Testing a Nutrient Removal Option

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The James River Treatment Plant conducted a full-scale demonstration study to test whether an IFAS process could meet tough nutrient limits. Retrofitting the existing tanks with IFAS was more cost-effective in terms of achievable nitrogen removal when compared to other options.

IFAS enables Virginia plant to meet permit demands

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When Hampton Roads Sanitation District (HRSD; Virginia Beach, Va.) received a tough new nitrogen wasteload allocation nitrogen limit — 6 million lb (2.7 million kg) per year — the James River Treatment Plant (JRTP; Newport News, Va.) — one of HRSD's nine large plants — set out to perform a full-scale demonstration study of an integrated fixed-film activated sludge (IFAS) system. The 20-mgd (760,000-m^3/d) JRTP estimated it could remove about 760,000 lb (340,000 kg) of nitrogen by switching to a moving-carrier IFAS process from its conventional single-stage activated sludge process.

The IFAS process provides additional capacity for nitrification by including suspended media in the activated sludge process for more biofilm to grow. The goal was to produce an annual average effluent total nitrogen (TN) concentration between 8 and 12 mg/L.

Through the demonstration study, JRTP staff members were able to gain experience operating a moving-carrier IFAS system, confirm the ability of the process to meet the needed requirements, and identify ways to improve the performance, operability, and economy of the full-scale design.

The IFAS Choice

HRSD chose IFAS for JRTP for several reasons. First among them were space limitations. The current arrangement of tanks at the plant provided a constrained site with little room for expansion. Second, retrofitting the existing tanks with IFAS was more cost-effective in terms of achievable nitrogen removal when compared to other options. Finally, an IFAS process could be installed and implemented within the limited time available to meet the new permit requirements — HRSD had only 30 months to meet its new nitrogen wasteload allocation.

After a competitive selection process, HRSD chose a five-cell AnoxKaldnes (Providence, R.I.) system. The process for the demonstration study (see Figure 1, p. 65) consisted of two anoxic cells for denitrification (R-1 and R-2), an anoxic–aerobic swing cell for denitrification or nitrification (R-3), a complete-mix IFAS zone for nitrification (R-4), and a reaeration cell for further reduction of ammonia (R-5).

HRSD hired CH2M Hill (Englewood, Colo.) to design how the IFAS process would fit in the demonstration tank. T.A. Sheets Mechanical

Contractors Inc. (Norfolk, Va.) executed the design, and on Oct. 5, 2007, the demonstration unit was put into service.

Small plastic media float in the IFAS cell and provide a place for extra biofilm to develop. To keep the media from washing into the reaeration tank, cylinders made of metal mesh were installed at the effluent end of the IFAS tank to serve as a screen. The design also included two internal mixed liquor recycle (IMLR) pumps placed to recycle nitrate-rich wastewater from the influent and effluent ends of the IFAS cell back to the anoxic cells. The media fill fraction, based on a wastewater temperature of 14°C (57°F), was 50%. Because of the plant's low influent alkalinity, it was determined that caustic would be added to influent entering the demonstration tank. Finally, due to the significant increase in air requirements for the IFAS system, a new high-speed, 200-hp (150-kW) APG–Neuros Inc. (Boisbriand, Quebec) turboblower was installed and dedicated to supplying air to the tank.

Within 4 weeks, a good biomass layer had formed on the media.

Early Lessons

Initially, controlling influent to the IFAS demonstration unit was difficult. The system was designed to handle about 2.2 mgd (8300 m^3/d) but was receiving as much as 3.7 mgd (14,000 m^3/d). After some troubleshooting, the plant switched to using an influent slide gate to control the flow to the IFAS system.

Resolving the flow issue delayed the demonstration study by a few months. But despite the setback, operators gained valuable experience on how to operate an IFAS system during high-flow conditions.

Operators learned that the amount of recycle from IMLR Pump No. 2 depended on the amount of biomass on the media, as well as flow. More biomass makes it more difficult to distribute the media in the IFAS zone. Reducing the flow of Pump No. 2 helps prevent pulling the media toward the effluent cylinder screens. Depending on the amount of biomass on the media, Pump No. 2 could move up to 1.5 times the design flow — about 3.4 mgd (13,000 m^3/d).

