

The Second Generation of IFAS and MBBR: Lessons to Apply

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ABSTRACT

Powerful models and a wealth of data are available for designing integrated fixed film activated sludge (IFAS) and moving bed biofilm reactor (MBBR) facilities today, that were not available when designing the “first generation” of North American facilities in the 1990’s. This paper discusses lessons learned in the design and startup of several full-scale facilities. Operator observations at these facilities have proven to be invaluable in the design of “second generation” facilities in Broomfield, Colorado; West Haven, Connecticut; Westchester County, New York; Fort Myers, Florida and several others. Pilot and bench testing, optimum media placement, sieve design and approach velocities, residual dissolved oxygen, mixing requirements and dynamic process modeling are discussed with regard to the first-generation facilities. Second generation design configurations are also compared for a hypothetical new plant, using BioWin. This paper summarizes the current state of science, and identifies future research needs for IFAS and MBBR design.

KEYWORDS

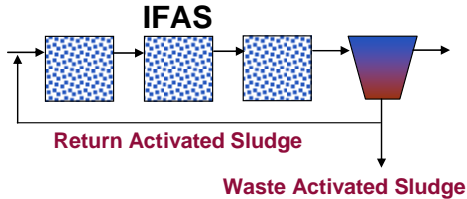
integrated fixed film activated sludge, moving bed biofilm reactor, modeling, nutrient removal, full-scale, operations

INTRODUCTION

Integrated fixed film activated sludge (IFAS) and moving bed biofilm reactors (MBBR) are growing in popularity for wastewater treatment plant expansions, and many studies have found them to be economically competitive with conventional activated sludge. While the technologies apply the same equipment, the presence or absence of the suspended growth component often drives the process selection. The presence of suspended growth in an IFAS system allows substantial capacity expansion within existing aeration basins, while the minimal suspended growth in an MBBR is favourable at plants with small existing clarifiers (replacing rotating biological contactors or trickling filters, for example). Differentiators for the IFAS and MBBR processes are summarized on Figure 1, and photographs of media and media retention sieves are shown on Figure 2.

IFAS

- Site constraints or restrictions
- Upgrade existing activated sludge for N&P removal
- Can integrate with biological phosphorus removal
- Clarifiers designed for high solids loading rate
- Volume limitations require both suspended and fixed film inventory
- Resiliency to peak wet weather flows since about half of the solids inventory remains on the media



MBBR

- Site constraints or restrictions
- Post nitrification and denitrification applications also common
- Chemical phosphorus removal only
- Upgrade trickling filters or rotating biological contactor plants that have poor final clarifier designs
- Utility preference for fixed film; concern of operational complexity of activated sludge or IFAS
- Resiliency to peak wet weather flows - very low MLSS of 200 to 300 mg/L

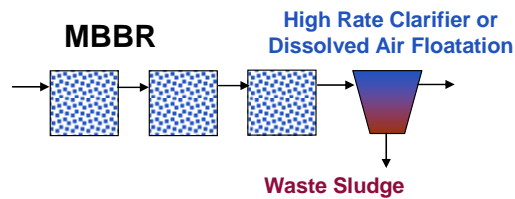


Figure 1. IFAS and MBBR Process Differentiators



**Kruger /
AnoxKaldnes**



**Headworks /
IDI (Hydroxyl)**



**Lotepro /
Linpor**



**Siemens /
AGAR**



Cylindrical Media Sieves



Wall Media Sieves

Figure 2. IFAS and MBBR equipment

In 2003, the City and County of Broomfield, Colorado was the first community in North America to implement free-floating plastic media in an IFAS configuration. The Phase 1 facilities performed better than expected, which led to cost-saving modifications to the Phase 2 expansion in 2009 (Phillips *et al.*, 2008; Rutt *et al.*, 2008). Nearby in Henderson, Colorado, the South Adams Water and Sanitation District began operating their MBBRs at the Williams Monaco Wastewater Treatment Plant (WWTP), also in 2003. These two facilities began the “first generation” of IFAS and MBBR facilities in North America, with several more to follow including the Dry Creek WRF (IFAS) and Crow Creek WRF (MBBR) in Cheyenne, Colorado; the Henry N. Wochholz WWTP in Yucaipa, California and many others that are shown on Figure 3.



Figure 3. North American IFAS and MBBR experience (examples of domestic facilities)

The design approach for each of the facilities on Figure 3 varied, depending on the media type, raw wastewater characteristics, condition of existing facilities, and discharge limitations. Extensive pilot testing was conducted for many of the facilities with stringent nutrient limits (Mamaroneck, NY for example), while utilities with less stringent, seasonal ammonia limits chose to rely on existing data and research (South Adams County for example). Regardless of whether onsite pilot testing was conducted, modeling was essential in the design process. Once modeling determined the optimum process configuration and media placement, the design team focussed on hydraulics, and the design of the sieves, aeration system, mixers, scum/foam control,

and instrumentation. Models were also used to assist with start-up and commissioning in many cases, since IFAS and MBBR facilities behave very differently when they are under-loaded compared to the design conditions. Each of these topics is discussed in the following sections, with specific details from first generation facilities (Broomfield WRF and Williams Monaco WWTP). A hypothetical “second generation” facility is also presented with three different media placement strategies, in an effort to optimize effluent quality, while minimizing capital and operating costs.

DEMONSTRATION, PILOT AND BENCH TESTING

When designing an IFAS or MBBR facility, it is essential to use site-specific data to calibrate process models. The extent of the data collection process depends highly upon the discharge limits, and the level of risk associated with permit compliance. Facilities that have seasonal ammonia limits and a relatively low risk of violating these limits may choose to conduct bench tests and wastewater characterization studies only. Utilities with stringent nutrient limits will likely operate a small-scale pilot study of the proposed design for several months, or implement a full-scale demonstration study by upgrading one aeration basin with the proposed design. There has been several recent pilot and demonstration studies evaluating nitrification and denitrification kinetics, and population dynamics (Thomas *et al.*, 2009; Peric *et al.*, 2009; Shrestha *et al.*, 2009; Stinson *et al.*, 2009; Kim *et al.*, 2009). Westchester County, New York is an example of a community facing challenges that necessitated extensive pilot testing (Johnson *et al.*, 2007).

Through its State Pollutant Discharge Elimination System (SPDES), the New York State Department of Environmental Conservation (NYSDEC) has imposed Waste Load Allocation (WLA) limits for nitrogen, which translates into a 12-month rolling average limit of approximately 4 mg/L for the Mamaroneck WWTP. This low discharge limit and a number of other challenges led the County to pilot both the IFAS and MBBR technologies for 6 months during the winter of 2004/2005, since they were among the few expansion options. Initial modeling concluded that a modified Ludzack-Ettinger (MLE) configuration would not meet treatment objectives due to the low aeration basin retention time (less than 3 hours) and low influent waste strength at the plant (primary effluent COD 124 mg/L, TSS 44 mg/L and TKN 18 mg/L). Therefore, the configurations shown on Figure 4 were piloted, using methanol as the carbon source.

Pilot tests should be designed not only to prove that the technology will work for a specific wastewater, but they must collect appropriate data in sufficient quantities to support design efforts. The use of online monitors can greatly simplify efforts; however, an outside laboratory should always be used for quality control since instruments tend to drift or produce inaccurate results if not properly maintained. It may also be beneficial to coordinate pilot efforts with local universities, since they may be able to offset some of the analytical costs in exchange for technical experience for its graduate students and professors. While it may be tempting to limit testing to reduce costs, the purpose of pilot testing is to generate a calibrated model for design efforts, which requires the following information at a minimum:

- Influent (or primary effluent) characteristics: flowrate, BOD, COD, ffCOD, TSS, VSS, TKN, NH₃-N, TP, PO₄-P and alkalinity – daily average and diurnal (on occasion).
- Temperature (influent or primary effluent), and within each reactor – daily.
- MLSS and MLVSS – daily.
- Waste sludge flow and TSS – daily.
- Recycle flow settings – confirm daily.
- Attached biomass (gTSS/m²) within each reactor – 2 to 3 times weekly.
- Approximate biofilm thickness within each reactor (close-up photos of media samples) – 2 to 3 times weekly.
- Nutrient and soluble COD profiles within each reactor – 2 to 3 times per week.
- Dissolved oxygen concentration within each reactor – 2 to 3 times daily.
- Airflow measurements – 2 to 3 times daily or continuous monitoring.
- Nitrification and denitrification rate tests – at least once for every condition pilot tested.
- Effluent BOD (or cBOD), ffCOD, TSS, NH₃-N, NO₃-N, NO₂-N, TKN, filtered TKN, alkalinity and pH – daily, depending on the type of permit limits.

