# Compact Technology: Increasing Treatment Capacity Without Building More Basins

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Economically adding capacity to wastewater treatment facilities is especially important in these times of rising construction costs. Jordan, Jones & Goulding (JJG) is working with Palm Beach County Water Utilities to investigate two innovative treatment systems that could reduce the footprint of an expansion of their South Regional Water Reclamation Facility (WRF) and potentially reduce the cost.

These processes are coupled fixed-film/activated sludge processes, termed the moving bed bioreactor system (MBBR), and the integrated fixed-film activated sludge system (IFAS). The concept underlying the use of either system in this application would be to increase the total biomass contained within existing aeration basins by introducing a media for fixed-film activated sludge growth into a portion of the available aeration basin volume.

In order to establish the treatment efficiencies and parameters of the MBBR and IFAS processes and determine if either process could be used to expand the plant's treatment capacity without constructing additional aeration basins, pilot testing of both types of treatment systems was conducted. The goal of the pilot test was to determine if the plant could be expanded from its current 35-MGD three-month average daily flow capacity to a 50-MGD three-month average daily flow capacity without adding aeration basins.

The treatment goal of the facility's biological process is to meet effluent standards for deep well injection, wetlands irrigation, or reuse. Achieving this goal involves a short sludge retention time (SRT) target of two days in order to oxidize five-day carbonaceous biochemical oxygen demand ($CBOD_5$) but leave ammonia unnitrified to the greatest extent possible.

Pilot test results indicated that both the MBBR and IFAS systems could provide excellent BOD and chemical oxygen demand (COD) removal. Both systems provided low levels of nitrification at a two-day SRT, though the IFAS system did provide a slightly higher level of nitrification under the test conditions.

Both systems operated well at peak-day flows. The solids in the MBBR system washed out after a few days at peak-hour flow, but the IFAS system operated at peak-hour flow for two weeks without washout.

Based on the results of pilot testing, it appears that either system could meet the effluent $CBOD_5$ goal for discharge to deep well injection, wetlands irrigation, or reuse.

A BioWin™ process simulation model was prepared and calibrated based on the pilot-scale results. This allowed a comparison to be drawn between the MBBR and IFAS systems and a conventional activated sludge process using the same basin volume.

Based on the BioWin™ modeling results, it appears that a conventional plug-flow activated sludge process using the existing aeration basins could be adapted to treat 50-MGD three-month average daily flow with aeration modifications and a higher mixed liquor suspended solids (MLSS) concentration. The results also indicated that it may be possible to re-rate the existing basins to handle 50-MGD three-month average daily flow without increasing MLSS levels if the IFAS system is used.

Both the MBBR and IFAS systems use inert media in the aeration basins which support the growth of biomass on the surface. Carrier media movement is provided by coarse bubble aeration in the portion of the reactor containing the media. The process has been used successfully in treating both municipal and industrial wastewaters. Because this technology allows more biomass to be contained in the system, it can be used to increase the capacity of existing aeration basins without increasing the basin volume.

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The main difference between the two variations is the return sludge feed point. In the MBBR process, the return sludge is fed downstream of the carrier media section, while in the IFAS system the return sludge is fed upstream of the carrier media section.

Kaldnes, a manufacturer of fixed-film treatment systems, provided a pilot unit that could be operated in either the MBBR or IFAS mode. Sampling was conducted during the pilot test to determine the removal of BOD/COD using these treatment processes and to provide design parameters and the best physical configuration for a full-scale treatment system.

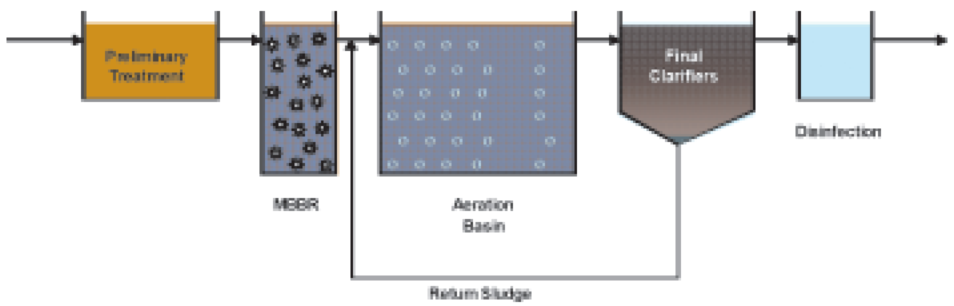


Figure 1 – MBBR Schematic

## MBBR Process

In the MBBR process, the carrier media is contained in the first portion of the aeration basin. Raw wastewater is introduced at the head of the aeration basin, and return activated sludge (RAS) is fed downstream of the portion of the basin that contains the carrier media.

