WRF 4973 Fact Sheet: ID 1510

Strategy: Instrumentation and Controls

Improve Control, Stability, and Efficiency

Local Monitor.
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Various Sensors.
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This fact sheet acts as an extension of Fact Sheet 1501: Instrumentation and Controls and a companion to Fact Sheet 1560: Sensors and Instrumentation. While Fact Sheet 1501 introduces the use of advanced instrumentation and controls (I&C) schemes for nutrient optimization at water resource recovery facilities (WRRFs), this fact sheet, 1510, focuses on the discussion of control strategies in further detail. Different types of control schemes working in concert with advanced instrumentation are discussed in this fact sheet. Control schemes discussed include dissolved oxygen (DO) control, airflow control, ammonia-based aeration control (ABAC), chemical feed control, and others.

Fact Sheet Application Checklist

R = fact sheet relevant to item
PR = fact sheet is potentially relevant to item depending on application, existing conditions, etc.

Category	PR	Intensification
	PR	Chemical addition
	PR	Carbon management
	R	I&C strategies
	PR	Sidestream mgmt.
	PR	Energy savings
	PR	Chemical savings
	PR	Operational savings
		Other means of NutRem
Nutrient	R	Ammonia
	R	NOx
	PR	TN
	R	Ortho-P
	PR	TP
Scale (design flow)	R	Small (<1 mgd)
	R	Medium (1–10 mgd)
	R	Large (>10 mgd)

Goal	R	Improve reliability
	R	Reduce nutrient
	R	Reduce O&M cost
Group	R	Optimize existing CNR
	R	Optimize existing TNR
	PR	NutRem in secondary plant
Process		Small
		Pond
		Fixed film (secondary)
		Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
	R	Tertiary NutRem (TNR)
		Other

CAS = conventional activated sludge (BOD only)
NAS = nitrifying activated sludge (without denitrification)
CNR = conventional nutrient removal no chemical/no filter, etc.
TNR = tertiary nutrient removal with chemical, filter, etc.

Technology Summary Evaluation

Footprint	1	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	4–5	Technology ranking based (LIFT) see below*
Energy efficiency	2	Scale 1–5: 1 = use much less; 3 = use similar to conventional; 5 = use much more
O&M impact	2	Scale 1–5: 1 = cost much less; 3 = cost similar to conventional; 5 = cost much more
Material/consumable	2	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1	Scale 1–3: minimal/none = 1; some = 2; significant = 3 (e.g., chemical process)

* Technology ranking based on Leaders Innovation Forum for Technology (LIFT) Water Research Foundation (WRF) Technology Development Level (TDL) definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional

Descriptions/Evaluation

Strategy	Instrumentation and controls: control, stability, and efficiency
Description	As introduced in Fact Sheet 1501, I&C is a key part of nutrient removal process control. This fact sheet discusses specific control strategies oriented toward improving stability and efficiency of nutrient removal processes giving an overall optimization.
Application	Multiple applications are listed here and presented in more detail in Table 1: • Feedback controller • Feedforward controller • Air supply • DO controller • DO control • ABAC • Ammonia vs. NO_x (AvN) • Internal nitrified recycle control for denitrification • Chemical dose
Constituents removed	Ammonia, oxidized nitrogen (nitrate + nitrite) (NO_x), total nitrogen (TN), Ortho-P, total phosphorus (TP)—all are potentially optimized by I&C improvements
Development status*	LIFT TDLs 4–5. Most strategies are well developed. New control approaches and probes continue to emerge.
O&M considerations	Operations and maintenance (O&M) considerations are focused primarily on sensor maintenance, which is discussed in the companion Fact Sheet 1560.
Benefits	Provide accurate and continuous monitoring of process streams to verify performance and maintain stable operation Allow for fine tuning and early warning of process performance Optimize chemical and energy use Reduce operator effort (offset by increased maintenance)
Limitations	Instrument and probe maintenance (offset by decreased operator time). Self-cleaning probes can reduce maintenance requirements.
Design considerations	Probe locations must be carefully evaluated to collect representative samples.
Potential fatal flaws	I&C cannot overcome equipment limitations—for example, blower control may be limited by equipment capacity (high end) and ability to turn down to low demands (low end)
Footprint requirements	Small
Residuals	None
Cost considerations	Depends on probe type and function. Determine specific cost based on life-cycle analysis (LCA) and include both capital and O&M cost.
Past experience	Raleigh, North Carolina San Antonio Water System (SAWS) Lincoln, Nebraska Denver, Colorado, Metro Wastewater Reclamation District (MWRD) in Robert Hite Facility
Publications	Miller, M.; P. Regmi, J. Jimenez. 2019. Sensors Versus Analyzers: The Case for Ammonia-based Aeration Control. Proceedings of the 92nd Water Environment Federation's Technical Exhibition Conference (WEFTEC), Chicago, Illinois. Regmi, P., B. Holgate, D. Fredericks, M.W. Miller, B. Wett, S. Murthy, C.B. Bott. 2015. Optimization of a mainstream nitritation-denitritation process and anammox polishing. Water Science Technology. 72(4), 632–642.

