Lessons learned from operating advanced instrumentation to support nutrient removal

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Sensor calibration, maintenance, and validation of

Operators at the Hampton Roads Sanitation District (Virginia Beach, Va.) Nansemond Treatment Plant in Norfolk, Va., validate probes with side-by-side grab sampling and filtration for lab analysis. Hampton Roads Sanitation District

Analytical devices are emerging as an integral component of water resource recovery facilities (WRRFs); these devices help automate data collection and can be used for controlling operations. To facilitate more widespread adoption of sensors for beneficial use at WRRFs, there is a need to increase knowledge transfer among utilities regarding best practices for selection of appropriate sensors, as well as appropriate methods of maintenance, calibration, and data validation. Standardizing approaches and identifying strategies for troubleshooting problematic sensors can help counteract any distrust in sensor data quality and accuracy in measurements. Other utilities can benefit by learning from three case studies from

An operator at the H.L. Mooney Advanced Water Reclamation Facility (Woodbridge, Va.) validates the readings of a dissolved oxygen probe with handheld DO probe. Prince William County Service Authority

WRRFs in the Mid-Atlantic region, where sensors have been used for various purposes.

Sensor fundamentals

In the framework of this study, *sensor* refers to a broad spectrum of measuring devices that includes probes and analyzers. Probes are considered submersible measuring elements, such as ion selective electrodes (ISEs), optical, and galvanic/Clark probes, which are used for *in situ* measurement.

ISE instruments are probes that use a measuring electrode and reference electrode to detect and convert ionic activity of analytes into an electrical signal that is proportional to concentration, as defined in "Online Nitrogen Monitoring and Control Strategies" by T.M. Palmer *et al.* in *WERF Final Report* from 2007. An ISE can be used for measuring pH, oxidation–reduction potential (ORP), ammonium, potassium, chloride, and nitrate.

Galvanic/Clark probes typically are used to measure dissolved oxygen (DO). In the probe, DO diffuses through a membrane and into an electrolyte – typically an aqueous potassium chloride solution. When a constant polarizing voltage is applied across the gold and silver electrodes, oxygen is reduced at the cathode. The resulting current flow is directly proportional to the electrolyte's dissolved oxygen content, according to *Automation of Water Resource Recovery Facilities, WEF Manual of Practice No. 21* from 2013.

Optical probes rely on the principle that water quality analytes absorb light energy at specific wavelengths and the degree of light absorption is proportional to the concentration of the analyte. Optical probes can be used to measure ultraviolet transmittance, ammonium, nitrate, nitrite, soluble chemical oxygen demand (COD), and total suspended solids (TSS).

An analyzer is an *ex situ,* wet chemical sensor. It may require filtration and could be optical and/or colorimetric utilizing a similar principle to optical sensors, except that reagents are added to the sample to generate a chemical reaction with a specific analyte. This reaction typically produces a compound with magnified light absorption at a specific wavelength. Analyzers also may require a meter or controller. Analyzers can be used for measuring ammonium, nitrate, nitrite, and phosphorus.

A meter or controller is the actual display/transmitter for the probe or analyzer and also may be used for some limited control. There also are two types of sensors discussed in this study: discrete single-point sensors for measuring a single point/location with a single sensor, or decentralized sensors, which may require sample pumping to a central analyzer.

Proper maintenance of all types of sensors is needed to ensure that data generated are reliable and accurate. This involves calibration and validation of performance. Calibration is the

Table 1. Summary of sensors for three case studies

Facility	Process configuration	Design flow, ML/d (mgd)	Permit limits		Sensor and quantity
			Total nitrogen (mg/L)	Total phosphorus (mg/L)	
Nansemond Treatment Plant	5-Stage BNR + struvite recovery	113.5 (30)	8	1	(6) Nitrate optical probes (2) Orthophosphate analyzers (2) Ammonium analyzers (1) Combination nitrate, nitrite, TSS probe (1) Ammonium ISE probe (3) Ammonium ISE probe (21) DO probes (5) Blanket indicator
H.L. Mooney Advanced Water Reclamation Facility	2-step (MLE or 4-stage) + denitrification filters	90.8 (24)	3	0.18	(1) Nitrate optical probe (2) Nitrate, nitrite, ammonium analyzers (30) DO probes
Broad Run Water Reclamation Facility	5-stage BNR + MBR	41.6 (11)	4	0.1	(9) DO probes (3) Oxidation–reduction potential probe (4) pH probe (1) Blanket indicator

TSS = total suspended solids.
ISE = ion selective electrode.
DO = dissolved oxygen.
BNR = biological nutrient removal.
MLE = Modified Ludzack-Ettinger.
MBR = membrane bioreactor.

process used to ensure that the sensor is capable of measuring an accurately known input/analyte concentration. Validation/verification is the process by which predicted values from the sensor are compared to a different and independent data set typically obtained through grab samples. Both procedures should be performed regularly, especially when data from sensors are used to guide process decisions.