Because the return sludge is fed downstream of the carrier media, the biomass in the first section of the aeration basin is mainly attached to the carrier media, and the MLSS concentration in this section is low. Figure 1 shows a schematic diagram of the MBBR process.

## IFAS Process

In the IFAS process, the section of the basin that contains the carrier media is determined by the treatment objective. If the objective is BOD removal, the media would be included in the

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first section of the basin. If the treatment objective includes nitrification and denitrification, the carrier media could be contained in one of the downstream compartments.

In the IFAS process, both the raw wastewater and the RAS are fed at the head of the aeration basin. Because the compartment containing the carrier media is receiving return sludge, the MLSS concentration in this section is about the same as in the aeration basin section. Figure 2 shows a schematic of the IFAS process.

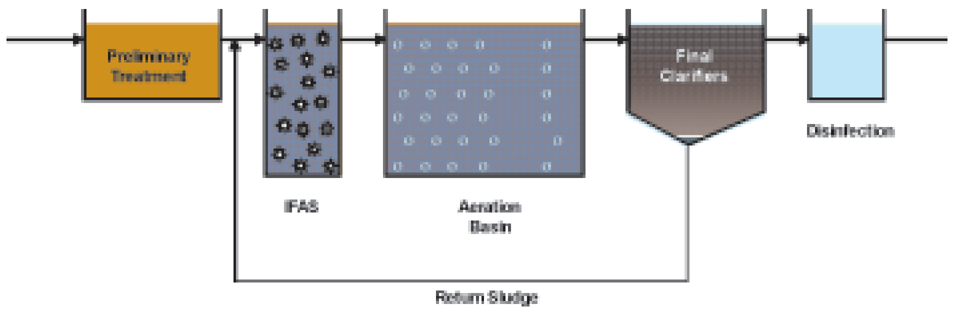


Figure 2 – IFAS Schematic

Table 1 – Pilot Plant Operating Parameters

| Parameter | Target Value |
|---|---|
| Bioreactor Tank Capacity (4 total) | 156 +/- gallons each |
| Pilot Plant Influent Flow | 2.6 gpm |
| Retention Time in MBBR/IFAS Reactor at Design Flow | 1.01 hours |
| Carrier Media Surface Area | 500 $m^2/m^3$ |
| Total Retention Time in all Reactors | 4.04 hours |
| Goal MLSS Concentration in Activated Sludge Reactors | 2000 mg/L |
| Goal SRT in Activated Sludge Reactors | 2.8 days |
| Return Sludge Flow | 1.3 gpm |
| Volumetric Fill with Carrier Elements | 29% |
| Blower Capacity | 75 scfm maximum |
| Aeration System | Coarse bubble |
| Goal Dissolved Oxygen in Media Reactor | 3.0 mg/L |
| Goal Dissolved Oxygen in Activated Sludge Reactors | 2.0 mg/L |

Table 2 - Comparison of Pilot Scale Plant to Full Scale Design

| Parameters | Units | Full Scale | Pilot Unit |
|---|---|---|---|
| *Aeration* | | | |
| Target MLSS | mg/L | 2000 | 2000 |
| Target SRT | days | 2.0 | 2.0 |
| MBBR/IFAS compartments/train | each | 1 | 1 |
| Target DO in MBBR/IFAS compartment | mg/L | 3.0 | 3.0 |
| Volume each MBBR/IFAS compartment | gal | 575,000 | 156 |
| HRT in each MBBR/IFAS compartment | hours | 1.01 | 1.01 |
| Number of activated sludge compartments/train | each | 3 | 3 |
| Target DO in activated sludge compartment | mg/L | 2.0 | 2.0 |
| Volume each aeration compartment | gal | 575,000 | 156 |
| HRT in each aeration compartment | hours | 3.03 | 3.03 |
| *Clarification* | | | |
| Clarifier area | sq ft | 50,000 | 21.1 |
| Surface overflow rate | gpd/sf | ~ 450 | 175 |
| Return sludge rate | % | 50 | 50 |

