

# Technical Publication

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Process: Technology Overview and Case Studies

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## **Advanced Technology for Monitoring and Controlling a BNR Process Technology Overview and Case Studies**

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### Process Control Strategy

Several types of processes are currently in use for Biological Nutrient Removal, including processes designed to remove nitrogen and those designed to remove both nitrogen and phosphorus. It is advisable to monitor the concentrations of ammonia, nitrite and nitrate in each stage of nitrification and denitrification. Process upsets can easily be identified by monitoring the individual components at regular intervals from each sample point where a transition is expected. If phosphorous removal is included in the process, it is advisable to monitor the nitrogen species and orthophosphate at each stage in the treatment process. This can assure that a phosphate deficiency will not exist during nitrification or denitrification and can assure that re-circulation type processes do not return excessive oxygen to the anaerobic zone.

### Apparatus

Utilize one multiple wavelength process analyzer to monitor ammonia, nitrite, nitrate and (if necessary) phosphate in samples from each process stage. Sample filtration is required to remove high solids prior to analysis. A single high capacity (30 gpm) pump is used to process samples from multiple sample points. Each sample point is controlled by a motor operated ball valve on the vacuum side of the pump, activated by signals from a sequence controller. Filtered samples are accumulated and pumped to the analyzer for analysis. A dedicated signal for each parameter and each sample point is provided by the system for process control.

### Technology

The analyzer utilizes multi-wavelength UV absorbance technology for detection, which can provide results that correspond closely with EPA approved laboratory methods. One big advantage of using the full spectrum is the amount of information contained in the absorbance signature, which is typically contributed from multiple chemicals in the sample. While the initial impression is that absorbance from many chemicals would present a problem for the analysis of any chemical, each chemical has its own unique absorbance signature. This information is used to compensate for interference when analyzing a single chemical and, since the sample signature is the starting point for all analysis, use the same information to analyze for other chemicals in the sample. Site-specific pattern recognition algorithms process this information and calculate the concentration of each parameter of interest, while automatically compensating for interferences and turbidity variations. This enables the use of one analyzer to detect multiple parameters for process control without the use of expensive or hazardous reagents, and in some cases, with no reagents at all. This technology also lends itself to accurate, repeatable analysis in a unit with very low maintenance requirements when compared to other systems.

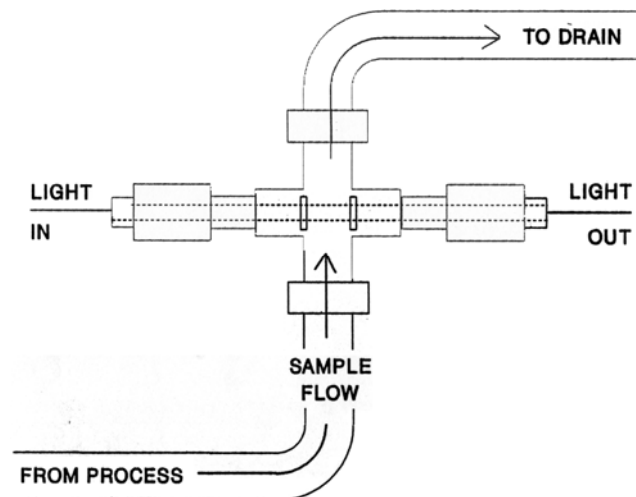
This new advanced technology gives us the tools necessary to better control the BNR process, save on operating costs, and meet ever tightening discharge limits.

## Fundamentals

The multiple wavelength absorbance spectrometry technology used in the ChemScan<sup>®</sup> Process Analyzer was originally developed with funding from NASA (for on-line analysis of nutrient solutions) and the US Navy (for on-line analysis of seawater) in 1989 and 1990, but since then has been applied to a variety of water and wastewater process monitoring and control applications. Control strategies that use direct on-line analysis of the process chemistry offer numerous advantages over process adjustment based on periodic grab samples or analysis of surrogate parameters.