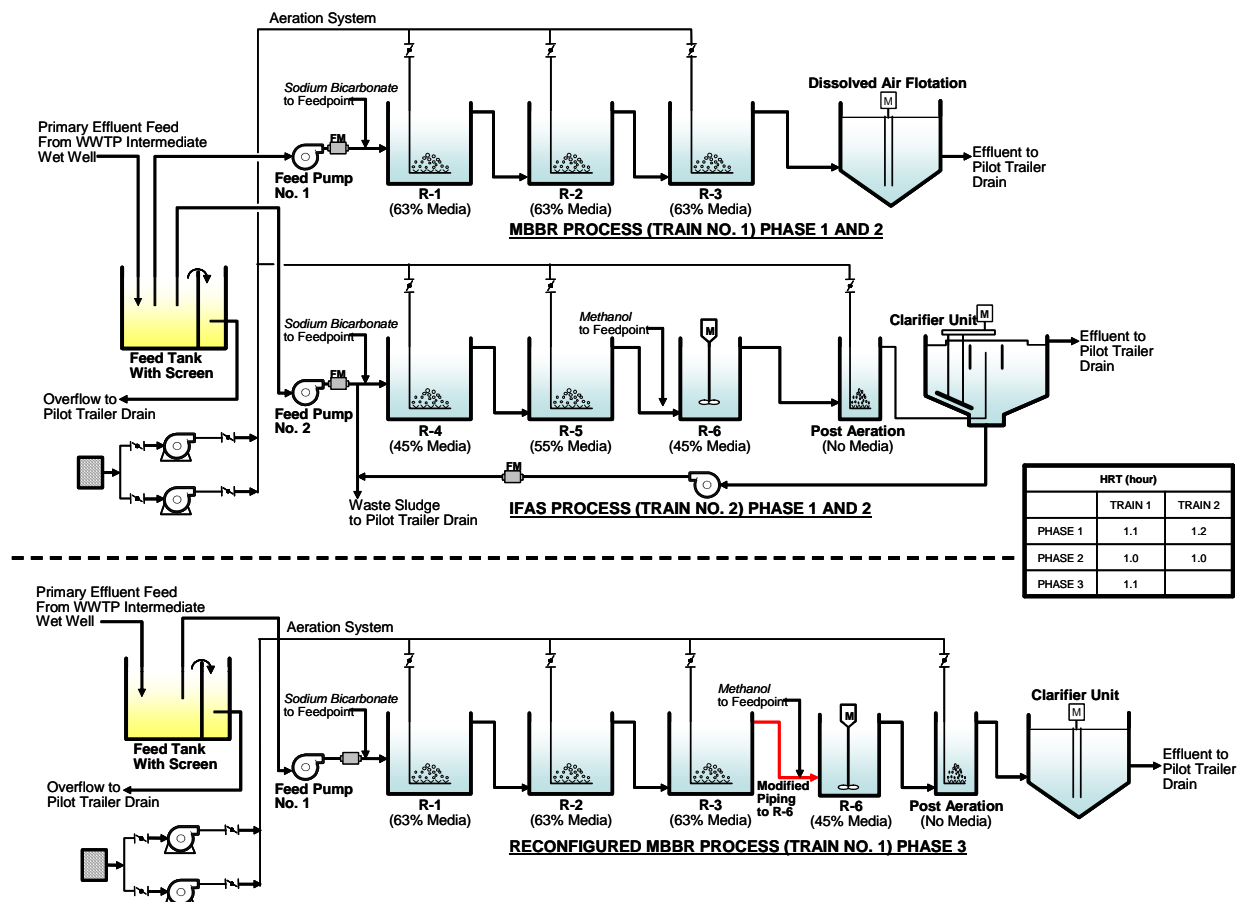


Figure 4. Three phases of IFAS and MBBR pilot testing at the Mamaroneck WWTP

Another important factor to consider in pilot testing is start-up time. Biofilm systems can take several weeks to reach equilibrium, so it is important to build this additional time into the pilot schedule and closely monitor performance before commencing the official pilot test period. In

the case of the Mamaroneck study, the pilot trailer was delivered onsite in September 2004 and was not removed until May 2005. Even if the pilot system is seeded with sludge from a full-scale facility, adequate equilibrium time is necessary to produce reliable results. The pilot testing at the Mamaroneck WWTP proved to be well worth the time and investment, since both the IFAS and MBBR technologies met the treatment objectives. Construction of the IFAS upgrades is currently underway, and the design will allow for the eventual conversion to MBBR with dissolved air flotation for solids separation.

DYNAMIC PROCESS MODELING

Early fixed film models developed for trickling filters were simplistic, empirical equations that approximated biochemical oxygen demand (BOD) removal as a function of the BOD load per filter volume and the flow ratio (e.g. Velz, 1948) or semi-empirical equations that considered the influence of kinetics such as the work presented by Bruce and Boon (1971). In the 1970's, models were updated to include one-dimensional substrate flux, transport and utilization, and in the 1980's the models began to include different types of organisms in the biofilm. In the 1990's with the advent of increased computer processing power models began to include two- and three-dimensional biofilm mechanisms, though most of these models still reside in the research arena and are too complex for practical design applications. Wanner *et al*, (2006) provide a good description of the development of biofilm models over the years and the different levels of complexity in current models.

In recent years, commercially available and user-friendly simulator packages such as GPS-X (Hydromantis) and BioWin (Envirosim) have brought process modeling out of research and into the world of wastewater practitioners. In North America, consultant engineers in particular have embraced process models in their design work. In the field of biofilm modeling, Hydromantis originally developed their "hybrid" model for the AnoxKaldnes MBBR process in the late 1990's and it can also be used to model IFAS. They include this model in their GPS-X simulator along with models for RBCs, BAFs and trickling filters that use the same biofilm model. More recently, Envirosim has developed a biofilm model for their BioWin simulator (Takács *et al*, 2007) for IFAS and MBBR modeling. The biofilm models in these simulators use a similar framework, with the biofilm defined by several layers within which kinetic transformations occur using the same kinetic expressions as their activated sludge models. Material is transferred between individual biofilm layers using diffusion and other mass transfer expressions, as shown on Figure 5. Biofilm models are available in other simulators and modeling programs, including WEST, Aquasim and Aquifas.

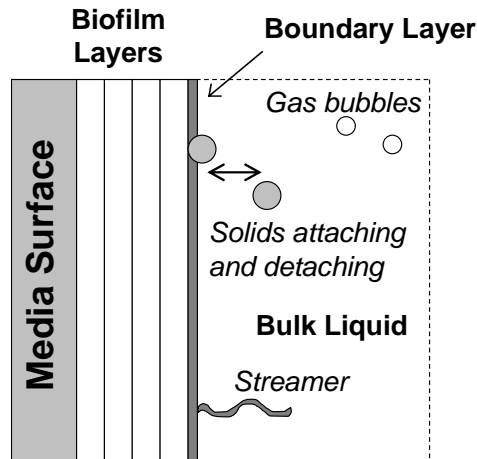


Figure 5. Concept of a one-dimensional biofilm model

Model calibration and validation are important steps to ensure accurate results in any process model, and this is especially true with biofilm modeling. These models have been used less widely than their activated sludge counterparts which means that acceptable ranges for model parameters are not widely known. Bench, pilot or demonstration testing will increase the accuracy of model predictions, as previously discussed. The first step in calibrating a biofilm model is obtaining agreement between the model and the data for the following parameters:

- The quantity of biomass attached to the media, expressed as mg of TSS per m² of available surface area.
- Removal rates of substrates (usually COD and ammonia, but also applicable to nitrate in denitrifying systems), expressed as mg per unit time per available surface area.

The first characteristic (biomass on the media) is a function of the biofilm thickness and density. The modeler can produce a model with a thin film and a relatively high density or a thicker film with lower density and achieve the same mg of TSS per m². A thicker film will be more influenced by diffusion effects, which is particularly important to consider for biofilm systems where simultaneous nitrification and denitrification is observed. A thicker film will limit the penetration of dissolved oxygen into the biofilm and create localized anoxic layers where denitrification can occur. The attachment and detachment rates of particulate material have a significant impact on the quantity and types of particulates on the media.

Removal rates are calibrated by adjusting kinetic parameters such as growth rates, half-saturation coefficients, switching function parameters, or inhibition parameters (for GPS-X). Normally, kinetic parameters should not have to be adjusted significantly from values used for conventional activated sludge. If the model is set up with the correct number of reactors in series and reactor-specific biofilm properties, the model should be able to predict the soluble BOD and nutrient profiles through the system. This was the case when calibrating an operations model for the Williams Monaco WWTP. Table 1 summarizes the kinetic parameters that were used to calibrate the model to the full-scale ammonia profiles shown on Figure 6. Heterogeneous biofilm growth dynamics and nitrification were also observed at the full scale MBBR in Moorhead, Minnesota (Bjornberg *et al.*, 2009).