	Rieger, L., R.M. Jones, P.L. Dold, and C.B. Bott. 2012. “Myths about Ammonia Feedforward Aeration Control.” Proceedings of the 85th Water Environment Federation’s Technical Exhibition and Conference, New Orleans, Louisiana. Rieger, L., R.M. Jones, P.L. Dold, and C.B. Bott. 2014. “Ammonia-Based Feedforward and Feedback Aeration Control in Activated Sludge Processes.” Water Environment Research. 86(1), 63–73. Schraa, O., L. Rieger, J. Alex, I. Miletic. 2019. Ammonia-based aeration control with optimal SRT control: improved performance and lower energy consumption. Wat. Sci. Tech. 79(1), 63–72.
Related fact sheets	1150: Use of chemicals to improve nutrient removal 1401: Optimize Carbon Use for Nutrient Removal 1410: Fermentation 1450: DO Control to Increase Denitrification 1501: Overview of Instrumentation and Control Strategies 1560: Sensors and Instrumentation 1701: Reduce Energy Consumption Overview 1740: Reduce Process Power Demand 1820: Chemical Testing and Selection 1901: Optimize Operation and Maintenance
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Note

* Technology ranking based on LIFT WRF TDL definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional (https://www.waterrf.org/sites/default/files/file/2019-07/LIFT%20Scan%20Application-LIFT%20Link%2BHub_0.pdf : accessed September 2020)

Instrumentation and Controls Applications

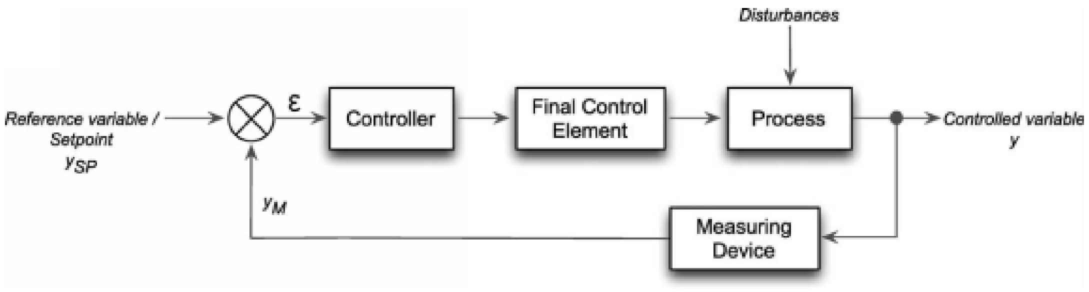

Figure 1. Schematic Representation of Feedback Controller.
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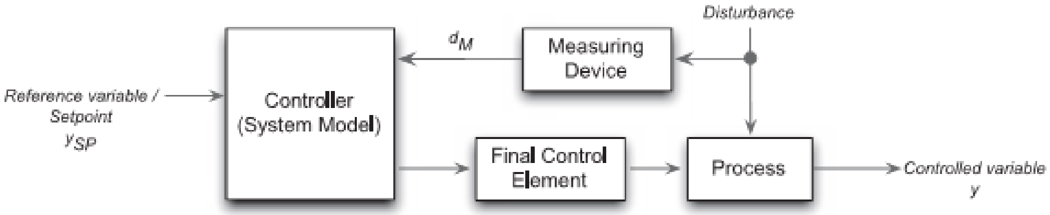

Figure 2. Schematic Representation of Feed-Forward Controller.
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Table 1. Strategies that Rely on Instrumentation and Controls.