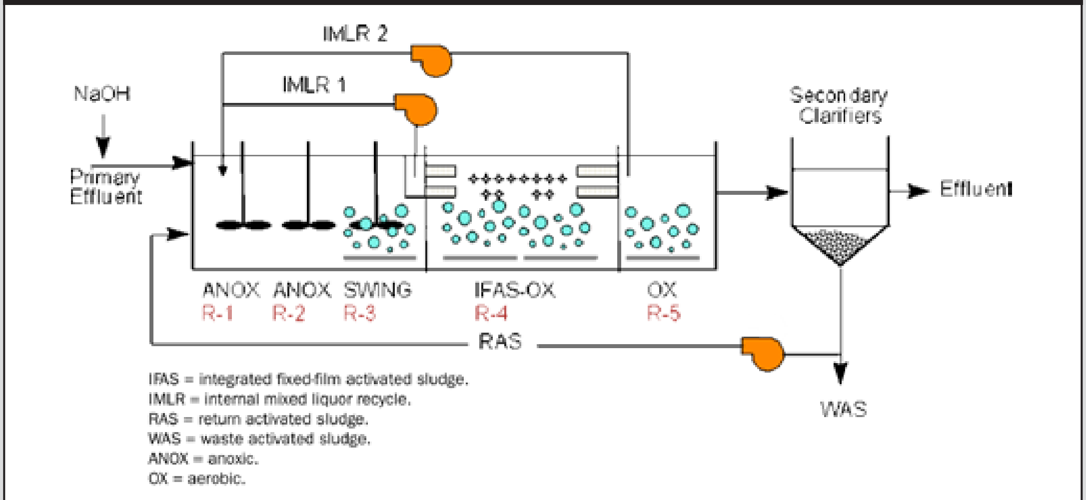
Operators also learned that high flows can lead to large variations in return activated sludge concentrations. When flows were high, biomass growth on the media was considerable. When a piece of media was overwhelmed with growth, the biomass would slough off. This increased the IFAS tank's mixed liquor concentration and, therefore, the return sludge concentration. Return sludge concentrations were particularly high when bunching of the media at the cylinder screens resulted in excessive sloughing.

The wide swings in the return sludge concentration made controlling the mean cell residence time (MCRT) difficult, because wasting was being performed from the return line. To solve this problem, wasting was performed directly from the IFAS cell on a volumetric basis. Throughout the study, an MCRT of 5 to 5.5 days was found to be optimal.

IFAS Operation

With these initial problems resolved, the demonstration study began in February 2008 and continued until June 2009. The IFAS system was operated primarily with flow from the anoxic cells entering the IFAS cell through a gate in the wall separating the two areas. The gate was located along the side wall of the IFAS tank. The velocity of the flow through the gate would direct flow to the center of the IFAS reactor.

Figure 1. James River IFAS Demonstration Study Tank



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Cylindrical mesh screens keep the media contained to the aeration zone.

The designers were concerned with how fast the media approached the effluent cylinder screens, so they designed the system with nitrified recycle pumps at both the upstream and downstream ends of the IFAS reactor. For denitrification, Pump No. 1 would return flow to the anoxic cells at a rate of 200% of the influent flow, and Pump No. 2 would operate at 50% of the influent flow. The designers also planned for nitrate from the return activated sludge (RAS) to be denitrified in the anoxic cells at a return rate of 100% of the influent flow.

During the evaluation period, the system worked optimally with Pump No. 1 operated in the 200% to 250% flow range and Pump No. 2 operating in the 50% to 150% flow range.

The recycle used on Pump No. 2 was highly dependent on the amount of biomass on the media. During colder months, when the biomass on the media was greater, Pump No. 2 was operated closer to 50%. During warmer weather, when the biomass on the media was less, Pump No. 2 was operated closer to 150%.

Because only one secondary clarifier was needed during the evaluation period, the RAS return was forced below 100%. The loss in nitrate returned through the RAS recycle was made up with higher recycle rates on Pump No. 2.

Based on experience gained during the demonstration study, the optimum design flow recycle rates for the IFAS tank appear to be 200% for Pump No. 1, 100% for Pump No. 2, and 50% for RAS.

