United States Environmental Protection Agency

Emerging Technologies

for Wastewater Treatment and In-Plant Wet Weather Management

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Emerging Technologies

for

Wastewater Treatment and In-Plant Wet Weather Management

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Prepared by:

Parsons Corporation
Fairfax, Virginia

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Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management

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Prepared by the Parsons Corporation
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Preface

The U.S. Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of environmental laws, the Agency strives to formulate and implement actions leading to a balance between human activities and the ability of natural systems to support and sustain life. To meet this mandate, the Office of Wastewater Management (OWM) provides information and technical support to solve environmental problems today and to build a knowledge base necessary to protect public health and the environment well into the future.

This publication has been produced, under contract to the U.S. EPA, by the Parsons Corporation, and it provides current state of development as of the publication date. It is expected that this document will be revised periodically to reflect advances in this rapidly evolving area. Except as noted, information, interviews, and data development were conducted by the contractor. Some of the information, especially related to embryonic technologies, was provided by the manufacturer or vendor of the equipment or technology, and could not be verified or supported by full-scale case study. In some cases, cost data were based on estimated savings without actual field data. When evaluating technologies, estimated costs, and stated performance, efforts should be made to collect current and more up-to-date information.

The mention of trade names, specific vendors, or products does not represent an actual or presumed endorsement, preference, or acceptance by the U.S. EPA or Federal Government. Stated results, conclusions, usage, or practices do not necessarily represent the views or policies of the U.S. EPA.

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List of Acronyms and Abbreviations

Acronym/ Abbreviation	Definition
A/O	Anaerobic/Oxic (Phoredox)
A2/O	Anaerobic/Anoxic/Oxic
AACE	American Association of Cost Engineers International
ABW®	Automatic Backwash Filters
AEBR	Anaerobic Expanded Bed Reactor
AGAR®	Attached Growth Airlift Reactor
AGRS	Advanced Grit Removal System
AGSP	Aerobic Granular Sludge Process
AIZ	Air Intercept Zone
AMBR®	Anaerobic Migrating Blanket Reactor
ANFLOW	Anaerobic Fluidized Bed Reactor
AN-MBR	Anaerobic Membrane BioReactor
AOP	Advanced Oxidation Process
ASBR®	Anaerobic Sequencing Batch Reactor
ASCE	American Society of Civil Engineers
atm	Atmosphere
AT3	Aeration Tank 3
AWTP	Advanced Wastewater Treatment Plant
AWWA	American Water Works Association
BABE	Bio-Augmentation Batch Enhanced
BAF	Biological Aerated Filters
BAR	Bio Augmentation Regeneration and/or Reaeration
BCFS	Biological-Chemical Phosphorus and Nitrogen Removal
BCDMH	1-Bromo-3 Chloro-5,5 DiMethylHydantoin
BHRC	Ballasted High Rate Clarification
BioMEMS	Biological Micro-Electro Machine System
BNR	Biological Nutrient Removal
BOD	Biological/Biochemical Oxygen Demand
BOD/N	Biochemical Oxygen Demand Ratio to Nitrogen
BOD/P	Biochemical Oxygen Demand Ratio to Phosphorus
CASS™	Cyclic Activated Sludge System
CCAS™	CounterCurrent Aeration System
CDS	Continuous Deflection Separator
cfu	Colony forming unit
CMAS	Complete Mix-Activated Sludge
CMF®	Compressed Media Filter (WWETCO CMF®)
CMOM	Capacity, Management, Operations, and Maintenance
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWA	Clean Water Act
DAF	Dissolved Air Flotation
DEMON	DEamMONification
DEPHANOX	DE-nitrification and PHosphate accumulation in ANOXic
DF	Disc Filter
DO	Dissolved Oxygen
EBPR	Enhanced Biological Phosphorus Removal
EDC	Endocrine Disrupting Compound

List of Acronyms and Abbreviations (Contd)

Acronym/ Abbreviation	Definition
ELISA	Enzyme-Linked ImmunoSorbent Assay
EMS	Environmental Management Systems
FBBR	Fluidized Bed BioReactor
FISH	Fluorescence In Situ Hybridization
GAC	Granular-Activated Carbon
GPD	Gallons per day
gpm/ft^2	Gallons per minute per square foot
HANAA	Handheld Advanced Nucleic Acid Analyzer
HFMBfR	Hydrogen-based hollow-Fiber Membrane Biofilm Reactor
HFO	Hydrous Ferric Oxide
HPO	High-Purity Oxygen
HRC	High-Rate Clarification
HRT	Hydraulic Retention Time
ICAAS	Immobilized Cell-Augmented Activated Sludge
ICEAS™	Intermittent Cycle Extended Aeration System
IFAS	Integrated Fixed-film Activated Sludge
IIT	Illinois Institute of Technology
ISE	Ion Selective Electrode
LOT	Limit Of Technology
IWA	International Water Association
MAB	Multi-stage Activated Biological
MABR	Membrane-Activated BioReactor
MAUREEN	Main-stream AUtotrophic Recycle Enabling Enhanced N-removal
MBR	Membrane BioReactor
MBRT	Mobile-Bed Reactor Technology
MFC	Microbial Fuel Cell
MGD	Million Gallons per Day
mg/L	Milligram per Liter
MISS	Moderate Isotope Separation System
MLE	Modified Ludzack-Ettinger
MLSS	Mixed Liquor Suspended Solids
mph	Miles per hour
MSABP™	Multi-Stage Activated Biological Process
MUCT	Modified University of Cape Town
NACWA	National Association of Clean Water Agencies
NADH	Nicotinamide Adenine Dinucleotide
NF	NanoFiltration
NOB	Nitrite Oxidizing Bacteria
ntu	Nephelometric turbidity unit
O&M	Operation and Maintenance
ORP	Oxidation Reduction Potential
OWM	Office of Wastewater Management (U.S. EPA)
PAC	Powdered Activated Carbon
PAO	Phosphorus Accumulating Organisms
PBDE	PolyBrominated Diphenyl Ether
PCR	Polymerase Chain Reaction
PeCOD™	Photo-electro Chemical Oxygen Demand
PhACs	Pharmaceutically Active Compounds

List of Acronyms and Abbreviations (Contd)

Acronym/ Abbreviation	Definition
POTW	Publicly Owned Treatment Works
PPCP	Pharmaceutical and Personal Care Products
ppm	Parts per million
PVC	Poly Vinyl Chloride
psig	Pounds per square inch (gauge)
RAS	Returned Activated Sludge
RBC	Rotating Biological Contactor
R-DN	Regeneration DeNitrification
rDON	Refractory Dissolved Organic Nitrogen
SBR	Sequencing Batch Reactor
SCFM	Standard Cubic Feet per Minute
SHARON	Single reactor High-activity Ammonia Removal Over Nitrite
SHARON – ANAMMOX	Single reactor High-activity Ammonia Removal Over Nitrite – ANaerobic AMMonia OXidation
SNdN	Simultaneous Nitrification deNitrification
SRBC	Submerged Rotating Biological Contactor
SRT	Sludge Retention Time; Solids Retention Time
SSO	Sanitary Sewer Overflow
STRASS	Similar to SHARON named after Strass, Austria
SVI	Sludge Volume Index
TDH	Total Dynamic Head
TDS	Total Dissolved Solids
TF	Trickling Filter
TF/PAS	Trickling Filter and Pushed Activated Sludge
TF/SC	Trickling Filter and Solid Contactor
TMP	Trans Membrane Pressure
TOC	Total Organic Carbon
TSS	Total Suspended Solids
U.S. EPA	United States Environmental Protection Agency
UASB	Upflow Anaerobic Sludge Blanket
UCT	University of Cape Town
UV	UltraViolet
VIP	Virginia Initiative Plant
VIS	Visibility
VMI	Virginia Military Institute
VRM®	Vacuum Rotation Membrane
WAS	Waste Activated Sludge
WASA	Water and Sewer Authority
WEF	Water Environment Federation
WEFTEC	Water Environment Federation's Annual Technical Exhibition and Conference
WERF	Water Environment Research Foundation
WPAP	Water Pollution Abatement Program
WPCF	Water Pollution Control Facility
WRF	Water Reuse Facility
WWEMA	Water and Wastewater Equipment Manufacturers Association
WWPF	WasteWater Production Flow
WWTF	WasteWater Treatment Facility
WWTP	WasteWater Treatment Plant

List of Technologies

List of Technologies (Contd)

List of Technologies (Contd)

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Overview

In 2004, there were 16,583 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 800 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. The CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2004, nearly 30 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment.

This document provides information regarding emerging wastewater treatment and in-plant wet weather management technologies organized into four categories of development:

1. **Embryonic** – Technologies in the development stage and/or have been tested at a laboratory or bench scale only.
2. **Innovative** – Technologies that have been tested at a demonstration scale, have been available and implemented in the United States for less than five years, or have some degree of initial use (i.e., implemented in less than 1 percent of treatment facilities).
3. **Established** – Technologies that have been used at more than 1 percent of treatment facilities throughout the United States or have been available and implemented in the United States for more than five years.
4. **Innovative Uses of Established** – Some wastewater treatment processes have been established for years, but they are not static. **In some cases, an established technology may have been modified or adapted resulting in an emerging technology. In other cases, a process that was developed to achieve one treatment objective is now being applied in different ways or to achieve additional treatment objectives.** During the operation of treatment systems using these established technologies, engineers, and operators have altered and improved their efficiency and performance. This document includes established technologies that have undergone recent modifications or are used in new applications.

This document also provides information on each technology, its objective, its description, its state of development, available cost information, associated contact names, and related data sources. For each innovative technology, this document further evaluates technologies against various criteria, although it does not rank or recommend any one technology over another. Research needs are also identified to guide development of innovative and embryonic technologies and improve established ones.

Chapter 1

Introduction and Approach

1.1 Introduction

In 2004, there were 16,583 municipal wastewater treatment plants operating in the United States. These plants ranged in size from a few hundred gallons per day (GPD) to more than 800 million gallons per day (MGD). Early efforts in water pollution control began in the late 1800s with construction of facilities to prevent human waste from reaching drinking water supplies. Since the passage of the 1972 Amendments to the Federal Water Pollution Control Act (Clean Water Act [CWA]), municipal wastewater treatment facilities have been designed and built or upgraded to abate an ever-increasing volume and diversity of pollutants. The CWA requires that municipal wastewater treatment plant discharges meet a minimum of secondary treatment. However, in 2004, nearly 30 percent of the municipal facilities produced and discharged effluent at higher levels of treatment than the minimum federal standards for secondary treatment.

To meet the challenge of keeping progress in wastewater pollution abatement ahead of population growth, changes in industrial processes, and technological developments, EPA is providing this document to make information available on recent advances and innovative techniques.

The goal of this document is straight forward—to provide a guide for persons seeking information on innovative and emerging wastewater treatment technologies. The guide lists new technologies, assesses their merits and costs, and provides sources for further technological investigation. This document is intended to serve as a tool for wastewater facility owners and operators.

Emerging technologies typically follow a development process that leads from laboratory and bench-scale investigations to pilot studies and to initiate use or “full-scale demonstrations” before the technology is considered established. Not all technologies survive the entire development process. Some fail in the laboratory or at pilot stages; others see limited application in the field, but poor performance, complications, or unexpected costs may cause them to lose favor. Even technologies that become established may lose favor in time, as technological advances lead to obsolescence. In short, technologies are subject to the same evolutionary forces present in nature; those that cannot meet the demands of their environment fail, while those that adapt to changing technological, economic and regulatory climates can achieve long-standing success and survival in the market.

Some wastewater treatment processes have been established for many years, but that does not mean that they are static. During the operation of treatment systems using these established technologies, engineers and operators have altered and improved efficiency and performance. In other cases, established technologies applied to one aspect of treatment have been modified so that they can perform different objectives. Often, better performance can be achieved by linking established processes in innovative ways. This document includes established technologies that have undergone recent modifications or are used in new applications. These technologies are evaluated in the chapters alongside the innovative and embryonic technologies.

1.2 Approach

To develop this guide, the investigators sought information from a variety of sources, identified new technologies, prepared cost summaries, where information was available, for all technologies, and evaluated technologies deemed to be innovative. This method is described below and in Figure 1-1.

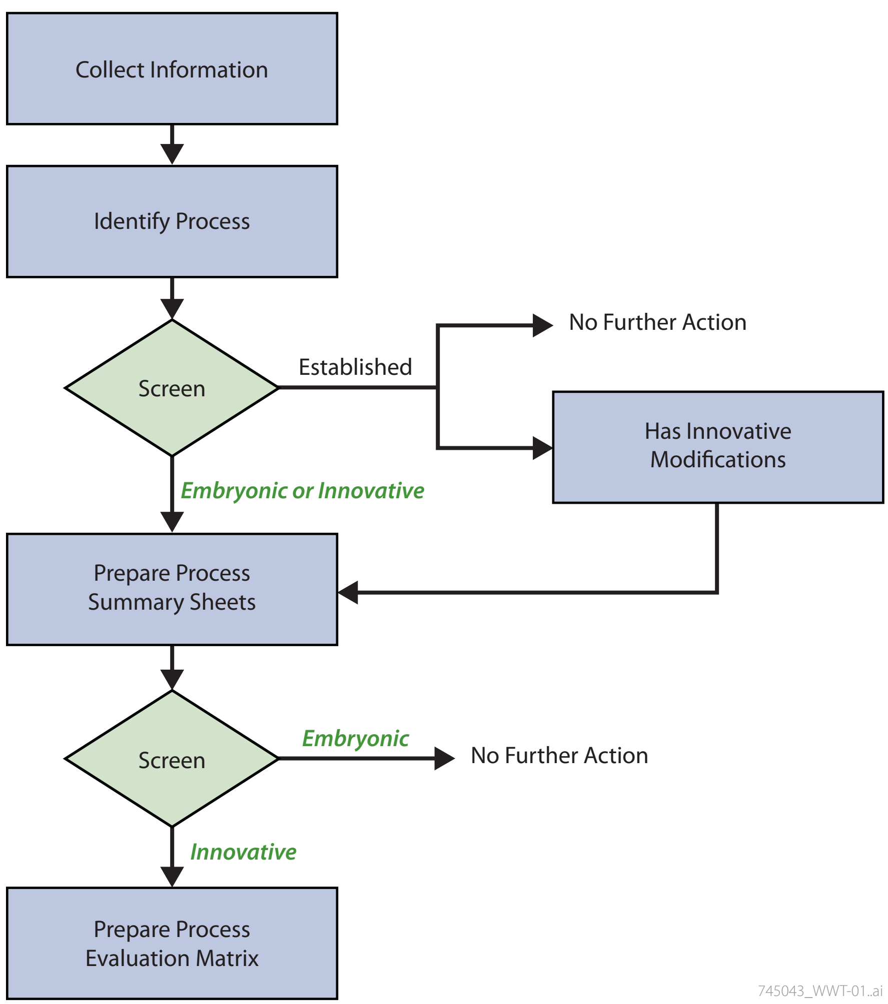

Figure 1.1—Flow Schematic for Guide Development

1.2.1 Information Collection and New Process Identification

The collection of information and identification of new technology provided the foundation for subsequent work. To identify new treatment process technologies, investigators gathered information and focused on relevant Water Environment Federation (WEF) and American Society of Civil Engineers (ASCE) conference proceedings, as well as monthly publications from these and other organizations such as International Water Association (IWA).

"Gray" Literature – Vendor-supplied information, Internet research, and consultants' technical reports comprise the information collected in this category.

Technical Associations – Investigators contacted a variety of professional and technical associations in the United States to identify emerging wastewater treatment technologies.

Interviews and Correspondence – Individuals known to the project investigation team, including consultants, academics, and municipal wastewater treatment plant owners and operators, were consulted.

Technologies identified through search of the above sources were screened to determine their classification as described below.

1.2.2 Initial Screened Technologies

This project focuses on emerging technologies that appear to be viable, but have not yet been accepted as established processes in the United States. Specific screening criteria used to define the state of development for processes are described in the following paragraphs. This screening resulted in:

- 23 embryonic technologies
- 52 innovative technologies
- 8 established technologies with innovative modifications

Embryonic – These technologies are in the development stage and/or have been tested at laboratory or bench scale. New technologies that have reached the demonstration stage overseas, but cannot yet be considered to be established there, are also considered to be embryonic with respect to North American applications.

Innovative – Technologies that meet one of the following criteria were classified as innovative:

- They have been tested as a full-scale demonstration.
- They have been available and implemented in the United States for less than five years.
- They have some degree of initial use (i.e., implemented in less than 1 percent of municipalities throughout the United States).

- They are established technologies from overseas.

Established – In most cases, these processes are used at more than 1 percent of full-scale facilities in North America; but there are some exceptions based upon specific considerations. The established category may include technologies that are widely used although introduced more recently in North America. Due to the extensive number of established technologies and variations in each technology, only established technologies are listed. None are described in depth in this document and Technology Summary sheets are not provided for established technologies.

Innovative Uses of Established – In some cases, an established technology such as the UCT (University of Cape Town) process may have been modified or adapted, resulting in an emerging technology such as the Modified UCT. In other cases, a process like Actiflo® was developed to remove solids from wet weather flows but is now also being used to polish final effluent.

The focus of this document is on Innovative Technologies along with preliminary information of Embryonic Technologies. Early in the development process (the laboratory stage), data was usually insufficient to prove or disprove technology viability at full scale. Available information on these embryonic technologies is presented in this document. Technologies on the other end of the developmental scale, those defined as established in North America, are excluded from the detailed assessments on the assumption that they are proven, although still relatively new.

The differentiation between technologies established in Europe or Asia and those that have reached similar status in the United States can be critical since technologies that have been applied successfully in other countries have not always flourished here in the United States. Because the viability of imported technologies is not guaranteed, established processes from overseas are classified as innovative technologies for this project, unless they are proven in North American applications.