Table 1. Kinetic Parameters for the Williams Monaco WWTP Operations Model

Parameter (GPS-X 5.0, Mantis Model)	Default Value	Value Used	Unit
Heterotrophic biomass			
Maximum specific growth rate (Arrhenius)	3.2 (1.123)	3.2 (1.029)	d ⁻¹
Readily biodeg. substrate half sat. coefficient	5	5	mgCOD/L
Aerobic oxygen half saturation coefficient	0.2	0.2	mgO ₂ /L
Anoxic oxygen half saturation coefficient	0.2	1.2	mgO ₂ /L
Anoxic growth factor	1	1	-
Nitrate half saturation coefficient	1	1	mgN/L
Heterotrophic decay rate (Arrhenius)	0.62 (1.029)	0.62 (1.029)	d ⁻¹
Autotrophic biomass			
Maximum specific growth rate (Arrhenius)	0.75 (1.123)	0.85 (1.072)	d ⁻¹
Oxygen half saturation coefficient	0.15	0.2	mgO ₂ /L
Autotrophic decay rate (Arrhenius)	0.37 (1.072)	0.17 (1.072)	d ⁻¹
Ammonification rate	0.016	0.04	L/mgCOD/d

Note: Default values used for all other kinetic, stoichiometric and inhibition parameters.

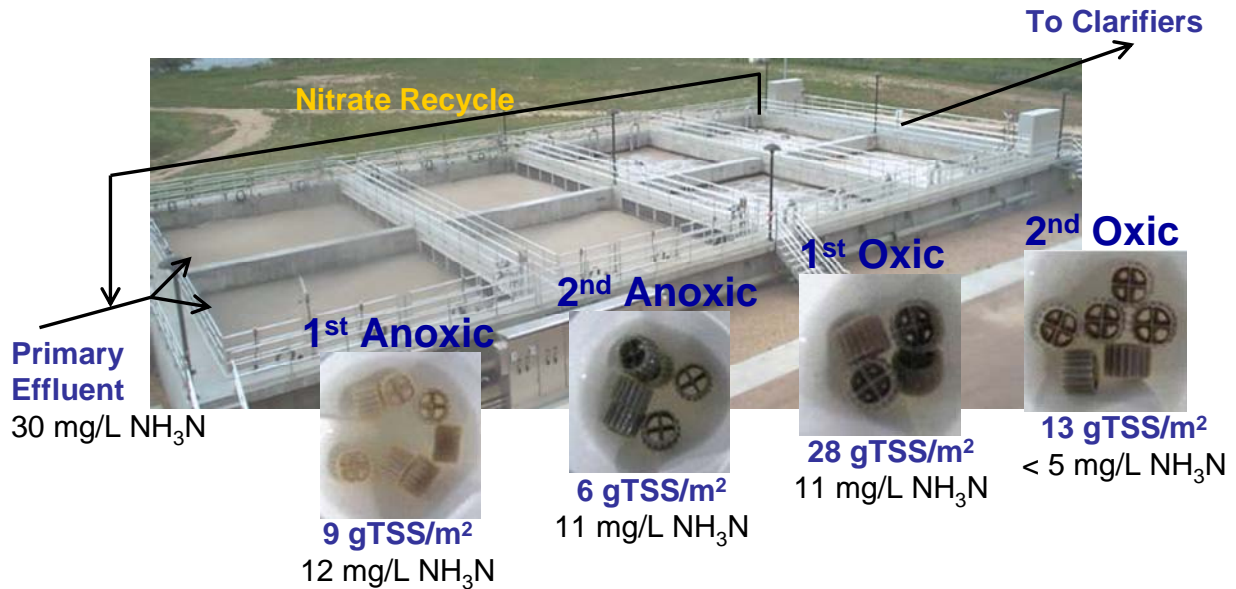


Figure 6. MBBR biomass and ammonia profiles at the Williams Monaco WWTP

When modeling sponge-type IFAS media, a completely different approach is typically taken. While plastic and static rope media provide a surface on which a true attached biofilm can become established, it is believed that sponge media serves as a temporary carrier in which activated sludge enters and exits regularly. In these systems, it is prudent to use a suspended growth model with a mechanism to retain a portion of the biomass within the aeration basin, rather than using a biofilm model.

When modeling any process, it is important to incorporate biosolids processing to account for sidestream loads. Anaerobic digestion in particular can release a high percent of the phosphorus and ammonia in the solids back into solution, which increases demands for oxygen for nitrification, and rbcOD for denitrification and biological phosphorus removal. If the plant

dewaters during dayshifts or on weekdays only, sidestream nutrient loads can be substantial. Incorporating dynamic sidestream loads with biofilm models can be processor-intensive; however it is necessary to ensure accurate predictions of effluent quality and airflow demands.

Dynamic modeling is also important for plants with combined sewers, or high inflow and infiltration. For the Mamaroneck IFAS design, dynamic modeling was important for determining the impacts of wet weather on the 12-month rolling average effluent quality. Since the aeration basins have less than 3 hours of hydraulic retention time at the design flowrate, there was concern that nitrifier washout could occur if wet weather occurred during the winter. When modeling a 2 day peak flow event, the model predicted an initial spike in effluent ammonia and total nitrogen, but the IFAS system quickly recovered as shown on Figure 7. The design includes provisions for chemically-enhanced primary settling to help manage wet weather flows. Wet weather modeling is discussed further in the “Evaluation of the Second Generation of IFAS” section below.

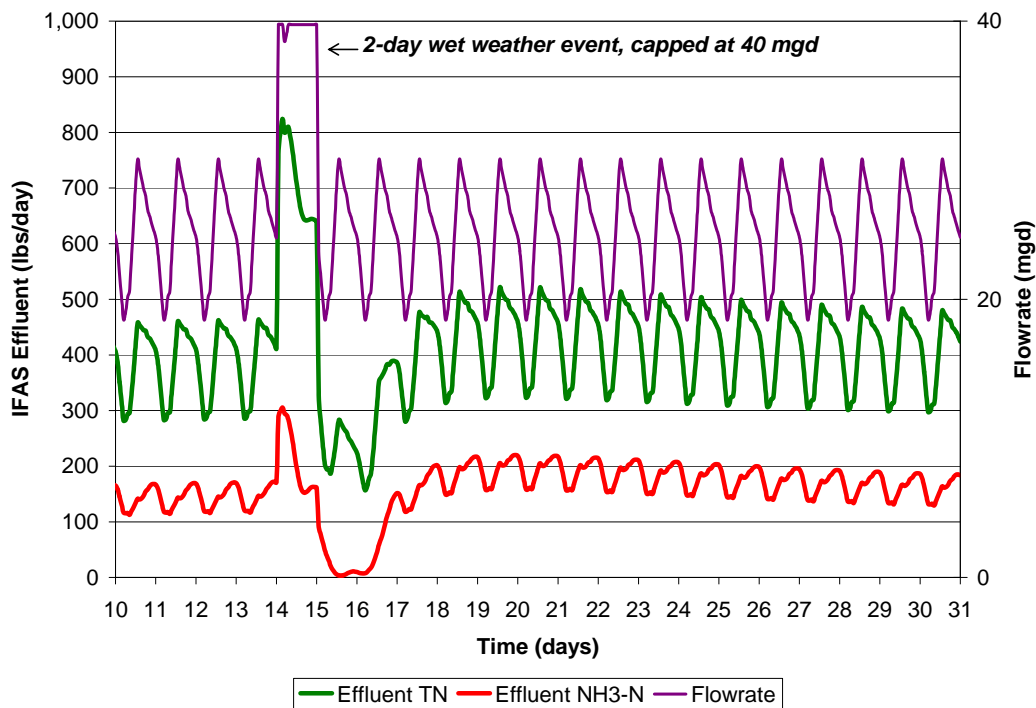


Figure 7: Model predictions for the Mamaroneck IFAS effluent quality during a 2-Day wet weather event

PROCESS DESIGN

In general, the design of an MBBR is similar to that of a trickling filter since BOD, ammonia and nitrate removal rates are highly dependent upon the media properties and surface area loading rates. Since IFAS is a hybrid process of MBBR and activated sludge, designers often consider both loading rates (as with an MBBR) and solids retention time (as with activated sludge). The following sections address important design considerations for IFAS and MBBR systems.

Configuration and Media Placement

The process configuration for IFAS and MBBR systems depends on the treatment objectives, and is often similar to that of conventional activated sludge. For nitrification, two or three oxic reactors in series can be used, and anoxic zones can be added for denitrification if needed. Anaerobic zones can be incorporated for biological phosphorus removal in IFAS systems, but MBBRs must rely on chemical precipitation of phosphorus since there is no return activated sludge to support biological phosphorus removal. Common process configurations for IFAS and MBBR are shown on Figures 8 and 9, respectively. There are always exceptions, however; the Mamaroneck WWTP IFAS design includes two oxic cells followed by post-anoxic denitrification with methanol due to the dilute influent wastewater strength. Modeling and/or pilot testing should always be used to determine the ideal process configuration for specific facilities.