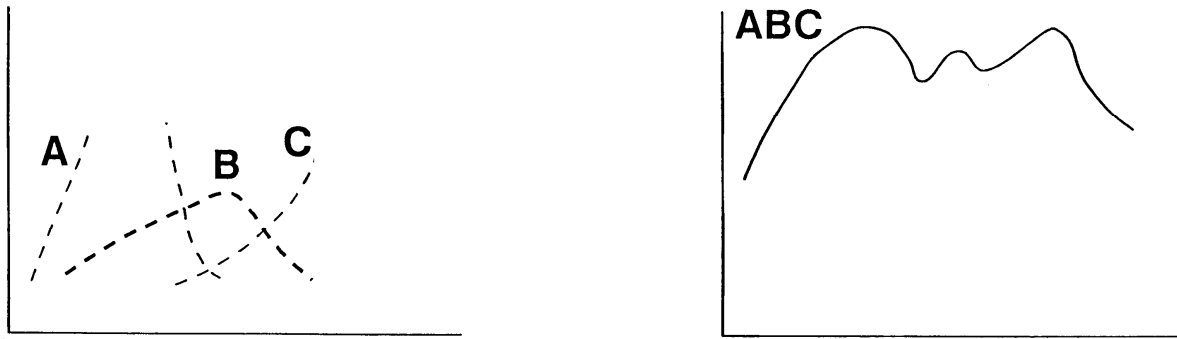
## Capabilities

The ChemScan<sup>®</sup> Process Analyzer can be thought of as a multiple wavelength ultraviolet absorbance spectrometer, similar to spectrometry systems used in the laboratory but designed to function continuously as an on-line instrument in harsh operating environments. The analyzer is capable of detecting any chemical substance that absorbs light in the ultraviolet (and blue visible) wavelength range. A total of 256 individual wavelengths are simultaneously detected by projecting light through a sample as it passes through a flow cell (Figure 1). These 256 wavelengths define an absorbance signature of a solution. This signature is a function of the solution's chemical composition (Figure 2). A branch of applied mathematics known as pattern recognition (sometimes called "chemometrics") is used to extract information concerning the presence and concentration of specific chemicals in a solution from the detected absorbance signature for the solution.



**Figure 1. Flow Cell**

Numerous chemical substances can be individually or simultaneously detected in a process sample using multiple wavelength absorbance spectrometry techniques. Wastewater process analysis typically involves detection of nutrients such as nitrate, nitrite, ammonia and phosphate and may also involve detection of dissolved organics, metals, hardness, halogens, de-chlorination agents and/or UV254 percent transmittance.



**Figure 2. Spectral Composition**

### Advantages

Spectrometers have numerous advantages over other types of chemical sensors and analyzers. Spectrometry does not use ion specific electrodes and therefore avoids the maintenance, accuracy and reliability issues associated with the use of ion probes for wastewater analysis. Unlike some methods, spectrometry can perform rapid analysis of samples from several sample points in the process without excessive time delays resulting from electrode equilibration, titration procedures or reaction time for color reagents, even if these sample points have substantial nutrient and background chemistry variations.

Multiple wavelength detection permits spectrometry to avoid the need for extensive chemical alteration of samples prior to analysis, although high solids that could block or scatter light must be removed prior to analysis. Numerous dissolved substances can be detected directly in process samples without any chemical alteration. Other substances can be detected with very simple conditioning procedures such as pH buffering or one step reagent additions prior to measurement. This means that for many applications a single analyzer can perform multiple functions and that both capital and operating costs can be substantially reduced compared to other process instrumentation alternatives.

ChemScan<sup>®</sup> Process Analyzers have been designed to automatically compensate for turbidity variations in the process samples. All ChemScan<sup>®</sup> analyzers are designed to perform automatic zeroing and to automatically clean the manifold and flow cell using an appropriate cleaning solution. Analyzer systems can be configured to monitor multiple sample lines, monitor one or more parameters and communicate analog or serial information for each parameter at each sample point to meet the monitoring and control needs for a specific application.