Some technologies fall into a "gray area" between the embryonic and innovative categories. Technologies that fall into this category are incorporated into the innovative category. The screening assessment is summarized by chapter in Tables 1.1 through 1.4.

- Table 1.1 summarizes the treatment technologies for Chapter 2 – Physical/Chemical Treatment Processes.
- Table 1.2 summarizes the treatment technologies for Chapter 3 – Biological Treatment Processes.
- Table 1.3 summarizes the treatment technologies for Chapter 4 – In-Plant Wet Weather Management Processes.
- Table 1.4 summarizes the treatment technologies for Chapter 5 – Process Monitoring Technologies.

All the cost estimates provided in this document contain a certain degree of expert judgment or educated guesswork concerning the various cost elements that comprise the estimates. This is true when cost estimates are based on limited or no information where in some cases little more than process type, location, and plant capacity are known. Therefore, cost estimates are at best order-of-magnitude level per American Association of Cost Engineers (AACE) International classification. However, numerous peripheral factors that could also interfere with the accuracy of the order-of-magnitude level cost estimates. Considering these facts, the reader should keep in mind that site-specific applications and local requirements should be considered to increase the accuracy of cost estimates provided in this document.

1.2.3 Development of Technology Summary Sheets

Technologies defined as embryonic or innovative are each summarized on an individual Technology Summary sheet. Each process includes the following information:

- **Objective** – Description of the goal of the technology.
- **State of Development** – Where and how the technology has been applied (i.e., laboratory study, demonstration scale, full scale, etc.).
- **Description** – A brief overview of the technology.
- **Comparison to Established Technologies** – Advantages and disadvantages of innovative and embryonic technologies are compared to more commonly used technologies.
- **Available Cost Information** – Approximate range of capital and operations and maintenance costs, and assumptions made in developing them (when reliable information was available).
- **Vendors Name(s)** – Name, address, telephone numbers, web address, and other contact information for equipment manufacturers and suppliers.
- **Installation(s)** – Name, address, telephone numbers, and other contact information for utilities and facilities where the technology has been used (full or pilot scale).
- **Key Words for Internet Search –** Because this document is not intended to provide a comprehensive list of vendors for these technologies, key words have been added to aid the reader in finding additional vendors and current product information on the Internet.
- **Data Sources** – References used to compile the technology summary.

Table 1.1—Summary of Treatment Technologies
Chapter 2 – Physical/Chemical Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies									
Air Stripping			●			●			
Screening									
▪ Fine Screening					●				
▪ Micro Screening					●				
▪ Rotary Screening					●				
▪ Step Screening					●				
▪ Microsieves		●			●	●			
Grit Removal									
▪ Travelling Bridge					●				
Fine/Advanced Grit Removal System (AGRS)									
▪ HEADCELL™					●				
▪ GRITKING™					●				
▪ PISTAGRIT™					●				
▪ HYDROGRIT™					●				
Flocculation					●				
Chemical Precipitation*									
▪ Alum Addition		●			●				
▪ Iron Salts Addition		●			●				
▪ Zeolite					●				
High Rate Dissolved Air Flotation (DAF) Treatment/Settling					●				
Chemically Enhanced Primary Treatment		●			●				
Solids Contact Clarifier for P Removal		●	●		●				
Ion-Exchange						●			
Chemical Oxidation*									
▪ Hydroxyl Radical						●	●		
▪ Oxygen (Atomic and Molecular)						●	●		
▪ Ozone						●	●		
▪ Hydrogen Peroxide						●	●		
▪ Hypochlorite/Chlorine/Chlorine Dioxide						●	●		

Note:
* Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Table 1.1—Summary of Treatment Technologies (Contd)
Chapter 2 – Physical/Chemical Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (Contd)									
Advanced Oxidation Processes									
▪ Supercritical Water Oxidation						●	●		
▪ Catalytic Oxidation						●	●		
▪ Photo Catalysis (UV + TiO_2)						●	●		
▪ Fenton's Reagent (H_2O_2 + Ferrous Ion)						●	●		
Electodialysis					●	●			
Filtration through Membranes									
▪ Reverse Osmosis		●			●	●			
▪ Microfiltration		●			●	●			
▪ Ultrafiltration		●			●	●			
Filtration through Media									
▪ Cloth Media									
– Disc Filter (DF)		●			●				
– Drum Filter		●			●				
– Diamond-Shaped Filters		●			●				
▪ Silica Media (One- and Two-Stage)									
– Conventional Downflow		●			●				
– Deep-Bed Downflow Filters		●			●				
– Deep-Bed Upflow Continuous Backwash Filters		●			●				
▪ Activated Alumina Media						●			
▪ Powdered Activated Carbon (PAC)		●			●				
▪ Granular-Activated Carbon (GAC)		●		●	●				
Denitrification Filters		●		●	●				
Automatic Backwash Filters (ABW®)		●			●				
Pulsed Bed Filter		●			●				
Disinfection									
▪ Ozone							●		
▪ Chlorine/Chlorine Dioxide/Liquid Chlorine/Dechlorination							●		
▪ Halogens (Bromine)							●		
▪ UltraViolet (UV) Disinfection							●		

Table 1.1—Summary of Treatment Technologies (Contd)
Chapter 2 – Physical/Chemical Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Innovative Technologies									
Compressible Media Filtration	●	●			●				
Nanofiltration		●			●	●			
Innovative Use of Established Technologies									
Ballasted High Rate Clarification (BHRC) Processes*									
▪ Actiflo® Process		●			●				
▪ Densadeg® Process		●			●				
Microwave UV Disinfection							●		
Embryonic Technologies									
Blue CAT™		●			●	●			
Blue PRO™		●			●				
CoMag™		●			●				
Solar Disinfection							●		

Note:

* Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Table 1.2—Summary of Treatment Technologies
Chapter 3 – Biological Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies									
BOD Removal and Nitrification									
▪ Biolac-Aerated Lagoon	●		●						
▪ Complete Mix-Activated Sludge (CMAS) Process	●		●						
▪ Contact Stabilization	●		●						
▪ Conventional Extended Aeration	●		●						
▪ Countercurrent Aeration System (CCAS™)	●		●	●					
▪ Cyclic Activated Sludge System (CASS™)	●		●	●					
▪ High-Purity Oxygen (HPO)	●		●						
▪ Intermittent Cycle Extended Aeration System (ICEAS™)	●		●	●					
▪ Kraus Process	●		●						
▪ Oxidation Ditch/Aerated Lagoons	●		●						
▪ Sequencing Batch Reactor (SBR)	●		●	●					
▪ Staged Activated-Sludge Process	●		●						
▪ Step Feed	●		●						
▪ Step Feed (Alternating Anoxic and Aerobic)	●		●	●					
Biological Nutrient Removal (BNR)									
▪ Bardenpho® (Four Stage)	●		●	●					
▪ Biodenitro™	●		●	●					
▪ Ludzack-Ettinger	●		●	●					
▪ Modified Ludzack-Ettinger (MLE)	●		●	●					
▪ Orbal™ Process	●		●	●					
▪ Schreiber™ Process	●		●	●					
▪ Simultaneous Nitrification denitrificatioN (SNdN) Process	●		●	●					
▪ Step Feed BNR Process	●		●	●					
▪ Wuhrman	●		●	●					
Enhanced Biological Phosphorus Removal (EBPR)									
▪ Anaerobic/Anoxic/Oxic (A2/O)	●	●	●	●					
▪ Bardenpho® (Five Stage)	●	●	●	●					
▪ Johannesburg Process	●	●	●	●					
▪ Phoredox (Anaerobic/Oxic [A/O])	●	●							
▪ Phostrip	●	●							
▪ University of Cape Town (UCT)	●	●	●	●					
▪ Virginia Initiative Plant (VIP)	●	●	●	●					

Table 1.2—Summary of Treatment Technologies (Contd)
Chapter 3 – Biological Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies (Contd)									
Other Biological Processes									
▪ Fluidized Bed Bioreactor (FBBR)	●		●						
▪ Rotating Biological Contractor (RBC)	●		●						
▪ Submerged Rotating Biological Contactor (SRBC)	●		●						
▪ Trickling Filter (TF)	●		●						
Anaerobic Processes									
▪ Anaerobic Attached Growth System									
– Upflow Packed-Bed Attached Growth Reactor	●								
– Upflow Attached Growth Anaerobic	●								
– Expanded-Bed Reactor (Anaerobic Expanded Bed Reactor [AEBR])	●								
– Downflow Attached Growth Process	●								
▪ Anaerobic Contact Process	●								
▪ Anaerobic Sequencing Batch Reactor (ASBR®)	●								
▪ Upflow Anaerobic Sludge Blanket (UASB)	●								
▪ ANFLOW (ANaerobic FLuidized Bed Reactor)	●								
Biological Aerated Filters (BAF)									
▪ Biofor®	●		●	●					
▪ Biostyr®	●		●	●					
Innovative Technologies									
Bioaugmentation									
▪ External Bioaugmentation									
– Seeding from Commercial Sources of Nitrifiers	●		●	●					
– Trickling Filter and Pushed Activated Sludge (TF/PAS) Process	●		●	●					
– Seeding from External Dispensed Growth Reactors Treating Reject Waters (Chemostat)	●		●	●					
– In-Nitri® Process	●		●	●					
– Immobilized Cell-Augmented Activated Sludge (ICASS) Process	●		●	●					
– Seeding from Parallel Processes	●		●	●					
– Seeding from Downstream Process	●		●	●					

Table 1.2—Summary of Treatment Technologies (Contd)
Chapter 3 – Biological Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Innovative Technologies (Contd)									
▪ In Situ Bioaugmentation									
– DE-nitrification and PHosphate accumulation in ANOXic (DEPHANOX) Process	●		●	●					
– Bio-Augmentation Regeneration/Reaeration (BAR) Process	●		●	●					
– Bio-Augmentation Batch Enhanced (BABE) Process	●		●	●					
– Aeration Tank 3 (AT3) Process	●		●	●					
– Main stream AUtotrophic Recycle Enabling Enhanced N-removal (MAUREEN) Process	●		●						
– Regeneration DeNitrification (R-DN) Process	●		●	●					
Cannibal®	●		●	●					
CATABOL™	●	●	●						
Deep-Shaft Activated Sludge/VERTREAT™	●								
Integrated fixed-Film Activated Sludge (IFAS)									
▪ IFAS – Submerged Mobile Media									
– Attached Growth Airlift Reactor (AGAR®)	●		●						
– Captor®	●		●						
– LINPOR®	●		●						
▪ IFAS – Submerged Fixed Media									
– CLEARTEC®	●		●						
– AccuWeb®	●		●						
– BioMatrix™	●		●						
– HYBAS™	●		●						
– BioWeb™	●		●						
– RINGLACE®	●		●						
Membrane Bioreactor (MBR)									
▪ Tubular	●	●	●		●				
▪ Hollow-Fiber	●	●	●		●				
▪ Spiral Wound	●	●	●		●				
▪ Plate and Frame	●	●	●		●				
▪ Pleated Cartridge Filters	●	●	●		●				
Mobile-Bed Reactor Technology (MBRT) Process									
▪ Kaldnes® HYBAS™/ Active Cell™	●		●	●					
▪ Hydroxyl-F3R	●		●	●					
▪ GeoReactor®	●		●	●					

Table 1.2—Summary of Treatment Technologies (Contd)

Chapter 3 – Biological Treatment Processes

Technology and Advancements (Listed in process flow sequence)	Applications: C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Innovative Use of Established Technologies									
Bardenpho® (Three Stage) with Returned Activated Sludge (RAS) Denitrification	●	●	●	●					
Biological-Chemical Phosphorus and Nitrogen Removal (BCFS)*	●	●	●	●					
Modified University of Cape Town (MUCT) Process	●	●	●	●					
Modified Anaerobic/Oxic (A/O) Process	●	●	●	●					
Trickling Filter/Solids Contactor (TF/SC)	●		●						
Embryonic Technologies									
Aerobic Granular Sludge Process (AGSP)	●	●	●	●					
ANaerobic Membrane BioReactor (AN-MBR)	●	●							
Anaerobic Migrating Blanket Reactor (AMBR®)	●								
DEamMONification (DEMON) Process	●		●	●					
Hydrogen-based hollow-Fiber Membrane Biofilm Reactor (HFMBfR)		●				●			
Membrane-Aerated BioReactor (MABR)	●		●		●	●			
Microbial Fuel Cell (MFC) Based Treatment System	●	●							
Multi-Stage Activated Biological Process (MSABP™)	●		●	●					
Nereda™	●								
Single reactor High-activity Ammonia Removal Over Nitrite (SHARON)	●		●	●					
SHARON – ANAMMOX (ANaerobic AMMonia OXidation)	●		●	●					
STRASS Process	●		●	●					
Vacuum Rotation Membrane (VRM®) System	●	●			●				

Note

* Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Table 1.3—Summary of Treatment Technologies
Chapter 4 – In-Plant Wet Weather Management Processes

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies									
Dispersed Air Flotation		●			●				
Dissolved Air Flotation (DAF)		●			●				
Enhanced Clarification/High Rate Clarification (HRC)									
▪ Ballasted Flocculation (Actiflo® and Microsep®)		●			●				
▪ Lamella Plate Settlers		●			●				
Screening					●				
Vortex Separation					●				
Innovative Technologies									
Continuous Deflection Separator (CDS)					●				
HYDROSELF® Flushing Gate					●				
Tipping Flusher®					●				
TRASHMASTER™ Net Capture System					●				
WWETCO Compressed Media Filtration® or WWETCO CMP® System		●			●				
Innovative Use of Established Technologies									
None at this time									
Embryonic Technologies									
Alternative Wet Weather Disinfection							●		

Table 1.4—Summary of Treatment Technologies
Chapter 5 – Process Monitoring Technologies

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Established Technologies									
Ammonia and Nitrate Probes									
▪ ChemScan								●	
▪ Myratek								●	
▪ Hach Evita								●	
▪ Hach NITRATAX								●	
▪ NitraVis® System								●	
Dissolved Oxygen Analyzer									●
Online Cl_2 Residual								●	
pH Probes								●	
Sludge Blanket Level Detector								●	
Solids Retention Time (SRT) Controller									●
Total Suspended Solids Analyzer								●	
Innovative Technologies									
Ammonia and Nitrate Probes									
▪ ChemScan N-4000								●	●
▪ Hach Evita In Situ 5100								●	●
▪ Hach NITRATAX								●	●
▪ Myratek Sentry C-2								●	●
▪ NitraVis® System								●	●
▪ Royce 8500 Series Multi-Parameter								●	●
Fluorescence In Situ Hybridization (FISH) for Filamentous and Nitrifiying Bacteria									●
Microwave Density Analyzer								●	●
Microtox®/Online Microtox®									●
SymBio™ – Nicotinamide Adenine Dinucleotide (NADH) Probes									●
Online Respirometry									●
NITROX™ – Oxidation Reduction Potential (ORP) Probe									●

Table 1.4—Summary of Treatment Technologies (Contd)
Chapter 5 – Process Monitoring Technologies

Technology and Advancements (Listed in process flow sequence)	Applications								
	C-BOD Removal	Phosphorus Removal	Nitrification-Ammonia Removal	Denitrification – Nitrogen Removal	Solids – Liquid Separation (TDS and TSS)	Targeted Contaminants Removal	Disinfection	Physical/Chemical Monitoring	Biochemical Monitoring
Innovative Use of Established Technologies									
None At This Time									
Embryonic Technologies									
Biological Micro-Electro Machine System (BioMEMS)									●
FISH for Phosphorus Accumulating Organisms (PAOs)									●
Handheld Advanced Nucleic Acid Analyzer (HANNA)									●
Immunosensors and Immunoassays									●
Photo-electro Chemical Oxygen Demand (PeCOD™)									●

1.2.4 Evaluation of Technologies

Technologies defined as innovative in the initial screening were subjected to a detailed evaluation. Each technology was evaluated with respect to the descriptive and comparative criteria described below. Descriptive criteria include:

- **State of Development** – Describes the stage of development for each technology, ranging from development to full-scale operations.
- **Applicability** – Qualitatively assesses in which market the technology is designed to be used.
- **Effluent Reuse** – Discusses the reuse of treated effluent.
- **Benefits** – Considers the benefits gained (e.g., capital or operational savings) from implementation of the technology.

Designations for each descriptive criterion are presented in Table 1.5.

Table 1.5—Descriptive Evaluation Criteria

Criterion	Designation	Description
State of Development	B	Bench scale
	P	Pilot scale
	I	Full-scale industrial applications
	M	Full-scale municipal applications
	O	Full-scale operations overseas
	N	Full-scale operations in North America
Applicability	I	Industrywide
	F	Few plants
	S	Primarily small plants
	L	Primarily large plants
Effluent Reuse	Dp	Direct potable
	Dn	Direct nonpotable
	Ip	Indirect potable
	In	Indirect nonpotable
Potential Benefits	C	Capital savings
	O	Operational/maintenance

Comparative criteria include:

- **Impact on Existing Facilities or Other Processes** – Describes whether or not the technology requires the involvement of extensive design changes, and the degree to which the existing facilities will be disturbed.
- **Complexity** – Considers the installation, startup, and shutdown methods for the technology.
- **Air/Odor Emissions** – Considers if the process has impacts on air and odor emissions for the facility.
- **Energy** – Considers the amount of energy required to adequately maintain the process and if any energy saving is possible.
- **Footprint** – Considers how the footprint helps to identify the land needed to expand a facility for increased capacity.
- **Retrofitting** – Considers if the process can be used to modify old treatment plants without extensive reconstruction.

The above criteria compared individual technologies with other technologies in the same category, and were scored positive, neutral/mixed, or negative.

