OPTIMIZING BIOLOGICAL NUTRIENT REMOVAL FROM AN SBR SYSTEM IN NORTHERN VIRGINIA

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A northern Virginia WWTP at Dale City utilizes a system consisting of a Sequencing Batch Reactor (SBR) and a cloth media filter to process their municipal wastewater. The SBR and filter technologies were chosen due to their ability to efficiently provide wastewater with low values of BOD and TSS, with the added ability to perform nutrient removal without the need for supplemental carbon addition or separate anoxic mixing tanks. In operation of the plant, the operators have seen the low effluent BOD and TSS values they expected, but are also achieving very high removals of phosphorus and nitrogen biologically. The system utilizes minimal amounts of metal salts, and is achieving low effluent total phosphorus values.

The system at Dale City consists of a four basin SBR and two 10 disk cloth media filters designed to treat an average flow of 4.25 MGD, and a peak flow of 9.25 MGD. Each SBR basin is designed to operate 5 cycles per day. The influent for the system was designed for a BOD of 300 mg/l, TSS of 300 mg/l, TKN of 68 mg/l, and Total P of 7.9 mg/l. The effluent required by the design was 3.2 mg/l soluble CBOD, 6.0 mg/l TSS, 8.0 mg/l Total N and 0.18 mg/l Total P. Actual influent data (July 2003) showed an average flow of 3.61 MGD, with influent BOD of 291 mg/l, TSS of 147 mg/l, TKN of 23.2 mg/l and Total Phosphorus of 4.52 mg/l. Effluent from (May-October 2004) showed a CBOD of < 2 mg/l, TSS of 1.49 mg/l, Total Nitrogen of 3.8 mg/l and Total Phosphorus of 0.10 mg/l.

Nitrogen removal is being achieved in the SBR system via a combination of nutrient uptake and the nitrification and denitrification processes. The SBR system is able to achieve low levels of effluent nitrogen by adjusting the MLSS to optimize nutrient uptake. In order to achieve nitrification and denitrification in the system, the SBR goes through a series of aerated and nonaerated periods in the cycle structure, controlled by the SBR control panel.

One complete cycle in the SBR system consists of 5 distinct phases. The sum of the phases at the Dale City plant lasts for a duration of 4.8 hours. It should be noted that the AquaSBR® is a true batch system (utilizing influent valves) and that there are separate mixing and aeration devices in each SBR tank. The phases can be defined as follows:

Mix Fill – Anoxic phase where the mixer is in operation, influent is entering the SBR basin, and the aeration system is off.

React Fill – A phase that can be either aerated or anoxic. When the aeration system is in operation, the system is aerobic, when the aeration system is off, the system goes anoxic. Influent continues to enter the basin.

React – A phase that can be either aerated or anoxic. No influent enters the tank during the React phase, due to the fact that the influent valve has been closed to the SBR tank, and a batch of wastewater has been created.

Settle – The SBR undergoes a quiescent settling period prior to removal of supernatant.

Decant – The SBR removes clarified effluent. Note that sludge waste occurs automatically at the end of the Decant phase.

Nitrification/Denitrification

The Dale City installation is designed to perform nitrification and denitrification in order to meet effluent limits for total nitrogen. Nitrification is defined as the oxidation of ammonia to nitrate (nitrite is further oxidized into nitrate in this process). The autotrophic bacteria *Nitrosomonas* and *Nitrobacter* perform the two-stage nitrification reaction. Nitrification occurs in the aerated portions of the React and React Fill phases. Denitrification is defined as the conversion of nitrate to nitrogen gas. Denitrification is performed under anoxic conditions by many of the same heterotrophic bacteria that perform carbonaceous removal in an activated sludge system. Anoxic conditions are defined as conditions where oxidized nitrogen is present but there is little or no dissolved oxygen present in the mixed liquor. Facultative bacteria use nitrate as an oxygen source (their terminal electron acceptor). Denitrification generally occurs during the Mix Fill phase, and during anoxic portions of the other treatment phases.