### Applications and Case Studies

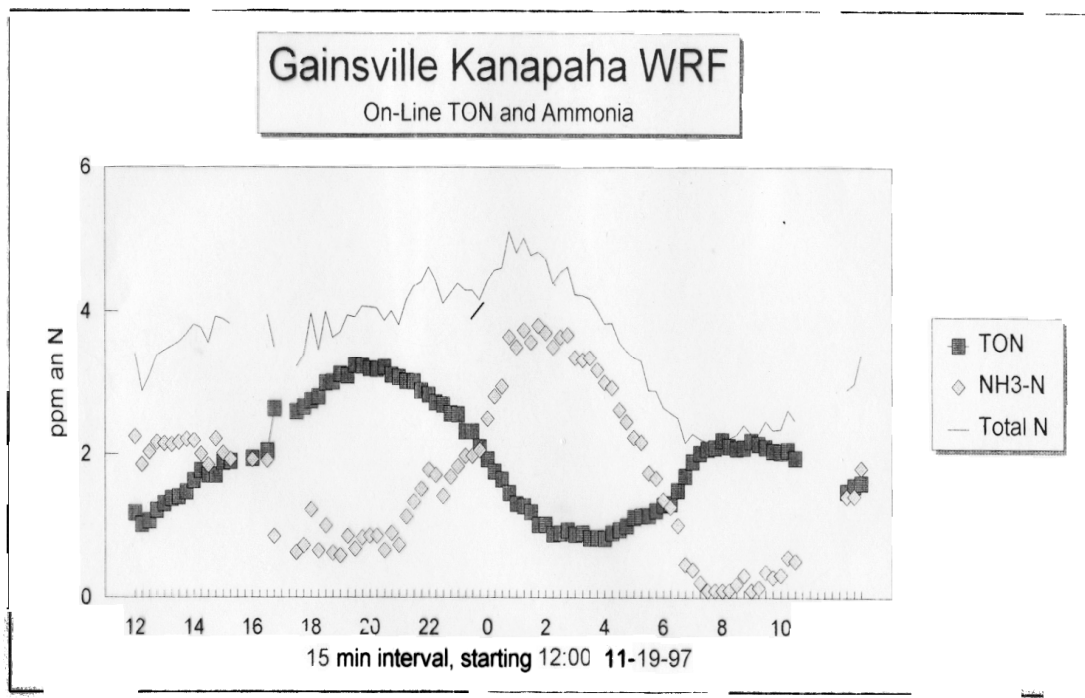
#### Nitrification

Nitrification is a biological wastewater treatment process for the conversion of ammonia to an oxidized form of nitrogen. Two specialized microorganisms accomplish the transformation. The first microorganism, *nitrosomonas*, converts ammonia into nitrite (NO<sub>2</sub>). The second microorganism, *nitrobacter*, converts nitrite into nitrate (NO<sub>3</sub>). Complete nitrification is achieved when substantially all of the ammonia present is fully converted into nitrate, leaving little or no remaining ammonia or intermediate nitrite in the effluent.

Assuming that continuous, real-time measurements are available, one of the first signs of a decrease in the nitrification rate is a corresponding decrease in the NO<sub>3</sub>-N concentration, accompanied by an increase in the NH<sub>3</sub>-N and NO<sub>2</sub>-N concentrations. Frequent automatic analysis of ammonia, nitrite and nitrate from sample points within the aeration basin can be used to monitor nitrification process

and to observe the results of operational changes such as increased or decreased aeration rates, RAS rates and retention times.

When the process is achieving full nitrification under variable influent ammonia conditions, aeration rates may be able to be reduced without sacrificing nitrification efficiency, thus saving substantial energy costs. Some plants, such as the Northwest WWTP in Gwinnett County Georgia and the Mesa WWTP in Arizona monitor sample points in secondary effluent, while plants such as the Kanapaha WWTP in Gainesville Florida and the Conserv II plant in Orlando Florida monitor sample points directly in the aeration basins. Gwinnett and Mesa can use the information at the secondary effluent sample point to feed back process control information for the aeration basins and can also feed forward information to downstream processes such as filtration and disinfection. Gainesville displays the process chemistry trend information on a screen in the control room and relies on operators to manually adjust the aeration rate based on this information. Orlando automatically controls the aeration rate based on the process chemistry measurements.



