WRF 4973 Fact Sheet: ID 1110

Strategy: Process Intensification

Increase Biomass (MABR, IFAS, Step feed, inDense)

Mobile Organic Biofilm Media Recovery Screen.
Source: HDR Engineering, Inc.

BioMag (magnetite separator).
Source: HDR Engineering, Inc.

Many biological nutrient removal (BNR) optimization strategies can benefit from increasing the solids retention time (SRT) of a treatment process by increasing the biomass in its bioreactors. Increasing the biomass in a process helps stabilize the process performance to accommodate variable influent loads and allow for slow-growing organisms, such as nitrifiers, to proliferate. Additionally, the ability to raise the biomass in the reactor can provide additional treatment capacity in the BNR process.

An increase in suspended biomass will increase the mixed liquor suspended solids (MLSS) concentration in a BNR process and increase the solids loading on its secondary clarifiers. It is therefore important to consider the implications of a higher solids loading on the secondary clarifiers' performance.

Some densification strategies that focus on increasing the biomass within a BNR process can do so without increasing the solids loading to a process's secondary clarifiers. Examples of such strategies include growing biomass in granules, growing biofilms on fixed or suspended media, and step-feed operation.

Densification with granules or the addition of media creates a hybrid bioreactor where a large portion of the biomass grows in biofilms. The biofilms create diffusion-controlled biokinetics that may help to sustain nitrification, denitrification, and even biological phosphorus (P) removal. Additionally, the biomass growing in biofilms operates at a far longer SRT than the organisms in suspension, which aids in retaining slower-growing organisms such as nitrifiers.

Fact Sheet Application Checklist

R = fact sheet relevant to item
PR = fact sheet is potentially relevant to item depending on application, existing conditions, etc.

Category	R	Intensification
		Chemical addition
		Carbon management
		I&C strategies
		Sidestream mgmt.
		Energy savings
		Chemical savings
		Operational savings
		Other means of NutRem
Nutrient	R	Ammonia
	R	NOx
	R	TN
	R	Ortho-P
	R	TP
Scale (design flow)	R	Small (<1 mgd)
	R	Medium (1–10 mgd)
	PR	Large (>10 mgd)

Goal	R	Improve reliability
	R	Reduce nutrient
		Reduce O&M cost
Group	R	Optimize existing CNR
		Optimize existing TNR
	R	NutRem in secondary plant
Process		Small
		Pond
	R	Fixed film (secondary)
		Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
		Tertiary NutRem (TNR)
		Other

CAS = conventional activated sludge (BOD only)
NAS = nitrifying activated sludge (without denitrification)
CNR = conventional nutrient removal no chemical/no filter, etc.
TNR = tertiary nutrient removal with chemical, filter, etc.

Technology Summary Evaluation

Footprint	2	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	4	Technology ranking based (LIFT) see below*
Energy efficiency	1–5	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M impact	2–4	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
Material/consumables	2	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	2	Scale 1–3: minimal/none = 1; some = 2; significant = 3 (e.g., chemical process)

* Technology ranking based on Leaders Innovation Forum for Technology (LIFT) Water Research Foundation (WRF) Technology Development Level (TDL) definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional