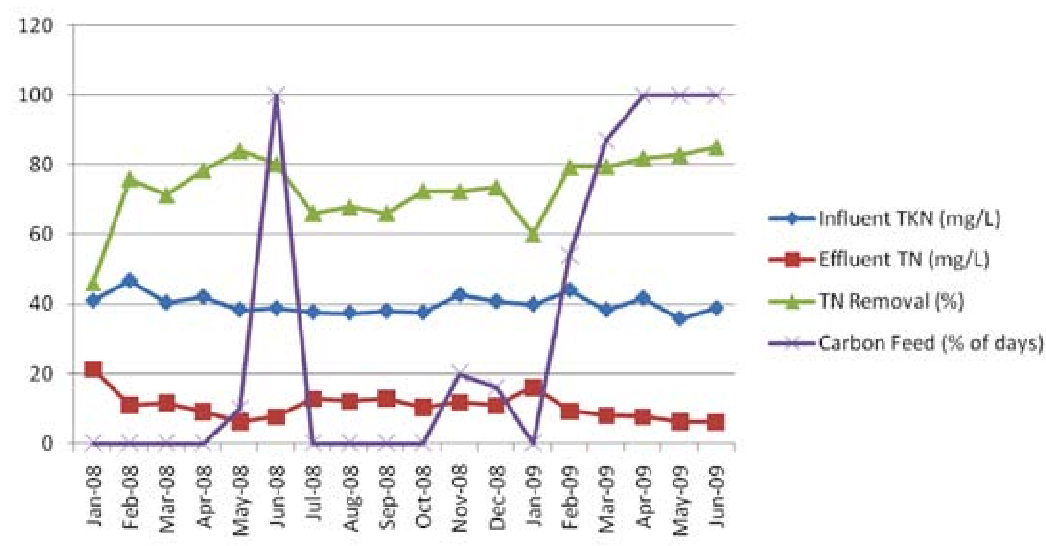
Nitrification

The IFAS system nitrified effectively from February 2008 through June 2009. Effluent ammonia concentrations from the process train averaged 1.41 mg/L.

Operators noted that the ammonia concentration at the effluent end of the IFAS cell (R-4) was almost the same as the effluent from the entire process. This indicated that almost all the nitrification was occurring in R-4, and almost none was occurring in the reaeration cell (R-5).

Though the IFAS system bounced back quickly, full nitrification was affected by several events during the course of the study. The event with

Figure 2. IFAS Total Nitrogen Removal With Supplemental Carbon



IFAS = integrated fixed-film activated sludge.
TKN = total Kjeldahl nitrogen.
TN = total nitrogen.

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Transforming one of the aeration basins at the James River Treatment Plant (Newport News, Va.) from a conventional single-stage activated sludge process to an integrated fixed film activated sludge process required reconfiguring the basin with new concrete dividing walls and aeration equipment.

the most effect was the presence of yeast on the media and in the suspended growth after feeding a sugary waste from a soft-drink factory — the waste was fed as a carbon source for denitrification.

The yeast's effects lasted about 6 weeks. To eliminate the yeast, the IFAS cell was overaerated. The pH also was increased to about 7.1 to enhance nitrification.

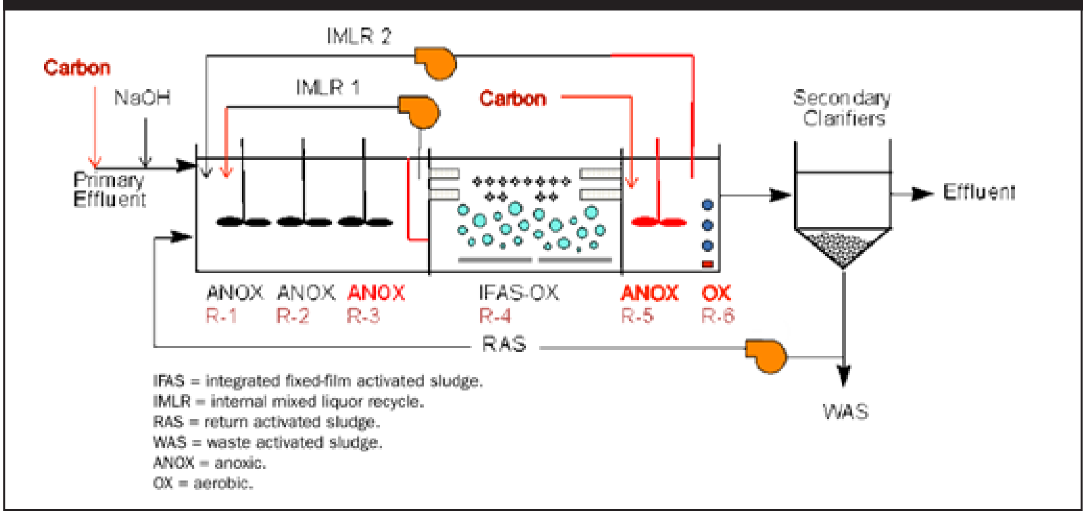
Other events affected nitrification, but only for a day or two. These included an overdosing of centrifuge centrate during a need to drain the centrate equalization tank, an overdosing of defoamer, the blower being off-line for about 5 hours for nonmechanical problems, overdosing caustic up to a pH of about 9 due to a mechanical malfunction, and two high-flow events.