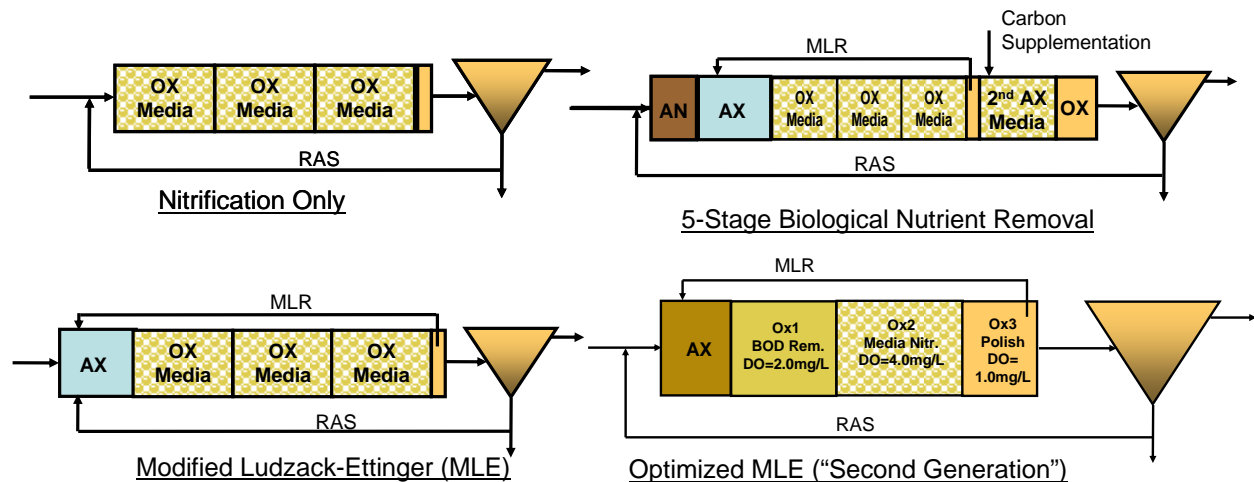


Figure 8. Common process configurations for IFAS facilities

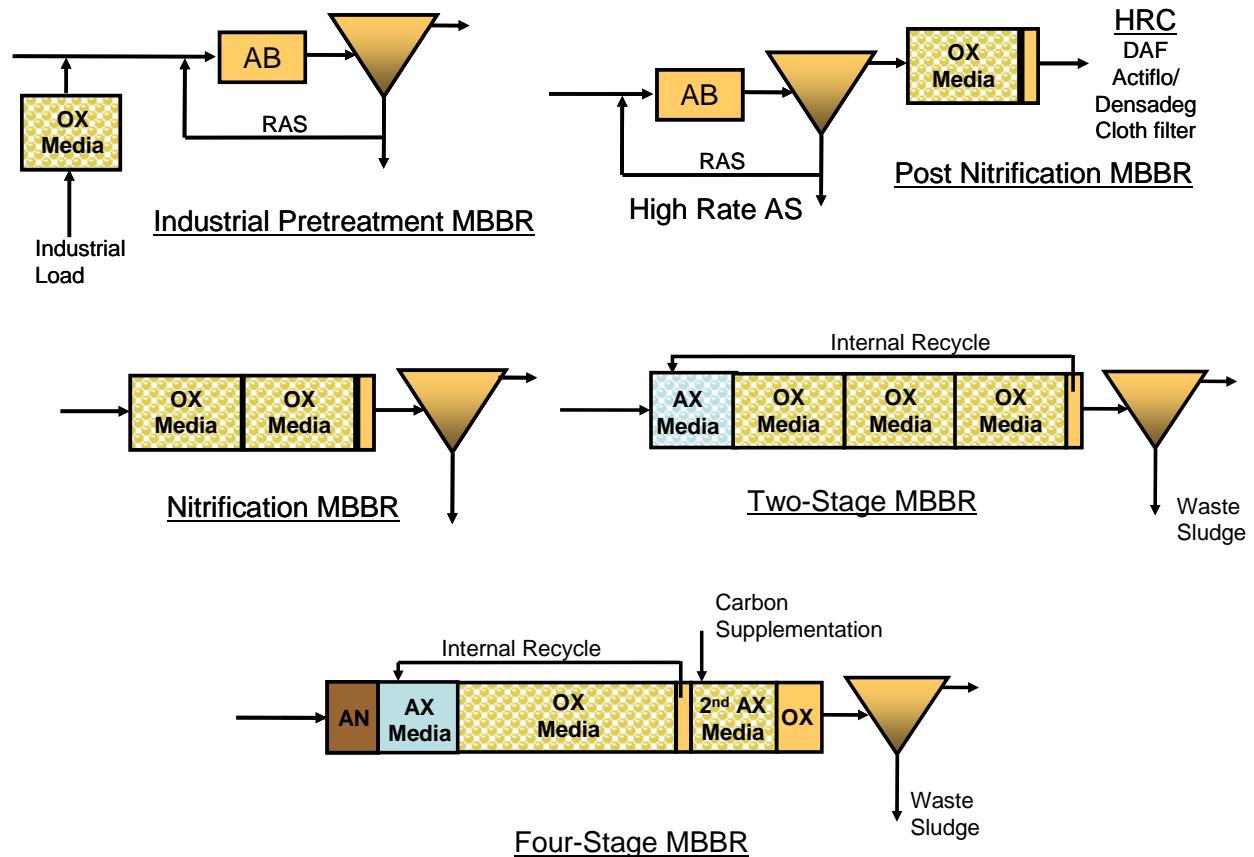


Figure 9. Common process configurations for MBBR facilities

Screening (Pre-treatment) Requirements

Additional pre-treatment is required for IFAS and MBBR systems, to remove debris that may entangle the media or plug the sieves. A general design guideline for fine screens is 6 mm for plants with primary treatment, and 3 mm for plants without primary treatment. The media size and shape should be considered, and there will always be exceptions to these guidelines. For example, the MBBRs at the Williams Monaco WWTP have been in operation since 2003 without any problems, and pre-treatment consists of a 15 mm (5/8-inch) mechanical filter screen before the primary clarifiers.

Sieve Design

When considering IFAS or MBBR, the first consideration should be the basin geometry and sieve placement. Plug flow basins that have high length to width ratios may require special attention to prevent media migration problems. As a rule of thumb, the velocity of water in the basin, including all recycle flows under peak hydraulic conditions, should be less than 30 to 35 meters per hour (m/hr) to prevent media “stack up” around the sieves. A hypothetical “second generation” solution for a plug flow basin is shown on Figure 10.

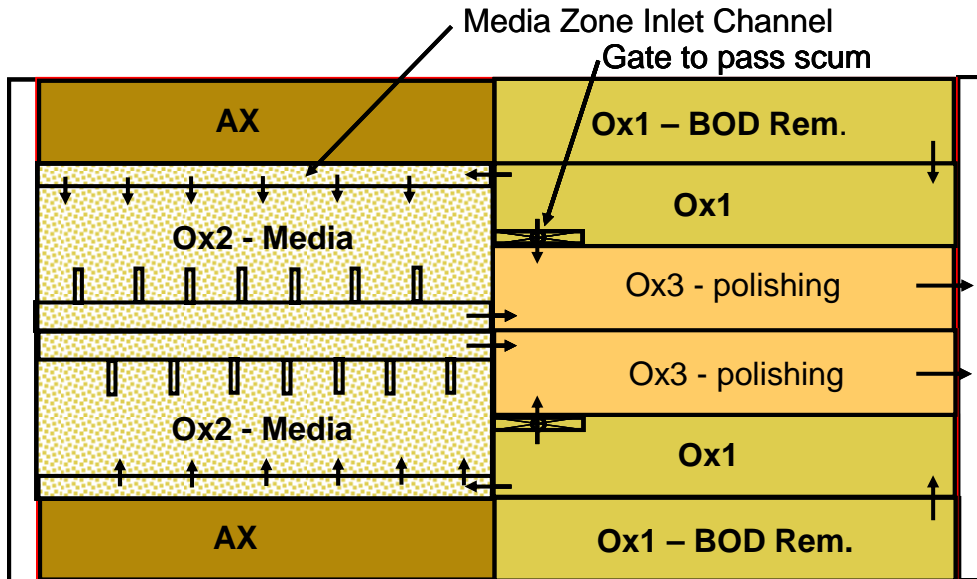


Figure 10. Potential solution to media “stack up” for plug flow basins

Media sieve designs will vary depending on the manufacturer, since the opening size is a function of the media size and shape. It is common to use cylindrical sieves in oxic zones since they are self-cleaning (the majority of the flow that passes through the sieves occurs perpendicular to the forward flow in the basin). In anoxic zones, it is more common to use flat wall sieves, since cylindrical sieves can interfere with mixing patterns. Typical cylindrical sieve diameters are 12-inch and 16-inch, and typical lengths are 5, 10 and 12 feet. Hydraulic loading rates should not exceed 24 gallons per minute per square foot (gpm/sf) of sieve surface area, and the maximum velocity through the wall orifice should be less than 1.5 foot per second to control headloss. Under peak flow conditions, the headloss across a sieve can approach 2 inches; therefore, it is important to carefully examine the hydraulic design.