Descriptions/Evaluation

Strategy	Increase biomass
Description	Process or technology solutions that increase the active biomass within existing tankage. The increase in active biomass can have one or more of these outcomes: (1) It allows operation at a higher SRT, which could allow nitrification and nutrient removal; (2) it increases the treatment capacity within the basins; (3) it can increase process reliability. The biomass concentration within a BNR process can be increased by adding biofilm carriers, such as integrated fixed-film activated sludge (IFAS), Mobile Organic Biofilm (MOB), ballast like and ballasted magnetite carriers (BioMag), or growing aerobic granular sludge (AGS). Membrane bioreactors (MBRs) or step-feed operation are also able to operate at higher active biomass concentrations. See Table 1 for some of the technologies that fit in this category and their main features.
Application	The increase in biomass that can be accommodated in an activated sludge system is limited by the settleability of the solids in the clarifier capacity/capability. Satisfactory secondary clarifier performance is essential to retain the additional biomass and produce a clear effluent. The bioreactor may also require improvements to maintain the proper environment in the bioreactor (mixing, dissolved oxygen [DO], etc.). Common applications for these types of process intensification strategies include: • Achieving nitrification in facilities designed only designed for biochemical oxygen demand (BOD) removal by raising the SRT • Freeing up reactor volume for anoxic and/or anaerobic zones to achieve denitrification and enhanced biological phosphorus removal (EBPR) • Reducing clarifier solids load by retaining solids on media carriers • Increasing capacity of existing plant when physical expansion is not possible or cost-prohibitive
Constituents removed	These strategies help remove a variety of constituents from wastewater, depending on the technology and existing process. Typical applications include providing more, or more reliable, ammonia (NH_3), total nitrogen (TN), and/or total phosphorus (TP) removal.
Development status*	The development status of these strategies varies. Some, like IFAS, are fully developed (LIFT TDL 5) with hundreds of full-scale installations, while others, like MOB technology, are still in the pioneering stage (LIFT TDL 3).
O&M considerations	Operations and maintenance (O&M) impacts depend on the selected technology, but in general O&M does not change significantly. Processes like MOB or BioMag have consumable chemicals, media, or additives that are added and retained, along with new equipment and infrastructure that will require maintenance. For example: • **MOB:** organic media replacement and retention screens • **BioMag:** magnetite addition and recovery
Benefits	Increasing biomass inventory can increase treatment capacity and the process reliability of the bioreactor. Additional treatment capacity, including nitrification, nitrogen (N) removal, and/or EBPR, can be achieved with the higher biomass available.
Limitations	Process and hydraulic limitations need to be evaluated. The key process limitations are the oxygen transfer capacity and process kinetics (hydraulic retention time [HRT], mixing conditions, etc.) in the bioreactor and the solids separation/clarification performance in the secondary clarifiers. For options that add ballast the impact on clarifier mechanism torque requires verification. IFAS options that require media retention screens would add hydraulic head loss through the basin and need foam routing around the IFAS units. Many intensification technologies require capital investment. A life-cycle analysis is required to determine if the application has a favorable return on the investment period.

Design considerations	Design considerations for technologies that increase the biomass inventory are dependent on the specific technology and the existing infrastructure, including basin geometry, depth, diffusers, etc. See Table 1 for more technology-specific information.
Potential fatal flaws	The flaws vary depending on the selected technology. See Table 1 for more technology-specific information.
Footprint requirements	For retrofits, the footprint requirements are limited to auxiliary equipment like shear mills and magnetite separators for BioMag or hydrocyclones for gravity selective wasting. For new facilities, the footprint reduction can be as much as 50% compared to a conventional treatment process, but in most cases the range is about 20% to 40%.
Residuals	Biomass usually is increased to add capacity or improve treatment performance. Residuals will remain similar to prior operation. Residuals may decrease with modified operation for nutrient reduction and/or higher SRT.
Cost considerations	Depends on the selected technology.
Past experience	Depends on the selected technology.
Publications	Depends on the selected technology.
Related fact sheets	1101: Process Intensification Overview 1120: Nutrient Removal in Existing Secondary Processes 1130: Improve Nutrient Removal in Existing Basins 1140: Optimize BNR Effectiveness 1150: Use of Chemicals to Improve Nutrient Removal
Date updated	9/10/2022
Contributors	JB Neethling, James Barnard, Stephanie Klaus, Michael Liu, Erika Bailey, Mario Benisch, Justin Macmanus, Adam Hendricks, Anand Patel

Note

* Technology ranking based on LIFT WRF TDL definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = Conventional (https://www.waterrf.org/sites/default/files/file/2019-07/LIFT%20Scan%20Application-LIFT%20Link%2BHub_0.pdf : accessed September 2020)

Additional Information

Table 1 contains information about the applicability and features of some commonly used optimization strategies to increase process biomass. The following process technologies/strategies are presented:

- Aerobic granular sludge (AGS)
- Step feed
- Selective wasting
- Integrated fixed-film activated sludge (IFAS)
- Biomass ballasted process
- Biofilm carriers

Table 2 contains descriptions of the principles and design features of some technologies that can be used to increase biomass.

Table 1. Application of Technologies and Strategies to Increase Biomass.