**Figure 3. On-line Nitrogen Measurements**

Some operational strategies may allow a small concentration of ammonia to bleed through in order to provide a source of ammonia for chloramine formation during disinfection. This strategy, used at the 91<sup>st</sup> Ave WWTP in Phoenix, requires careful and continuous analysis of ammonia, nitrite and nitrate, especially under variable influent ammonia loading conditions. High nitrite concentrations can result in excessive consumption of chlorine during disinfection. Continuous monitoring of the nitrogen profile can assure that the process is fully nitrifying at all times. This approach is superior to measurement of dissolved oxygen, which is at or near zero when ammonia is fully converted to nitrate. Dissolved oxygen is only measurable after a surplus has been established, which is long after nitrification is complete. This is the major reason why operation of nitrification using process chemistry information offers substantial energy savings compared to D.O. control. (See Figure 4)

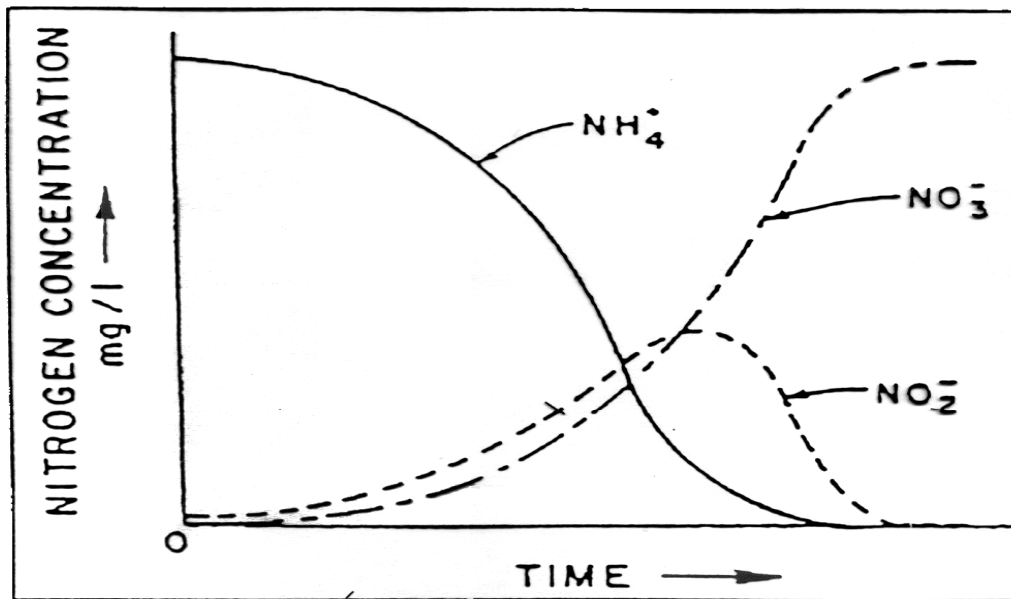


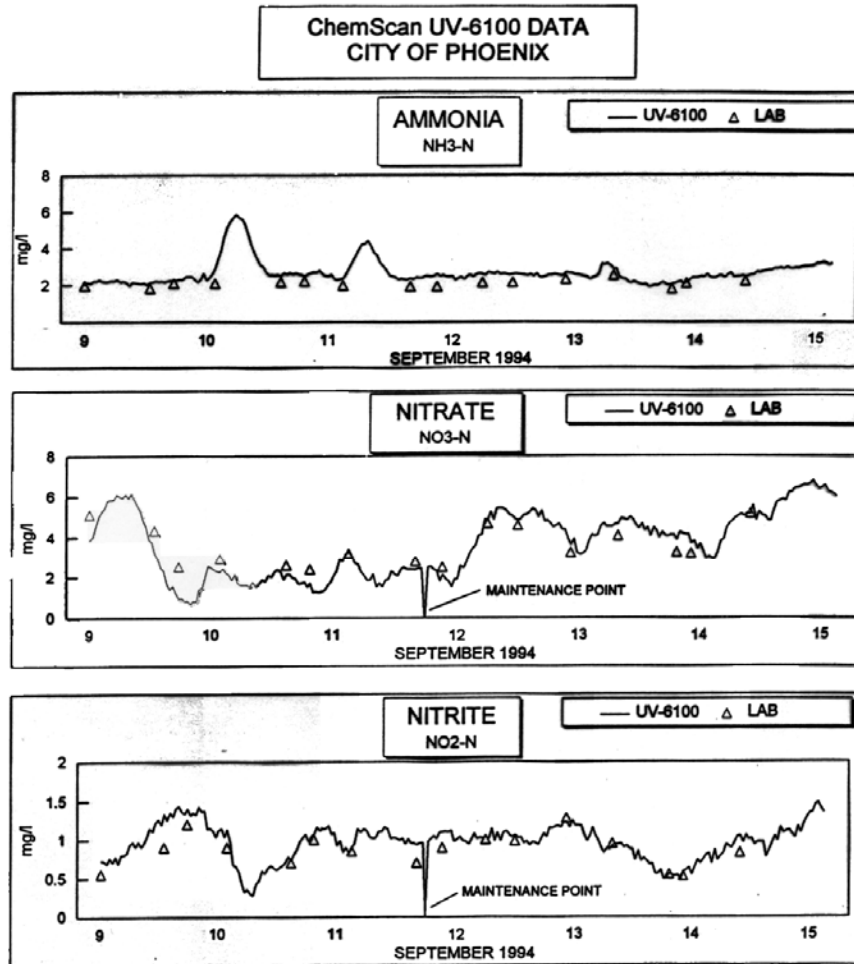
Figure 4. Schematic of nitrogen transformations during noninhibited nitrification, batch experiment.

#### Denitrification

Denitrification is a term applied to a biological wastewater treatment process used to convert nitrate ( $\text{NO}_3^-$ ) into nitrite ( $\text{NO}_2^-$ ) and then into nitrogen gas. The process employs a special class of aerobic bacteria that will metabolize carbon. Under anaerobic (low/no oxygen) conditions in nitrified wastewater, these bacteria are forced to strip an atom of needed oxygen from a nitrate or nitrite molecule. Carbon is typically obtained by the bacteria from a natural carbon source such as the influent wastewater or an artificial carbon source such as methanol, which can be added to the treatment process.

Nitrogen removal processes employ successive nitrification and denitrification steps, which can be designed to occur within the same tank at different intervals (such as in an SBR), at different locations within a circular tank or in separate tanks. Recirculation between tanks or zones allows denitrification to be performed under anaerobic conditions in combined wastewater that contains carbonaceous material, in a tank or zone preceding aerobic BOD removal and nitrification. It is important that the appropriate process conditions be maintained in each tank or zone. Denitrification in the anaerobic zone depends on special organisms that metabolize carbon and oxygen. A source of carbon must be available and, if carbon is not deficient, the organisms are forced to strip oxygen from the nitrite or nitrate available in the process.

It is advisable to monitor the concentrations of ammonia, nitrite and nitrate in each stage of nitrification and denitrification. Measurement of nitrite as a parameter separate from nitrate is always advisable to assure that nitrification and denitrification processes are stable and complete, since nitrite is an intermediate state in both nitrification and in denitrification. Process upsets can be identified by monitoring the individual components at regular intervals from each sample point where a transition is expected. This is also very important if chlorine is used for disinfection, since delivery of ammonia and nitrite to the disinfection process is a major source of excess chlorine consumption. (See figure 5)