The criteria and ratings were applied to each innovative technology and the results are presented in matrix format. Where available information was insufficient to rate a technology for a criterion, no rating is given. The project team and reviewers assessed each technology based on the limited information gathered and their collective judgment, experience, and opinions. Results of the evaluation are presented in subsequent chapters.

1.3 Guidance Document Format and Use

The remainder of the document is divided into chapters based upon general technologies, one chapter is dedicated to each of the following categories:

- Chapter 2 – Physical/Chemical Treatment Processes
- Chapter 3 – Biological Treatment Processes
- Chapter 4 – In-Plant Wet Weather Management Processes
- Chapter 5 – Process Monitoring Technologies

Each chapter provides an overview of the appropriate technologies, discusses the state of development for each, presents an evaluation matrix for innovative technologies, and concludes with a Technology Summary Sheet for each embryonic and innovative technology.

The technology summaries and evaluation matrices are the cornerstones of each chapter, broadly overviewing the innovative technologies. Neither the summaries nor the matrices should be considered definitive technology assessments. Rather, they should be considered stepping stones to more detailed investigations.

Chapter 6 discusses research needs and Appendix A contains applicable trade associations.

This document will be updated from time to time. Technologies were reviewed in mid-2006 to early 2007.

1.4 Chapter References

U.S. EPA, 2004 Report to Congress: Impacts and Control of CSO and SSOs, EPA 833-R-04-001, Office of Water.

U.S. EPA, Clean Watershed Needs Survey 2004 Report to Congress, EPA 832-R-07-001, Office of Water, 2007.

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Chapter 2

Physical/Chemical Treatment Processes

2.1 Introduction

For the purpose of this report, physical and chemical treatment processes are defined as treatment technologies that do not include any biomass in the process to achieve the treatment objective. Physical processes remove solids from wastewater by flowing through screens or filter media, or solids are removed by gravity settling. Particles entrapped with air float to the surface and can be removed. Chemicals are used in wastewater treatment to create changes in the pollutants that increase the ability to remove them. Changes may include forming floc or a heavier particle mass to improve removal by physical processes. As a result, chemical addition and physical processes are usually employed together to provide treatment. This chapter focuses on advances in basic physical and chemical treatment processes.

2.2 Technology Assessment

A summary of innovative, embryonic, and established technologies for physical and/or chemical treatment processes is provided in Table 2.1. A comparative evaluation among innovative technologies is provided in Figure 2.1. Most of the physical chemical processes are established, and they are still very essential unit processes that are widely used in various applications in wastewater treatment.

Innovative development in physical and chemical technologies includes membrane filtration and compressible media filters. These technologies focus on the separation of liquids and solids. Advanced solids separation is critical as a preliminary process step and as an advanced treatment step to reduce suspended solids, plus nutrients and other compounds, in the effluent. The application of these technologies has promoted the reuse of wastewater by providing a very high-quality effluent.

This chapter also discusses some of the innovative uses or unique applications of already established technologies. For example, the Ballasted High Rate Clarification (BHRC) process is a high-rate chemical/physical clarification process that involves the formation of suspended solids onto a ballast particle with the aid of a coagulant and polymer. The BHRC process includes the patented DensaDeg® and Actiflo® processes. Embryonic technologies currently under development include solar disinfection and Blue PRO™ for phosphorus removal. These technologies are discussed in the technology summaries in this chapter. Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Table 2.1—Physical/Chemical Treatment Processes – State of Development

Established Technologies
Air Stripping
Screening
▪ Fine Screening
▪ Micro Screening
▪ Rotary Screening
▪ Step Screening
▪ Microsieves
Grit Removal
▪ Traveling Bridge
Fine/Advanced Grit Removal System (AGRS)
▪ HEADCELL™
▪ GRITKING™
▪ PISTAGRIT™
▪ HYDROGRIT™
Flocculation
Chemical Precipitation*
▪ Alum Addition
▪ Iron Salts Addition
▪ Zeolite
High Rate Dissolved Air Flotation (DAF) Treatment/Settling
Chemically Enhanced Primary Treatment
Solids Contact Clarifier for P Removal
Ion-Exchange
Chemical Oxidation*
▪ Hydroxyl Radical
▪ Oxygen (Atomic and Molecular)
▪ Ozone
▪ Hydrogen Peroxide
▪ Hypochlorite/Chlorine/Chlorine Dioxide
Advanced Oxidation Processes
▪ Supercritical Water Oxidation
▪ Catalytic Oxidation
▪ Photo Catalysis (UV + TiO_2)
▪ Fenton's Reagent (H_2O_2 + Ferrous Ion)
Electodialysis
Filtration through Membranes
▪ Reverse Osmosis
▪ Microfiltration
▪ Ultrafiltration

Established Technologies (Contd)
Filtration through Media
▪ Cloth Media
– Disc Filter (DF)
– Drum Filter
– Diamond-Shaped Filters
▪ Silica Media (One- and Two-Stage)
– Conventional Downflow
– Deep-Bed Downflow Filters
– Deep-Bed Upflow Continuous Backwash Filters
▪ Activated Alumina Media
▪ Powdered Activated Carbon (PAC)
▪ Granular-Activated Carbon (GAC)
Denitrification Filters
Automatic Backwash Filters (ABW®)
Pulsed Bed Filter
Disinfection
▪ Ozone
▪ Chlorine/Chlorine Dioxide/Liquid Chlorine/Dechlorination
▪ Halogens (Bromine)
▪ UltraViolet (UV) Disinfection
Innovative Technologies
Compressible Media Filtration
Nanofiltration
Innovative Use of Established Technologies
Ballasted High Rate Clarification (BHRC) Processes*
▪ Actiflo® Process
▪ Densadeg® Process
Microwave UV Disinfection
Embryonic Technologies
Blue CAT™
Blue PRO™
CoMag™
Solar Disinfection

Note:

* Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Figure 2.1—Evaluation of Innovative Physical/Chemical Treatment Technologies

Process	Evaluation Criteria									
	Development	Applicability	Benefits	Impact on Processes	Complexity	Air/Odor Emissions	Reuse	Energy	Footprint	Retrofitting
Compressible Media Filters	I, M, N	I	C	⊖	⊖	⊖	Dn	⊖	▲	▲
Nanofiltration	I, M, N	F	O	▲	⊖	⊖	Ip, Dp	▼	▲	▲

Key

Statement of Development
- B = Bench scale
- I = Full-scale industrial applications
- M = Full-scale municipal applications
- O = Full-scale operations overseas
- P = Pilot
- N = Full-scale operations in North America

Applicability
- F = Few plants
- I = Industrywide
- L = Primarily large plants
- S = Primarily small plants

Potential Benefits
- C = Capital savings
- I = Intense operational demand
- O = Operational/maintenance savings
- S = Shock load capacity
- W = Wet weather load capacity

Effluent Reuse
- Dp = Direct potable
- Dn = Direct nonpotable
- Ip = Indirect potable
- In = Indirect nonpotable

Comparative Criteria
- ▲ Positive feature
- ⊖ Neutral or mixed
- ▼ Negative feature

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Technology Summary

Compressible Media Filtration

Objective:

Enhanced filtration where the porosity of the media can be adjusted.

State of Development:

Innovative. This technology has gained widespread use and may be approaching an established process.

Description:

This synthetic medium was developed in Japan. The porosity of the filter bed can be adjusted by compressing the filter medium and the size of the filter bed can be increased mechanically to backwash the filter. It is an enhanced filtration process where the filtration media is more effective in capturing more solids per filter volume than other media. The filtration unit is designed such that the porosity of the media can be adjusted and the solids can be removed by air scouring.

Comparison to Established Technologies:

Effluent to be filtered flows through the media as opposed to flowing around the media as in sand and anthracite filters. This feature permits higher hydraulic loadings of 30 gpm/ft^2 of media and higher as opposed to other filtration systems with 2 to 6 gpm/ft^2.

Available Cost Information:

Approximate Capital Cost: $80,000 to $90,000 for a 3-ft by 3-ft filter operating at 0.25 to 0.55 MGD.

Approximate O&M Costs: Not disclosed.

Vendor Name(s):

Fuzzy Filters
Schreiber Corporation
100 Schreiber Drive
Trussville, AL 35173
Telephone: 205-655-7466 or 800-535-0944
Email: larryw@schreiberwater.com

Installation(s):

University of California, Davis, CA
Columbus CSO Facility, Columbus, GA
Clayton County Northeast WPCF, GA
Yountville Sanitary District, Yountville, CA
Rogersville, MO
Golden Poultry/Gold Kist, Sanford, NC
Orange County Sanitary District, Fountain Valley, CA
King County, Seattle, WA

Key Words for Internet Search:

Compressible media filter, wastewater treatment, fuzzy

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.
http://www.schreiberwater.com/

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Technology Summary

Nanofiltration

Objective:

Nanofiltration is used as an advanced treatment system to remove priority organic pollutants and biodegradable organics, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS), bacteria, and viruses.

State of Development:

Innovative.

Description:

The nanofiltration process uses membranes with an operating pore size range of 0.01 to 0.2 micron in a pressure-driven separation. Operating pressures are 75 to 150 psig. Nanofiltration is used for the removal of priority organic pollutants, biodegradable organics, TSS, bacteria, some viruses, and proteins from wastewater. It is used in certain municipal treatment plants for disinfection purposes and softening of wastewater or it is used in process where the reuse of water is the treatment goal. Typically, microfiltration or ultrafiltration is used as a pretreatment process for water that is required to be treated through nanofiltration or reverse osmosis. The membranes are typically made of cellulose acetate or aromatic polyamides and are spiral wound and hollow fiber.

Comparison to Established Technologies:

The nanofiltration process helps eliminate TSS, TDS, and other pathogens better than the ultrafiltration process.

Available Cost Information:

Approximate Capital Cost: Not available.

Approximate O&M Costs: Not available.

Vendor Name(s):

GE Infrastructure Water and Process Technologies
4636 Somerton Road
Trevose, PA 19053
Telephone: 215-355-3300
www.gewater.com

Koch Membrane Systems, Inc.
850 Main Street
Wilmington, MA 01887
Telephone: 888-677-5624
Email: info@kochmembrane.com

Installation(s):

Clifton Water District, CO

Key Words for Internet Search:

Nanofiltration, wastewater treatment, NF

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

www.eurodia.com/html/index.html

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Technology Summary

Actiflo® Process

Objective:

Treatment of primary and tertiary effluents.

State of Development:

Innovative Use of Established Technology.

Description:

The Actiflo® process is a high-rate chemical and physical clarification process that involves the formation of suspended solids onto a ballast particle (microsand) followed by lamellar settling. It is considered an established process for the treatment of wet weather flows, but is also being applied to primary and tertiary effluents. The process starts with the addition of a coagulant to destabilize suspended solids. The flow enters the coagulation tank for flash mixing to allow the coagulant to take effect then overflows into the injection tank where microsand is added. The microsand serves as a "seed" for floc formation, providing a large surface area for suspended solids to bond to and is the key to Actiflo®. It allows solids to settle out more quickly, thereby requiring a smaller footprint than conventional clarification.

Polymers may either be added in the injection tank or at the next step, the maturation tank. Mixing is slower in the maturation tank, allowing the polymer to help bond the microsand to the destabilized suspended solids. Finally, the settling tank effectively removes the floc with help from plate settlers allowing the tank size to be further reduced. Clarified water exits the process by overflowing weirs above the plate settlers. The sand and sludge mixture is collected at the bottom of the settling tank with a conventional scraper system and pumped to a hydrocyclone, located above the injection tank. The hydrocyclone converts the pumping energy into centrifugal forces to separate the higher density sand from the lower density sludge. The sludge is discharged out of the top of the hydrocyclone while the sand is recycled back into the Actiflo® process for further use. Screening is required upstream of Actiflo® so that particles larger than 3 to 6 mm do not clog the hydrocyclone.

Several startup modes may be used for a full scale Actiflo® system. If a wet weather event is expected within 7 days of a previous wet weather event, the units should be shut down, but not put on standby. Wastewater would remain in the tanks and a wet startup would ensue at the time of the next wet weather event. In summer months, when freezing is not possible, the intermittent flush standby mode could be used; and when freezing is possible, the continuous flush standby mode should be used. These standby modes should results in a successful wet method, dry startup.

Comparison to Established Technologies:

Fundamentally, this process is very similar to conventional coagulation, flocculation, and sedimentation water treatment technology. Both processes use coagulant for the destabilization and flocculent aid (polymer) for the aggregation of suspended materials. These materials are then subsequently removed by settling for disposal. The primary technical advance made in the Actiflo® process is the addition of microsand as a "seed" and ballast for the formation of high-density flocs that have a relatively high-density microsand nucleus and are easily removed by settling. Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

Kruger USA

401 Harrison Oaks Blvd.
Suite 100
Cary, NC 27513
Telephone: 919-677-8310
Fax: 919-677-0082
Email: krugerincmarketing@veoliawater.com
Web site: http://www.krugerusa.com

Installation(s):

City of Greenfield, IN

Lincolnton, NC

Lawrence WWTP, IN

Williamette WTP, OR

Fort Worth, TX

Technology Summary

Actiflo® Process (Contd)

Key Words for Internet Search:

Actiflo®, Ballasted High Rate Clarification, BHRC

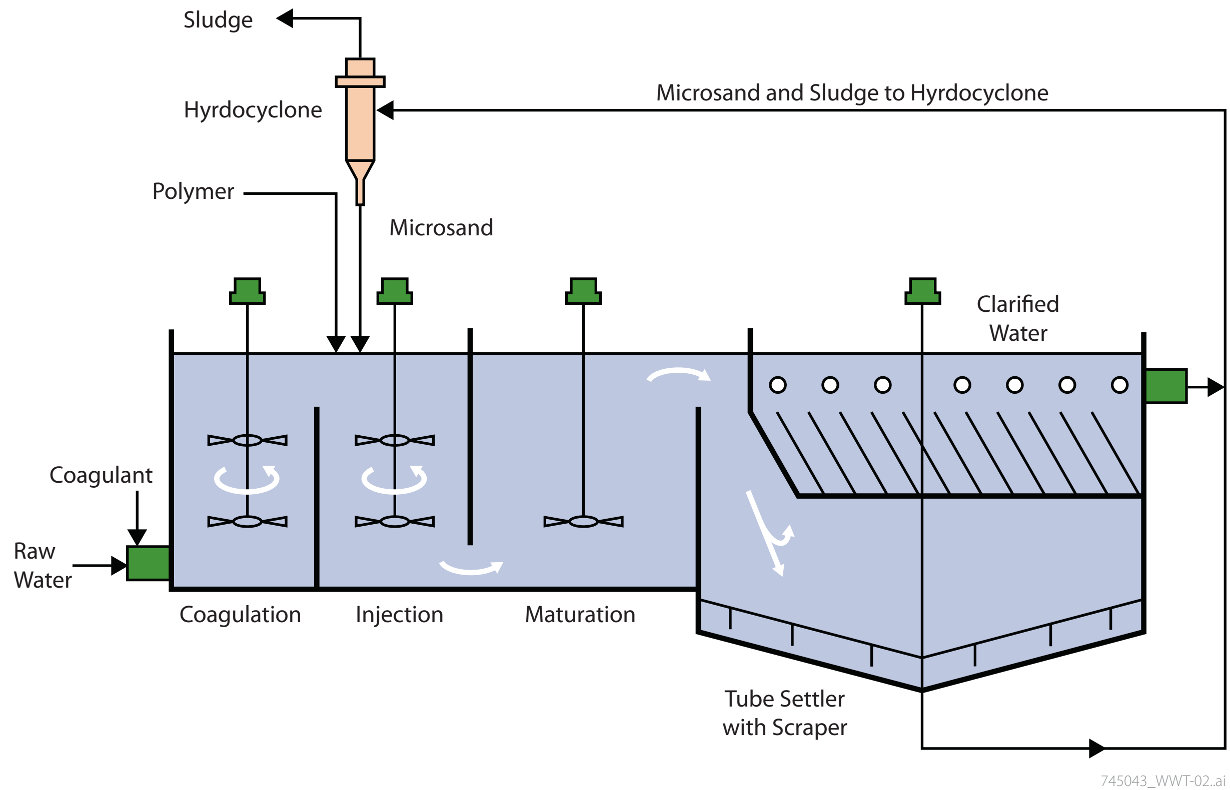
Data Sources:

Web site owned by Kruger USA.

Keller, John, et al., "Actiflo®: A Year's Worth of Operating Experience from the Largest SSO System in the U.S.," Water Environment Federation's Annual Technical Exhibition and Conference (WEFTEC), 2005.

Ponist, Jeffrey B., David Scheiter, "Ballasted High Rate Clarification Process Removes City of Greenfield, Indiana as a CSO Community."

Sigmund, Thomas, et al., "Operating Chemically Enhanced Clarification for Optimum Disinfection Performance," WEFTEC, 2006.



Actiflo® Process Diagram

Technology Summary

DensaDeg® Process

Objective:

Treatment of primary and tertiary effluents and wet weather flows.

State of Development:

Innovative Use of Established Technology.

Description:

The DensaDeg® process is a high-rate chemical and physical clarification process that combines sludge ballasted clarification and lamellar filtration, both established processes. The DensaDeg® process starts with the addition of a coagulant to destabilize suspended solids. The flow enters the rapid-mix tank for flash mixing to allow the coagulant to take effect then overflows into the reactor tank where sludge and polymer are added. A draft tube and mixer in the reactor allow for thorough mixing of the wastewater with the recirculated sludge and added chemicals. The sludge serves as a "seed" for floc formation providing a large surface area for suspended solids to bond to and is the key to DensaDeg®, allowing solids to settle out more quickly, thereby requiring a smaller footprint than conventional clarification.