Table 1 (p. 58) provides a summary of the sensors used at the three WRRFs featured in the following case studies.

Nansemond Treatment Plant

The Hampton Roads Sanitation District (Virginia Beach, Va.) operates the Nansemond Treatment Plant in Suffolk, Va. The facility is designed to treat 113.5 million L/d (30 mgd) using a five-stage biological nutrient removal (BNR) process with supplemental carbon addition to meet 8 mg/L total nitrogen (TN) and 1 mg/L total phosphorus (TP) discharge limits. This facility also operates a struvite recovery facility.

The plant uses on-line sensors for process monitoring and control. The aeration system is designed to use input from up to 21 DO probes to modulate 19 motorized butterfly valves with airflow measurements from 19 associated Venturi meters. Carbon addition initially was controlled in flow-paced mode to verify that the nitrate probes were reliable, and then switched to nutrient-paced feedback mode. Orthophosphate and ammonia analyzers are used to monitor for biological phosphorus removal and nitrification, respectively. Ammonium ISE probes also are used for process monitoring in addition to a probe to monitor nitrite, nitrate, and TSS in the aerobic effluent.

This facility has full-time instrumentation and control (I&C) personnel available for maintenance and calibration of sensors. This staffing is supplemented with purchased maintenance contract held with certain manufacturers. Facility or other technical service staff perform regular maintenance and validation. This consists of cleaning probes and automated wipers and replacing filters and reagents (for wet chemistry analyzers). Calibration of the sensors is performed on a weekly/biweekly basis (nitrate, phosphorus, DO) or monthly (ammonium), as needed based on the results from validation. This facility has estimated that routine efforts for all sensors takes approximately 26 hours per week. This estimate is based on validating sensors once to three times per week based on the sensor (probe or analyzer).

H.L. Mooney Advanced Water Reclamation Facility

The Mooney facility (Woodbridge, Va.) is a two-step BNR facility consisting of an activated sludge process that can be operated in Modified Ludzack-Ettinger or four-stage mode (current mode). This is followed by tertiary filters that can be operated as denitrification filters or conventional sand filters (current mode). The facility, owned and operated by the Prince William County Service Authority, was designed for an average daily flow of 90.8 million L/d (24 mgd) and currently meets TN and TP limits of 3 mg/L and 0.18 mg/L, respectively.

The facility uses membrane DO probes in the aeration basins, one nitrate probe located in the aeration tank effluent, and two side-by-side analyzer units to measure nitrate, nitrite, and ammonia from secondary clarifier effluent and filter effluent. The two analyzers were selected to provide redundancy and ensure final effluent quality. DO measurements are used to control blower operations and air supply control valves. Nitrate concentration in the aeration tank effluent is used to control methanol addition to the post-anoxic zone. Nitrate measurements on the two analyzer units are used to monitor secondary and final effluent quality and to control methanol feed to the filters when filters operate in denitrification mode.

The Mooney facility uses a monthly preventive maintenance schedule, which involves cleaning and calibrating one DO probe per day followed by validating with a handheld DO meter. The hand-held probe is air calibrated. Analyzer units are cleaned and maintained over 8 hours each week, estimated as 6 hours for one unit (includes flushing and maintaining the sample lines) and an additional 2 hours to maintain the duplicate unit. The analyzer measurements are validated with side-by-side grab sampling and laboratory analysis. Grab samples are collected 5 days per week. The nitrate probe is validated with side-by-side grab samples collected on a daily basis. Mixed liquor grab samples collected for validation are delivered to the lab immediately after collection to minimize holding times. It is estimated that routine efforts for all sensors takes approximately 15 to 18 hours per week.

Broad Run Water Reclamation Facility

Loudoun Water (Ashburn, Va.) operates the Broad Run Water Reclamation Facility as a five-stage BNR facility with membrane bioreactors (MBR). The Broad Run facility is designed to treat 41.6 million L/d (11 mgd) and to meet TN and TP limits of 4 mg/L and 0.1 mg/L, respectively.

The facility uses DO probes for controlling aeration at various points across each biological reactor basin, differential ORP digital probes in the first anoxic zone, flowmeters for flow pacing methanol, pH probes for monitoring caustic feed, and a hand-held sludge interface detector for monitoring sludge blankets in the primary clarifiers.

