# Biological Nutrient Removal (BNR) Control Systems Matrix

| Control System | Description | Outcomes & Performance | Potential configurations | Related Instrumentation[1] | Additional Considerations |
|---|---|---|---|---|---|
| **Dissolved Oxygen (DO)** | DO control is an aeration control system where a DO setpoint is compared to measured DO within the aerobic zone of the BNR tanks, and based on the difference between those values, a controller adjusts the airflow rate by opening or closing modulating control valves along the air delivery piping and/or turning up or down the aeration device(s). | • Improve energy efficiency<br>• Better control of DO concentrations returned to non-aerated zones within bioreactors (improving denitrification and EBPR performance) | Feedback control with DO setpoints with direct aeration control, flow-based control, or pressure-based control | • DO sensor(s)<br>• Airflow meter(s) and/or pressure indicator(s) | Combine with flow-based most-open-valve (MOV) control or floating-pressure-based control of the blowers to optimize energy savings.<br><br>Programming should include maximum and minimum DO setpoints to mitigate risk of performance impacts from over- or under-aeration and the ability to alarm potentially-faulty instrument readings and unstable control.<br><br>Separate mixing may be needed, especially at the end of the aerobic zone and near the IMLR pumps, to keep MLSS in suspension if the minimum DO setpoints result in inadequate mixing from the aeration system. |
| **Timer-based Aeration Control (also called intermittent or cyclic aeration)** | Timer-based aeration control is an aeration control system where aeration devices cycle on and off based on a set time or based on ammonium and nitrate concentrations to provide both aerated and unaerated periods within the same bioreactor zone. Typically, a DO concentration is set for the aerobic portion of the cycle. | • Improve energy efficiency by utilizing the "oxygen credit" recovered from denitrification, operating at lower dissolved oxygen concentrations than traditional aerobic processes, and eliminating internal mixed liquor pumping that would otherwise demand power | Timer for aeration on/off OR aeration cycles based on ammonium and nitrate concentrations<br><br>DO control for aerated portion of cycle | • DO probe(s)<br>• ORP probe(s)<br>• Combination of ammonium and nitrate sensors and/or analyzers | Requires adequate BNR tank size to maintain needed aerobic SRT for nitrification if the objective is to remove nitrogen.<br><br>May require supplemental mixing when the air is off to keep the mixed liquor suspended solids in suspension. |
| **Ammonium-Based Aeration Control (ABAC)** | ABAC is an aeration control system where an ammonium setpoint is compared to the measured ammonium in the system, which could be measured at the beginning, end, and/or somewhere in-between in the BNR tanks. For direct control, based on the difference between those ammonium values and the setpoints, a controller adjusts the airflow rate by opening or closing modulating control valves along the air delivery piping and/or turning up or down the aeration device(s). For cascaded control, the controller adjusts the dissolved oxygen concentration setpoint(s) within the aerobic zone(s) based on the measured ammonium concentrations. | • Improve energy efficiency by minimizing over-aeration especially during low loading periods<br>• Better control of DO concentrations returned to non-aerated zones within bioreactors (improving denitrification and EBPR performance)<br>• Create environment for simultaneous nitrification-denitrification at the end of the aerobic zone during periodic low loading periods<br>• Reduce alkalinity consumption and/or improve alkalinity recovery (via denitrification) and minimize supplemental alkalinity addition | Feedforward and feedback OR feedback only<br><br>Direct ammonium control or cascaded control with DO | • Ammonium analyzer(s) and/or ammonium sensor(s)<br>• DO sensor(s)<br>• Airflow meter(s) and/or pressure indicator(s)<br><br>Others:<br>• TSS sensor(s)<br>• Temperature sensor(s) | Ammonium analyzers are typically used at the end of aerobic zones to detect low-level ammonium (<1 mg/L) where ammonium sensors may be used to detect higher ammonium concentrations in front half of aerobic zone (ammonium >1 mg/L).<br><br>Compatible with BNR systems achieving nitrification.<br><br>May cause nitrite accumulation which can increase chlorine demand and total nitrogen discharge.<br><br>Multiple proprietary controllers are available. |

