For most US distribution systems using chloramination, nitrification is the leading water quality concern. However, by combining active mixing with regular tank maintenance and efficient operation, nitrification can be tamed in even the most challenging climates.

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NITRIFICATION IS THE process by which specific nitrifying bacteria proliferate in a distribution system, causing rapid loss of water quality. If not detected early, nitrification can sweep through a distribution system, requiring tank flushing and chemical cleaning. As a result, chloramine-using utilities must test their water quality frequently, especially during summer months.

Chloraminated systems are prone to nitrification for several reasons.
- Chloramine, a less powerful disinfectant than chlorine, requires longer contact times to achieve comparable disinfection rates.
- Reacting with chlorine to form chloramines, ammonia is a fertilizer, which provides the nitrifying bacteria with plenty of food to grow and multiply.

These features make chloraminated water storage tanks particularly susceptible to nitrification problems. Thermal stratification, which can occur with as little as 1°F difference between bottom and top water temperatures, can trap water at the top of a tank, leading to disinfectant loss and ammonia buildup. Hot air inside a water tank can accelerate bacterial growth and prompt nitrification.

In the absence of regulatory requirements to monitor or control nitrification, a few operators have taken steps to prevent nitrification and maintain water quality in storage tanks and reservoirs by installing submersible active mixers. The theory is that active mixing
- prevents tank thermal and chemical stratification that leads to disinfectant residual loss in upper water layers.
- reduces the temperature of a tank’s top layer of water and slows biological growth.
- continuously circulates disinfectant-rich water throughout a tank to lower biofilm growth and expose hard-to-reach places in the tank to disinfectant.
However, theory is one thing; results are another. Can submersible active mixers really lower nitrification risks for chloraminated systems? So far, results are promising.

PROOF IN REDWOOD CITY

Redwood City, Calif., is one of 24 municipalities in the San Francisco Bay Area that receives its water from the San Francisco Public Utility Commission (SFPUC). Several years ago, SFPUC switched to chloramination to reduce disinfection by-product (DBP) levels. Since that time, however, many municipalities receiving SFPUC water have struggled to avoid nitrification, particularly during summer months.

In summer 2005, Redwood City had several episodes of nitrification in a short period of time. Multilevel water quality sampling revealed that cool water at the bottom of the tank had plenty of disinfectant, but water at the top of the tank often had little or no residual, as well as elevated nitrite—a sure sign that another nitrification episode was imminent. The city team tried several operational changes to increase tank mixing, including deep-cycling the tank to increase turnover by as much as 60 percent and valving modifications to increase fill velocities. Neither operation had much effect on thermal stratification or nitrification. Deep cycling increased Redwood City’s energy costs during peak electrical rates and decreased water storage for fire protection.

In summer 2006, the city installed a submersible active mixer in the most problematic tank. In the first few hours, temperature measurements showed complete elimination of thermal stratification. In the days following installation, temperatures remained uniform; chlorine levels improved and stabilized; and nitrite readings at the top of the tank dropped to nominal levels.

For the rest of 2006, Redwood City experienced no further nitrification episodes. With water quality stabilized, water quality sampling frequency was reduced from several times each week to weekly. Because samples drawn from a tap at the base of the tank were representative of all water inside the tank, water quality measurements were easier to obtain and more reliable.

Since 2006, water quality at the problematic tank has remained under control. Chlorine residuals have remained consistent in the tank’s upper water levels (Figure 1), and nitrite has remained at nominal levels, even during summer months (Figure 2).

OTHER SYSTEMS, SAME SUCCESS

In the years since Redwood City installed a submersible active mixer, several other area municipalities also have installed mixers with similar results. Hillsborough, Calif., another SFPUC customer, installed a submersible active mixer in 2009. According to Cary Dahl, water operations supervisor, frequent tank flushing had been necessary to prevent nitrification.
Installation of a submersible active mixer in the most problematic tank eliminated the need to flush, and water chemistry stabilized with no nitrification.

In addition, water treatment personnel in Calexico, Calif., discovered that active mixers eliminated nitrification problems and lowered DBP levels. Another system in Southern California was able to eliminate the need for on-site dosing of large amounts of chlorine after installing active mixers.

**NO SILVER BULLET**

Despite these success stories, active mixing can’t single-handedly eliminate nitrification risks. The magnitude of thermal stratification, tank turnover, and tank geometry and size are critical factors that must be considered. Ensuring that an active mixer is powerful enough to overcome these dynamics and provide frequent turnover is key to proper equipment selection. For example, a computational fluid dynamics study of Redwood City’s submersible mixer revealed that it produces more than 10,000 gpm of pumping within the tank. Passive systems that operate only during fill cycles or small-volume pumping systems may not produce adequate tank turnover. Tank conditions are also critical. Poorly maintained tank infrastructure, infiltration through roof openings, excessive sediment, and deteriorated coatings increase nitrification risks. However, by combining active mixing with regular tank maintenance and prudent operational precautions, nitrification can be tamed in even the most challenging climates.

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**Figure 2. Nitrate Levels**

Nitrate levels in Redwood City’s Cambridge 2 tank improved, particularly during warm weather.

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**WATER QUALITY AND TREATMENT CONDITIONS**

**WHAT CAUSES NITRIFICATION IN WATER DISTRIBUTION SYSTEMS?**

Nitrifying bacteria are ubiquitous in chloraminated distribution systems, and ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) can proliferate under favorable conditions. Water quality and treatment conditions primarily affect the chloramine residual’s stability and the growth rate of nitrifiers. According to AWWA M56, *Fundamentals and Control of Nitrification in Chloraminated Drinking Water Distribution Systems*, these affect chloramine residual:

- chloramine dose entering the system.
- chlorine-to-ammonia weight ratio.
- chloramine demand (affected by total organic carbon [TOC] and treatment factors).
- chloramine decay (affected by temperature, pH, and alkalinity).

**Chloramine Residual.** In general, higher residuals (greater than 2.0 mg/L Cl₂) appear to be more effective in preventing nitrification by limiting excessive AOB growth. However, there are drawbacks in using higher chloramine residuals. For example, higher free ammonia levels are potentially available to the AOB as the chloramine residual decays in the system. Chloramine demand and decay rate are key parameters that will determine whether and which residual levels will be sufficient to control nitrification.

**Chlorine-to-Ammonia-N Ratio.** The chlorine-to-ammonia-N weight ratio necessary to form monochloramine varies from 3:1 to 5:1. In general, maintaining higher chlorine-to-ammonia-N weight ratios (up to 5:1) are preferred at the entry to the distribution system, as less ammonia is initially available for nitrification.

**Impacts of Water Treatment.** An optimized water treatment process typically improves chloramine stability and reduces susceptibility to nitrification. In general, the removal of particulate matter and TOC during treatment is beneficial to nitrification control.

**Water Temperature.** AOB and NOB grow faster at temperatures greater than 15°C. As a result, some utilities experience more nitrification during the summer. Also, the chloramine decay rate will increase as temperature increases, and more free ammonia will be released.

**Water pH and Alkalinity.** The optimal pH range for nitrification is 7.5 to 8.0, but nitrification can occur at pH values of 6.6–9.8. In general, pH will decrease during nitrification depending on the alkalinity of the water. However, pH data should be evaluated carefully, because pH may vary throughout the system.