Wastewater flows over a weir from the reactor tank through a transition zone before entering the clarifier. The clarifier effectively removes the flow with help from settling tubes, allowing the tank size to be further reduced. Clarified water exits the process by overflowing weirs above the settling tubes. Sludge is collected at the bottom of the clarifier with a conventional scraper system and recirculated back to the reactor tank. Periodically, a separate sludge pump energizes and wastes a small portion of the sludge from the system. Scum is removed from the process at the top of the transition zone by a cylindrical collector that automatically rotates periodically.

Several startup modes may be used for a full-scale DensaDeg®. If a wet weather event is expected within 6 hours of a previous wet weather event, the units should be shut down, but not drained. After 6 hours, the units may be drained except for three feet of depth in the clarifier. Both of these scenarios, which would include keeping the sludge collector running while the system is idle, would maintain a sludge inventory and a wet startup would ensue at the time of the next wet weather event. After 12 hours the tanks should be completely drained to prepare for a dry startup.

Comparison to Established Technologies:

Fundamentally, this process is very similar to conventional coagulation, flocculation, and sedimentation treatment technology. Both processes use coagulant for the destabilization and flocculent aid (polymer) for the aggregation of suspended materials. These materials are then subsequently removed by settling for disposal. The primary technical advance made in the DensaDeg® process is the recirculated sludge as a "seed" for the formation of high-density flocs for easy removal by settling. Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors, and excessive inorganic precipitant requirements need to be reduced.

Available Cost Information:

Approximate Capital Cost: Cost estimates are dependent upon local requirements and specific applications.

Approximate O&M Costs: Cost savings are linked to the relative ease of installation, operational flexibility, and low-energy consumption.

Vendor Name(s):

Infilco Degremont Inc.
P.O. Box 71390
Richmond, VA 23255-1930
Telephone: 804-756-7600
Web site: http://www.infilcodegremont.com

Installation(s):

Turlock, CA
Gainsville, GA
Toledo, OH
Halifax, Nova Scotia
Shreveport, LA

Technology Summary

DensaDeg® Process (Contd)

Key Words for Internet Search:

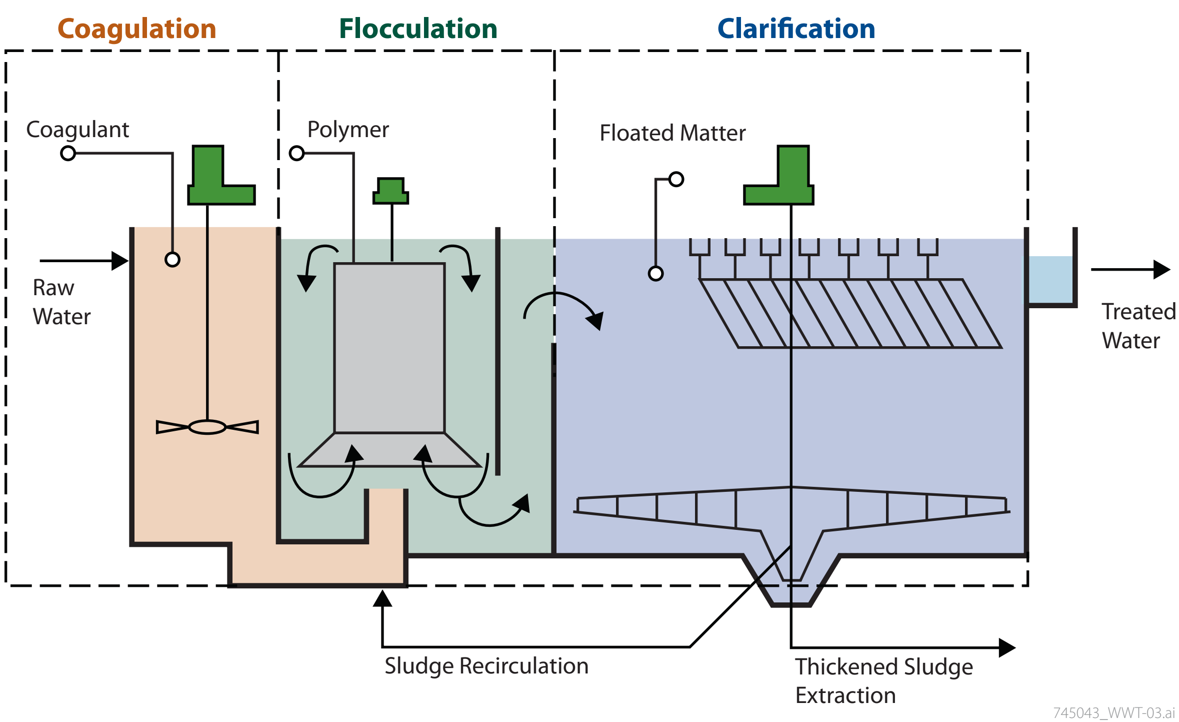
DensaDeg®, High Rate Clarification, HRC

Data Sources:

Web site owned by Infilco Degremont.

http://www.infilcodegremont.com/separations_4.html

Sigmund, Thomas, et al., "Operating Chemically enhanced Clarification for Optimum Disinfection Performance," WEFTEC, 2006.



Process Diagram of the DensaDeg® High-Rate Clarifier and Thickener

Technology Summary

Microwave UV Disinfection

Objective:
Tertiary Disinfection of Wastewater Effluent.

State of Development:
Innovative Use of Established Technology.

Description:
Ultraviolet (UV) disinfection transfers electromagnetic energy from a mercury arc lamp to wastewater. Electromagnetic radiation, between the ranges of 100 to 400 nm (UV range), penetrates bacterial cells, and works as a bactericide. Lamps containing mercury vapor, which are charged by striking an electric arcs emits UV radiation. Currently, the disinfection lamp has three main categories: (1) low-pressure, low-intensity; (2) low-pressure, high-intensity, and (3) medium-pressure, high-intensity. All of these lamps contain electrodes that facilitate the generation of UV radiation. These electrodes are of delicate construction and their deterioration is the primary source of failure in UV disinfection systems. Microwave UV disinfection technology eliminates the need for electrodes by using the microwave-powered electrodeless mercury UV lamp. In this technology, microwave energy is generated by magnetrons and directed through wave guides into the quartz lamp sleeves containing argon gas. The directed microwave energy excites the argon atoms, which in turn excite the mercury atoms to produce radiation as they return from excited states to lower energy states, as is the case with other mercury UV lamps. Electrodless lamps operate at higher pressures than medium-pressure lamps, in the range of 5 to 20 atm, compared to 1 to 2 atm for medium-pressure lamps. Microwave UV lamps allow greater flexibility for variations in parameters such as lamp diameter, operating pressures, and fill materials due to the absence of electrodes. This allows for greater optimization of radiation at specific wavelength regions. The intensity of the radiation increases when the applied microwave power is increased.

Comparison to Established Technologies:
The lamps warm up quickly and are capable of disinfection within 12 seconds compared to startup times of 20 seconds to three minutes for electrode lamps. Eliminating the electrode using from the lamp eliminates the primary deterioration process associated with UV lamps, resulting in a lamp life approximately three times that of electrode-using lamps. Furthermore, elimination of the electrodes allows for narrower lamps, which reduces the amount of reabsorption, as well as the heat capacity and infrared radiation generated. The lamp has very low residual radiation of energy, thus almost instant shut-off capability, which prevents overheating heat-sensitive materials near the lamps. Radiation is produced through the entire length of the lamp and there is no energy loss associated with electrodes. Nevertheless, the electrodeless lamp system has more components than the conventional electrode-using system, including the magnetron, wave guides, and cooling fans. Magnetron life is limited and requires replacement. Magnetrons usually are warranted for up to 10,000 hours of operation.

Available Cost Information:
Approximate Capital Cost: Not disclosed by vendor as cost estimates are dependent upon local requirements and vary with specific applications.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):
Severn Trent Services
3000 Advance Lane
Colmar, PA 18915
Telephone: 215-997-4000
Fax: 215-997-4062
Email: info@severntrentservices.com
Web site: www.severntrentservices.com

Installation(s):
Scotland WWTP, UK

Technology Summary

Microwave UV Disinfection (Contd)

Key Words for Internet Search:

Microwave UV disinfection of wastewater, electrodeless UV lamps

Data Sources:

Gutierrez, Richard L., et al., "Microwave UV – A New Wave of Tertiary Disinfection," WEFTEC Proceedings, 2006.

Microwave UV Technology, a Presentation by MicroDynamics™, Severn Trent Services.

Vendor-supplied information.

Technology Summary

Blue CAT™

Objective:

Remove emerging contaminants, such as endocrine disruptors, pharmaceuticals, and other complex organics from wastewater; simultaneously accomplish removal of contaminants such as phosphorus and disinfection.

State of Development:

Embryonic. Pilot studies of the Blue CAT™ system have been conducted at 10 gpm. Results include Total Organic Compound (TOC) reduction from 4 to 1.5 mg/L, disinfection to <2 cfu/100 mL, turbidity reduction to 0.1 to 0.3 ntu, and 95% total phosphorus removal.

Description:

The Blue CAT™ process is a combination of the Blue PRO™ process with an Advanced Oxidation Process (AOP) for advanced treatment of effluent. The Blue PRO™ process optimizes adsorption of contaminants such as phosphorus in an up-flow sand filter with hydrous ferric oxide-coated media and a proprietary pre-reactor.

The occurrence of chlorination byproducts, such as trihalomethanes, in environmental waters has led to enhanced concern and regulatory interest about chlorine disinfection of wastewater. This concern has lead to significant research into alternative AOPs in water treatment. AOPs can provide a mechanism for destructive removal of micropollutants and pathogens. AOPs are applied to water treatment UV, ozone, hydrogen peroxide, Fenton's reagent (Fe_2 + H_2O_2), acoustic or hydrodynamic cavitation, photocatalytic oxidation (UV + TiO_2), and super critical water oxidation among the other processes. In recent years some of these technologies, such as ozonation, have seen wider implementation in municipal wastewater treatment plants (WWTPs).

There are two ways to increase the rate of AOPs. These are by combining multiple AOPs or by adding catalysis. Manufacturer of the Blue Cat™ has not disclosed the type of AOP used.

Current pilot test results are promising that significant reductions of turbidity, fecal coliforms, phosphorus, and endocrine disrupters or TOC can be achieved.

The residual Blue CAT™ waste stream may be recycled to the head of the plant to accomplish additional contaminant removals and other secondary process enhancements. For increased contaminant-removal rates, destruction of organics, or disinfection, two passes through Blue CAT™ may be combined in series.

Comparison to Established Technologies:

Based on recent investigations, there is some evidence that Blue CAT™ requires less power than other AOPs due to the catalytic configuration of the system to maximize oxidative capability. The only metal salt chemical used is a small amount of iron reagent (4–10 mg/L Fe) for the Blue PRO™ process. No polymer is used. The process appears to require lower chemical dosing than typical chemical wastewater treatment processes and consequently produces fewer solids. The iron-based reactive agent also provides odor control.

The Blue CAT™ system is suitable for smaller plants (less than 10 MGD) since it would be difficult to operate and maintain due to sheer number of modules required for treatment.

Available Cost Information:

The following estimates are for a 1.0 MGD system. Economies of scale are expected for larger systems. Systems may be designed with a minimum flow of 5 gpm; intermittent flow systems are also possible at small installations.

Approximate Capital Cost: $463,800 – This price includes pre-reactor and filter assemblies, chemical pumps, air compressor, controls and electronics, sand, and freight to the site.

Approximate O&M Costs: $66,330 per year – This annual O&M expense includes $8,700 for energy (108,834 kWh), $48,500 for chemicals (ferric sulfate and liquid oxygen), and $9,130 for labor (1 manhour per day).

Technology Summary

Blue CAT™ (Contd)

Vendor Name(s):

Blue Water Technologies, Inc.
10450 North Airport Drive
Hayden, ID 83835
Telephone: 888-710-BLUE (2583)
Web site: www.blueh2o.net

Installation(s):

Hayden Area Regional Wastewater Treatment Plant, Hayden, ID

Key Words for Internet Search:

Blue CAT™, catalytic oxidation, advanced phosphorus removal, endocrine disruptors

Data Sources:

Blue PRO™, "Hydrous Ferric Oxide (HFO) Coated Sand, Adsorptive Media Technical Summary," 2006.

CH2M Hill, Technical Memorandum, "Evaluation of Blue PRO Process at the Hayden Wastewater Research Facility – Final Summary Report," 2006.

Newcombe, R.L., B.K. Hart, and G. Möller, "Arsenic Removal from Drinking Water by Moving Bed Active Filtration," Journal Environmental Engineering, 132(1): 5–12, 2006.

Newcombe, R.L., R.A. Rule, B.K. Hart, and G. Möller, "Phosphorus Removal from Municipal Wastewater by Hydrous Ferric Oxide Reactive Filtration and Coupled Chemically Enhanced Secondary Treatment: Part I. Performance," In review, 2007.

Newcombe, R.L., D.G. Strawn, T.M. Grant, S.E. Childers, and G. Möller, "Phosphorus Removal from Municipal Wastewater by Hydrous Ferric Oxide Reactive Filtration and Coupled Chemically Enhanced Secondary Treatment: Part II. Mechanism," In review, 2007.

Pilot-scale Blue CAT™ equipment, including pre-reactor assembly on the left and reactive filter in the middle

Technology Summary

Blue PRO™

Objective:

Remove phosphorus from tertiary wastewater.

State of Development:

Embryonic. Pilot studies of the Blue PRO™ system have been conducted at a 1.2 MGD wastewater treatment plant in Hayden, ID.

Description:

The Blue PRO™ filtration system includes moving-bed filtration technology preceded by chemical addition and the proprietary pre-reactor zone. This is used to remove phosphorus from tertiary wastewater and it combines co-precipitation and adsorption in an up-flow sand filter with reactive filter media and a proprietary pre-reactor. Hydrous ferric oxide-coated sand media accomplish phosphorus removal by adsorption rather than coagulation and filtration. This process does not require the media to be changed, as it has continuous regeneration via a patent-pending process and is continuous flow without the need to backwash. After adsorption, the iron and phosphorus are abraded from the sand grains. The iron and phosphorus passes out in a waste stream while the sand is retained in the system.

The Blue PRO™ system is considered under the continuous backwash filter category, which is suitable for smaller plants (less than 10 MGD), and relatively by small modules are usually available. For a larger plant, it would be difficult to operate and maintain due to sheer number of modules required for treatment. The Blue PRO™ process may be run in series to achieve lower phosphorus removal. The residual waste stream may be recycled to the head of the plant to accomplish chemically enhanced primary treatment. It has been demonstrated that chemical sand can achieve monthly average effluent total phosphorus levels varying between 0.06 µg/L and 0.009 µg/L.

Comparison to Established Technologies:

A testing program conducted by an independent party for evaluation of the Blue PRO™ system against direct filtration systems using the same chemicals for phosphorus removal indicated that the short-term and long-term testing by Blue Water Technologies, Inc., produced promising results for phosphorus removal from tertiary wastewater. The long-term steady-state test of 0.25 MGD through the system produced effluent phosphorus levels equivalent to the best technologies currently available for phosphorus removal in the wastewater industry.

Available Cost Information:

Approximate Capital Cost: 1 MGD $178,300.
3 MGD $494,000 uninstalled.

Approximate O&M Costs: 1 MGD $29,380.
3 MGD $84,000 annually.

Vendor Name(s):

Blue Water Technologies, Inc.
10450 North Airport Drive
Hayden, ID 83835
Telephone: 208-209-0391
Web site: http://www.blueH2O.net

Installation(s):

Hayden Area Regional Wastewater Treatment Plant, Hayden, ID

Technology Summary

Blue PRO™ (Contd)

Key Words for Internet Search:

Blue PRO™, advanced phosphorus removal, phosphorus adsorption

Data Sources:

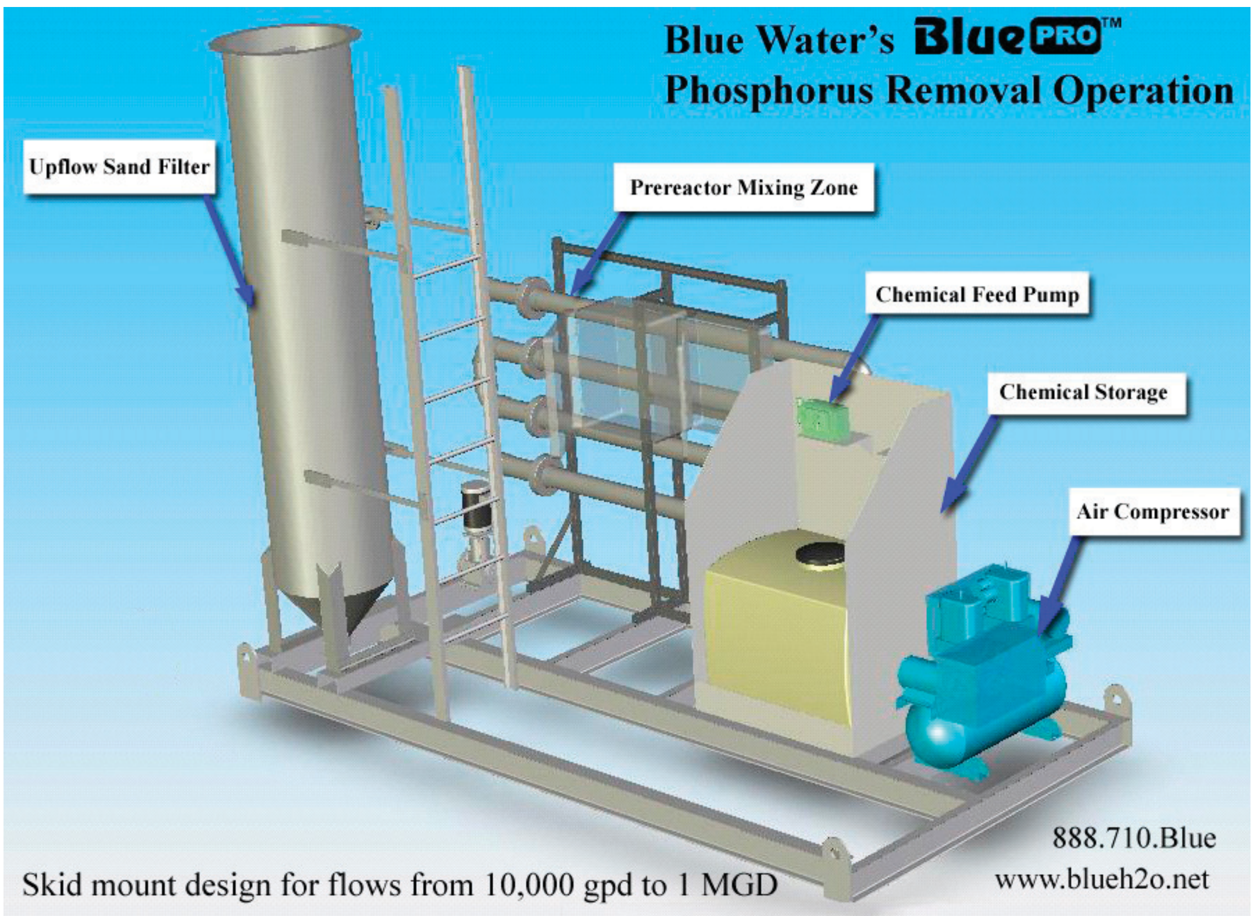
Blue PRO™, "Hydrous Ferric Oxide (HFO) Coated Sand. Adsorptive Media Technical Summary," 2006.

