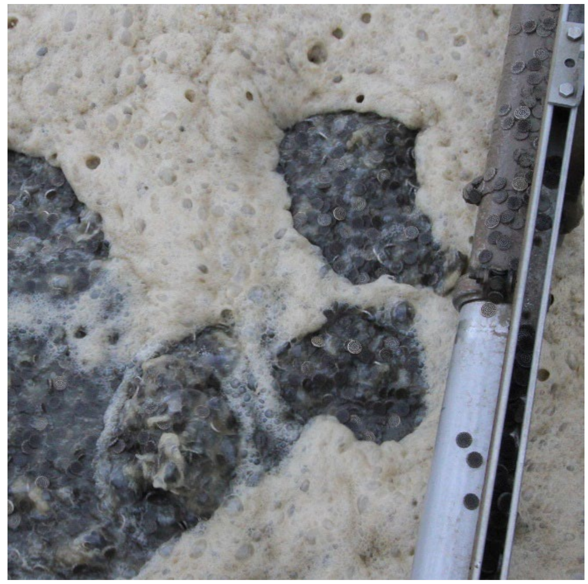
WRF 4973 Fact Sheet: ID 1101

Strategy: Process Intensification

Process Intensification Overview

inDENSE Gravity Selective Wasting.
Source: HDR Engineering, Inc.



Integrated Fixed-Film Activated Sludge.
Source: HDR Engineering, Inc.

Process intensification refers to approaches to modify the treatment process to provide "more biological treatment capacity within a basin." The goal is typically to change the treatment process to do something different (such as achieve nutrient removal), to improve the performance, or to increase the capacity of a treatment process by retaining more biomass and, in doing so, gain improved performance or gain additional treatment capacity.

Many different approaches or combinations of strategies can be used to achieve process intensification. Strategies can broadly be categorized into three groups. The first group of strategies are those that increase the biomass in the system by changing the operating conditions. This can be achieved by changing the biological process to grow granules, increasing the mixed liquor suspended solids (MLSS) in the basins by reduced wasting, and operating in step feed mode, among other options. The second group of strategies includes control changes to operate with more aggressive solids retention time (SRT) or reduced dissolved oxygen (DO) concentrations to reduce aeration cost, operating in simultaneous nitrification and denitrification (SND) mode, and improving nutrient removal. The third group of strategies are those that add equipment to the biological process, such as membrane aerated bioreactor (MABR) technologies or biomass carriers including integrated fixed-film activated sludge (IFAS) or Mobile Organic Biofilm (MOB), to enhance biomass and environmental conditions to improve the nutrient removal capacity.

This fact sheet provides an overview of these strategies. See related fact sheets for additional information.