The rate of nitrification at the plant is affected by many factors, some of which are controlled by the operational staff. The primary factors associated with nitrification are as follows:

1. Temperature
2. Sludge Age, MLSS and Mixed Liquor Volatile Suspended Solids (MLVSS) Concentration
3. Dissolved Oxygen (D.O.) Levels
4. pH/Alkalinity
5. Inhibitory Substances
6. BOD_5/TKN Ratio

Temperature is a very important factor in determining the rate of nitrification in the system, but it is a factor that the operators have little control over. Nitrifying bacteria reproduce more slowly and are less active as wastewater temperatures decrease. Therefore, the rate of nitrification would generally be expected to decrease with decreasing temperature. The Dale City plant has responded by increasing the operating MLSS concentration (and thereby the nitrifier population) and increasing the sludge age during cold weather operations to help offset the lower nitrification reaction rate at lower temperatures. The plant has been operating a sludge age in the 8-10 day range corresponding to a mixed liquor concentration of 1,200 mg/l during the warmer months and a sludge age of 15-17 days in colder weather, corresponding to a mixed liquor concentration of 1,800 mg/l. The minimum temperatures observed in the basins have been as low as 13.5 degrees C.

The Dale City plant typically targets a D.O. concentration of approximately 2.0 mg/l during aerated periods, in order to optimize the nitrification process. D.O. profiles are performed monthly to optimize blower usage and electrical consumption, as well as to monitor the process.

Optimum rates of nitrification occur in the pH range of 7.0-8.5. It is possible to nitrify when the pH is outside of this range, but the nitrification reaction will not occur as quickly. To maintain the optimal pH, it is essential that the wastewater have sufficient alkalinity (resistance to changes in pH). In order to control the pH to a range of 6.8-7.0, the plant utilizes a system that adds up to 15 gallons per basin per day of 62% magnesium hydroxide. It should also be noted that the denitrification that occurs at the facility recovers alkalinity as well, which reduces the amount of magnesium hydroxide which is added.

As the Dale City plant has a total nitrogen limit of 8 mg/l they not only need to nitrify but also denitrify. As mentioned earlier, the denitrification process is carried out under anoxic conditions by heterotrophic bacteria that are present in all activated sludge systems. The rate of denitrification is a function of the dissolved oxygen concentration, temperature, MLVSS concentration, pH/alkalinity, and the availability of a carbon source.

Obviously if denitrification is to occur, then it must occur after nitrification has taken place. Therefore, the oxygen supply system during the React Fill and React phases is set up to operate in a specific "on then off" pattern. This alternately creates aerobic conditions (where nitrification takes place) and anoxic conditions (where denitrification should occur). Efficient denitrification is accomplished during the React Fill phase by providing an appropriate aeration "off" time period to create an anoxic environment as wastewater continues to enter the reactor. This aeration system cycling is performed in the React Fill and React phases so that denitrification can take place prior to the Settle and Decant phases. It is desirable to perform all required denitrification prior to the Settle phase because the reactor is in a completely mixed condition, and the carbon source and nitrates required to perform denitrification are both present.

In order for denitrification to occur, anoxic conditions where D.O. < 0.5 mg/l are required. These conditions are achieved in Mix Fill and the non aerated portions of React Fill and React by operating the mixer without the aeration system operating. The raw influent is used as a carbon source to drive the denitrification reaction. Another source of carbon is that generated through cell lysis caused by endogenous decay in the reactor. The carbon is required in the basin to serve as an electron donor during the conversion of nitrates to nitrogen gas. The carbon also serves to provide the organic substrate necessary for the heterotrophic bacteria to create new cell mass.

Biological Phosphorus Removal

The basic principle in biological phosphorus removal at the Dale City plant is to expose bacteria to alternating aerobic and anoxic to anaerobic conditions. Under anoxic to anaerobic conditions such as those found in the Mix Fill phase, some bacteria (especially *Acinetobacter*) have the ability to take in organic substrate, such as BOD_5. In order to obtain the energy to incorporate BOD_5 into the microbial cell under anaerobic conditions, the bacteria release phosphorus into the wastewater. When aerobic conditions are restored at the beginning of the React Fill phase, the organic substrate that has been taken in is converted to energy and cell mass. This allows the bacteria to take in phosphorus, and after being exposed to anaerobic conditions, the bacteria can take in more phosphorus then they need to fulfill their nutrient needs. This will lead to an excess of phosphorus in bacteria exposed to anoxic to near anaerobic followed by aerobic conditions. The biomass contains 3-5% phosphorus in a system designed to perform biological phosphorus removal. This is compared to approximately 1-3% phosphorus in the biomass of a system not designed for enhanced biological phosphorus removal.