## Process Requirements

More than the MBBR system, the IFAS system allows the treatment capacity of an aeration basin to be increased by increasing the amount of biomass that is carried in the basin. IFAS accomplishes this by combining fixed-film biomass and activated sludge biomass into the same basin volume. This increase in biomass requires additional oxygen, which would require a retrofit of the existing aeration system in the aeration basins at the South Regional WRF to accommodate greater air requirements.

Kaldness MBBR and IFAS systems require coarse bubble aeration in the section of the basin containing the carrier media in order to keep the media suspended. Other manufacturers claim that they can use fine bubble aeration as well. In the MBBR process, the carrier media would be contained in the first pass and return sludge would be fed at the start of the second pass in each basin. In the IFAS process, the carrier media could be contained in any pass, but for the purposes of this evaluation, it was assumed that it would be carried in the first pass.

## Pilot Plant Description & Design Criteria

The pilot plant was housed in a 20-foot trailer and consisted of an influent tank followed by a media reactor tank and a clarifier. Piping was installed to allow flow from the reactor tank to be diverted outside the trailer into three additional tanks that were used as activated sludge reactors without media. The media reactor tank and three exterior activated sludge tanks were configured in series and had a volume of 156 gallons each. At a flow of 2.6 gallons per minute (gpm), the four tanks had a total detention time equal to the total existing aeration volume at the South Regional WRF under a flow of 50 MGD.

The media reactor tank and the three activated sludge tanks in series were equipped with coarse bubble aeration. The effluent from the third activated sludge tank was routed back into the trailer and to the clarifier.

Influent flow to the pilot plant was taken from the headworks of the treatment facility. Aeration was provided by a dedicated blower. RAS was pumped from the pilot unit's clarifier underflow to the appropriate location in the pilot unit based on the operating mode being tested.

Operating parameters for the pilot unit at design flow (50 MGD three-month average daily flow) were set to mimic operation of the aeration basins at future design flow. Operating parameters and targets are shown in Table 1.

## Operating Protocol

The pilot unit was operated at the equivalent of the projected future three-month average daily flow design flow of 50 MGD, peak-day flow of 59 MGD and peak-hour flow of 91 MGD in each of the two operating modes. The goal was to operate the system for three weeks at design flow, one week or until solids washout at peak-day flow, and one day or until solids washout at peak-hour flow for each operating mode.

A summary of the pilot scale operating criteria versus the full scale design, including the projected future flow rates, is shown in Table 2.

Data was collected regularly from the pilot unit. Additional data was collected to gather sufficient information to allow a BioWin™ model of the pilot unit to be constructed and calibrated. The calibrated BioWin™ model was used to confirm performance at full scale and to investigate situations not tested in the pilot study.

## Performance Data

The pilot plant was started up in late March of 2007. Performance of the system was monitored to determine when the system reached steady-state conditions. Once the system had reached equilibrium, pilot testing was started.

The influent flow to the pilot unit consisted of raw wastewater pumped directly from the headworks of the treatment plant. Over the course of the pilot test period, the influent to the pilot unit was monitored. Table 3 presents the influent characterization for the pilot unit.

The results of the pilot test were analyzed by calculating the percent removal of carbonaceous BOD, soluble BOD, COD, TKN and ammonia-nitrogen ( $NH_3$-N). Suspended solids results were not analyzed because the pilot unit clarifier operating parameters did not reflect the design of the existing clarifiers.

Effluent objectives for $CBOD_5$ from the treatment plant are shown in Table 5. Other effluent parameter are not regulated for the current disposal methods ( $NH_3$-N, nitrogen, and phosphorus) or are not primarily treated by the biological treatment process (TSS, chlorine, fecal coliform, pH).