Feature	AGS	Step Feed	Selective Wasting	IFAS	Biomass Ballast	Biofilm Carriers
Goal						
Improve reliability	✓		✓	✓	✓	✓
Reduce nutrient	✓	✓	✓	✓	✓	✓
Reduce O&M cost						
Group						
Optimize existing CNR	✓	✓	✓	✓	✓	✓
Optimize existing TNR						
NutRem in secondary plant			✓	✓		✓
Process						
Small					✓	✓
Pond						
Fixed film (secondary)						
Conventional act. sludge (CAS)			✓	✓	✓	✓
Nitrifying act. sludge (NAS)	✓	✓		✓	✓	✓
Conventional NutRem (CNR)	✓	✓	✓	✓	✓	✓
Tertiary NutRem (TNR)						
Category						
Intensification	✓	✓	✓	✓	✓	✓
Chemical addition					✓	
Carbon management						

Feature	AGS	Step Feed	Selective Wasting	IFAS	Biomass Ballast	Biofilm Carriers
I&C strategies						
Sidestream management						
Energy savings						
Chemical savings						✓
Operational savings	✓		✓			✓
Other means of nutrient removal						
Nutrient						
Ammonia	✓	✓	✓	✓	✓	✓
NOx	✓	✓		✓	✓	✓
TN	✓	✓		✓	✓	✓
Ortho-P	✓		✓		✓	✓
TP	✓				✓	✓
Overview						
Footprint (scale 1–5)	1	2	2	1	1	2
Development status (scale 1–5)	3	5	3	4	5	3
Energy efficiency (scale 1–5)	2	3	3	3	3	3
O&M impact (scale 1–5)	3	3	3	3	3	4
Material/consumables (scale 1–3)	1	1	1	1	2	1
Chemical use (scale 1–3)	1	1	1	1	3	1

Table 2. Design Considerations for Technologies to Increase Biomass.

Technology	Functioning Principle	Design Considerations
Aerobic granular sludge (AGS)	Dense microbial granules are selected by applying fundamental biological selection and physical selection principles for granular growth and selection. These granules have far greater settling velocities than flocs typically formed in CAS systems, allowing a plant to operate at higher biomass concentrations. Furthermore, a single granule may contain aerobic, anoxic, and anaerobic zones, allowing for simultaneous nitrification, denitrification, and EBPR reactions to occur in a single granule. Granules may also be exposed to these different redox conditions in time or space through an anaerobic feed phase or zone(s) followed by simultaneous nitrification, denitrification, and EBPR in an aerated phase or zone(s).	Currently, AGS is most widely commercially available as a sequencing batch reactor (SBR)-based process. Therefore, an existing plant that operates with continuous-flow reactors would need to be retrofitted with SBRs to employ this technology. Selecting for AGS in continuous-flow reactors is an ongoing field of research. Thus far, continuous-flow systems have yet to achieve the same degree of granulation as SBR-based systems. Nevertheless, similar granule selection principles apply and have proved effective at achieving capacity improvements through densified activated sludge with enhanced size and settleability characteristics compared to conventional flocculent activate sludge.
Suspended integrated fixed-film activated sludge (IFAS)	Extruded plastic media is added to provide surface to grow biofilms to increase biomass inventory. Media is retained by screens. Typically uses medium-bubble diffuser for aeration and to maintain biofilm thickness.	Fine screening required upstream (headworks). Media retention screens in biological basins add head loss. Long rectangular basins should not be used to avoid media to “bunch” up at the end of the basin. Maintain sufficient mixing energy to keep media in suspension. Add ability to manage biomass carrier media during maintenance. Higher operating DO is required to penetrate biofilm. Because of the media retention, there is not surface overflow and provisions are required to manage scum and foam. Excessive foaming can lead to media loss over walls.
Fixed integrated fixed-film activated sludge (IFAS)	Fabric web or caged plastic media is installed in an existing aeration basin to provide surface for biofilm growth and increase biomass retention. Typically, no change to diffusers is required. Media modules may be removed to access diffusers for maintenance.	Fine screens required upstream (headworks). Worms could be a problem as fabric media can be prone to red worm infestation. Sufficient scour air is required to keep the biofilm free of red worms. Fixed media must be protected from the hydraulic forces (piped basin influent, return activated sludge [RAS], or mixed liquor recycle [MLR]).
Mobile Organic Biofilm (MOB) carriers	Fine milled, organic media (0.5–1.0 millimeter) is added to activated sludge to provide ballast to biomass, grow larger flocs, and improve settling. Organic media travels with MLSS and is recovered from waste activated sludge (WAS) with screens. Some organic media is added periodically because of media loss.	Higher mixing energy to keep media in suspension. Retrofits must consider hydraulic, kinetic, and aeration limitations. Added organic carriers increase the torque of the clarifier mechanism. Verify that installed clarifier sludge removal equipment can handle the additional torque.