When the bacteria are removed from the basin in the form of waste sludge during the Settle and Waste Sludge phases, the sludge has been enriched in phosphorus, and the supernatant has been depleted of phosphorus. This overall sequence of events is referred to as “enhanced biological phosphorus removal”. The biological phosphorus uptake in the SBR system is followed by metal salt and polymer addition prior to the cloth media filtration system in order to achieve low levels of effluent Total Phosphorus. Through this mode of operation the Dale City plant is achieving less than 0.5 mg/l of Total Phosphorus biologically out of the SBR, and with chemical addition and filtration, the final effluent total phosphorus is around 0.1 mg/l.

The amount of phosphorus taken in by the bacteria present in the reactor can be affected by many factors which the operators have control over. The main factors in biological phosphorus removal are listed and discussed below.

1. Nitrate and Dissolved Oxygen Concentrations in the Mixed Fill phase
2. Effluent Suspended Solids
3. Availability of Organic Substrate
4. Sludge Age

In order for enhanced biological phosphorus removal to occur, anaerobic conditions must occur in the reactor during the Mix Fill phase. Anaerobic conditions are achieved through the introduction of wastewater in the Mix Fill phase while the aeration system remains off. The influent wastewater acts as a food source (organic substrate) for the bacteria in the reactor, leading to consumption of the oxygen and nitrate in the reactor, and eventually to the release of phosphorus by the bacteria. Upon return of aerobic conditions in the React Fill phase, the bacteria will take in the phosphorus that was released in the Mix Fill phase and the phosphorus that enters the reactor during the Mix Fill phase and early stages of the React Fill phase. The operators vary the duration of Mix Fill as needed to ensure that anaerobic conditions occur during the Mix Fill phase. Typical durations for the Mix Fill phase range from 30-45 minutes. If nitrates are present in the reactor, they will be reduced as the Mix Fill phase takes place. However, the bacteria that perform denitrification during the Mixed Fill phase utilize BOD_5 and/or COD that would otherwise be available to the bacteria that store phosphorus. This has the net effect of reducing the phosphorus release in the Mix Fill phase, and therefore reducing the overall amount of biological phosphorus removal in the AquaSBR®. For AquaSBR® systems that are designed to perform biological phosphorus removal, the nitrate level in the reactor as the system begins the Mix Fill phase must be minimized.

Another important aspect in achieving low effluent phosphorus concentrations is to maintain low effluent suspended solids concentrations because the solids will contain phosphorus. Therefore, increased effluent solids concentrations will lead to an increase in effluent total phosphorus concentrations. At the plant, the effluent solids concentration is controlled through adjustment of the duration of the Settle phase, as well as through tertiary filtration.

Since the plant is designed to perform biological phosphorus removal, it must perform both nitrification and denitrification. This is due to the fact that very low nitrate concentrations are required in the reactor as the Mix Fill phase begins. In order to maximize biological phosphorus removal, the operators adjust the process so that it is not operated at a sludge age in excess of that required for overall treatment needs.

Many AquaSBR® systems that are designed to achieve low effluent phosphorus concentrations remove phosphorus by adding chemicals to precipitate the phosphate present in the wastewater. The Dale City plant utilizes approximately 450 gallons per day of 21% aluminum chloride to aid in phosphorus removal. There are solids contact clarifiers that were part of the existing system prior to the installation of the SBR, that are being reused to aid in phosphorus removal. The primary mechanism for chemical phosphorus removal is interaction of the metal ion with orthophosphate to form an insoluble precipitate that is filtered or settled out of the wastewater stream.

Summary

The AquaSBR® system at Dale City has been in operation for over two years and has been consistently within discharge permit requirements. The ability of the SBR to remove nutrients biologically has allowed the operators to reduce the amount of chemical addition required to meet the effluent phosphorus limit. The combination of the AquaSBR® and AquaDisk® cloth media filter has allowed the operators flexibility in adjusting the process to meet effluent requirements as the influent characteristics vary.