Media sieves need to be placed at every location where water leaves the basin, including dewatering ports and basin overflows. Also, since media has a tendency to “creep” up the basin walls, it is important to provide adequate freeboard. Appropriate conservatism should always be applied, since the basins will not always operate under design conditions, especially during start-up when construction may complicate operations. Figure 11 shows media creep at the Williams Monaco WWTP, and basin overflow sieves at the Broomfield WRF.

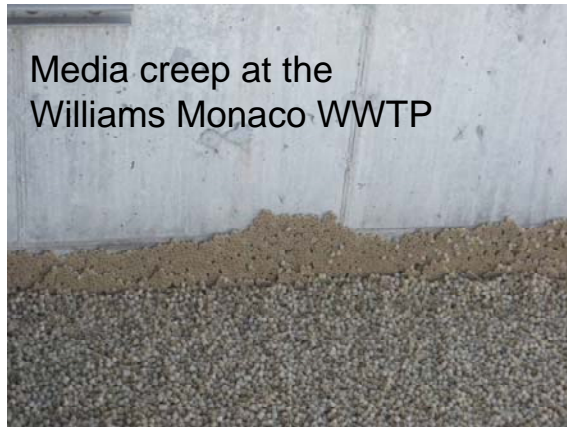


Figure 11. Important sieve design considerations

Aeration

The aeration system serves three purposes: (1) supporting process demands for nitrification and BOD removal; (2) providing mixing of the media; and (3) providing scouring of the sieves. Fine or coarse bubble diffusers can be used; however, coarse bubble is more common since it requires virtually no maintenance. Changing fine bubble diffusers presents challenges with IFAS and MBBR systems, since draining the basins will cause the media to sit on top of the diffusers. Therefore a plan must be in place to pump the media from the aeration basins to a storage area where it can be kept wet (an equalization tank for example), while maintenance is conducted on the diffusers. While this can be a challenge, there are IFAS plants (Westerly, Rhode Island) that use fine bubble diffusers because of their higher oxygen transfer capability compared to that of coarse bubble diffusers.

Selecting residual dissolved oxygen concentrations for designs is very important, especially for MBBRs since nearly all of the treatment occurs on the biofilm. Higher dissolved oxygen concentrations will result in higher ammonia removal rates. When operators at the Williams Monaco WWTP were struggling with high organic loads due to a gravity thickener failure in 2008, they were able to instantly reduce ammonia concentrations by turning on another blower. Dissolved oxygen sensitivity was also observed in modeling that was conducted for the Fort Myers, Florida MBBR design, as shown on Figure 12. Ideally, aeration systems should be designed considering the discharge permit and seasonal needs. Since nitrification rates are highest in the summer, low dissolved oxygen set-points (2 to 3 mg/L) may be able to be used which can greatly reduce operating costs. In the winter, however, higher set-points (4 to 5 mg/L) are recommended for MBBRs to ensure complete nitrification for plants with low ammonia limits.

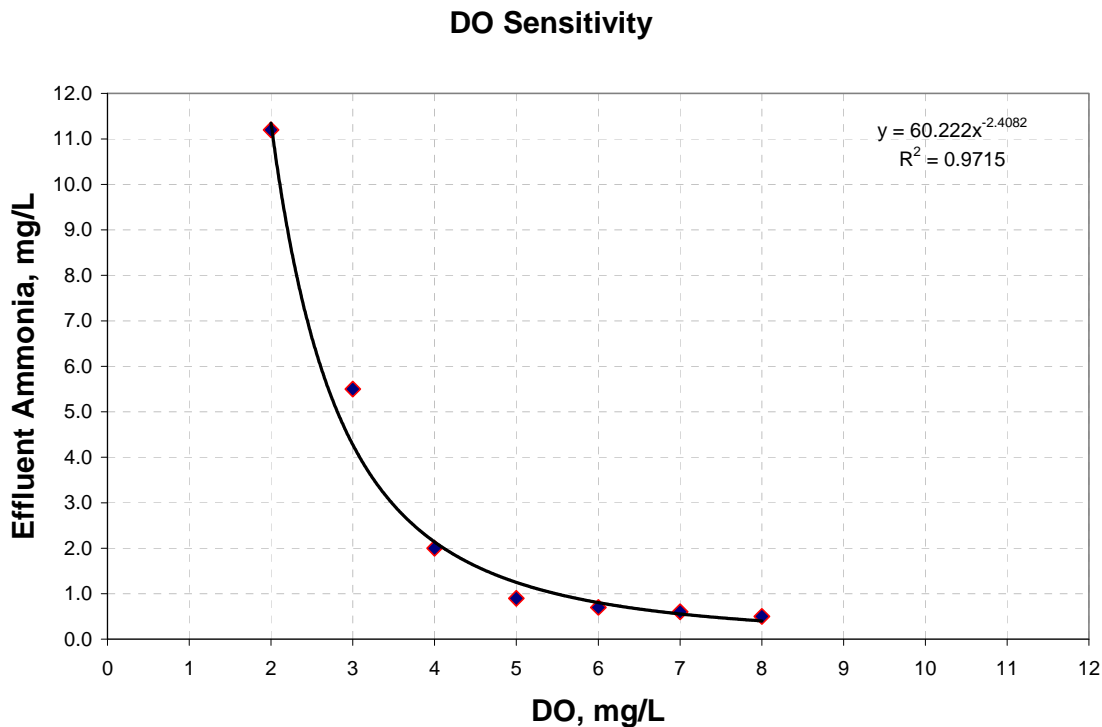


Figure 12. Fort Myers, Florida MBBR model sensitivity to residual dissolved oxygen

Since MBBRs and some IFAS systems operate at higher dissolved oxygen concentrations than conventional activated sludge (CAS) systems, there has been recent interest in quantifying the effects of media on oxygen transfer efficiency. Full-scale off-gas testing at the Lakeview WWTP suggested that IDI/Headworks (Hydroxyl) media had very little or no affect on the OTE of ceramic fine-bubble discs, when side-by-side IFAS and CAS trains were operating identically (Viswanathan *et al.*, 2008). The ratio of oxygen transfer in wastewater to that in clean water (alpha) was determined to be 0.6 for the IFAS system and 0.646 for the CAS system. The researchers also conducted shop tests comparing fine and coarse bubble diffusers, and concluded that the media had a slight negative impact on the OTE of fine bubble diffusers, but a slightly beneficial impact on OTE of coarse bubble diffusers at both 25 percent and 50 percent media fill fractions (Pham *et al.*, 2008).

At the full-scale IFAS facility in Broomfield, Colorado, Kruger/AnoxKaldnes K1 media appears to have a slightly beneficial impact on the oxygen transfer efficiency of coarse bubble diffusers. When designing the Phase 2 expansion, Phase 1 operating data was used to calibrate a process model and the alpha factor had to be adjusted from 0.85 to 0.9 to align the model predictions with full-scale airflow and dissolved oxygen measurements. While off-gas testing was not conducted, the City and County elected to reduce the number of blowers for the Phase 2 design based on several years of full-scale operating experience (Phillips *et al.*, 2008). Another lesson learned at the Broomfield WRF is that dissolved oxygen probes need to be fit with special shields to protect them from media abrasion.

While additional research is needed on this topic, the selection of fine or coarse bubble diffusers

for an IFAS or MBBR design should be based on maintenance requirements. If there is not an easy way to pump and store media from the basins, coarse bubble diffusers offer a clear advantage despite their lower oxygen transfer efficiency compared to that of fine bubble diffusers. Another factor to consider is the media type; Lotepro/Linpor sponge media systems are typically designed with fine bubble diffusers and residual dissolved oxygen concentrations of around 2.0 mg/L. These design features, coupled with the propensity for sponge media to encourage significant simultaneous nitrification/denitrification, result in energy savings as well as low effluent total nitrogen (≤ 6 mgN/L) at the Westerly, Rhode Island MLE IFAS facility (Masterson *et al.*, 2004).

Mixing

In anoxic zones, mechanical mixers are used to keep the media in suspension, and wall sieves are used to retain the media since cylindrical sieves can interfere with mixing patterns. Most plants use slow speed submersible mixers (Landia, EMU, ABS), with impellers designed to protect the media. Mixers are normally placed along one side of the basin to create a spiral roll pattern, and provide mixing energy ranging from 0.75 to 0.95 brake horsepower per thousand cubic feet of basin volume (bhp/kcf). Other mixer types are also possible, such as Enersave or Hyperclassic Invent mixers.