Blue Water Technologies, Cleaning the World's Waterways One Treatment Plant at a Time, Brochure, 2006.

CH2M Hill, Technical Memorandum, "Evaluation of Blue PROTM Process at the Hayden Wastewater Research Facility – Final Summary Report," 2006.

Newcombe, R.L., B.K. Hart, and G. Möller, "Arsenic Removal from Drinking Water by Moving Bed Active Filtration," Journal Environmental Engineering, 132(1): 5–12, 2006.

http://www.blueh2o.net



Blue Water Blue PRO™ Phosphorus Removal System

Technology Summary

CoMag™

Objective:
Enhanced phosphorus and suspended-solids removal.

State of Development:
Embryonic.

Description:
The process uses magnetite for ballasted flocculation, solids contact, and high-gradient magnetic separation to meet treatment objectives. Metal salts are added to the wastewater and pH is adjusted. The wastewater is mixed with fine magnetic ballast to increase floc density and permit floc removal using magnetic separator.

The ballasted floc settles rapidly in a small clarifier.

Comparison to Established Technologies:
High-gradient magnetic separation has not been applied to treat wastewater prior to this technology development. Magnetite is denser than sand, so it creates a heavy floc that settles rapidly in a small clarifier. Its magnetic properties allow the effluent to be further polished using a magnetic filter, and the magnetite seed is recovered from sludge using a magnet instead of gravity. Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Available Cost Information:
Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):
Cambridge Water Technology
Ray Pepin, PE
41 Hutchins Drive
Portland, ME 04102
Telephone: 207-774-2112, x3349
Fax: 207-774-6635

Installation(s):
City of Concord, MA

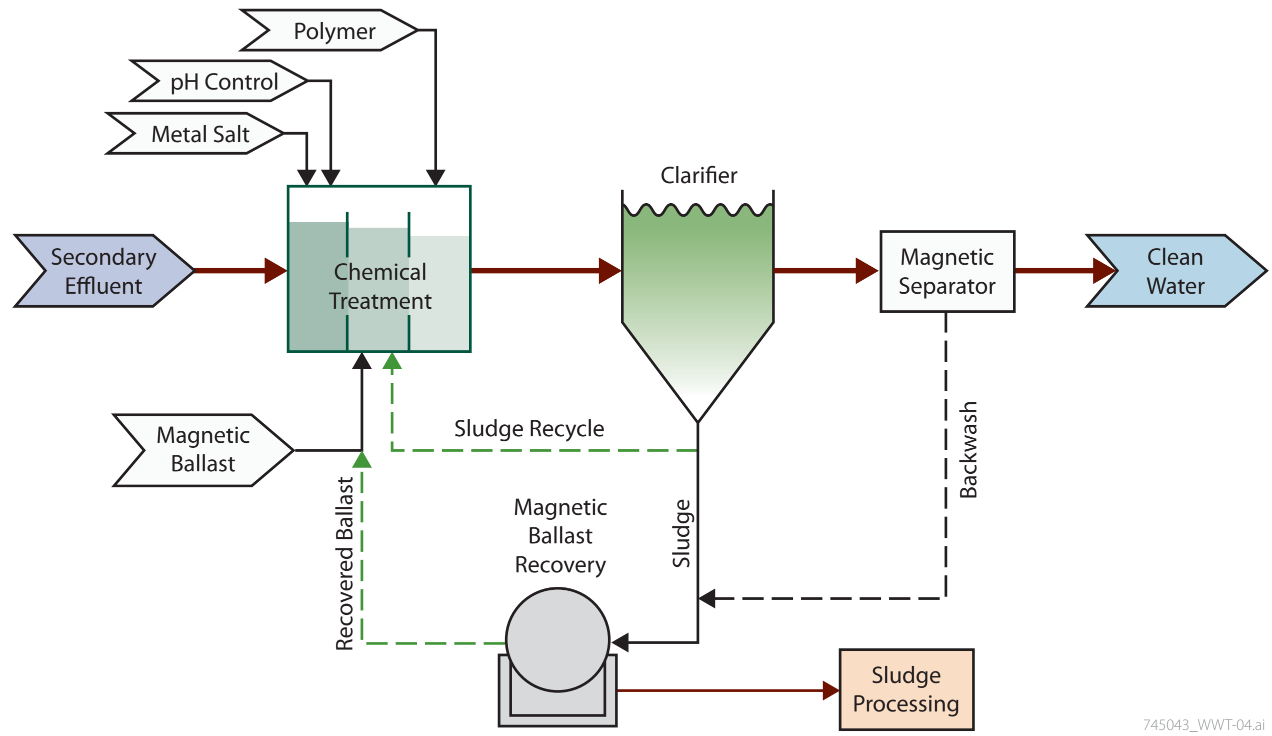
Key Words for Internet Search:
CoMag™, Cambridge Water Technology, Concord WWTP

Data Sources:
Cambridge Water Technology

Woodard and Curran

Technology Summary

CoMag™ (Contd)



CoMag™ Process Flow Diagram

Technology Summary

Solar Disinfection

Objective:

Use of solar energy for low-cost, low-maintenance, and effective disinfection system for the improvement of wastewater before discharge.

State of Development:

Embryonic.

Description:

Several portable, low-cost, and low-maintenance solar units to disinfect treated wastewater have been designed and tested by researchers at the Department of Chemical Engineering in Lafayette College, PA. The solar disinfection unit was tested with both river water and partially processed water from two wastewater treatment plants. In less than 30 minutes in mid-day sunlight, the unit eradicated more than 4 log_{10} U (99.99%) of bacteria contained in highly contaminated water samples. This is similar to chlorination with a standard 20-minute contact time, but it is cheaper to operate and uses no hazardous chemicals. May only be applicable in the Sun Belt region of the United States.

Comparison to Established Technologies:

The process uses the cheapest source of energy (solar); and it is, therefore, favorable in regions of the nation were there is ample sunshine.

Available Cost Information:

Approximate Capital Cost: Cost range not known at this time for commercial purposes.

Approximate O&M Costs: Cost range not known at this time for commercial purposes.

Vendor Name(s):

Lafayette College
Department of Chemical Engineering
Easton, PA 18042
Telephone: 610-330-18042
Email: tavakoli@lafayette.edu

Installation(s):

There are no installations at this time.

Key Words for Internet Search:

Solar disinfection, wastewater treatment, portable solar units

Data Sources:

Archer, A., Fischer, E., Turnheim, R., Manor, Y., "Ecologically Friendly Wastewater Disinfection Techniques," Water Research (WATER RES), Vol. 31, No. 6, pp. 1,398–1,404, June 1977.

Caslake, Laurie F., Daniel J. Connolly, Vilas Menar, Catriona M. Duncanson, Ricardo Rojas and Joavad Tavakoli, "Disinfection of Contaminated Water by Using Solar Irradiation," Applied and Environmental Microbiology, February 2004.

Journal of Environmental Systems, Issue, Volume 26, No. 2, 1997–1998.

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Chapter
3

Biological Treatment Processes

3.1 Introduction

Biological treatment processes are systems that use microorganisms to degrade organic contaminants from wastewater. In wastewater treatment, natural biodegradation processes have been contained and accelerated in systems to remove organic material and nutrients. The microorganisms metabolize nutrients, colloids, and dissolved organic matter, resulting in treated wastewater. Excess microbial growth is removed from the treated wastewater by physical processes.

In the last decade, there have been major advancements in the area of biological treatment processes. Biological processes are now the preferred way of treatment as they have become cost effective in terms of energy consumption and chemical usage. For example, biological nutrient removal (BNR) has emerged as the preferred approach for nutrient removal. BNR processes involve modifications of biological treatment systems so that the microorganisms in these systems can more effectively convert nitrate nitrogen into inert nitrogen gas and trap phosphorus in solids that are removed from the effluent.

3.2 Technology Assessment

Table 3.1 presents a categorized list of emerging and established biological treatment technologies. The list includes most established biological treatment processes and recent developments in cost-effective methods to retrofit older systems or result in systems with smaller footprints. Experience in operation of biological systems and the ongoing effort to maximize process performance has resulted in established biological treatment processes undergoing modifications that warrant discussion in this chapter on emerging technologies. Generally, the improvements in established biological treatment processes provide treatment of recycle streams, optimize recycle, and maximize nutrient-removal capabilities.

An evaluation of the innovative technologies identified for biological treatment processes relative to their state of development, applicability, potential for effluent reuse and the potential benefits of the technology is presented in Figure 3.1. Summary sheets for each innovative and embryonic technology are provided at the end of the chapter. The innovative technologies are as follows: Bioaugmentation, Cannibal®, CATABOL™, Deep-Shaft Activated Sludge/VERTREAT™, Integrated fixed-Film Activated Sludge (IFAS), Membrane BioReactor (MBR), and Mobile-Bed Reactor Technology (MBRT) processes. The innovative use of established technologies are as follows: Bardenpho® (Three Stage) with Returned Activated Sludge (RAS) Denitrification, Biological-Chemical Phosphorus and Nitrogen Removal (BCFS) Process, Modified University of Cape Town (MUCT) Process, Modified Anaerobic/Oxic (A/O) Process, and Trickling Filter/Solids Contactor (TF/SC). These processes have various configurations and modules to fit the specific needs of any individual treatment plant. Most of these technologies can be easily retrofitted into existing treatment systems that enable treatment processes to achieve better nutrient removal.

This chapter also lists a number of biological processes that are in embryonic stages of development. Processes like Single Reactor High-activity Ammonia Over Nitrite (SHARON), Single Reactor High-activity Ammonia Over Nitrite – ANaerobic AMMonia OXidation (SHARON – ANAMMOX), and Vacuum Rotation Membrane (VRM®) are now being used in full-scale application in the United States after being selected as a preferred technology in Europe and other parts of the world. These processes provide energy-efficient biological nutrient removal with reduced external carbon requirements. Another advantage of these processes is a reduced footprint, although footprint reduction has not been a priority in the United States as much as in the rest of the world, where availability of land is often more restricted.

Other embryonic technologies included at the end of this chapter are as follows: Aerobic Granular Sludge Process (AGSP), ANaerobic Membrane BioReactor (AN-MBR), Anaerobic Migrating Blanket Reactor (AMBR®), DEamMONification (DEMON) Process, Hydrogen-based hollow-Fiber Membrane Biofilm Reactor (HFMBfR), Membrane-Aerated BioReactor (MABR), Microbial Fuel Cell (MFC) Based Treatment System, Multi-Stage Activated Biological Process (MSABP™), Nerada™, and STRASS Process (Nitrification and Denitrificaiton in SBR).

Table 3.1—Biological Treatment Processes – State of Development

Established Technologies
BOD Removal and Nitrification
▪ Biolac-Aerated Lagoon
▪ Complete Mix-Activated Sludge (CMAS) Process
▪ Contact Stabilization
▪ Conventional Extended Aeration
▪ Countercurrent Aeration System (CCAS™)
▪ Cyclic Activated Sludge System (CASS™)
▪ High-Purity Oxygen (HPO)
▪ Intermittent Cycle Extended Aeration System (ICEAS™)
▪ Kraus Process
▪ Oxidation Ditch/Aerated Lagoons
▪ Sequencing Batch Reactor

Established Technologies (Contd)
▪ Staged Activated-Sludge Process
▪ Step Feed
▪ Step Feed (Alternating Anoxic and Aerobic)
Biological Nutrient Removal (BNR)
▪ Bardenpho® (Four Stage)
▪ Biodenitro™
▪ Ludzack-Ettinger
▪ Modified Ludzack-Ettinger (MLE)
▪ Orbal™ Process
▪ Schreiber™ Process
▪ Simultaneous Nitrification denitrificatioN (SNdN) Process
▪ Step Feed BNR Process
▪ Wuhrman

Table 3.1—Biological Treatment Processes – State of Development (Contd)

Established Technologies (Contd)
Enhanced Biological Phosphorus Removal (EBPR)
▪ Anaerobic/Anoxic/Oxic (A2/O)
▪ Bardenpho® (Five Stage)
▪ Johannesburg Process
▪ Phoredox (Anaerobic/Oxic [A/O])
▪ Phostrip
▪ University of Cape Town (UCT)
▪ Virginia Initiative Plant (VIP)
Other Biological Processes
▪ Fluidized Bed Bioreactor (FBBR)
▪ Rotating Biological Contractor (RBC)
▪ Submerged Rotating Biological Contactor (SRBC)
▪ Trickling Filter (TF)
Anaerobic Processes
▪ Anaerobic Attached Growth System
– Upflow Packed-Bed Attached Growth Reactor
– Upflow Attached Growth Anaerobic
– Expanded-Bed Reactor (Anaerobic Expanded Bed Reactor [AEBR])
– Downflow Attached Growth Process
▪ Anaerobic Contact Process
▪ Anaerobic Sequencing Batch Reactor (ASBR®)
▪ Upflow Anaerobic Sludge Blanket (UASB)
▪ ANFLOW (ANaerobic FLuidized Bed Reactor)
Biological Aerated Filters (BAF)
▪ Biofor®
▪ Biostyr®
Innovative Technologies
Bioaugmentation
▪ External Bioautmentation
– Seeding from Commercial Sources of Nitrifiers
– Trickling Filter and Pushed Activated Sludge (TF/PAS) Process
– Seeding from External Dispensed Growth Reactors Treatment Reject Waters (Chemostat)
– In-Nitri® Process
– Immobilized Cell-Augmented Activated Sludge (ICASS) Process
– Seeding from Parallel Processes
– Seeding from Downstream Process
▪ In Situ Bioaugmentation
– DE-nitrification and PHosphate accumulation in ANOXic (DEPHANOX) Process

Innovative Technologies (Contd)
– Bio-Augmentation Regeneration/Reaeration (BAR) Process
– Bio-Augmentation Batch Enhanced (BABE) Process
– Aeration Tank 3 (AT3) Process
– Main stream AUtotrophic Recycle Enabling Enhanced N-removal (MAUREEN) Process
– Regeneration DeNitrification (R-DN) Process
Cannibal®
CATABOL™
Deep-Shaft Activated Sludge/VERTREAT™
Integrated fixed-Film Activated Sludge (IFAS)
▪ IFAS – Submerged Mobile Media
– Attached Growth Airlift Reactor (AGAR®)
– Captor®
– LINPOR®
▪ IFAS – Submerged Fixed Media
– CLEARTEC®
– AccuWeb®
– BioMatrix™
– HYBAS™
– BioWeb™
– RINGLACE®
Membrane Bioreactor (MBR)
▪ Tubular
▪ Hollow-Fiber
▪ Spiral Wound
▪ Plate and Frame
▪ Pleated Cartridge Filters
Mobile-Bed Reactor Technology (MBRT) Process
▪ Kaldnes® HYBAS™/ Active Cell™
▪ Hydroxyl-F3R
▪ GeoReactor®
Innovative Use of Established Technologies
Bardenpho® (Three Stage) with Returned Activated Sludge (RAS) Denitrification
Biological-Chemical Phosphorus and Nitrogen Removal (BCFS)* Process
Modified University of Cape Town (MUCT) Process
Modified Anaerobic/Oxic (A/O) Process
Trickling Filter/Solids Contactor (TF/SC)
Note: * Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors and excessive inorganic precipitant requirements need to be reduced.