The pilot unit was operated in MBBR mode at design flow for 54 days. The flow was increased to peak-day flow and the pilot unit was operated in this mode for 20 days. Increasing the flow to peak-hour flow resulted in washout of the system after only one set of samples was taken. The results for three-month average daily flow design flow in MBBR mode are shown in Table 5.

Removal of BOD and COD was excellent. Nitrification was very low. Washout did occur, however, when peak-hour flow rates were simulated.

The pilot unit was operated in IFAS mode at design flow for 34 days. The flow was increased to peak-day flow, and the pilot unit was operated in this mode for 18 days. The flow was then increased to peak-hour flow for 15 days. The results for three-month average daily flow design flow in IFAS mode are shown in Tables 6.

Removal of BOD and COD was excellent for all flow conditions. Nitrification was low but higher than the MBBR system in all cases. The IFAS system handled peak-hour flow much better than the MBBR system, operating for two weeks without washout.

## BioWin™ Modeling

BioWin™, a wastewater treatment process simulator, was used to predict the full-scale performance of the MBBR and IFAS systems and compare that performance to the performance of a conventional activated sludge process under the same conditions. Six scenarios were simulated:

- MBBR system at summer and winter temperatures
- IFAS system at summer and winter temperatures
- Conventional plug-flow activated sludge at summer and winter temperatures

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Table 3 – Influent Characterization

| Parameter | Units | Average |
|---|---|---|
| BOD | | |
| Carbonaceous | mg/L | 186 |
| Soluble (0.45 µ) | mg/L | 42 |
| COD | | |
| Total | mg/L | 554 |
| Filtered (1.2 µ) | mg/L | 169 |
| Filtered & flocculated (0.45 µ) | mg/L | 144 |
| Ammonia | | |
| TKN | mg/L | 54.0 |
| Soluble $NH_3$-N (0.45 µ) | mg/L | 34.1 |
| Soluble $NO_3$-N (0.45 µ) | mg/L | 0.117 |
| Soluble $NO_2$-N (0.45 µ) | mg/L | ND |
| Suspended Solids | | |
| TSS | mg/L | 295 |
| VSS | mg/L | 247 |
| Percent Volatiles | % | 83.6 |
| Alkalinity (as $CaCO_3$) | mg/L | 189 |
| Temperature | °C | 29.3 |
| pH | SU | 6.7 |

Table 4 – Effluent Objectives for $CBOD_5$

| Period | Treatment Objective |
|---|---|
| Annual Average | 20 mg/L |
| Monthly Average | 30 mg/L |
| Weekly Average | 45 mg/L |
| Maximum | 60 mg/L |

Table 5 – Performance at Three-Month Average Daily Flow Design Flow, MBBR Mode

| Parameters | Average Concentration | | % Removal |
|---|---|---|---|
| | Influent | Effluent | |
| $CBOD_5$, mg/L | 175 | 14 | 92 |
| Soluble BOD, mg/L | 40.7 | 5.7 | 86 |
| COD, mg/L | 573 | 116 | 80 |
| TKN, mg/L | 58.0 | 40.3 | 31 |
| $NH_3$-N, mg/L | 34.1 | 30.2 | 11 |

Table 6 – Performance at Design Flow, IFAS Mode

| Parameters | Average Concentration | | % Removal |
|---|---|---|---|
| | Influent | Effluent | |
| $CBOD_5$, mg/L | 225 | 9 | 96 |
| Soluble BOD, mg/L | 38.5 | 4.4 | 89 |
| COD, mg/L | 543 | 73 | 87 |
| TKN, mg/L | 49.8 | 22.9 | 54 |
| $NH_3$-N, mg/L | 32.1 | 20.5 | 36 |