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

Goal	R	Improve reliability
	R	Reduce nutrient
	R	Reduce O&M cost
Group	R	Optimize existing CNR
	R	Optimize existing TNR
	R	NutRem in secondary plant
Process		Small
		Pond
	R	Fixed film (secondary)
	R	Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
	R	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	1	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	1–5	Technology ranking based (LIFT) see below*
Energy efficiency	2–4	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M impact	1–5	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
Material/consumables	1–3	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1–3	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	Process intensification
Description	Process intensification strategies include technologies and process configurations that increase the treatment performance and/or capacity of existing infrastructure without adding any significant major concrete structures or equipment. Some capital investment may still be required for some of these strategies. Examples of intensification strategies include the following: • Increase biomass to raise aeration basin SRT by promoting aerobic granular sludge (AGS), step feed operation, adding media for biofilm growth (IFAS), selective solids separation, etc. • Modify process operation to achieve nutrient removal by increasing SRT, improve settleability with high food to microorganism (F/M) selectors, modify operation to SND, control changes such as ammonia-based aeration control (ABAC), etc. • Modify basins by creating anaerobic/anoxic/aerobic zones for biological nutrient removal (BNR), eliminate short-circuiting in basins, install equipment to promote nutrient removal such as MABR, etc. • Reduce loading to BNR process with improved primary treatment performance, chemically enhanced primary treatment (CEPT)
Application	Intensification strategies include technologies and modifications that achieve the following goals: • Increase the biomass concentration to achieve some or improved nutrient removal • Gain additional process treatment capacity to accommodate higher flows and loads • Improve the efficiency of a treatment process by modifying operation or adding new equipment Intensification is an attractive approach for the following scenarios: • Existing plant with limited space available for expansion or achieving nutrient removal • Convert existing conventional activated sludge (CAS) or nitrifying activated sludge (NAS) process to achieve some nutrient removal • Improve reliability of nutrient removal with increased biomass • Improve operational ease with increase settleability Intensifying opportunities for fixed-film processes, such as trickling filters, are more limited. Intensification can be achieved with equipment changes (modifying wetting rate, recirculation, mechanical airflow/blower, etc.) and by reducing organic loading (using CEPT or series operation) to achieve nitrification.
Constituents removed	NH_4, TN, and/or P Intensification is used to achieve nitrogen (N) and/or phosphorus (P) removal, increase treatment capacity, and improve treatment reliability. See the specific technologies in Table 1 below for their specific nutrient removal capabilities and more information.
Development status*	Varies depending on technology (i.e., CEPT = 5, ABAC = 4, gravity selective wasting = 3)
O&M considerations	Some intensification strategies may require the use of new, major equipment that needs regular replacement and/or is an operational and maintenance concern. See the tables below for more information.
Benefits	Varies depending on the existing conditions and selected technical solution/strategy. Possible benefits include: • More capacity or treatment within the same footprint • Avoid or limit additional infrastructure required to meet new treatment objectives • Improved nutrient removal and/or reliability • Reduce cost
Limitations	Intensification is generally an incremental improvement and outcomes are very site-specific. Intensification tends to impact other related unit processes (clarifiers, solids management, equipment, etc.) and should be evaluated for specific applications.

	Intensification can also improve the treatment reliability of a process in day-to-day operation and may require more proactive operational strategies and real-time monitoring and control (e.g., ABAC). Intensification generally requires operation strategies that are moving closer to real-time operation. For instance, intensification may reduce the hydraulic retention time (HRT), causing less "wiggle room" operationally. If the HRT is 6 hours vs. 24 hours, there is significantly less time to respond to any process upset.
Design considerations	Varies depending on the specific solution. Examples include: • Some IFAS configurations require media retention screens that increase head loss through the basins. • CEPT increases the load to solids processing. • Some technologies, such as IFAS and MABR, require 6-millimeter screens.
Potential fatal flaws	Varies depending on the specific solution. Examples include: • CEPT can add capacity and increase potential resource recovery (gas/energy), but it removes carbon that may be critical for nutrient removal. • Submerged overflow from the biological reactor can result in scum and foam accumulation; make provisions for control and removal and routing of scum around IFAS basins. • Densification of MLSS can impact aeration efficiency and transfer. • Elevated MLSS may require higher mixing intensity to keep solids in suspension (not significant).
Footprint requirements	Auxiliary equipment for process intensification strategies typically requires a minimal footprint area. Some examples of intensification auxiliary equipment include: • Preliminary treatment upgrades (i.e., screens, grit) • Magnetite recovery and shear mills (BioMag) • Hydrocyclones (gravity selective wasting) • MOB recovery screens (Nuvoda) • Wasting mixed liquor and foam
Residuals	Typically, the amount of residuals generated after implementation of a process intensification strategy remains similar to that of the conventional treatment processes.
Cost considerations	The cost of process intensification strategies is usually attractive because of the avoidance and reduction of construction costs. See Table 1 below for more cost-related information on specific strategies and technologies.
Past experience	Technology specific. See the specific technologies in Table 1 below for their specific nutrient removal capabilities and more information.
Publications	Technology specific. See the specific technologies in the tables below for more information.
Related fact sheets	1110: Increase Biomass 1120: Nutrient Removal in Existing Secondary Process 1130: Improve Nutrient Removal in Existing BNR Process 1140: Optimize BNR Effectiveness 1160: Clarifier Optimization 1301: Overview of Chemical Addition 1310: External Carbon Sources 1320: Chemical Phosphorus Removal 1401: Optimize Carbon Use for Nutrient Removal 1701: Reduce Energy Consumption Overview
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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

Several technologies and process arrangements can provide intensification. Table 1 below has summaries of some technologies applicable to intensification and nutrient optimization. For more information on these strategies, see their respective fact sheets. The technologies in the tables are based on strategies such as:

- Increasing biomass by raising aeration basin SRT, promoting AGS, or operating in step feed operation.
- Modifying process operation to achieve some or more nutrient removal by increasing SRT, operating with SND, or changing aeration control strategies such as switching to ABAC.
- New process equipment can be used such as media addition for biofilm growth (IFAS), selective solids separation using screens or hydrocyclones, or other special equipment (MABR, membrane bioreactor [MBR], magnetite ballast, etc.).
- Modifying basins by creating anaerobic/anoxic/aerobic zones for BNR, eliminating short-circuiting in basins, reducing DO recycle into unaerated zones, or nitrate into anaerobic zones.
- Reducing loading rate to BNR process with improved primary treatment performance, CEPT to reduce MLSS or increase capacity.
- Optimize secondary clarifier performance to increase solids separation capacity and effluent quality by adding influent flocculation or baffles to improve hydrodynamics.
- In some cases, multiple strategies can be implemented within the same process intensification—for example, “selective wasting” plus “ABAC.”
- Some strategies build upon each other—for example, compartmentalize a basin to create plug flow anaerobic and anoxic zones, then adding high F/M unaerated zone, then automate controls, etc.

Table 1. Intensification Strategies and Application.

Intensification Strategy	Brief Description	Application
Aerobic granular sludge (AGS)	Promote growth of granules in activated sludge process in flow-through activated sludge process by modifying feeding strategy and introducing selective wasting. Increase biomass inventory allowing nutrient removal. Granular sludge settles rapidly and increases clarifier capacity.	Partial granulation is achieved in many enhanced biological phosphorus removal (EBPR) processes. Process modifications may include staging anaerobic and anoxic process, adding selective wasting to retain granules, etc. Process can improve conventional nutrient removal (CNR) reliability and performance. Conversion from continuous flow to batch process requires more extensive upgrades.

Intensification Strategy	Brief Description	Application
Step feed	Implementing step feed will concentrate biomass in front of the aeration basin. This allows for a modest increase in biomass inventory and sludge age, potentially achieving nitrification. Activated sludge processes can be converted to step feed to increase SRT and achieve nitrification under favorable conditions (temperature, tankage, etc.). Placing anoxic zones at feed locations provides opportunity for denitrification.	Convert CAS (biochemical oxygen demand [BOD] only) plant to nitrification or NAS to include denitrification. Requires creation of anoxic zones, aeration improvements, clarifiers, wasting strategies, etc.
Simultaneous nitrification and denitrification (SND)	Operate nitrifying process at low DO or on/off operation to nitrify and denitrify in a single basin.	Strategies to achieve or improve denitrification. If strict ammonia limits exist, consider ABAC. Requires aeration and SRT control changes, etc. Degree of optimization depends on available spare capacity.
Partial denitrification with anammox (PdNA)	PdNA is a BNR process that uses partial denitrification with anaerobic ammonia oxidation for total nitrogen (TN) removal. During this process, approximately half of the influent ammonia is fully nitrified to nitrate in an aerobic zone before being partially denitrified to nitrite in an anoxic zone. Anammox bacteria in the anoxic zone, or in another anoxic zone farther downstream, then oxidize the remaining ammonia to nitrogen gas using the produced nitrite as an electron acceptor.	Strategies to achieve or improve/ increase N removal and provide operational savings, particularly because of lower external carbon and aeration demands. Works well with some form of biofilm technology, such as AGS, filters, or MBBR/IFAS media, to give the slow-growing anammox a surface to attach to. Requires separate aerobic and anoxic zones, online instrumentation (ammonia and nitrite/nitrate sensors), and associated controls.
Advanced process/aeration controls	ABAC, ammonia vs. NO_x (AvN) control, and other strategies to operate a lower DO. These aeration and blower operational strategies are used to achieve and control SND or achieve shortcut N removal.	Strategies to achieve or improve denitrification while maintaining target effluent ammonia. Requires online instrumentation (ammonia and nitrite/nitrate sensors) and associated controls.
Chemically enhanced primary treatment (CEPT)	CEPT refers to the addition of a coagulant (typically ferric or alum) and polymer to improve primary clarifier performance for total suspended solids (TSS) and BOD removal. Reduced BOD and TSS loads allow activated sludge processes to operate at longer SRT in the same basin volume. CEPT coagulant will reduce phosphorus.	Application limited to water resource recovery facilities (WRRFs) with primary clarifiers. Strategy is well suited for chemical P removal. Reduce BOD and TSS loading may allow CAS process to nitrify and perhaps denitrify. Strategy can be combined with other activated sludge strategies. CEPT will increase carbon diversion to digesters for energy recovery; it will also reduce carbon available for denitrification.
Selective wasting	Hydrocyclones, screens, selective settling or other techniques are used to selectively waste to remove lighter, less dense portions of the biomass and retain heavier and more dense flocs, thus improving settleability and promoting granulation of the activated sludge.	Selective wasting has been implemented in full scale with technologies such as inDENSE, screens, or other selective wasting. The process can be retrofitted to activated sludge processes.