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| **Simultaneous Nitrification-Denitrification (SND)** | SND is an aeration control system where the DO setpoint is low, less than 1.0 mg/L (typically between 0.2 mg/L and 0.5 mg/L), to drive both nitrification and denitrification reactions within the same reactor. The DO setpoint is compared to measured DO within the aerobic zone, and based on the difference between those values, a controller adjusts the airflow rate by opening or closing modulating control valves along the air delivery piping and/or turning up or down the aeration device(s). Ammonium and nitrate are typically monitored, too. | • Improve energy efficiency by operating at lower dissolved oxygen concentrations than traditional aerated zones, utilizing the "oxygen credit" recovered from denitrification, and eliminating internal mixed liquor pumping<br>• Optimize carbon usage efficiency and minimize supplemental carbon addition<br>• Improve alkalinity recovery (via denitrification) and minimize supplemental alkalinity addition | Feedforward and feedback OR feedback only<br><br>Direct DO control or cascaded control with ammonium | • DO sensor(s)<br>• Airflow meter(s) and/or pressure indicator(s)<br><br>Others:<br>• Ammonium analyzer(s) OR sensor(s)<br>• Nitrate analyzer(s) OR sensor(s)<br>• Nitrite analyzer(s) OR sensor(s) | Adequate mixing, typically separate from aeration, is required to ensure homogeneous oxygen transfer throughout the bioreactor and to keep MLSS in suspension.<br><br>Compatible with BNR systems achieving nitrification.<br><br>Ensure nitrite is not accumulating since it can increase chlorine demand and total nitrogen discharge. |
| **Ammonium versus NOx (AvN™)** | AvN™ is a patented aeration control system that utilizes online ammonium and nitrate/nitrite bioreactor concentrations along with measured DO concentrations to control air delivery in an intermittent (but automated) mode to produce equal effluent concentrations of ammonium and nitrate/nitrite. | • Improve energy efficiency by facilitating shortcut nitrogen removal (nitrite shunt)<br>• Optimize carbon usage efficiency and minimize supplemental carbon addition<br>• Improve alkalinity recovery (via denitrification) and minimize supplemental alkalinity addition | Patented control system | • DO sensor(s)<br>• Ammonium analyzer(s) OR sensor(s)<br>• Nitrate analyzer(s) OR nitrate sensor(s)<br>• Nitrite analyzer(s) OR nitrite sensor(s)<br>• Airflow meters and/or pressure indicators | Consider effluent ammonium limit that needs to be achieved; not compatible with low ammonium limits.<br><br>Compatible with BNR systems achieving nitrification.<br><br>Used in the Anammox® process. |
| **Internal Mixed Liquor Recycle (IMLR) Pumping with a nitrate analyzer/sensor** | IMLR pumping control optimizes the flow rate of nitrified mixed liquor return from aerated zones to anoxic zones according to an online nitrate measurement from an anoxic zone. IMLR pump speeds can be turned down during periods of high loading to avoid nitrate breakthrough of the anoxic zone. Such breakthrough would result in an overloaded anoxic zone that allows turndown of IMLR pumping rates to reduce energy use while not compromising denitrification. IMLR pump speeds can also be increased as necessary to maximize denitrification in the anoxic zone. | • Improve energy efficiency during periods of overloaded anoxic zones<br>• Minimize recycle of DO to the anoxic zone<br>• Improve denitrification | Feedback | • Nitrate analyzer(s) OR sensor(s)<br>• Flow meter(s) | Requires ability to automatically modulate the speed of the IMLR pump(s).<br><br>Consider installation of a flow meter on the IMLR line. |

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| **Solids Retention Time (SRT) using RAS/WAS Pumping** | RAS control is a pumping control system that adjusts RAS pump speed according to the facility's influent flow measurement, sludge blanket levels in the secondary clarifiers and/or a manual input of sludge settleability.<br><br>Load-based WAS control is a pumping control system that adjusts the WAS pump speed or the run time of the WAS pump according to the measured WAS TSS load and desired total SRT or WAS TSS load setpoint. Volumetric MLSS wasting is also employed at some WRRFs to achieve the desired SRT. | RAS Control<br>• Improve energy efficiency by minimizing RAS pumping<br>• Reduce risk of solids washout in secondary clarifiers (wet weather management strategy)<br><br>WAS Control<br>• Improve consistency of maintaining a total SRT target<br>• Improve accuracy of WAS TSS concentration measurement, which is often estimated from one or more grab samples during a wasting period | RAS Control: Feedback with % flow setpoints and maximum secondary effluent TSS setpoints or blanket depths<br><br>WAS Control: Feedback control using flow and WAS TSS concentrations to calculate WAS load target | • Flow meter(s)<br>• TSS sensor(s) | RAS pumping is often flow-paced and can be coupled with additional speed control based on secondary effluent TSS or secondary clarifier blanket-depth sensor.<br><br>SRT control using RAS/WAS pumping can be simplified if secondary effluent TSS is consistently low (and thereby negligible) by omitting TSS sensors and only using flow meters for control. Use of flow proportional RAS provides a consistent TSS to MLSS ratio and therefore a predictable RAS TSS concentration relative to any MLSS concentration. If the WAS flow is removed as a portion of RAS, an accurate estimate of the WAS TSS concentration allows for the calculation of the WAS flow necessary to maintain a specific SRT. |
| **Aerobic SRT** | Aerobic SRT control uses a RAS and/or WAS pumping control system(s) with MLSS and WAS TSS measurements to maintain a targeted aerobic SRT within the basin.<br><br>In some systems online sensors are used for continuous MLSS and WAS solids measurements and DO measurements (aerobic SRT-DO adjusted). | • Stabilize SRT to maintain nitrification and support a healthy biological population in the BNR system | RAS Control: Feedback with % flow setpoints and maximum secondary effluent TSS setpoints or blanket depths<br><br>WAS Control: Feedback control using flow and WAS TSS concentrations to calculate WAS load target needed to achieve aerobic SRT (can be adjusted depending on measured DO within aerated zone) | • TSS sensor(s)<br>• Flow meter(s)<br>• DO sensor(s) | Proprietary aerobic SRT control systems are available within the marketplace. |
| **Load-based equalization** | Load-based equalization control is a diversion or pumping system control that utilizes an online measurement from a sensor along with a flow meter to calculate a load to be used to equalize hydraulic and pollutant load to the main process. Can be used to equalize sewer system influent loads and/or side stream return loads. | • Reduce risk of overloading the BNR system<br>• Reduce load spikes to BNR process | Feedforward | • Ammonium analyzer(s) OR sensor(s)<br>• COD/BOD/TOC sensor(s) OR analyzer(s)<br>• Flow meter(s) | |