Control Strategy	Brief Description	Nutrient	Control Measurements
Feedback controllers	A disturbance causes a change in process that affects a measured process variable (controlled variable) that is input to the controller; e.g., DO concentration. In turn, the controller changes a process control variable (manipulated variable) to reduce the difference (error) between the measured and set point value; e.g., airflow.	Multiple: see below	Multiple: see below
Feed-forward controllers	A process disturbance is measured and input into the controller; e.g., change in influent ammonia load. The controller then uses a model to predict the impact on the controlled process. The controller predictions are then applied to determine or calculate the control action to be taken; e.g., airflow change. Feed-forward control must be complemented by a feedback controller or a feedback signal should be used in the feed-forward model.	Multiple: see below	Multiple: see below

Control Strategy	Brief Description	Nutrient	Control Measurements
Air supply control	The total airflow supplied by a set of blowers is typically controlled based on: ○ Pressure ○ Total airflows requested by air distribution controllers ○ Average DO over all trains and aeration grids Individual blower airflow may be adjusted by one or multiple methods including: ○ Inlet throttling ○ Blower turndown (variable-frequency drive [VFD], inlet vanes, etc.) ○ Discharge valve throttling An additional controller is required to assign parts of the required airflows to specific blowers. Most-open valve (MOV) control schemes are applied to coordinate between air distribution system demands and the air supply control system. The goal is to prevent blowers working against closed valves.	Ammonia, nitrate	Multiple
Air distribution control (DO, ABAC, etc.)	Control distribution of air to the BNR process to achieve control objectives such as DO control, ABAC, etc. See below.	Varies	Varies
DO control	Control biological process to maintain set DO concentrations. DO set point can be operator input or adjusted based on secondary control. It is typically in the form of a controller cascade: DO → airflow → valve position.	Ammonia Nitrate Ortho-P	DO
Ammonia-based aeration control (ABAC)	Manipulate DO set point to achieve a certain target ammonia concentration. ABAC represents a control scheme whereby aeration is throttled to provide the right amount of air to meet the ammonia targets. The result is a more efficient process with lower airflows and the potential for improved TN removal as a result of increased anoxic environments. Multiple ABAC options have been applied successfully. The standard approach is feedback cascade control, whereby measured effluent ammonia concentrations are used to control the DO set point, which in turn controls airflow. Extended ABAC strategies include feed-forward with feedback control.	Ammonia TN	Ammonia DO

Control Strategy	Brief Description	Nutrient	Control Measurements
Ammonia vs. NO_x (AvN)	AvN is an aeration control strategy to oxidize a fraction of the ammonia. In this approach ammonia and nitrate plus nitrite are measured and the ratio is calculated and input to a controller. The controller then adjusts to meet the optimum set point AvN ratio. AvN is an aeration control strategy commonly used in shortcut nitrogen (N) removal processes such as partial nitritation anammox (PNA) or partial denitrification annamox (PdNA).	Nitrogen	Ammonia Nitrate
Internal nitrified recycle control for denitrification	Control nitrified mixed liquor recycle (NMLR) flow rate based on target NO_x or oxidation-reduction potential (ORP) measurement to improve denitrification. Denitrification in pre-anoxic zones depends on recycle from the aerobic zone to supply nitrates or NMLR. The rate of NMLR typically varies between 100% and 400% of the influent flow rate. NMLR control is used to provide the optimum NMLR rate for efficient pumping. Nitrate, nitrate plus nitrite, or ORP is measured with a set point applied, and the controller adjusts the NMLR flow rate to align the set point with the measured value. NO_x controllers for NMLR should be carefully evaluated when ABAC is applied. Typically the NMLR flow is maximized as ABAC introduces simultaneous nitrification and denitrification (SND), leading to insufficient NO_x concentrations in the NMLR stream. In extreme cases, this can negatively impact nitrification performance and overall N removal performance.	NO_x	NO_x or ORP
Chemical dose to maintain dose concentration	Adjust chemical dose to maintain a set chemical dose concentration (milligrams per liter [mg/L]) in liquid as flow change.	NO_x Ortho-P	Flow at dose point
Chemical dose to maintain nutrient concentration	Control chemical dose based on nutrient concentration measurement (example ortho-P) to maintain concentration at target value.	Multiple	Nutrient concentration after dose point

Abbreviations

ABAC	Ammonia-based aeration control
AvN	Ammonia versus NO_x (aeration control)
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
DO	Dissolved oxygen
I&C	Instrumentation and controls
L	Liter(s)
LCA	Life-cycle analysis
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mg	Milligram(s)
mgd	Million gallons per day
MOV	Most-open valve
MWRD	Metro Wastewater Reclamation District
N	Nitrogen
NAS	Nitrifying activated sludge
NMLR	Nitrified mixed liquor recycle
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
ORP	Oxidation-reduction potential
PdNA	Partial denitrification with anammox
PNA	Partial nitritation anammox
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SAWS	San Antonio Water System
SND	Simultaneous nitrification and denitrification
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
UV	Ultraviolet
VFD	Variable-frequency drive
WRF	The Water Research Foundation

WRRF	Water resource recovery facility