Table 3.1—Biological Treatment Processes – State of Development (Contd)

Embryonic Technologies
Aerobic Granular Sludge Process (AGSP)
ANaerobic Membrane BioReactor (AN-MBR)
Anaerobic Migrating Blanket Reactor (AMBR®)
DEamMONification (DEMON) Process
Hydrogen-based hollow-Fiber Membrane Biofilm Reactor (HFMBfR)
Membrane-Aerated BioReactor (MABR)
Microbial Fuel Cell (MFC) Based Treatment System
Multi-Stage Activated Biological Process (MSABP™)
Nereda™

Embryonic Technologies (Contd)
Single reactor High-activity Ammonia Removal Over Nitrite (SHARON)
SHARON – ANAMMOX (ANaerobic AMMonia OXidation)
STRASS Process
Vacuum Rotation Membrane (VRM®) System

Figure 3.1—Evaluation of Innovative Biological Treatment Technologies

	Evaluation Criteria									
Process	Development	Applicability	Benefits	Impact on Processes	Complexity	Air/Odor Emissions	Reuse	Energy	Footprint	Retrofitting
Bioaugmentation	I, M, N, O	F	C, O	⊖	⊖	⊖	In	⊖	⊖	▲
Cannibal®	M, N	F	C, O	▲	⊖	⊖	In	▲	▲	▲
CATABOL™	M, N	F	C, O	⊖	⊖	▲	In	⊖	⊖	▲
Deep-Shaft Activated Sludge/VERTREAT™	M, N, O	F	C, O	▲	⊖	⊖	In	▲	▲	⊖
Integrated Fixed-Film Activated Sludge (IFAS)	I, M, N	I	C, O	▲	⊖	⊖	In	▲	▲	▲
Membrane Bioreactor (MBR)	I, M, N, O	I, F	C, O	▲	⊖	⊖	In	▲	▲	▲
Mobile-Bed Reactor Technology (MBRT) Process	I, N, O	F	C, O	▲	⊖	⊖	In	▲	▲	▲

Key

Statement of Development
- B = Bench scale
- I = Full-scale industrial applications
- M = Full-scale municipal applications
- O = Full-scale operations overseas
- P = Pilot
- N = Full-scale operations in North America

Applicability
- F = Few plants
- I = Industrywide
- L = Primarily large plants
- S = Primarily small plants

Potential Benefits
- C = Capital savings
- I = Intense operational demand
- O = Operational/maintenance savings
- S = Shock load capacity
- W = Wet weather load capacity

Effluent Reuse
- Dp = Direct potable
- Dn = Direct nonpotable
- Ip = Indirect potable
- In = Indirect nonpotable

Comparative Criteria
- ▲ Positive feature
- ⊖ Neutral or mixed
- ▼ Negative feature

Technology Summary

Bioaugmentation

Objective:

Achieve higher kinetic rates by addition of bacteria and enhance nitrification and denitrification

State of Development:

Innovative.

Description:

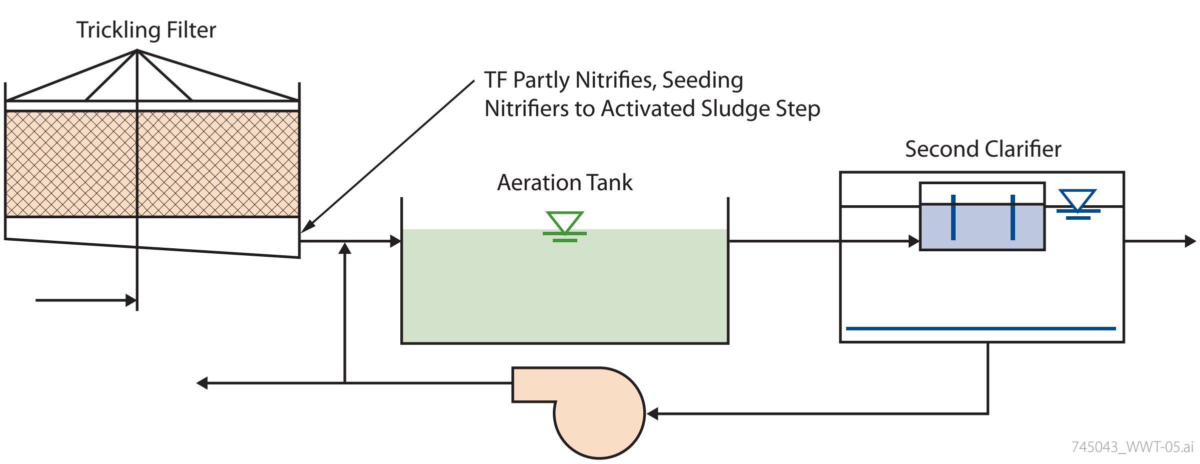
In Biological Nutrient Removal (BNR) plants designed for nitrogen and phosphorus removal, reactor volumes dedicated to nitrification constitute majority of reactor volume. Bioaugmentation aims to reduce the volume dedicated to nitrification by decreasing the required aerobic Sludge Retention Time (SRT) by increasing the rate of nitrification. There are two types of bioaugmentation schemes; these are (1) external bioaugmentation and (2) in situ bioaugmentation. External bioaugmentation includes addition of external-source nitrifiers, whereas in situ bioaugmentation provides internal process enhancements that increase activity or enrich nitrifier population. The advantage of external bioaugmentation schemes is that the promotion of nitrification within the main stream process can be decoupled from its aerobic SRT. The advantage of in situ schemes is that there is less concern about the loss of activity of the seed nitrifiers when transferred to the mainstream process because their conditions of growth are similar to those prevalent in the mainstream process.

EXTERNAL BIOAUGMENTATION

Examples of external bioaugmentation includes seeding from commercial sources of nitrifiers, Trickling Filter and Pushed Activated Sludge (TF/PAS) process, seeding from external dispersed growth reactors treating reject waters, seeding from external activated sludge reactors treating reject waters, seeding from parallel processes, and seeding from downstream processes. Some facilities having both air-activated sludge systems and high-purity oxygen systems have proven that nitrification in the high-purity oxygen can be significantly enhanced by seeding with nitrification solids from the parallel aerated BNR system. This procedure is not patented. External bioaugmentation is performed in Hagerstown, MD, Henrico County, VA, and Hopewell, VA. Note, nitrification in high-purity oxygen plants is typically limited due to pH inhibition.

Seeding from Commercial Sources of Nitrifiers: Although early attempts at bioaugmentation with commercial seed sources within wastewater treatment plants have produced controversial results, bioaugmentation for nitrification has readily measurable success. Adding external nitrifiers' sources has shown some success at both laboratory and field scale and allows operation at colder temperatures where nitrifiers would normally washout but required dosages of the nitrifiers were very high. Therefore, most investigators diverted to onsite production of seed organisms within the treatment plant.

TF/PAS Process: The earliest example of external bioaugmentation with nitrifiers generated within the plant from a wastewater source is likely that of the TF/PAS process, whereby the total organic loading on the trickling filter is adjusted to achieve about 50 percent nitrification, thereby seeding nitrifiers to a down-stream activated sludge step with a low SRT of 2 to 4 days. It appears that the enhanced nitrification rates achieved may be due to both the effect of seeding as well as removing toxicants in the wastewater by pretreatment of the trickling filter.

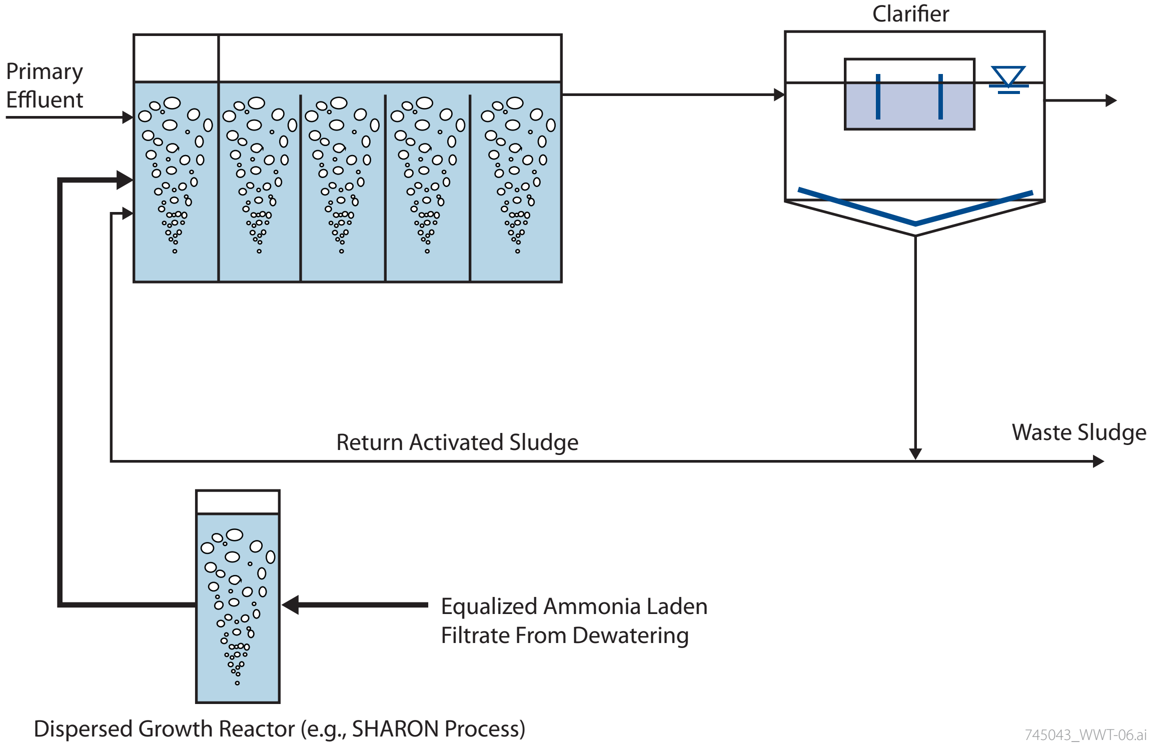


Process Flow Diagram for Trickling Filter/Pushed Activated Sludge

Technology Summary

Bioaugmentation (Contd)

Seeding from External Dispersed Growth Reactors Treating Reject Waters (Chemostat Type): There has been some success reported with chemostats seeding batch reactors simulating mainstream processes. Nitrifiers grown in batch-fed sidestream chemostats were more effective in stimulating the process efficiency in the simulated main-stream reactors than were those grown in continuously fed chemostats. It has been shown that the specific nitrifier types grown in the sidestream chemostats were able to replace the microbial population in the mainstream reactors, suggesting that population diversity leads to more robust mainstream reactors.

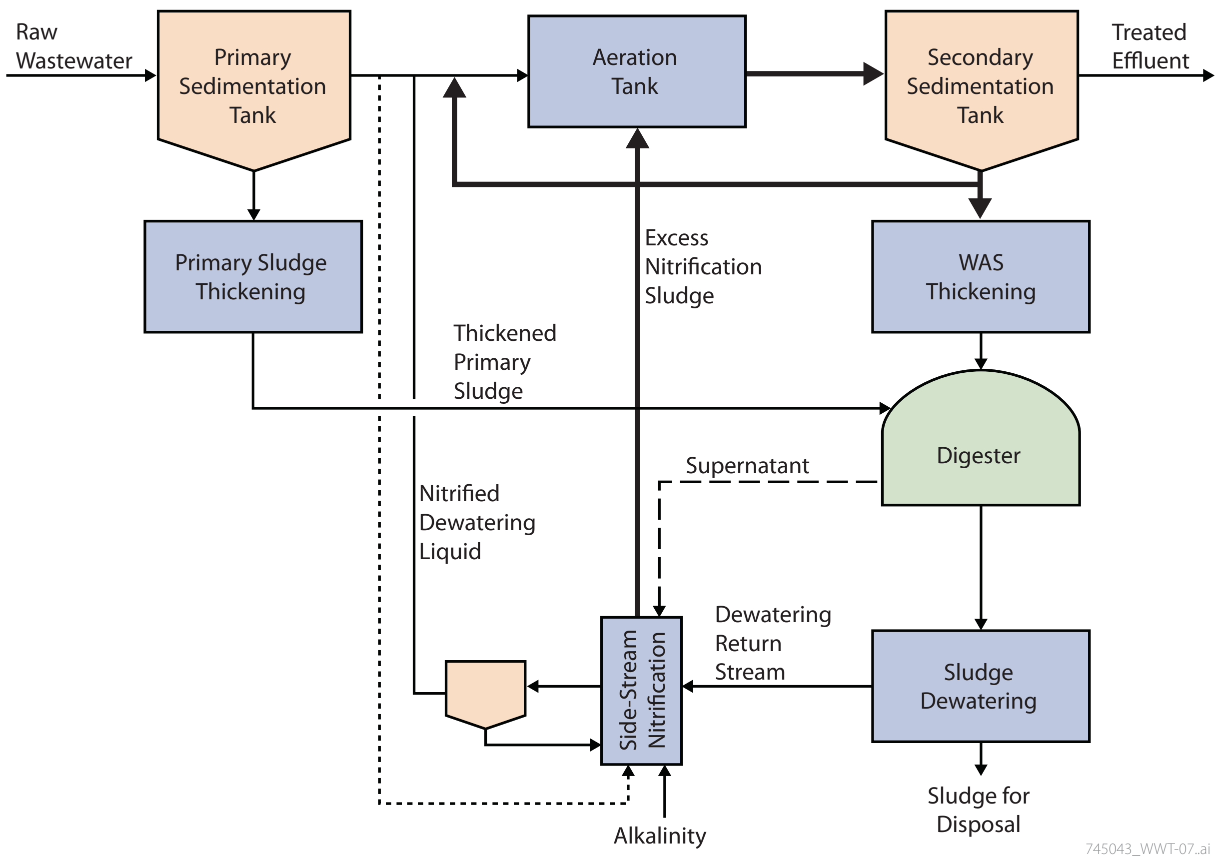


Process Flow Diagram for Seeding from External Dispersed Growth

In-Nitri® Process: Growing the nitrifiers in an external activated sludge plant using ammonia-laden digester filtrate has proven to be successful as it appears that the nitrifiers are protected within activated-sludge flocs. A process known as the Short SRT or In-Nitri® process used this principle and several bench or pilot-scale studies have proven its effectiveness. In-Nitri® consists of supplemental nitrifying bacteria constantly added to the main-stream activated-sludge process to replenish nitrifiers removed with the waste activated sludge. The nitrifiers are grown in a separate sidestream aeration tank using ammonia available either in the digested sludge dewatering liquid and in the digester supernatant or from commercial ammonia addition. The process has the advantage of achieving year-round nitrification by reducing the SRT by adding only a small aeration tank and clarifiers for growing nitrifiers.

Technology Summary

Bioaugmentation (Contd)



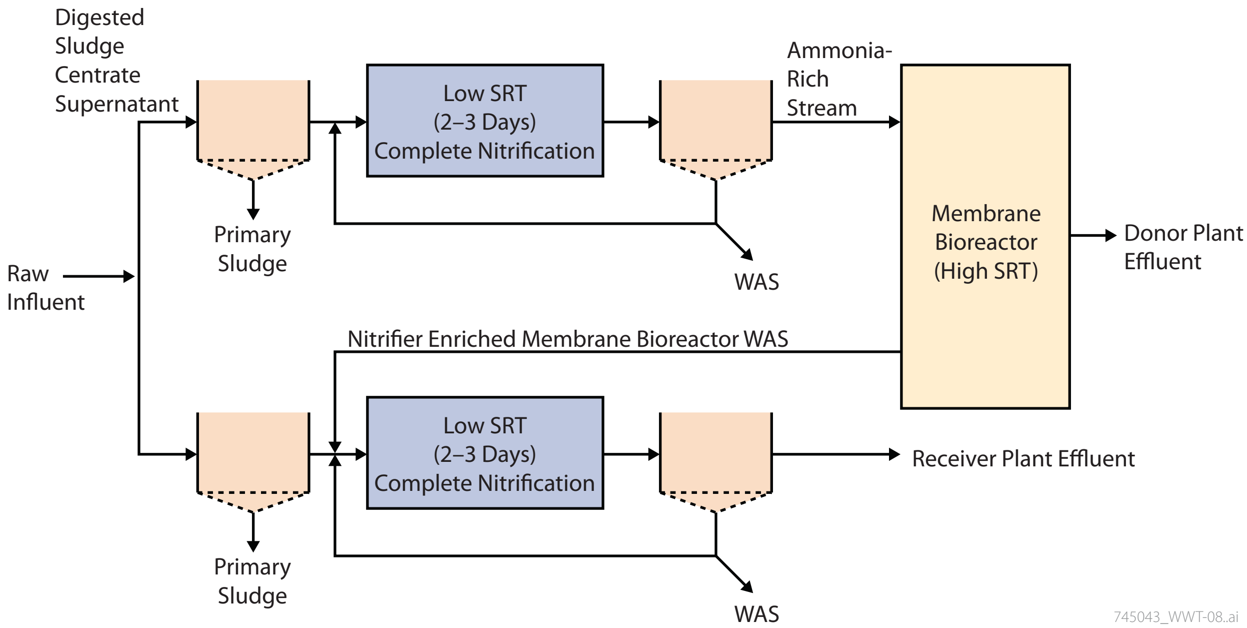
Process Flow Diagram for Inexpensive Nitrification

Immobilized Cell-Augmented Activated Sludge (ICAAS) Process: Immobilized cells are maintained for a specific treatment activity and are enriched in a reactor for bioaugmentation. The ICAAS process employs the immobilized cells that are activated and maintained for their specific treatment activity in an off-line enricher reactor for bioaugmentation. The process has been effectively used in bench-scale reactors for treating hazardous-compound shock loads, to achieve enhanced nitrate removal and to increase general performance of the treatment process.

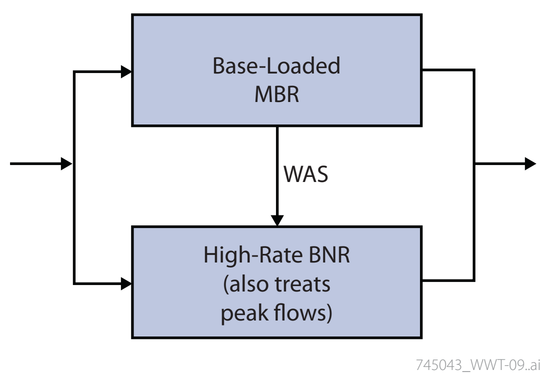
Technology Summary

Bioaugmentation (Contd)

Seeding from Parallel Processes: Two schemes have been proposed to grow nitrifiers in a MBR and seed a high-rate BNR process. However, results on pilot or full-scale trials have not yet been reported. Another approach included two parallel activated-sludge processes, tertiary nitrifying MBR seeding parallelling a high-rate activated sludge process. Some process issues in this scheme are as follows: membranes select for filtering, not settling biomass; seeding effectiveness is likely impacted by predation; and the process only fits some nutrient-removal flow diagrams.