Table 7 – Predicted Full Scale Performance Based on Calibrated Model

| Parameter | Units | Activated Sludge | 25% of Basin IFAS | 50% of Basin IFAS | 75% of Basin IFAS | 100% of Basin IFAS |
|---|---|---|---|---|---|---|
| **Input Influent** | | | | | | |
| Flow | MGD | 35 | 40 | 46 | 52 | 58 |
| Temperature | deg C | 20 | 20 | 20 | 20 | 20 |
| $CBOD_5$ | mg/L | 196 | 196 | 196 | 196 | 196 |
| COD | mg/L | 554 | 554 | 554 | 554 | 554 |
| TKN | mg/L | 54.0 | 54.0 | 54.0 | 54.0 | 54.0 |
| $NH_3$ | mg/L | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |
| $NO_3$ | mg/L | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 |
| TSS | mg/L | 321 | 321 | 321 | 321 | 321 |
| Alkalinity | mg/L | 189 | 189 | 189 | 189 | 189 |
| Ph | units | 6.5 | 6.5 | 6.5 | 6.5 | 6.5 |
| **Process Parameters** | | | | | | |
| MLSS | mg/L | 2,200 | 2,196 | 2,221 | 2,234 | 2,251 |
| SRT | days | 1.99 | 2.01 | 1.98 | 1.95 | 1.93 |
| Oxygen Transfer | lb/hr | 1,722 | 1,921 | 2,170 | 2,418 | 2,688 |
| Biofilm Mass | lb | 0 | 33,209 | 65,708 | 98,414 | 131,595 |
| Mixed Liquor Solids Mass | lb | 167,938 | 162,722 | 158,203 | 152,499 | 147,313 |
| Total Biomass | lb | 167,938 | 195,931 | 223,911 | 250,913 | 278,908 |
| **Predicted Effluent** | | | | | | |
| COD | mg/L | 92.2 | 92.3 | 92.4 | 92.6 | 92.7 |
| $CBOD_5$ | mg/L | 3.7 | 3.8 | 3.9 | 4.0 | 4.1 |
| $NH_3$-N | mg/L | 27.4 | 27.1 | 26.4 | 25.7 | 25.2 |
| $NO_3$-N | mg/L | 1.5 | 1.3 | 1.1 | 1.0 | 0.9 |
| $NO_2$-N | mg/L | 2.6 | 2.8 | 3.4 | 4.0 | 4.4 |
| Total N | mg/L | 34.1 | 33.9 | 33.6 | 33.4 | 33.2 |
| **Additional Capacity** | **%** | **0** | **+14** | **+31** | **+49** | **+66** |

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The model was calibrated based on the pilot test results, and the calibrated process kinetics were used to predict full-scale performance of the system at both summer and winter temperatures.

The following subsection describes in more detail the modeling approach used for the BioWin™ simulations. The information contained in the modeling approach section is not critical to understanding the modeling results, but is presented to provide those familiar with modeling some additional information regarding the way the models were set up and the modeling parameters used.

## Modeling Approach

**Influent**

In BioWin™, the influent COD is divided into several fractions, which in simplified terms are:

- Soluble biodegradable
- Soluble non-biodegradable
- Particulate biodegradable
- Particulate non-biodegradable

Some of the testing performed on the pilot plant influent was conducted to allow determination of influent COD fractions to facilitate modeling using BioWin™. The sampling data was reviewed for quality control, and some values were excluded because they did not meet quality control requirements. Also, it was noted that the BOD data in general had significant quality control issues and was therefore not considered reliable.

In general, the influent testing results indicated that a higher-than-average portion of the influent was non-biodegradable. The BioWin™ default influent fractions were used except for the following:

- $F_{up}$ (non-biodegradable COD fraction) – changed from default of 0.13 to 0.25
- $F_{zbh}$ (non-Poly P heterotrophic organism fraction) – changed from default of 0 to 0.24
- $F_{xsp}$ (particulate biodegradable portion of slowly biodegradable COD) – changed from default of 0.750 to 0.870

**Temperature**

A biological process temperature of 28°C was used for summer conditions, and a temperature of 20°C was used for winter conditions based on annual conditions at the South Regional WRF.