The best TN removal occurred when the biomass on the media was thinner during the warmer months. Nutrient profiling of the IFAS cell (R-4) showed nitrate concentrations increase toward the cell's effluent end. Ammonia was highest at the influent end.

One theory to explain the high concentration of nitrate at the effluent end was the higher concentration of media there; throughout the study, most of the media resided in the downstream half of R-4. With most or all of the nitrite-oxidizing bacteria activity occurring on the media, it makes sense that more nitrate would be found where the media are more concentrated.

Another theory credited the nitrate gradient to the lower dissolved-oxygen (DO) levels maintained at the influent end of the IFAS cell to keep DO from

Figure 3. James River IFAS Tank Final Design



being recycled back to the anoxic cells by Pump No. 1. With lower DO concentrations, less nitrification may be occurring at the influent of the IFAS reactor. The high nitrate levels at the effluent may be explained by a combination of both theories.

Denitrification

Once nitrification was stable, the focus shifted to improving denitrification, which proved more difficult. Efforts to improve denitrification focused on two areas: reducing air recycled to the anoxic cells and supplemental carbon.

DO reduction. One change early in the study switched the anoxic–aerobic swing cell (R-3) from aerobic to anoxic to provide more detention time for denitrification. The swing cell remained anoxic for the rest of the study.

Other areas also were examined to keep DO out of the anoxic cells. First, the amount of air delivered to the reaeration cell (R-5) was reduced, because Pump No. 2 recycled this flow back to the anoxic cells (R-1, R-2, and R-3). At first, the air was turned down enough to just keep things mixed. But, by August 2008, a mixer was installed and the air supply to the reaeration cell completely shut off. Even with only the mixer, the DO concentration in R-5 measured about 2 mg/L at the influent end and 0.6 mg/L at the effluent end. This was from oxygen carried over from the effluent end of the IFAS zone.

Second, operators worked to reduce the amount of DO recycled by Pump No. 1, which draws from the influent end of the IFAS zone. However, any air reduction had to consider its effects on nitrification, media distribution, and media mixing.

Operators found that a DO concentration of 2.5 to 3.0 mg/L during summer and 3.0 to 3.5 mg/L during winter was best at maintaining nitrification in the first half of R-4 while optimizing

James River IFAS Carbon-Testing Scenarios and Results

Carbon source	Feed point		IMLR pumps		Data and results (Average)				
	Anoxic	Reaeration	No. 1 (200%)	No. 2 (100%)	Temperature (°C)	TN (mg/L)	TN Removal (%)	Caustic (lb/d)	MLSS (mg/L)
Soft-drink waste	Yes	No	Yes	Yes	26	7.69	80.2	552	1903
Animal-based	Yes	No	Yes	Yes	21	7.01	80	886	1970
Animal-based	No	Yes	Yes	Yes	18	4.76	84.9	856	2220
Sugar water	Yes	No	Yes	Yes	16	7.38	81.2	874	2662
Sugar water	No	Yes	Yes	Yes	15	9.57	74.6	856	2605
Sugar water	No	Yes	Yes	No	16	6.7	80	954	2835
Glycerin-based	No	Yes	Yes	No	16	9.7	76.9	965	2780
Glycerin-based	Yes	No	Yes	No	17	7	79.9	993	2909
Glycerin-based	Yes	No	Yes	Yes	18	7.5	83.4	856	2683
Glycerin-based	Yes	Yes	Yes	Yes	20	6.23	86	849	2397
Vegetable-based	Yes	No	Yes	Yes	22	6.25	83	861	2484
Vegetable-based	Yes	Yes	Yes	No	23	6.1	82.2	979	2511
Vegetable-based	Yes	Yes	Yes	Yes	24	5.58	84.8	771	2666

IFAS = integrated fixed-film activated sludge.
IMLR = internal mixed liquor recycle.
TN = total nitrogen.
MLSS = mixed liquor suspended solids.

denitrification. In the second half of R-4, a DO concentration of 3.0 to 3.5 mg/L during summer and 3.5 mg/L to 4.0 mg/L during winter was found to be optimal.