**Figure 5. Process upset detection through nitrogen species analysis.**

The location of the denitrification zone can differ for each of several basic process types. One type of process makes use of the available carbon and the anoxic conditions in the early stages of the treatment process. Gainesville Florida pumps a fraction of the treated wastewater from the aeration basin effluent back to blend with the incoming raw influent. This strategy accomplishes some denitrification in the primary clarifier. Other plants like the Iron Bridge plant in Orlando have anaerobic zones in a circulating process (such as Bardenpho), where denitrification occurs at a stage in the process basin that provides mixing and a natural carbon source, but no aeration. These plants can optimize the process through control of the fraction of nitrified effluent that will be recirculated to the anaerobic zone, based on a process load calculation that includes flow and nitrate concentration.

Other plants like Blue Plains VA, Havelock NC and the Howard F. Curran plant in Tampa have separate tanks for denitrification, which are located after the aeration basin. Separate tank process may require some residual carbon from the secondary reactors, or may supplement the process through the addition of carbon from raw wastewater or from chemical addition such as methanol. At plants that feed a supplemental carbon source such as methanol, underfeed of the methanol will

limit the reduction of nitrate in the denitrification process reactors, while overfeed of methanol will result in a higher BOD value in the final effluent. The ideal is a methanol feed rate which is calculated to provide a desired amount of nitrogen removal given an overall influent nitrate demand but is trimmed based on measurement of a target effluent nitrate concentration in order to avoid surplus methanol bleed through.

### Phosphorous Removal

Domestic wastewater generally contains substantial inorganic phosphorous resulting primarily from the polyphosphates contained in synthetic detergents. Industrial wastewater may contain a variety of phosphate compounds. Polyphosphates gradually hydrolyze in wastewater and revert to orthophosphate form. This reversion is a function of pH, temperature and the presence of bacterial enzymes. Many wastewater treatment plants are required to remove phosphorous during the treatment process. This is done in order to inhibit the formation of algae and cyanobacteria in surface waters by limiting the amount of this essential nutrient in the treated wastewater. Phosphorous is essential for microbial reproduction, such that limiting the phosphorous in wastewater effluent can help avoid the reproduction of undesired microbes in bodies of water that receive the wastewater discharge, but the irony is that some treatment plants find that they must add phosphorous within their process in order to obtain the desired degree of biological treatment due to a deficiency of this nutrient.

There are two basic approaches for removal of phosphorous from wastewater. One approach uses coagulation of soluble phosphorous to form an insoluble precipitate that can be removed by sedimentation or filtration (Chemical Phosphorous Removal). The other approach relies on naturally occurring microorganisms that release stored phosphorous under anaerobic conditions and subsequently remove soluble phosphorous under aerobic conditions (Biological Phosphorous Removal). Some biological phosphorous removal processes also have supplemental chemical phosphorous removal capability for additional treatment.

### Biological Phosphorous Removal

A bioreactor can be managed in a way that promotes the development of naturally occurring microorganisms which release stored phosphorous under anaerobic conditions and remove dissolved phosphorous under aerobic conditions. These microorganisms can tolerate cyclic exposure to anaerobic and aerobic conditions, thus giving them a competitive advantage over other specialized microorganisms. These acclimated organisms store organics under anaerobic conditions and, therefore, do not need to compete for the small volume of soluble organics typically available in the aerobic zone. (See Figure 6).

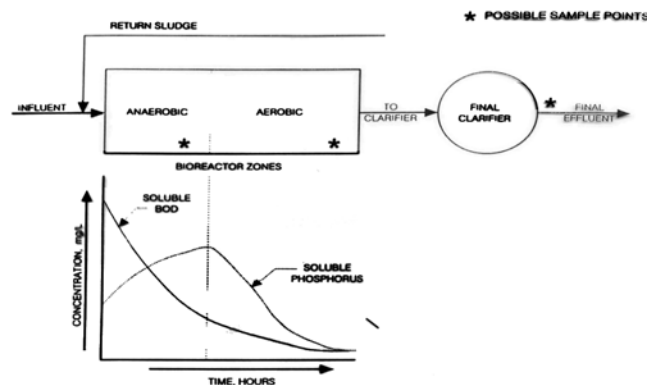


Figure 1. Soluble Biochemical Oxygen Demand and Phosphorous in Bioreactor  
(Source: WEF Manual of Practice MOP 11, Operation of Municipal Wastewater Treatment Plants)