This facility has full-time I&C personnel available for intensive maintenance and calibration of sensors. Daily cleaning and validation of the DO probes is performed by operations staff. It is estimated that routine efforts for all sensors takes approximately 2 to 4 hours per week.

Implementation and maintenance

To maximize the value of the data obtained by sensors, WRRFs often need to consider the tradeoff between installing multiple sensors across parallel tanks versus finding a single representative location. Based on the experiences of the WRRFs described above, examples regarding the location of different sensors are described in the figure on p. 61 for nutrient removal facilities. Actual sensor selection will be site-specific and dependent on the utility's preferences and resources.

Careful consideration should be given to methods employed for mounting instruments (angled, vertical, horizontal), in addition to methods used for cleaning (manual or automated). Sensors should be placed away from walls and in areas that are well-mixed and representative of the tank contents.

The required frequency of sensor maintenance and cleaning likely will vary among facilities, based on site-specific matrix considerations. However, if sensor data is to be used for making

Table 2. Considerations for sensor maintenance, calibration, and validation at WRRFs*

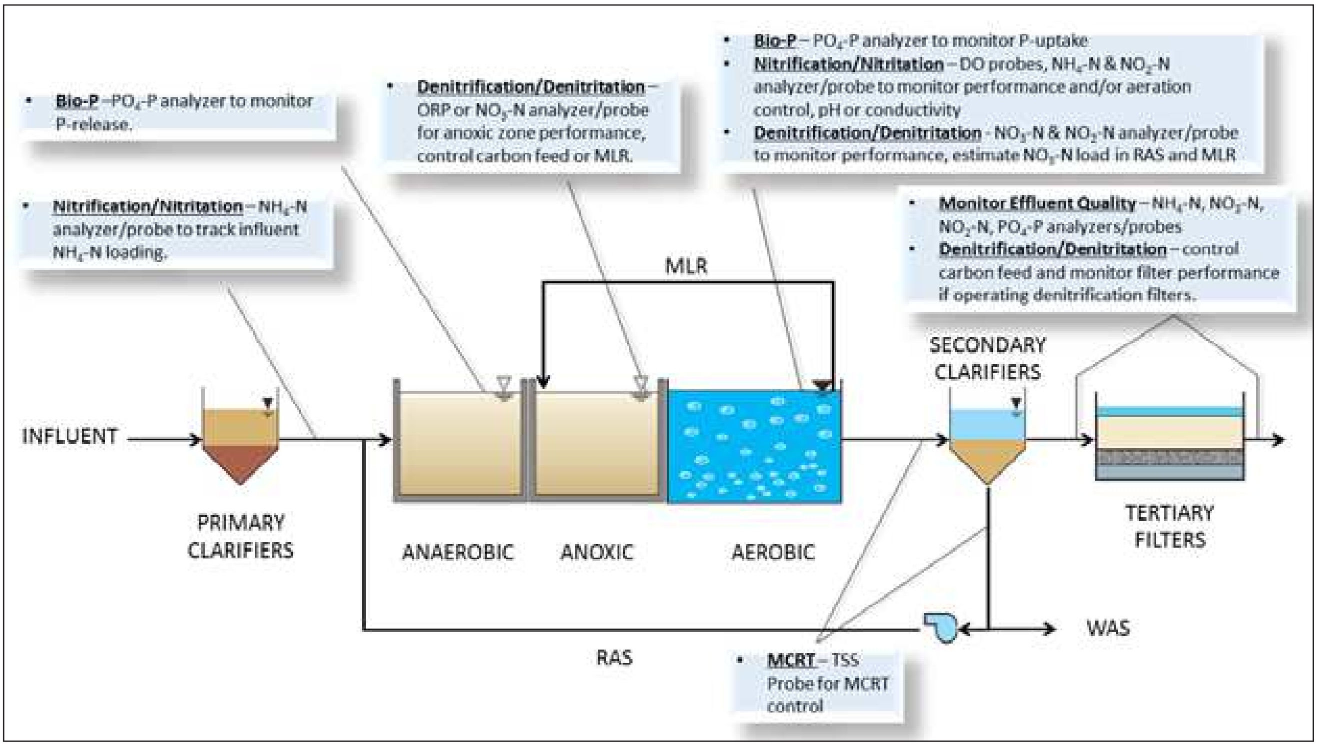
Sensor type	Analytes measured	Considerations	Maintenance	Calibration	Validation
ISE probe	Ammonium, nitrate, chlorine, or potassium	Automated air blast cleaning is a benefit but care should be exercised to ensure membranes are not damaged. Data drift is inevitable. Multipoint calibration and validation efforts should be undertaken. Replace membrane cartridge every 6 to 12 months (where applicable). Low concentration measurements should be verified frequently. For electrodes filled with electrolytes, care should be taken to avoid inversions of the sensor.	Monthly	Every 2 weeks or as needed based on validation	Three times a week
ISE probe	pH, oxidation–reduction potential	Works well, durable, and reliable probe.	Monthly	As needed based on validation	Weekly
Galvanic probe	Dissolved oxygen	Reliable and fairly easy to maintain. Air calibration often is adequate. Low concentration measurements should be verified frequently. Consideration should be provided to probe immersion depth to ensure representative reading is taken.	Every 2 weeks	Every 6 months or as needed based on validation	Three times a week
Optical probe	Nitrate, nitrite, soluble COD, total solids	Initial calibration efforts are significant but system works well thereafter. Depending on the manufacturer, multipoint calibration is possible. Data offset may be available. Response times (~5 min) can be slower than ISE or galvanic probes as the system has to step through analyses of different constituents. Automated air blast cleaning is a benefit. In some instances, wiper blades may not be adequate to keep optics clean. Interference in nitrate readings due to the presence of nitrite is possible without algorithms to differentiate both constituents.	Monthly	As needed based on validation	Three times a week
Optical probe	Dissolved oxygen	Membrane life can exceed 1 year if properly maintained. Automated air blast cleaning is a benefit but probes should be examined frequently to ensure measurement surfaces are not damaged. Occasional drift in measurement is possible. Validation is key to reduce effects of drift. Manual cleaning is required intermittently to remove slime buildup. Air calibration often is adequate.	Every 2 weeks	As needed based on validation	Three times a week
Wet chemistry analyzer	Ammonium, orthophosphate, nitrate, nitrite	Requires an in-line sample filtration system. Cleaning/replacing filtration system is maintenance intensive for samples drawn from aeration basin (MLSS). Measurements are very reliable and accurate.	Monthly	Monthly or as needed based on validation	Once a week

