared with the consumption in 2007 (before ADCS started), was approximately 485 tonnes of commercial coagulant, which equals 30% of the average traditional coagulant consumption. Thus, the annual savings by ADCS is approximately 780,995 NOK.

By saving 535 tonnes of coagulants, ADCS reduces the amount of sludge production. The actual dry sludge production per million m^3 of WW in the plant is shown in Figure 6. It illustrates that the annual unit dry sludge production gradually increases from 2008, while the sludge production due to coagulants reduces. From 2012, the dry sludge production increases as the TP % removal efficiency increases from 94% to 96%, and the sludge production from coagulation process increases slightly more than 2011. As the average reduction of dry sludge production due to coagulant saving is only about 3% of the total dry sludge production, it might not be influential in the total sludge increase in the plant. Thus, we can conclude that other

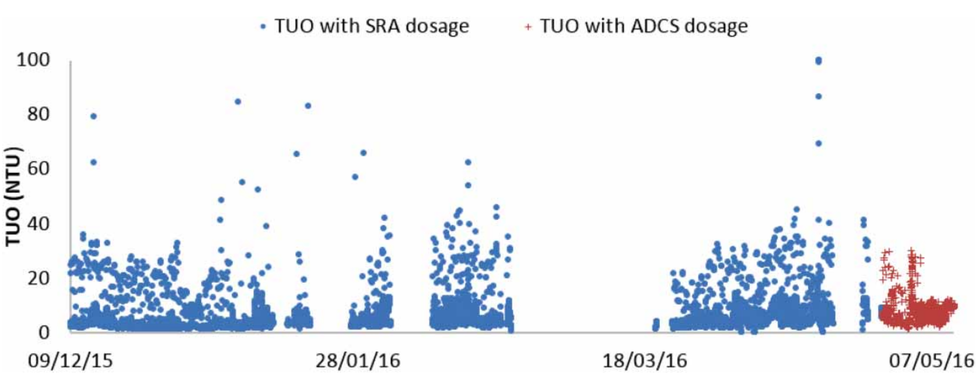

Figure 5 | The TUO with SRA dosage (crosses) and TUO with ADCS (circles).

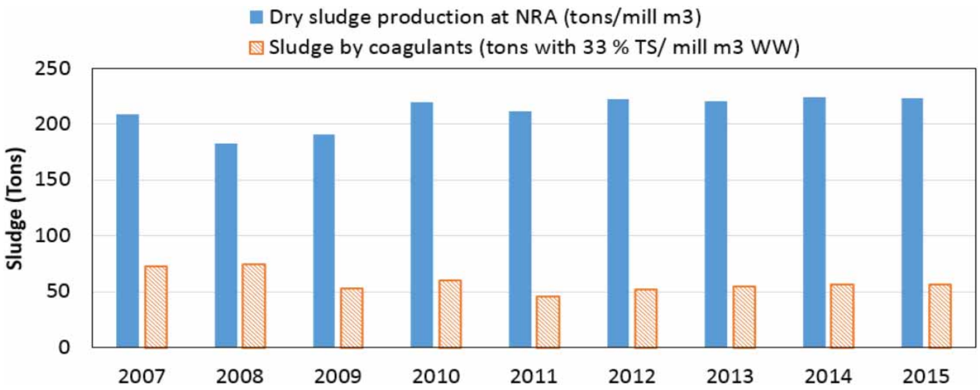

Figure 6 | Comparison of annual unit dry sludge production with the calculated sludge production (33%) by coagulants (VA-Support 2012).

reasons are the cause for the sludge increase over the last years.

CONCLUSIONS

The approach of the ADCS will secure a minimum use of chemical dosage while complying with treatment requirements. The system is flexible and can be installed with a varying number of online sensors – suitable for treatment plants of any size. It is compatible for all plants, with or without existing control systems, and can be simply integrated into any control system.

Generally, not only does the ADCS provide constant effluent water quality, it also reduces the coagulant consumption by up to 30% and sludge treatment costs by 30% in Norwegian plants.

The ADCS strongly depends on the accuracy of online measurements. The system may demand additional labour hours for instrument maintenance and calibrations. However, this cost is offset by the savings made against the chemical consumption required by the traditional dosing control system.

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