Scum and Foam Control

IFAS and MBBRs do not generate any more scum or foam than conventional activated sludge, but the sieves that are present to retain buoyant media also retain foam once it is formed. Many of the first generation IFAS facilities have not had serious foam accumulation, with the exception of the Lakeview WWTP in Ontario, Canada; the TZ Osborne demonstration plant in Greensboro, North Carolina; and the Henry N. Wochholz WWTP in Yucaipa, California (Wallis-Lage *et al.*, 2009). Incidences of foaming are typically associated with start-up conditions, when basins are under-loaded, or seeded with sludge that that has gone septic. Chlorinated surface spray systems, or RAS chlorination can help to control foam, but in some cases (Henry N. Wochholz WWTP) defoamers are necessary. To avoid foaming events in any activated sludge process, one can take the following steps:

- Avoid excessively long SRTs
- Eliminate areas of low residual dissolved oxygen
- Balance sidestream loads
- Avoid low alkalinity and pH
- Provide 2 to 3 feet of freeboard
- Provide chlorinated sprays

Figure 13 shows both a typical amount of foam for an IFAS system (Broomfield WRF, left), and foaming during the second week of start-up (Henry N. Wochholz WWTP, right).



Figure 13. Typical surface foam at the Broomfield IFAS facility, and foaming during start-up at the Henry N. Wochholz IFAS facility

THE SECOND GENERATION OF IFAS

There have been many lessons learned in the design, construction and operation of the first generation IFAS and MBBR facilities. In many cases, designs have performed better than expected, suggesting that there may be room for cost reductions in second generation facilities. This was the case for the Broomfield WRF Phase 2 expansion, when a dynamic BioWin model was calibrated with Phase 1 data and used to justify both (1) a reduction of the media fill fraction from 48 percent to 30 percent, and (2) the reduction of a blower (Water Environment Federation, in press; Phillips *et al.*, 2008). The general process schematic (Figure 14) was not modified for Phase 2, since the Phase 1 facilities performed well with regard to nitrification, denitrification, biological phosphorus removal and secondary clarification, plus the Phase 2 basins were new construction.

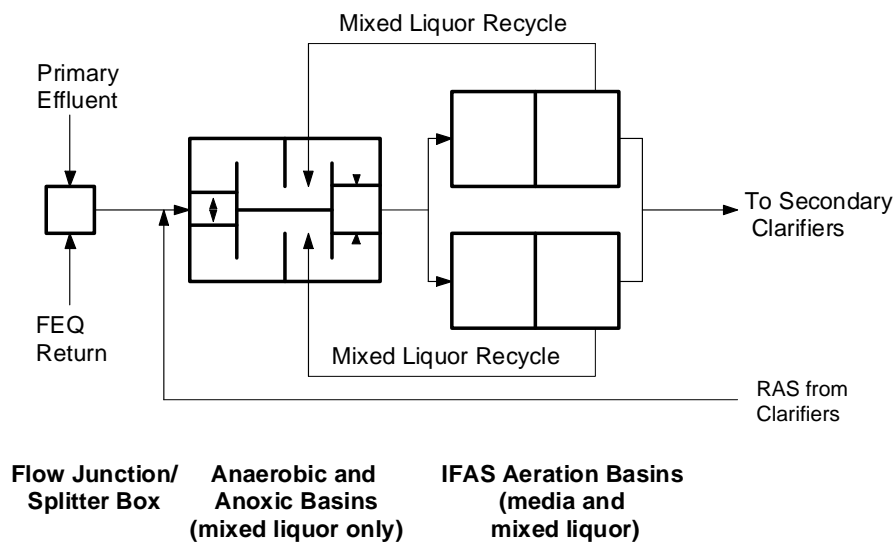


Figure 14. Schematic of the Broomfield IFAS process (Phase 1 and Phase 2)

To evaluate alternative process designs for a hypothetical second generation IFAS retrofit, a BioWin simulator was configured with three different media placement strategies. The objective of this exercise was to determine the optimum media placement in terms of the triple bottom line (relative cost, environmental, and social aspects). The hypothetical plant is assumed to have adequate pre-treatment for IFAS upgrades (6 mm fine screens), primary clarifiers, and secondary clarifiers. The aeration basins have a length to width ratio of 3.3:1, and three potential media placement strategies are shown on Figure 15. Raw influent wastewater characteristics which are based on an actual facility are summarized in Table 2, and basin dimensions are summarized in Table 3.

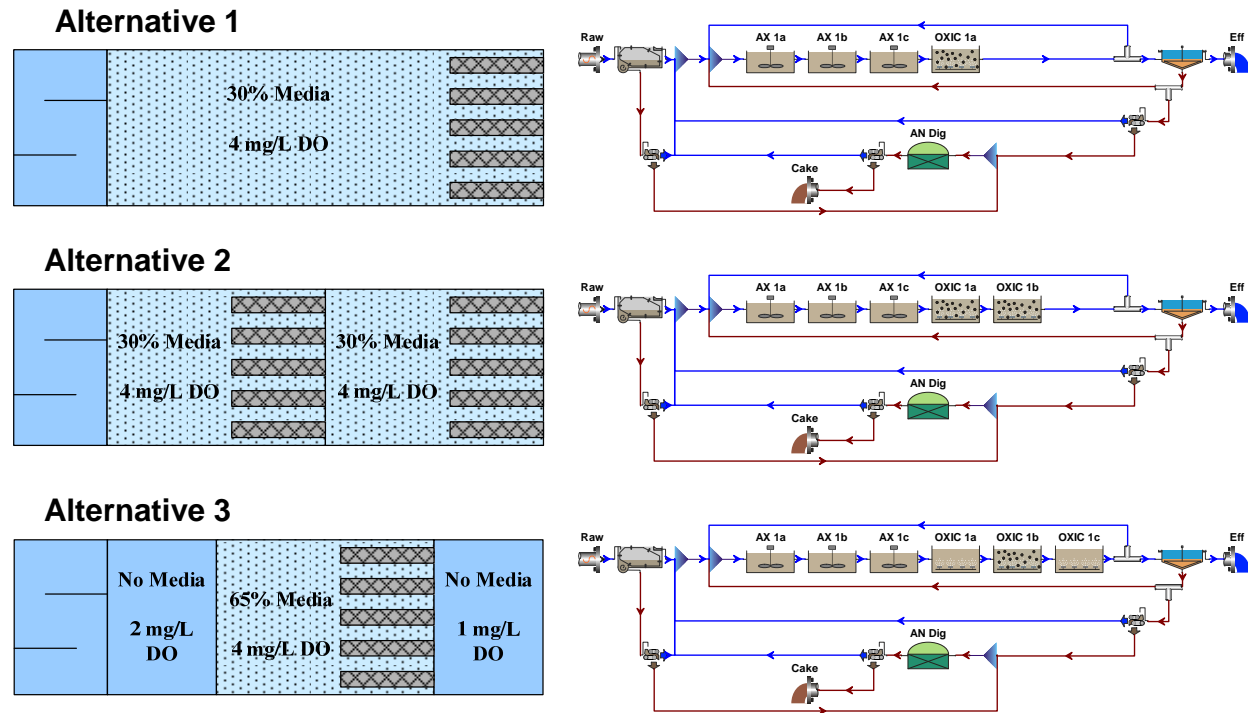


Figure 15. Three potential IFAS configurations (left) and plant-wide dynamic models (right) for a hypothetical 10 mgd plant

Table 2. Raw wastewater characteristics for a hypothetical WWTP

Parameter ⁽¹⁾	Flowrate, mgd	BOD, mg/L (ppd)	TSS, mg/L (ppd)	NH ₃ N, mg/L (ppd)
Annual Average	8.3	230 (15,900)	239 (16,500)	21 (1,450)
Maximum Month	10.0	230 (19,200)	280 (23,400)	20 (1,670)
Peak Week	17.9	66 (9,840)	96 (14,300)	4.1 (600)
Peak Day	37.3 ⁽²⁾	56 (17,500)	84 (26,000)	3.4 (1,060)
Peak Hour	49.6	167 (68,900)	334 (138,000)	10.8 (4,500)

⁽¹⁾Temperature = 12°C winter, 17°C average, 25°C summer

⁽²⁾If this flowrate is sustained for a full day or longer, the mixed liquor recycle will need to be turned down to 150% to maintain basin velocities less than 35 m³/hr (to prevent media accumulation at the sieves).