ISE = ion selective electrode.

COD = chemical oxygen demand.

*Note: Considerations were derived from surveys of three facilities listed in this article. These considerations should be adapted for site-specific conditions.

Examples for sensor implementation



MLR = mixed liquor return.
RAS = return activated sludge.
WAS = waste activated sludge.
MCRT = mean cell residence time.

decisions on operations, more frequent preventive maintenance schedules should be followed (weekly to monthly).

At the same time, careful consideration should be given to automated cleaning systems, such as air blast. Cleaning is critical for probes located where readily and/or slowly biodegradable COD is present due to the potential growth and accumulation of microorganisms and exopolymeric substances on the probes. However, excessive cleaning also can cause premature failure of sensors – for example, the "pinhole" effect on DO membrane caps. Therefore, protocols for operation and maintenance should be reviewed periodically and adjusted to ensure that a balance is met in prolonging sensor life and reliability, while also producing valuable data. These protocols must take into account the location of the probes as well as the *in situ* conditions in the reactor.

Calibration and validation

Calibration and validation efforts are linked intrinsically. These efforts should also take into account the matrix effect on results. Nutrient sensor (ammonia or nitrate) calibration in clean matrices may mask interferences present in wastewater. Therefore, spiked check additions and/or one multiple-point calibration check in the wastewater matrix are appropriate.

The most successful approach employed for validation by the WRRFs in this study involved direct parallel measurements using calibrated hand-held instruments alongside the *in situ* probe or use of side-by-side grab sampling and analyses. In this study, DO data validation ranged from daily or twice per week to once per week. In general, this frequency can be refined by examining trends in DO data drift over long periods. For other soluble constituents, it is suggested that sampling be conducted at a minimum of once per week – 3 to 5 days per week is preferred – depending on whether a sensor is used for monitoring or control. Again, this specific period between validation efforts would need to be refined by examining trends in data drift over defined intervals.

Sensor redundancy

As more emphasis is placed on utilizing real-time data from sensors, there is a need to ensure that a degree of redundancy is built into these systems. This redundancy needs to improve upon the validation approach that typically is employed whereby data is checked on a frequent basis. The deployment of multiple complementary probes, for example, ammonia and nitrate, potentially can be used to proactively detect when sensor drift or malfunction begins. In addition, data collected by the facility and analyzed in a laboratory can be integrated into the programming to serve as a backup in the event that on-line sensor data does not meet quality assurance tests. Together with the development of algorithms that monitor trends in sensor data, these approaches potentially can overcome the shortcoming of using a single probe or sensor to control unit process operation. These types of fail-safe controls are needed especially in facilities that are required to achieve enhanced nutrient removal limits.

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