The IFAS zone contains four drop legs that supply air to the IFAS reactor. To maintain the optimum concentrations, the first drop leg was opened about 33%, while the second drop leg at the IFAS influent was varied from as low as 33% to as high as 55%, depending on the season. The third and fourth drop legs were set at about 50% and 100%, respectively.

Supplemental carbon. During the course of 13 months, JRTP experimented with five carbon sources. They included a waste product from a nearby soft-drink factory, sugar water, and three proprietary products — one each that were glycerin-, animal-, and vegetable-based, respectively. During testing, the carbon sources were added in different locations and with different operations strategies (see table, p. 68).

The plant experienced only 6 months with an average IFAS effluent TN below 8 mg/L (see Figure 2, p. 66), and supplemental carbon was used substantially during 5 of these 6 months. The plant chose to incorporate the ability to feed either a glycerol-based or sugar-based carbon source for the full-scale design.

The best overall results were achieved when carbon was fed to the influent of the first anoxic cell (R-1) and both IMLR pumps were in use. But feeding to the R-1 influent with both IMLR pumps running presents two challenges that must be managed: higher mixed liquor concentrations and thicker media biomass thickness. Both challenges are due to high supplement-carbon feed rates.

Media covered with thicker growth require more air and, thus, more energy for good distribution in the IFAS cell. Testing scenarios with Pump No. 2 turned off yielded a much better distribution of media throughout the IFAS reactor but generally did not achieve the best TN removal and resulted in higher caustic use.

The solution to both problems is to feed enough carbon to meet a particular IFAS effluent TN but not enough to replace nitrifying bacteria on the media.

Demonstration Results and Design Improvements

During the course of the study period — February 2008 to June 2009 — the IFAS system met its goal of producing effluent with 8 to 12 mg/L TN. The average IFAS effluent TN concentration was 9.95 mg/L, with an average TN removal of 75.1%. Biochemical oxygen demand and total suspended solids tests also returned acceptable results: 8.3 mg/L and 5.4 mg/L, respectively.

The demonstration also led to several changes in the final IFAS system design, which is currently being implemented throughout JRTP. Among the many changes are increasing anoxic tank volume, eliminating unneeded aeration, and increasing the amount of time for oxygen to dissipate from nitrate-recycle flows.

Figure 3 (p. 67) shows the final configuration of the IFAS system, including switching the final reaeration cell (R-5) to a secondary anoxic zone. Because ammonia concentrations leaving the IFAS zone were about 1 mg/L, there was no need to provide further aeration in the reaeration cell. So, the air grid in this cell was eliminated, and a mixer was added.

Two changes not reflected on the schematic concern the IFAS cylinder screens that hold the floating media in the IFAS tank. First, the number and orientation of the cylinder screens were changed. Instead of two rows of six cylinders, the new design features three rows of four cylinders. This improves dispersion of flow and DO from the IFAS cell into the new secondary anoxic cell. It also enables flow to pass through the bottom row of cylinder screens in the event of a power failure — without mixing, the media float to the surface and cluster around the upper cylinder screens.

Second, JRTP is changing its headworks screening system to prevent trash and debris from reaching the IFAS cell and clogging the cylinder screens. The plant's two 20-mgd-rated (76,000-m^3/d-rated) bar screens will be replaced with three 6-mm, 20-mgd-rated (76,000-m^3/d-rated) step screens. Replacing the two bar screens with three step screens should provide improved screenings up to 60 mgd (230,000 m^3/d) — instead of 40 mgd (150,000 m^3/d) with the bar screens — and should adequately protect the IFAS system.

Through its full-scale demonstration study, JRTP met each of the goals it set. Operators gained experience managing an IFAS system. Influent control problems at the outset even provided experience dealing with high flows. The test system also proved its ability to remove nitrogen to help JRTP and HRSD meet the new wasteload allocation. And finally, by rigorously putting the process through its paces, the JRTP operators were able to identify several design changes that can be built into a more effective and efficient treatment process.

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