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| **Supplemental Carbon Addition with a nitrate analyzer/sensor** | Supplemental carbon addition control uses online instrument(s) to calculate a theoretical carbon demand to ensure denitrification is not carbon-limited. Based on the calculated carbon demand, the control system will adjust supplemental carbon pump speeds. | • Improve denitrification<br>• Minimize chemical usage | Feedback (only) OR Feedforward and Feedback (trim) | • Nitrate analyzer(s) OR sensor(s)<br>• Flow meter(s)<br>• Chemical flow meter(s) (or pump speed)<br>• DO sensor(s)<br>• COD/BOD sensor(s) | Proprietary carbon addition control systems are available within the marketplace. |
| **Supplemental Alkalinity Addition** | Supplemental alkalinity addition is a chemical pumping control system that uses online instrument(s) to automatically adjust the chemical feed rate. | • Minimize chemical usage<br>• Reduce risk of poor BNR performance due to loss of alkalinity from nitrification or metal salt addition | Feedback (only) OR Feedforward and Feedback (trim) | • pH sensor(s) and/or alkalinity analyzer(s)<br>And/or:<br>• Flow meter(s)<br>• Chemical flow meter(s) (or pump speed)<br>• COD/BOD/TOC sensor(s) or analyzer(s)<br>• Ammonium analyzer(s) OR sensor(s) | Need to establish relationship between pH and alkalinity for purpose of programming controller. |
| **Metal Salts (Alum, Ferric, PACl, etc.) Addition with a phosphate analyzer** | Metal salt addition control uses online instrument(s) to adjust the metal salt dose setpoint. This automatically-adjusted dose setpoint is typically used in conjunction with flow-paced metal salt feed controls. | • Increase phosphorus removal<br>• Minimize chemical usage | Feedforward and/or feedback | • Phosphate analyzer(s)<br>• Chemical flow meter(s) (or pump speed)<br>• Flow meter(s) | Often used in conjunction with EBPR to trim the nutrient concentrations. |
| **Polymer Addition** | Polymer addition control uses online instrument(s) to flow-pace or adjust the polymer feed system output in responses to a setpoint. | • Minimize chemical usage<br>• Temporarily improve settleability in secondary clarifiers | Feedforward and/or feedback | • Turbidity sensor(s)<br>• TSS sensor (s)<br>• Flow meter(s) (or pump speed) | Polymer addition should rarely be used in a well operated BNR process. |
| **Other** | Facilities can be controlled using a digital twin, which utilizes continuous, online measurements from instruments to predict the influent load and associated BNR system control setpoints utilizing a process model. | • Minimize O&M<br>• Optimize performance | Feedforward | • Multiple types of instruments including flow meters, pressure sensors, constituent sensors and analyzers | Proprietary control strategies are available utilizing a suite of online instrumentation types. |

Additional notes:

1. Although liquid and air flow meters are listed as related instrumentation for select control systems throughout the table, neither flow meter technology nor performance was assessed within this project.
2. Maintaining instrumentation used for control is critical for the successful implementation and operation of these automated control systems.
3. Programming should include adequate safeguards to prevent inaccurate (faulty) readings from adjusting control setpoints to values that will negatively impact overall BNR performance.
4. The accuracy and precision of control is limited by the physical constraints of the equipment and infrastructure as well as the instrumentation (e.g., blower turndown and airflow control valve and actuator pair).