Technology	Functioning Principle	Design Considerations
BioMag	Magnetite (fine inert iron ore particles) is added as ballast and infused in the biological floc. Magnetite has high specific gravity (5.2) and infused flocs have a very high settling velocity with sludge volume indices (SVIs) as low as 50 milliliters per gram (mL/g). Some magnetite is added to maintain system performance. Clarifiers can operate at increased surface overflow rates, resulting in expanded wet weather applications.	Mixing intensity of basins must be increased to keep heavy flocs in suspension. Retrofits must consider hydraulic, kinetic, and aeration limitations. Magnetite has to be fed to replace losses. The fate of the lost magnetite is not clear. For plants with solids processing consider impacts of magnetite in the solids stream. In addition to magnetite, ferric and polymer is added to “glue” biomass and magnetite together; therefore, EBPR is not compatible with BioMag. Added magnetite and dense flocs increase the torque on the clarifier mechanism. Verify that installed clarifier sludge removal equipment can handle the additional torque.
Step feed	Process modification to distribute influent feed to bioreactor in steps to create a higher biomass concentration in the front of the bioreactor and increasing total solids inventory by 20%–40% or more. Typically include anoxic zones at the step points to achieve denitrification.	Retrofits must consider hydraulic, kinetic, and aeration limitations. Step feed is generally used to address peak flow conditions and therefore infrastructure requires automation (i.e., gate or valve actuators).
Selective wasting	Adds ability to retain rapid-settling solids (larger granules) in WAS stream to selectively waste lighter biomass and select for a better settling sludge. Selection can be based on using hydrocyclones, screen, or upflow gravity separation “chimneys.” Biological growth conditions and kinetics impact the ability to grow heavier, more dense activated sludge flocs.	Selective wasting is a rapidly developing technique still in early development stages (LIFT TDL 3). Its effectiveness is impacted by the biological process.
Clarifier optimization	Optimize clarifier for solids handling to accommodate higher biomass in biological basin. Clarifier baffles and flocculation centerwells can be used. The Hydrograv Adapt clarifier inlet uses blanket filtration in the clarifier to produce consistently low total suspended solids (TSS) effluent. The Hydrograv Adapt equipment automatically adjusts to create optimal hydrodynamics in the clarifier by adjusting the centerwell up and down dynamically as flow and sludge settleability change. These technologies increase clarifier capacity for both hydraulic and solids load.	The use of baffles and flocculating centerwells is an established technology (LIFT TDL 5) that can be implemented in most clarifiers. The adaptive clarifier is still emerging in North America but there are nearly 100 installations worldwide (LIFT TDL 3) and one in the U.S. Can be used to retrofit existing clarifiers.

Abbreviations

AGS	Aerobic granular sludge
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
g	Gram(s)
HRT	Hydraulic retention time
I&C	Instrumentation and controls
IFAS	Integrated fixed-film activated sludge
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
MBR	Membrane bioreactor
mgd	Million gallons per day
mL	Milliliter(s)
MLR	Mixed liquor recycle
MLSS	Mixed liquor suspended solids
MOB	Mobile organic biofilm
N	Nitrogen
NAS	Nitrifying activated sludge
NH_3	Ammonia
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
RAS	Return activated sludge
SBR	Sequencing batch reactor
SRT	Solids retention time
SVI	Sludge volume index
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
RP	Reactive phosphorus
SNDN	Simultaneous nitrification and denitrification
SNR	Secondary nutrient removal
SNRP	Non-reactive soluble phosphorus

sq ft	Square feet
SRP	Soluble reactive phosphorus
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
TSS	Total suspended solids
UV	Ultraviolet
WAS	Waste activated sludge
WRF	The Water Research Foundation