**Biokinetic Coefficients**

Default biokinetic coefficients were used except for the following:

- Maximum specific growth rate for ammonia oxidizing biomass – changed from default of 0.90/day to 0.77/day (adjusted to match the effluent ammonia-nitrogen ($NH_3$-N) levels)
- Biofilm detachment rate for IFAS/MBBR media – change from default of 8x10$^4$ g/m$^3$d to 6x10$^4$ g/m$^3$d (adjusted to match the fixed-film biomass weight per unit area measured by Kaldness)
- Film surface area to media area ratio for IFAS/MBBR media – changed from default of 1.0 to 1.35 (adjusted to match the fixed-film biomass weight per unit area measured by Kaldness)

**Modeling Results**

With these adjustments, the performance predicted by BioWin™ was fairly consistent with pilot treatment results. The calibrated model was then turned to the task of estimating the additional capacity that could be gained by adding fixed-film media to the existing aeration basins at South Regional WRF.

The pilot results indicated that both MBBR and IFAS treatment could provide complete biological treatment of the wastewater BOD at the future design flow of 50 MGD three-month average daily flow; therefore, it appears that based on the pilot results, expansion of the existing plant to 50 MGD three-month average daily flow may be achievable with either of these treatment methods.

Of particular significance to treatment capacity, however, are the SRT and total pounds of biomass in each system. Systems that contain more biomass have higher capacity because they have more microorganisms available to consume the organic constituents in the wastewater. Because the IFAS system combines activated sludge and fixed-film biomass into one reactor, it contains considerably more biomass than either an MBBR or a conventional activated sludge system.

The pilot testing indicated that MBBR and conventional activated sludge systems of the same volume contain close to the same biomass. These results indicate that both an MBBR and an IFAS system can be adapted to handle the proposed 50 MGD three-month average daily flow, but that the IFAS system can handle considerably more load than the MBBR system or an activated sludge system.

To estimate how much more load an IFAS system could handle, the calibrated BioWin™ model was used to determine the increased flow that IFAS could handle while achieving the same effluent results as an activated sludge process. Table 7 summarizes the results of this investigation.

The South Regional WRF activated sludge process was first modeled as it operates today at its 35-MGD capacity. Then activated sludge reactor volume was replaced in this model with IFAS reactor volume, and the flow to the modified process was increased until comparable effluent quality results were achieved. This procedure was followed for replacement of 25 percent, 50 percent, 75 percent, and 100 percent of the activated sludge reactor volume with IFAS reactor volume.

As can be seen in Table 7, the estimated capacity increases ranged from 14 percent for 25-percent volume replacement with IFAS to more than 60 percent for 100-percent volume replacement with IFAS.

## Cost Implications

IFAS offers the potential to reduce expansion costs in many cases because it can avoid the need to construct additional aeration basin volume. It can also increase the biomass in a biological system without increasing the MLSS concentration. This in turn means that solids loading to secondary clarifiers is not increased as much as would occur if activated sludge biomass were simply increased to achieve greater capacity. For this reason, an IFAS system can reduce the additional clarifier area needed for an expansion and also reduce the aeration basin volume needed.

These potential savings in basin construction costs are counterbalanced by significant costs for the fixed-film media and aeration system modifications to accommodate the IFAS system. Table 8 presents the results of the cost estimate comparison of an expansion of South Regional WRF based on IFAS and an expansion based on conventional activated sludge. As can be seen in Table 8, the savings and additional costs for IFAS more or less cancel each other out in this particular case.

There are certainly many cases in which the potential savings using IFAS will outweigh the added costs. IFAS will be a favorable approach to expansion where site space is limited and new land acquisition will be necessary for expansion using conventional activated sludge treatment. IFAS offers a useful alternative means of treatment capacity expansion that should be considered for many wastewater treatment plant expansions. ◊

Table 8 – Comparison of Conceptual Cost Estimates

| Capital Cost Item | IFAS-Based Expansion (million $) | Conventional Activated Sludge Expansion (million $) |
|---|---|---|
| Existing Aeration Basin Modifications | 8.1 | 0.3 |
| New Aeration Basins | 0 | 3.6 |
| New Aeration Blower Capacity | 1.2 | 1.2 |
| New Clarifiers | 3.4 | 6.8 |
| New Clarifier Splitter Box | 0.5 | 0.5 |
| New Return Sludge Pump Station | 3.0 | 3.0 |
| **TOTAL** | **16.2** | **15.4** |