Process Flow Diagram for Tertiary Nitrifying MBR Seeding Parallel High-Rate BNR Process



Process Flow Diagram for High Rate BNR Seeded by Parallel MBR Reactor

Technology Summary

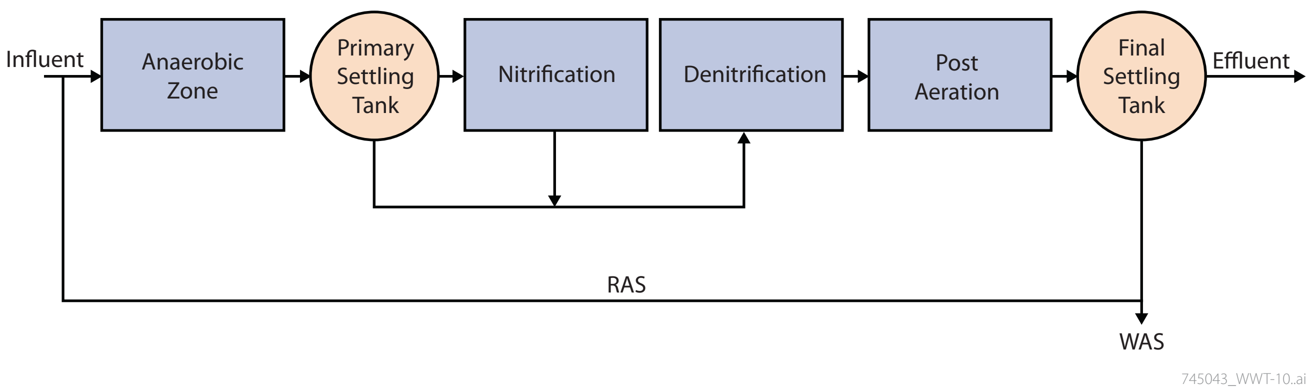
Bioaugmentation (Contd)

Seeding from Downstream Process: There are two seeding processes developed for the main treatment plant in Vienna, Austria. The plant is a two-stage plant, whereby carbon is removed in the first stage and nitrification occurs in the second stage. In this scheme, nitrifying mixed liquor is wasted to the first stage resulting in some nitrification in that stage. Effluent from the second stage is also recycled during dry weather for denitrification in the first stage while 10 to 40 percent of the influent is bypassed to the second stage to obtain additional denitrification. An alternative to the bypass mode is termed the hybrid mode, which includes exchange of mixed liquors between the stages.

IN SITU BIOAUGMENTATION

Separate-stage nitrification processes, where carbon is removed in an initial biological stage and then followed by a separate-stage nitrification process, are the first examples of in situ bioaugmentation. A three-sludge system incorporating separate-stage nitrification, was promoted as a preferred technology in 1970s. Main reason for this was that the separate steps of carbon removal, nitrification and denitrification could each be optimized. There have also been fixed-film systems employed for separate stage nitrification. Purpose of these systems was three-fold and as follows: (1) use of media with high-mass-transfer rates; (2) use of recirculation to improve media-wetting and gain maximum nitrifying biofilm coverage and minimization of influent solids to avoid competition for oxygen from heterotrophs; and (3) the control of predators with flooding and alkaline treatment.

DE-nitrification and PHosphate accumulation in ANOXic (DEPHANOX) Process: This process includes a combination of suspended growth and fixed-film systems in separate stages. DEPHANOX is based on the phenomenon of phosphate accumulation in the anoxic zone while undergoing simultaneous denitrification.

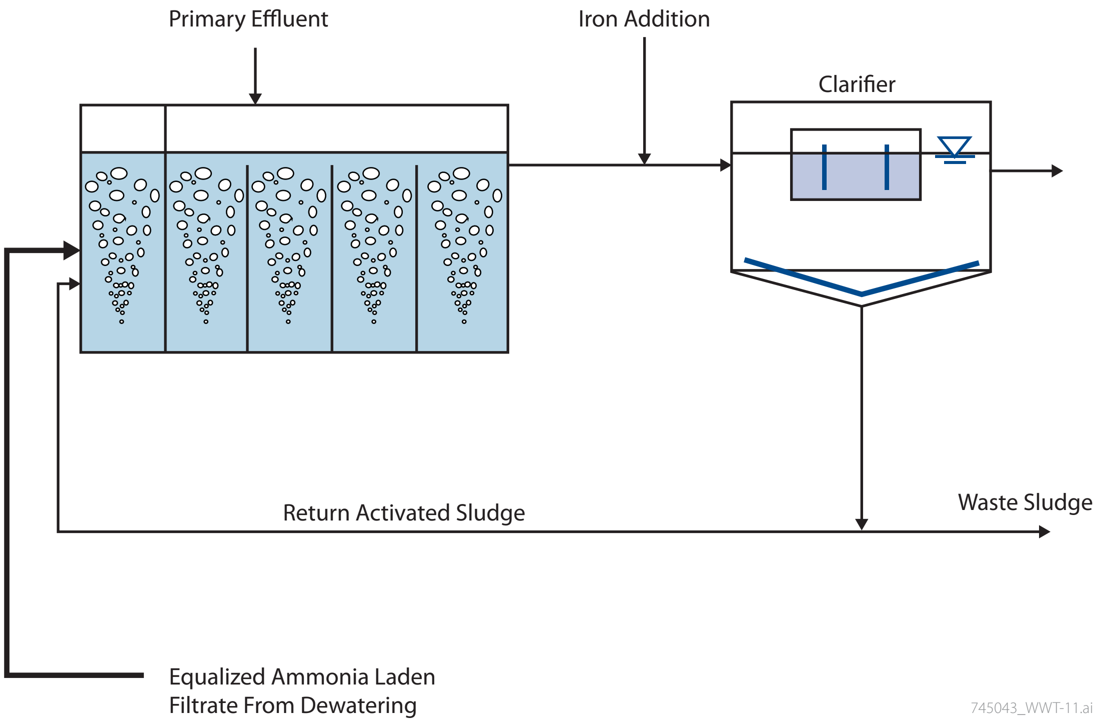


Process Flow Diagram for DEPHANOX Process

Technology Summary

Bioaugmentation (Contd)

BAR Process: In the Bio-Augmentation R Process, the R stands for regeneration zone in the Czech Republic and in the United States the R stands for reaeration. The BAR Process simply recycles the ammonia-laden filtrate or centrate from dewatering of aerobically digested sludge to a reaeration (regeneration) tank and receives return activated sludge. The stream is fully nitrified and the nitrifiers within activated-sludge flows are then carried forward to charge the main aeration tank, thereby reducing the SRT required for complete nitrification. The BAR process was independently developed in the United States and Czech Republic.

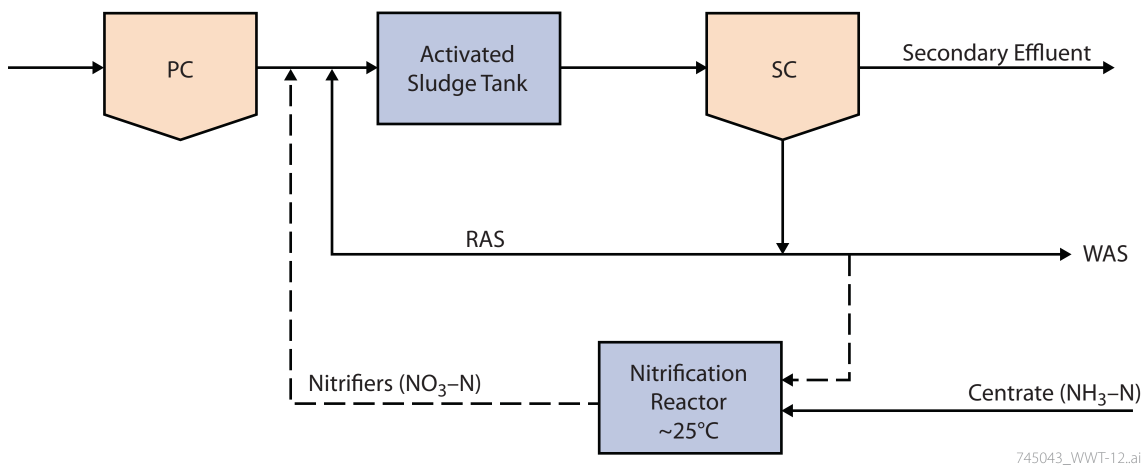


Process Flow Diagram for BAR Process

Technology Summary

Bioaugmentation (Contd)

Bio-Augmentation Batch Enhanced (BABE) Process: Comprised of a Sequencing Batch Reactor (SBR) which is fed with the reject water from the sludge dewatering process and the Returned Activated Sludge (RAS) from the treatment system. The RAS augments the batch reactor with the nitrifying bacteria from the activated sludge floc. The SBR follows the phases of the treatment cycle, i.e, fill and aerate, react, settling, and wasting. Longer sludge age can be achieved in the SBR tank, which helps the nitrifying bacteria to adapt and grow in the BABE reactor.



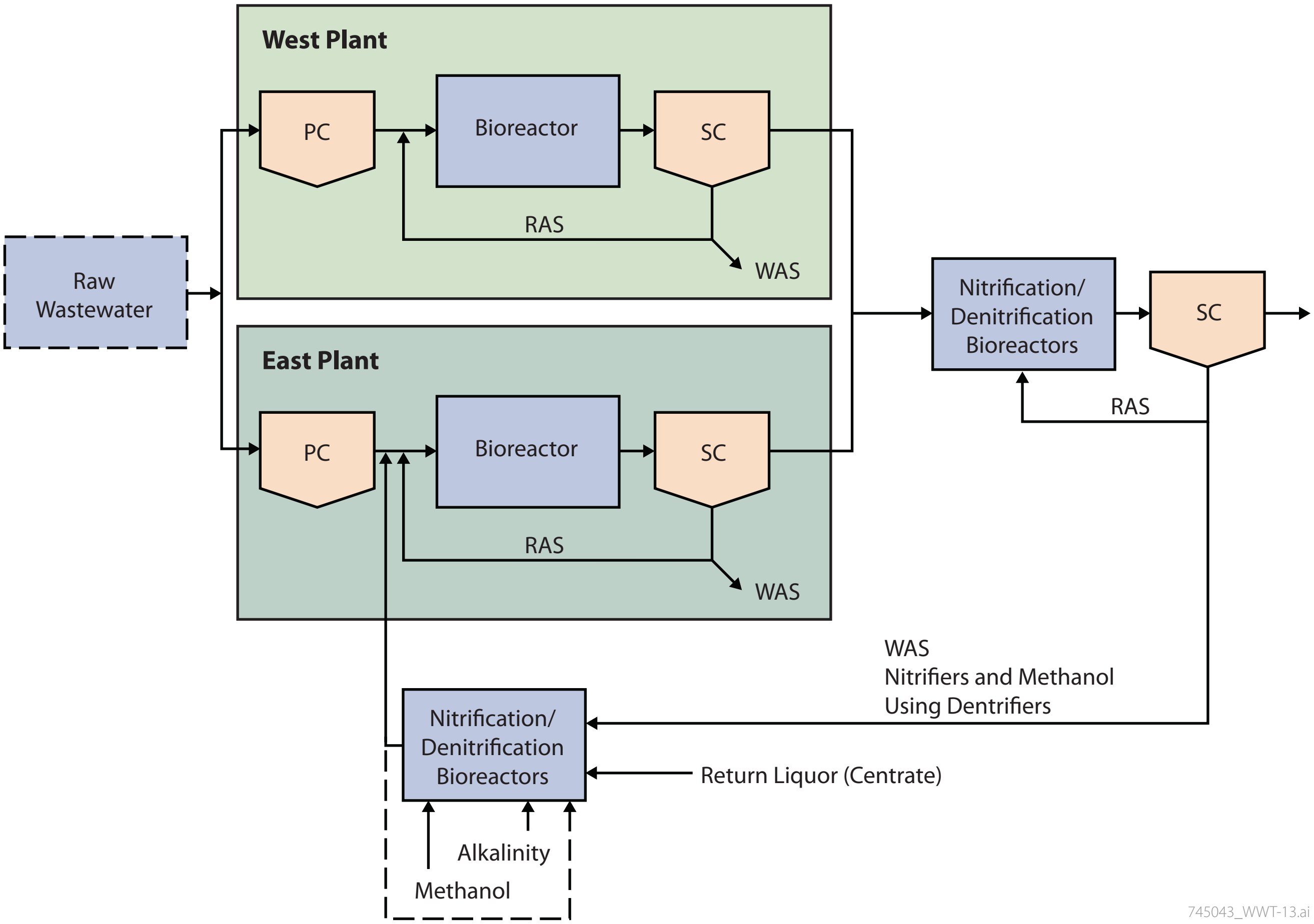
Process Flow Diagram for BABE Process

Aeration Tank 3 (AT3) Process: The AT3 Process is similar to BAR Process but it differs in sending a smaller fraction of the RAS to the reaeration tank. The process goal is to stop the nitrification process at nitrite stage by use of dissolved oxygen (DO) and pH control to reduce the consumption of carbon and oxygen for denitrification. Addition of an external carbon source may be needed to the reaeration tank to accomplish denitrification.

Main stream AUtotropic Recycle Enabling Enhanced N-removal (MAUREEN) Process: The MAUREEN process includes a sidestream bioreactor to allow for nitrification and denitrification of the centrate stream. This process was developed for the Blue Plains Advanced Wastewater Treatment Plan (AWTP) and provides significant flexibility when applied to the two-sludge system at the plant. Configuration includes preferential bioaugmentation of ammonia-oxidizing bacteria from the second to the first stage via the sidestream reactor and oxidation of ammonia in reject centrate to nitrite in the enrichment reactor resulting in reduced power and chemical consumption. This process has the ability to fortify the second-stage system with a combination of primarily ammonia oxidizers and anoxic methanol-degrading bacteria produced in the sidestream reactor under conditions that would limit the presence of nitrite-oxidizing bacteria and heterotrophic bacteria. Supernatant from the sidestream process can be used for odor and corrosion control in the headworks or within process streams at the plant. Key to the success of the process is the physical configuration and selection of operating conditions of the sidestream reactor.

Technology Summary

Bioaugmentation (Contd)



Process Flow Diagram for MAUREEN Process

Regeneration-DeNitrification (R-DN) Process: The R-DN process is identical to BAR process and also involves filtrate or centrate bioaugmentation. It was independently developed in the Czech Republic and the United States.

Bioaugmentation (Contd)

Comparison to Established Technologies:

The bioaugmentation process helps to achieve higher performance standards because the microorganisms added to the reactive phase in the treatment processes boosts microbial activity. These microorganisms are more adapted to the conditions in the reactive phase of the treatment process than the microorganisms in the influent.

Based on simulation results for a highly loaded activated-sludge process as the main treatment stage, use of the BABE technology lowers the ammonium concentration in the effluent by 20 to 100 percent, dependent on the temperature in the aeration tank and the nitrogen load of the BABE reactor. When the process temperature in the BABE reactor is lower than 20 degrees C, the volume of the BABE reactor is determined by the process temperature. The necessary reactor volume increases significantly with decreasing temperatures. Above a process temperature of 24 degrees C, the temperature has only a minor influence on the necessary reactor volume. About 50 percent of the ammonium reduction in the effluent is caused by the nitrification of the reject water in the BABE reactor. The remaining 50 percent is removed in the aeration tank by nitrifying bacteria washed out from the BABE reactor. This inoculation effect is a main feature of the BABE process design.

Available Cost Information:

Approximate Capital Cost: Costs information not available from vendors. However, bioaugmentation processes save capital costs in the main treatment systems due to reduced reactor volumes via the augmentation of nitrifying bacteria.

Approximate O&M Costs: The operating costs are mainly related to mixing and aeration requirements and depend upon local conditions and the available equipment. Bioaugmentation processes also save operating costs in the main treatment through the augmentation of nitrifying bacteria. Actual costs were not disclosed.

Vendor Name(s):

DHV Water BV
P.O. Box 484
3800 AL Amersfoort, The Netherlands
Telephone: 0031-33-468-2200
Email: info@wa.dhv.nl
Web site: http://www.dhv.com/water/

Mixing and Mass Transfer Technologies
P.O. Box 315
State College, PA 16804
Telephone: 814-466-6994 or 888-715-9600
Email: rjohansen@m2ttech.com or tgilligan@m2ttech.com
Web site: http://m2ttech.com/index.asp

Eakalak Khan
Associate Professor
Dept. of Civil Engineering
North Dakota State University
Fargo, ND 58105
Telephone: 701-231-7717
Fax: 701-231-6185
Email: eakalak.khan@ndsu.edu

Installation(s):

BAR Process: Appleton WWTP, Wisconsin; Theresa Street WWTP, Lincoln, Nebraska; Woodward Ave. WWTP, Hamilton, Ontario, Canada; and 20 plants in Czech Republic

AT3 Process: 26th Ward WWTP, New York City, NY

BABE Process: s'Hertozenbosch WWTP, The Netherlands

MAUREEN Process: Blue Plains AWTP, Washington, D.C.