**Figure 6. Biological Phosphorous Removal Process Dynamics**

A basic strategy for biological phosphorous removal allows all of the influent wastewater and the return activated sludge to enter an initial anaerobic zone and then enter a subsequent aerobic zone. The DO and nitrate concentrations in the anaerobic zone must be minimized. During the anaerobic period, soluble phosphorous will be released into the mixed liquor, while SBOD will be oxidized. A control strategy that focuses only on DO will not be able to account for oxygen contributed by nitrate. If either DO or nitrate are present in significant concentration, the zone will not be truly anaerobic and subsequent phosphorous removal in the aerobic zone will be inhibited. Supplemental metal salt coagulants may need to be added in the aerobic zone to increase phosphorous removal where stringent discharge limits apply. Some plants, such as McDowell Creek NC, add volatile fatty acids (VFA) to improve uptake of phosphate by the facultative microbes. Sample points for full control would include the anaerobic zone, aerobic zone and final effluent.

The most important component of a control strategy for biological phosphorous removal is to assure that soluble phosphorous is being released in the anaerobic zone and is being removed in the aerobic zone. The Iron Bride plant in Orlando was able to improve and re-rate a Bardenpho process, based in part on the benefits from on-line analysis of the nitrogen profile (nitrate, nitrite and ammonia) in addition to on-line analysis of ortho-phosphate at several sample points in the process. Proper control at this and other locations is difficult to achieve using techniques such as grab samples and DO monitoring. There are several reasons for this difficulty:

- incoming phosphate concentrations can vary in unpredictable ways as a result of industrial contributions.
- incoming phosphate concentrations do not necessarily vary in proportion to flow.
- long acclimation periods are required to cultivate a population of organisms that can survive alternating anaerobic and aerobic cycles.
- high recycle nitrate concentrations can inhibit anaerobic zone processes. Thus, DO can be low but the anaerobic zone can be inhibited for other reasons.
- DO is not the best indicator of aerobic zone phosphorous removal performance. Reduction of soluble phosphate is the most direct and most reliable indicator.

#### Chemical Phosphorous Removal

Chemical phosphorous removal uses coagulants such as aluminum sulfate (alum), lime, ferrous sulfate, ferric chloride or organic polymers added to the wastewater to form a precipitate with soluble phosphorous.

One strategy is to add coagulants to the raw wastewater as it enters the plant, with sedimentation in the primary clarifier. If this is done, care must be taken to assure that sufficient phosphorous remains after sedimentation so that biological treatment of the wastewater is not inhibited during subsequent stages of treatment. During a trial of the ChemScan system at Blue Plains VA a phosphorous deficiency was discovered by monitoring the residual ortho-phosphate present in the influent to the denitrification reactors. When the ferric addition in the primary clarifier was reduced, all biological treatment process steps were improved.

Another control strategy is to add the coagulant in the activated sludge aeration tank, where the agitation from aeration can provide flocculation of the phosphate precipitate. The resulting floc is removed in the secondary clarifier. Chemicals can also be added in the secondary clarifier or in a

separate tertiary treatment process, which can include chemical addition and mixing, followed by tertiary sedimentation or filtration.

The most important component of a control strategy for chemical phosphorous removal is the calculation of coagulant dosage based on the phosphorous demand. Dosage rates for aluminum salts or for iron salts are based on the molar ratio of available metal ion to phosphorous. Insufficient coagulant dosages can produce an effluent with excessive turbidity, but excessive coagulant dosage can also produce the same result. Surplus coagulants can also have an adverse effect on disinfection processes, by exerting an oxidation demand. Also, surplus iron salts can coat ultraviolet disinfection tube surfaces. Thus, it is important that the process be well controlled.