Table 3. Basin volumes for a hypothetical WWTP - 3 IFAS configuration alternatives

	Alternative 1	Alternative 2	Alternative 3
Primary Clarifiers			
Number	4	4	4
Diameter	70 ft (21.3 m)	70 ft (21.3 m)	70 ft (21.3 m)
Sidewater depth	13 ft (4 m)	13 ft (4 m)	13 ft (4 m)
TSS Removal	50%	50%	50%
BOD Removal	28%	28%	28%
Aeration Basins			
Number	4	4	4
Total Volume	4.37 MG (16,500 m ³)	4.37 MG (16,500 m ³)	4.37 MG (16,500 m ³)
% Anoxic	17%	17%	17%
% Oxid 1	83%	41.5%	18.5%
% Oxid 2	-	41.5%	46%
% Oxid 3	-	-	18.5%
Total Internal Recycle Capacity	30 mgd (4700 m ³ /hr)	30 mgd (4700 m ³ /hr)	30 mgd (4700 m ³ /hr)
IFAS Equipment			
Total Media	150,000 cf (4250 m ³)	150,000 cf (4250 m ³)	150,000 cf (4250 m ³)
Media Fill Fraction	30%	30%	65% in Oxid 2 only
Sets of Sieves	1 per basin	2 per basin	1 per basin
Secondary Clarifiers			
Number	4	4	4
Diameter	70 ft (21.3 m)	70 ft (21.3 m)	70 ft (21.3 m)
Sidewater Depth	15 ft (4.6 m)	15 ft (4.6 m)	15 ft (4.6 m)
RAS Capacity	10 mgd (1600 m ³ /hr)	10 mgd (1600 m ³ /hr)	10 mgd (1600 m ³ /hr)

Winter conditions were modeled for each of the three alternatives, using all model default parameters (BioWin, Version 3.1). The wastage rate was set to maintain a mixed liquor suspended solids concentration of 3,000 mg/L, and the model predicted an attached biomass of 10 to 11 gTSS/m², and a combined solids retention time (suspended plus attached biomass) of 10 days. Once the steady state conditions were established, dynamic simulations were run for each alternative to determine the impacts of wet weather on effluent quality. A 30-day period was simulated, with a normal diurnal pattern for the first 7 days, followed by a 7 day wet weather event, then 14 days of normal diurnal conditions. The dynamic influent conditions, which are based on actual data with a 4-hour “first flush” are shown on Figure 16.

All three IFAS configurations were able to recover from the peak event rather quickly, with minimal nitrifier washout, as shown on Figure 17. The average effluent ammonia was slightly lower for Alternatives 2 and 3 (0.7 mg-N/L) compared to that of Alternative 1 (1.0 mg-N/L), which is to be expected when modeling multiple reactors in series. Alternative 3 showed a significant advantage in denitrification, however, with an average effluent NO_x-N concentration of 5.1 mg/L, compared to 8.2 mg-N/L for Alternative 1, and 8.6 mg-N/L for Alternative 2, as shown on Figure 18. By tapering the residual dissolved oxygen concentration to 1 mg/L in the last oxid zone in Alternative 3, less oxygen was recycled to the anoxic zone which led to better denitrification.

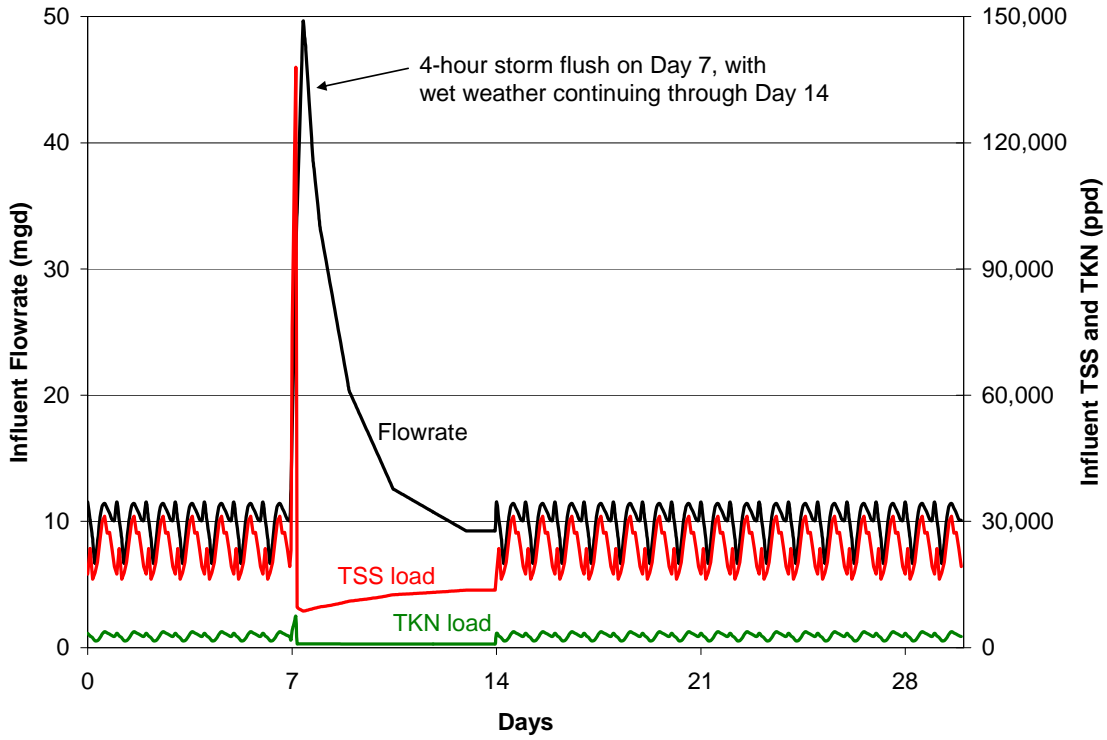


Figure 16. Wet weather event to test model sensitivity to nitrifier washout

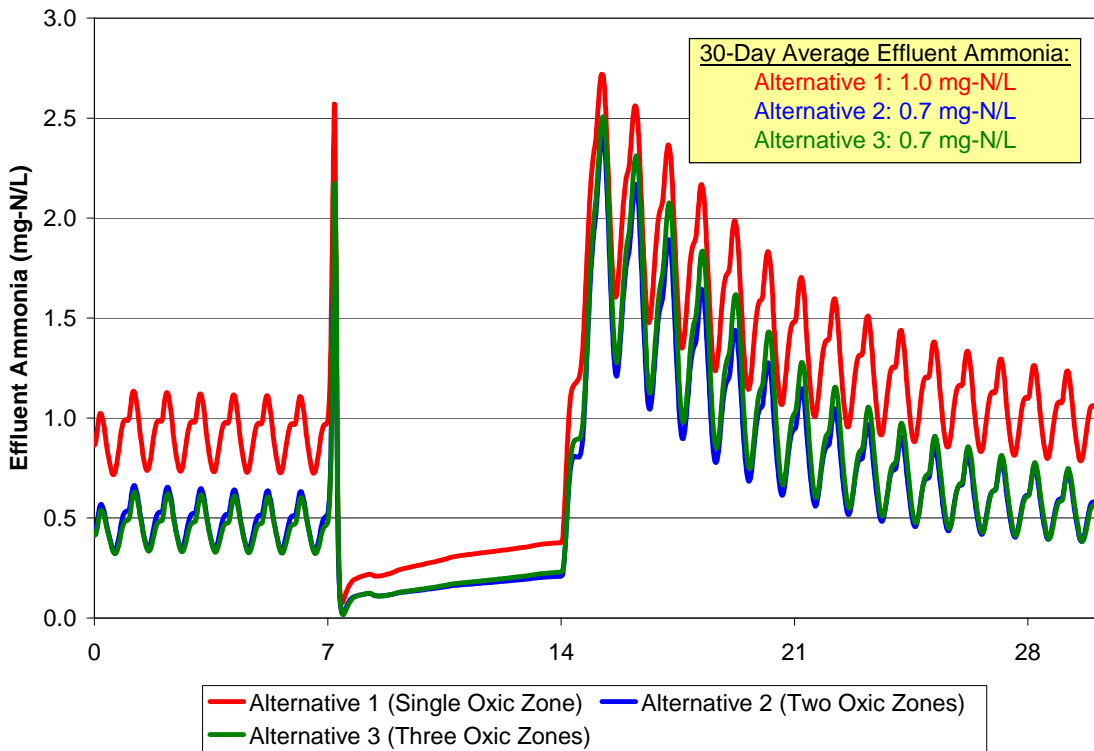


Figure 17. Wet weather model predictions for effluent NH_3N for 3 IFAS configurations