Intensification Strategy	Brief Description	Application
Organic biofilm carriers	Biofilm carriers are used to increase the biomass by adding an organic biofilm carrier that is recovered from WAS by screening. For example, MOB relies on added organic material to create a biofilm-controlled suspended biomass. In addition to increasing biomass, claimed benefits include functioning as a ballast to create dense, rapidly settling solids. Carriers traveling with the mixed liquor are captured in secondary clarifiers and returned with return activated sludge (RAS).	MOB carriers can be implemented in existing activated sludge or new processes. Capital improvements would be required to implement. Most activated process components (clarifiers, pumps, controls, etc.) can be retained with some modifications. MOB will overcome scum problems that plague IFAS systems.
Integrated fixed-film activated sludge (IFAS)	Suspended or fixed media is added to the process for biofilms to grow. The more common suspended media IFAS can double the biomass inventory compared to conventional activated sludge. Its potential benefit increases with decreasing design temperatures.	Various IFAS biomass carriers are commercially available. The IFAS process can be implemented in an existing activated sludge or new processes. Several improvements would be required such as aeration changes, installing retention screens, foam routing, etc.
Ballasted biomass	Add ballast to activated sludge floc to increase settling rate. For example, BioMag™ incorporates magnetite into the mixed liquor as a ballast with polymer and ferric chloride. The magnetite is recovered with magnetic separators from WAS.	The BioMag process can be implemented in existing activated sludge. Several improvements would be required such as magnetite addition and recovery facilities, aeration upgrades, mixer changes, clarifier improvements, etc.
Secondary clarifier optimization	Improve clarifier effluent quality and ability to operate at higher solids loading. Baffles or adaptive inlet (for example, Hydrograv Adapt™) to improve clarifier capacity for solids and/or hydraulic loads to increase capacity and/or performance. Inlet center well optimization for flocculation is automatically controlled to maintain optimal performance under varying operational conditions (sludge volume index [SVI], flow, etc.).	Clarifier retrofit to improve solids capture in some cases to consistently produce effluent in 2–5 mg/L range to reduce effluent total phosphorus (TP). Clarifier geometry (depth, floor slope, RAS removal equipment, etc.) impacts the ability to retrofit.
Degassing MLSS	Remove dissolved gases in the MLSS to improve settling velocities and raise solids loading rate to clarifiers. Pass mixed liquor through vacuum to release gas and improve settling (for example, Biodegradex).	Improved settling which can increase load capacity of plant. Developed in Poland and applied in China.

Abbreviations

ABAC	Ammonia-based aeration control
AGS	Aerobic granular sludge
AvN	Ammonia vs. NO_x (aeration control)
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CEPT	Chemically enhanced primary treatment
CNR	Conventional nutrient removal
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
F/M	Food-to-microorganism (ratio)
HRT	Hydraulic retention time
I&C	Instrumentation and controls
IFAS	Integrated fixed film activated sludge process
L	Liter(s)
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
MABR	Membrane aerated bioreactor
MBR	Membrane bioreactor
mg	Milligram(s)
mgd	Million gallons per day
MLSS	Mixed liquor suspended solids
MOB	Mobile Organic Biofilm
N	Nitrogen
NAS	Nitrifying activated sludge
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
PdNA	Partial denitrification with anammox
RAS	Return activated sludge
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
RP	Reactive phosphorus
SND	Simultaneous nitrification and denitrification
SRT	Solids retention time

SVI	Sludge volume index
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
WRRF	Water resource recovery facility