Proper control is difficult to achieve using manual techniques such as grab samples and periodic jar tests. There are several reasons for this difficulty:

- incoming phosphate concentrations can vary in unpredictable ways as a result of industrial contributions.
- incoming phosphate concentrations do not necessarily vary in proportion to flow.
- conversion of polyphosphate to orthophosphate prior to coagulant addition will affect coagulation efficiency. Process conditions, particularly pH and temperature, can significantly influence polyphosphate conversion.
- if reclaimed products such as pickle liquor are used as a coagulant, the concentration of available metal ion will also be variable. This will result in a highly variable phosphate coagulation rate and, in the absence of on-line monitoring, will require frequent manual adjustments to avoid overfeed or underfeed.

The monitoring strategy for chemical phosphorous removal will depend on the chemical addition point and on the control strategy to be employed. Ortho-phosphate should be monitored on-line at frequent intervals from a point in the process prior to coagulant addition. This sample point should be after the point at which polyphosphate has been fully converted to orthophosphate, if possible. This is usually not at the headworks, but after primary clarification or immediately after influent addition to the aeration tanks. Filtration of suspended solids may be required prior to analysis, but should not affect accuracy, since the soluble (ortho) phosphate is the parameter of interest. The most important control measurement is from a sample point following precipitation, which is selected to monitor the efficacy of the phosphorous removal process. The sample point may be the mix tank effluent or the effluent from sedimentation or filtration. Ortho-phosphate measured at this sample point represents the fraction of dissolved phosphate that remains after formation and removal of the precipitate. Ortho-phosphate residual at this sample point can be used for feedback control.

If a sample point is after sedimentation or filtration is used, an additional measurement can be made to assure that precipitate floc is not being carried over into the effluent. This is done by measuring either total phosphorous or by monitoring turbidity.

### UV Disinfection Control

Ultraviolet light is frequently used to disinfect water or wastewater because chlorine tends to form unwanted and potentially harmful by-products when combined with organics. Chlorine also may be harmful to aquatic life when discharged in wastewater.

Ultraviolet disinfection requires a minimum applied dosage to be effective. This applied dosage is a function of the lamp intensity and the exposure time. These parameters are directly affected by

equipment configuration, flow path of the water through the bank of lamps, plus the solids content and the light transmission characteristics of the water to be disinfected.

Each manufacturer has a proprietary equipment configuration. Some manufacturers offer UV disinfection systems with lamps configured in a manner that permits fewer lamps to be operated when the water to be disinfected offers less resistance to the transmission of UV light. Changes in turbidity, suspended solids, microbial populations and/or background water chemistry can result in substantial changes in the light transmittance characteristics of water at germicidal wavelengths. Substantial energy savings may be available if acceptable levels of disinfection can be achieved using a reduced number of lamps.

Some manufacturers offer an interval device, designed to measure the amount of ultraviolet light being received on the surface of an optical detector. Care should be taken so that changes in the output of the light source (due to age or fouling) and fouling of the detector surface can be separated from changes in the basic light transmission characteristics of the media to be disinfected. Otherwise, the internal sensor may be measuring conditions other than changes in the wastewater will possibly communicate false information.

An independent measurement of light absorbance at 254 nm should be used to characterize the absolute percent transmittance at 254 nm, independent of fouling. A side stream sample of the disinfection influent and effluent can be measured in a separate cell where a known intensity of ultraviolet light can be transmitted through a fixed path length of sample. Frequent automatic zeroing and cleaning of the optical surfaces within the flow cell eliminates the effect of fouling on the UV transmittance measurements being made. Simultaneously, a measurement of turbidity can be made at 404 nm to eliminate the effects of turbidity on the analysis.

Iron fouling is a significant issue for UV disinfection systems. Dissolved iron is oxidized by UV light and can plate out on the surfaces of the UV lamps, reducing their effectiveness. A measurement of dissolved iron in the influent to the UV disinfection process can be used to initiate alarms, adjust upstream processes or adjust UV dosages based on possible iron fouling.