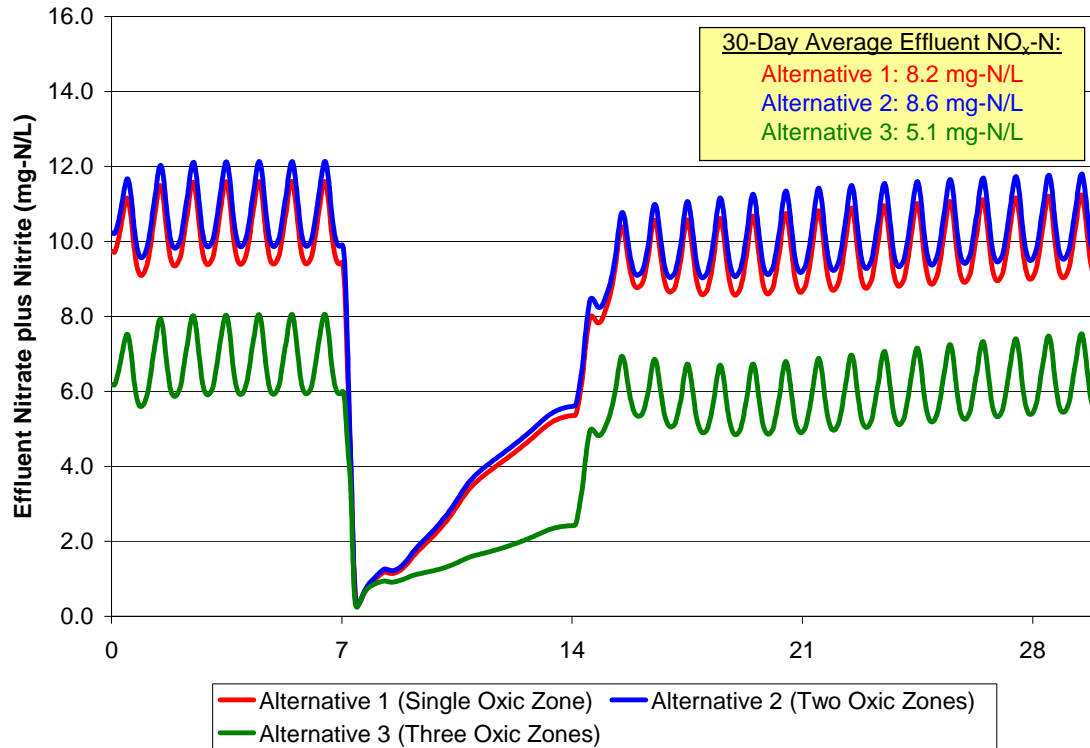


Figure 18. Wet weather model predictions for effluent NO_x-N for 3 IFAS configurations

The model was also used to compare aeration demands for summer maximum month conditions. Coarse bubble diffusers were assumed, with an alpha factor of 0.85 for all three alternatives (since off-gas testing data was not available). The model predicted a very similar actual oxygen requirement (AOR) for all three alternatives, which was expected since each configuration oxidized approximately the same amount of BOD and ammonia while denitrifying similar amounts of nitrate/nitrite. Figure 19 shows the model predictions for the nitrogenous and carbonaceous AOR for each alternative, within each oxalic zone. Note that the majority of the AOR for Alternative 3 is within Oxalic 1b, or the zone with a 65 percent media fill fraction.

Because of this high AOR demand in Oxalic 1b (and corresponding high uptake rate), Alternative 3 required approximately 10 percent more airflow at standard conditions than Alternatives 1 or 2. This may seem counterintuitive, since Alternative 3 has a lower dissolved oxygen set-point in part of the basins than Alternatives 1 and 2. However, Alternative 3 has a higher oxygen uptake rate in the media portion of the basin results in a lower oxygen transfer efficiency. Plus, by having a 65 percent media fill fraction (versus 30 percent), the media zone for Alternative 3 has less liquid volume for oxygen transfer, compared to Alternatives 1 and 2. While these results are based on hypothetical basin configurations without pilot data for model calibration, the trends are important to consider when evaluating long-term operating costs. With further optimization of dissolved oxygen set-points and diffuser design, it is likely that all three alternatives could result in similar power demands.

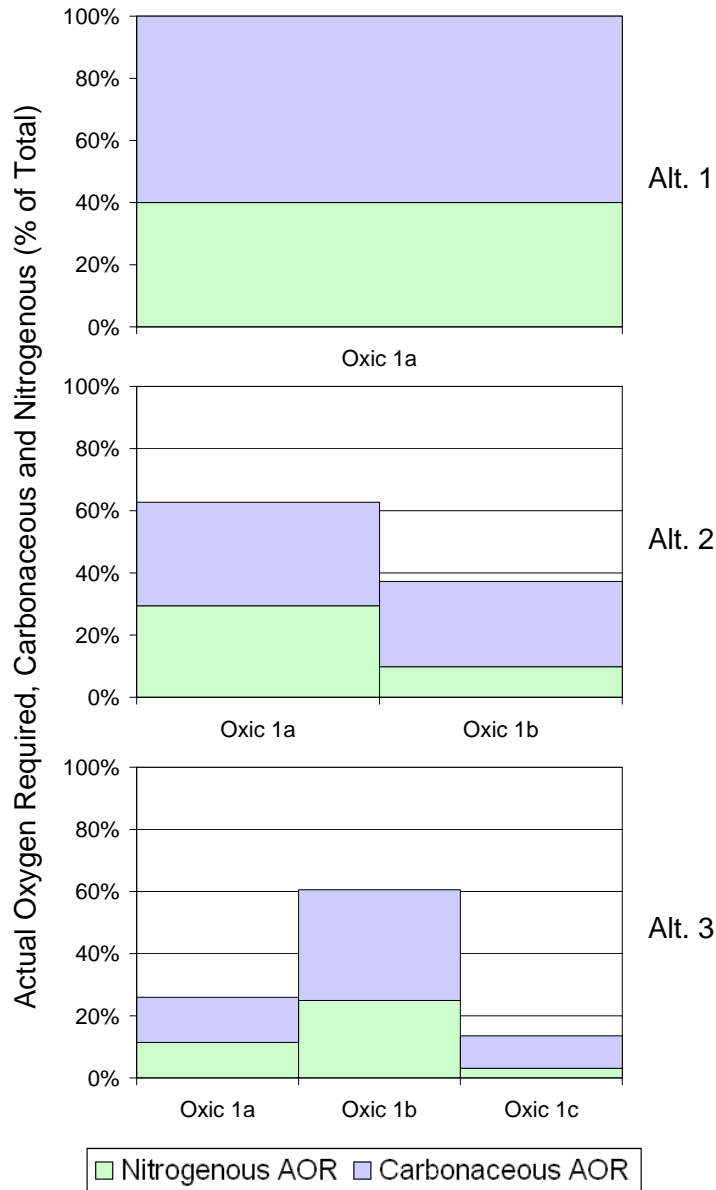


Figure 19. Distribution of actual oxygen required (AOR) for 3 IFAS configurations

CONCLUSIONS

Today's biofilm models provide a better understanding of IFAS and MBBR technologies. Coupled with full-scale, pilot or bench-scale data, engineers can model different basin configurations, diffuser designs, and media placement in order to reduce the capital and operating costs of second generation facilities. Lessons learned through first generation facility operations include the following:

- Attached biomass quantities and biofilm thicknesses will vary significantly depending on the temperature, loading conditions and the reactor in series.

- In IFAS systems, the suspended MLSS concentration will impact the amount of biomass that attaches to the media.
- Residual dissolved oxygen concentrations will greatly impact nitrification rates.
- Residual dissolved oxygen concentrations will impact denitrification rates, both directly in the oxic zone (simultaneous nitrification and denitrification) and indirectly in the anoxic zone (through recycle carryover).
- It may take several weeks for an IFAS or MBBR system to reach steady state conditions, even if seeded with sludge from another source. This time must be taken into account in startup and commissioning, as well as pilot testing.
- IFAS and MBBRs are resilient to wet weather events, as observed in the hypothetical modeling example, as well as first generation plants.
- IFAS and MBBRs do not generate any more scum or foam than conventional processes; however, the sieves that are in place to retain media will also retain foam. Control measures are discussed above.
- Media may be detrimental to oxygen transfer in fine bubble systems (by causing bubble coalescence), and beneficial in coarse bubble systems (by causing bubble separation) but more research is needed to quantify the specific impacts of different media types, fill fractions, basin configurations and loading conditions.
- IFAS and MBBRs were cost-competitive with conventional technologies in the first generation facilities, and knowledge gained from these facilities can further reduce the cost of second generation facilities.

Results obtained by modeling a hypothetical second generation IFAS facility found a significant advantage in effluent quality ($> 3 \text{ mg/L NO}_x\text{-N}$) by placing the media in the center of the aeration basin, versus throughout the basin. While this configuration may require slightly more airflow (10 percent) by concentrating the oxygen demand in the center of the basin, the advantages in relative cost (fewer sieves), process reliability and control, warrant further investigation. By placing media where it provides the most benefit for the investment, utilities that own and operate second generation facilities can ensure their stakeholders that they are meeting their community's economic, environmental and social responsibilities.

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