Technology Summary

Bioaugmentation (Contd)

Key Words for Internet Search:

Bioaugmentation, nitrification, wastewater treatment, bacteria

Data Sources:

Constantine, T.A., et al., "New Nitrifier Bioaugmentation Process Configure to Achieve Year Round Nitrification at Low SRTs," Proceedings of WEFTEC, 2001.

Daigger, G.T., et al., "Incorporation of Biological Nutrient Removal (BNR) into Membrane Bioreactors (MRBs)," Proceedings of the International Water Association (IWA) Specialized Conference on Nutrient Management in Wastewater Treatment Processes and Recycle Streams, Krakow, Poland.

Katehis, D., B. Stinson, J. Anderson, "Enhancement of Nitrogen Removal three Innovative Integration of Centrate Treatment," WEFTEC, 2002.

Parker, Denny S. and Jiri Wanner, "Improving Nitrification through Bioaugmentation," WEF, Nutrient Removal Conference, 2007.

Parker, Denny, Brown, and Caldwell, "Nutrient Removal, How low can we go and what is stopping us from going lower? Improving Nitrification through Bioaugmentation," WERF Presentation, 2007.

Stensel, H. David, "Sidestream Treatment for Nitrogen Removal," 11th Annual Education Seminar Central States Water Environmental Association, 2006.

http://m2ttech.com/index.asp

http://www.dhv.com/water/

Telephone conversation and email communication with Mixing and Mass Transfer Technologies.

Email communication with Tim Constantine of CH2M HILL.

Technology Summary

Cannibal® Process

Objective:

Biosolids volume reduction without digestion, thickening, dewatering, or polymer addition.

State of Development:

Innovative. A 1 MGD sequential batch reactor wastewater treatment plant in Georgia began using the Cannibal® solids reduction process in October 1998. The plant has purged solids once in 5 years to relieve the plant of extremely fine, inert material buildup. The plant removed 8,000 pounds of waste biosolids by using this process between January 2000 and September 2003. Favorable results also have been realized at other full-scale operations within the United States. This process also has been successful at the Alpine Cheese Factory in Holmes County, Ohio, and it has been the subject of bench-scale research at Virginia Polytechnic Institute and State University, Virginia.

Description:

A portion of sludge from the main treatment process is pumped to a sidestream bioreactor where the mixed liquor is converted from an aerobic-dominant bacterial population to a facultative-dominant bacterial population. Aerobic bacteria are selectively destroyed in this sidestream reactor, while enabling the facultative bacteria to break down and use the remains of the aerobes and their byproducts.

Mixed liquor from the bioreactor is recycled back to the main treatment process. There, the facultative bacteria, in turn, are out-competed by the aerobic bacteria and subsequently broken down in the alternating environments of the aerobic treatment process and the sidestream bioreactor.

Trash, grit, and other inorganic materials are removed from the process by a patented solid-separation module on the return sludge line. All of the return sludge is pumped through this module and recycled back to the main treatment process. Only a portion of this flow is diverted to the sidestream bioreactor for the selection and destruction process.

Comparison to Established Technologies:

Not similar to any established technology.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

According to the vendor, a 1.5 MGD WWTP could recognize an approximate net annual operating cost savings of $245,600 using the Cannibal® process.

Vendor Name(s):

Envirex Products
1901 S. Prairie Ave.
Waukesha, WI 53189
Telephone: 262-521-8570
Fax : 262-547-4120
Email: roehlm@usfilter.com
Web site: www.usfilter.com

Installation(s):

Alpine Cheese Factory, Inc.
1504 U.S. 62
Wilmont, OH 44689
Telephone: 330-359-5454
Fax: 330-359-5049

Bryon WWTP, Bryon, IL

Technology Summary

Cannibal® Process (Contd)

Key Words for Internet Search:

Cannibal® process, biosolids, sludge

Data Sources:

Novak, J.T., D.H. Chon, B-A. Curtis, and M. Doyle, "Reduction of Sludge Generation using the Cannibal® Process: Mechanisms and Performance," Proceedings of WEF Residuals and Biosolids Management Conference, 2006 and Bridging to the Future Conference, Cincinnati, OH, March 12 to 14, 2005.

Sheridan, J. and B. Curtis, "Casebook: Revolutionary Technology Cuts Biosolids Production and Costs," Pollution Engineering, 36:5, 2004.

Vendor-supplied information.

Technology Summary

CATABOL™

Objective:

Combined anaerobic and aerobic treatment to achieve reduced nitrogen and phosphorus levels in the treated wastewater.

State of Development:

Innovative.

Description:

In the CATABOL™ process, anaerobic microorganisms for phosphorus removal are combined with aerobic and facultative microorganisms for nitrogen removal. A schematic of the process for treatment of municipal wastewater is shown in the figure on the next page. The principal elements of the process include an anaerobic reactor, and aerobic reactor, sludge separation, inert solids removal, alkalinity and pH control, and a sludge conditioner. Additional equalization tanks, multi-stage reactors and tertiary treatment processes, as well as other CATABOL™ configurations may be used in particular applications. The inert solids are used as an anaerobic sludge conditioner. Solids from the aerobic zone of the CATABOL™ process are separated in a clarifier and sent to the anaerobic sludge conditioner for conversion to predominately anaerobic microorganisms with some facultative microorganisms prior to being reintroduced into the anaerobic zone of the CATABOL™ process. The anaerobic zone followed by the aerobic zone are the key processes for decomposing the wastewater and removing phosphorus. Passage through the sludge conditioner also stores the conditioned microorganisms for use as and when needed. Excess solids produced by the CATABOL™ process are wasted from the anaerobic sludge conditioner. To avoid process upset by acidification of the wastewater, alkalinity and pH must be controlled.

Comparison to Established Technologies:

This combined anaerobic-aerobic biological process has been developed to lower operating cost. The process also helps to eliminate odor problems and reduce sludge disposal costs.

Available Cost Information:

Approximate Capital Cost: $6.7 M for the upgrade of a 15-MGD plant, increasing capacity to 20 MGD.

Approximate O&M Costs: $600,000/year in operational saving and electricity consumption after the upgrade of the 20 MGD plant.

Vendor Name(s):

Khudenko Engineering, Inc.
744 Moores Mill Road
Atlanta, GA 30327
Telephone: 404-261-4452
Fax: 404-816-1611
Email: bkhudenko@comcast.net

Installation(s):

City of Cartersville, GA

Key Words for Internet Search:

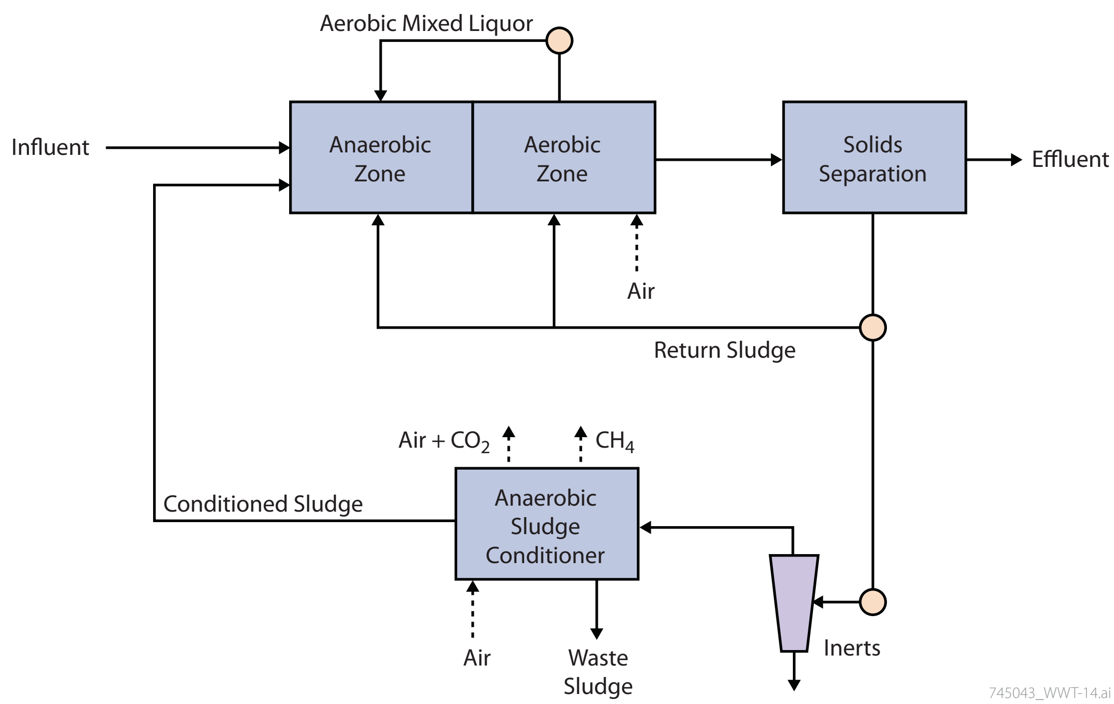
Khudenko Engineering, CATABOL™

Data Sources:

Vendor pamphlet and phone conversation with Khudenko Engineering staff.

Technology Summary

CATABOL™ (Contd)



Catabol™ Combined Treatment Process Schematic

Technology Summary

Deep Shaft Activated Sludge/VERTREAT™

Objective:

Increased oxygen transfer in the activated sludge process to decrease power requirements, saving both capital and operating costs.

State of Development:

Innovative. This technology has a well-established track record in Europe and Asia with over 30 years operation in municipal and industrial applications. There are a few operating facilities in North America in both Canada and the United States.

Description:

The Deep-Shaft Activated Sludge/VERTREAT™ process is a modification of the activated-sludge process. VERTREAT™ essentially uses a vertical "tank" or shaft in place of the surface aeration basins used in a conventional system. The result of this vertical configuration is a ten-fold increase in the dissolved oxygen content of the mixed liquor, which increases the level of biological activity in the bioreactor. The process can accommodate high-organic loading with lower aeration supply due to the enhanced oxygen transfer (a function of both increased pressure at depth and longer bubble-contact time).

Comparison to Established Technologies:

- Reduced footprint requirements.
- Lower power consumption and simple controls resulting in reduced O&M.
- Much higher-rate system due to increased oxygen transfer in process.

Available Cost Information:

Approximate Capital Cost: $3 to $5 per installed design gallon of flow.

Approximate O&M Costs: Dependent on power costs. Roughly half the aeration power requirement due to increased oxygen-transfer efficiency. Lower maintenance costs as a result of having no pumps or diffusers in the core system.

Vendor Name(s):

NORAM Engineering and Constructors Ltd.
Suite 1800, 200 Granville Street
Vancouver, BC, Canada V6C 1S4
Telephone: 604-681-2030
Fax: 604-683-9164
Web site: www.noram-eng.com

Installation(s):

City of Homer – Public Works Department
3575 Heath Street
Homer, AK, USA 99603
Telephone: 907-235-3174
Fax: 907-235-3178
Email: jhobbs@ci.homer.ak.us

Technology Summary

Deep Shaft Activated Sludge/VERTREAT™ (Contd)

Key Words for Internet Search:

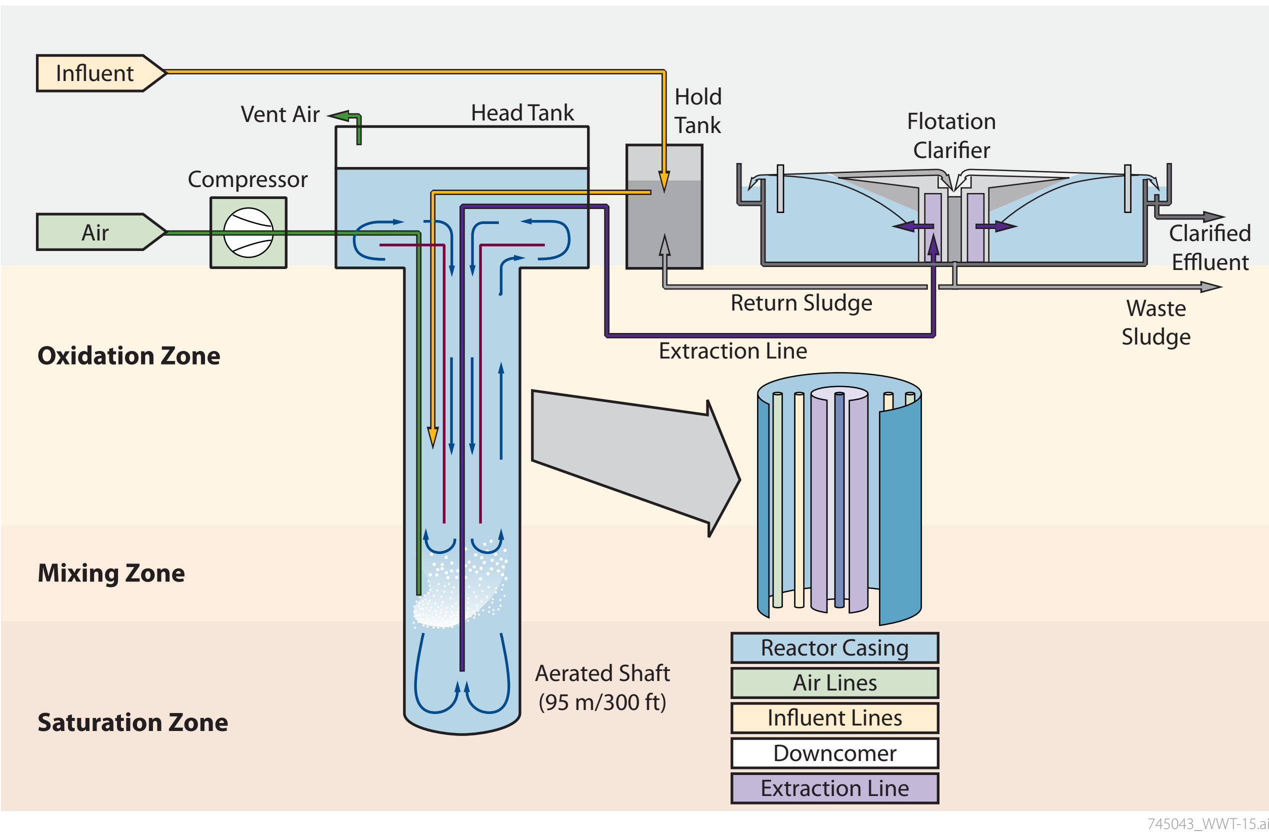
Deep shaft process, activated sludge, wastewater treatment, oxygen transfer, high rate, BOD, aerobic

Data Sources:

www.noram-eng.com

www.vertreat.com

Email communication with the vendor.



Flow Diagram of VERTREAT™ provided by NORAM Engineering and Constructors Ltd.

Technology Summary

Integrated fixed-Film Activated Sludge (IFAS) Systems

Objective:
This treatment process aims at increasing the biomass in the system without increasing the footprint of the tank to achieve higher rates of degradation.

State of Development:
Innovative.

Description:
The IFAS hybrid processes include any activated sludge system that has some type of fixed/film media in a suspended growth reactor to increase the amount of biomass available for treatment. The type of media varies in the different IFAS systems, which are usually rope, sponge, or plastic carrier. The IFAS systems can be retrofitted into existing activated sludge systems. There are two major types of IFAS: (1) Submerged Mobile Media IFAS and (2) Submerged Fixed Media IFAS.

SUBMERGED MOBILE MEDIA IFAS
The **AGAR®** (Attached Growth Airlift Reactor) process from Siemens is a fixed-film moving-bed process using thousands of special suspended biomass carriers designed to create an enormous total surface area for biofilm growth. The process uses the following features: (1) airlift-driven risers and down-comers for a unique mixing pattern; (2) non-clogging wedge-wire screens to retain the biomass carriers in the reactor; (3) biomass carriers suspended in the aerobic zones of the reactor; (4) partitions to create staged cascading reactors; (5) a mechanically mixed denitrification reactor; and (6) an aerobic reactor filled with biomass carriers. The carriers are small perforated media typically 2-cm diameter or less and made of rigid material designed to be resistant to stress or damage.

The **Captor®** process was tested at full-scale operation for three years at the Moundsville/Glen Dale WWTP at 2.3 MGD. The results of that test are published in the Water Science and Technology (see Data Sources). Captor® uses polyurethane foam media added to the activated-sludge process, raising the equivalent MLSS concentration. It was designed as a separate front portion of the activated-sludge process, with one third of the total HRT of the activated-sludge process.

LINPOR® is an activated sludge process and it was developed by Linde AG in the mid-1970s. It was commercially introduced in Europe during the early 1980s. LINPOR® uses a suspended porous plastic foam media, in combination with a freely suspended biomass portion, which allows substantially higher total biomass concentrations to be effectively maintained in the biological reactor. Equipment specific to the LINPOR® system typically includes the carrier media, the screens, screen-air system, media airlift pump hoods and piping, air blowers and fine bubble diffusers, internal mixed-liquor recycle pumps, and anoxic zone mixers. Based on extensive full-scale operations, LINPOR® systems have demonstrated the capability to substantially increase the treatment capacity of existing wastewater treatment facilities while solving biomass settleability and effluent quality problems.

SUBMERGED FIXED MEDIA IFAS
The **CLEARTEC®** system uses textile material arranged as sheets within a rigid frame as the fixed media. The fixed bed is made of polyethylene and presents itself as a mass of hollow tubes, each with a diameter of about 5 cm. Depending on the dissolved charge in the wastewater (chemical oxygen demand and/or biological oxygen demand [COD/BOD]) the openings of the fixed bed can vary and are expressed in square meters of solid support per cubic meter of fixed bed. This factor can range from 150 to 200 m^2/m^3 and, if necessary, 300 m^2/m^3 of fixed bed. The wastewater flows in cascades through the individual modules of the bioreactor and the contaminants are mineralized by the immobilized biomass.

Technology Summary

Integrated fixed-Film Activated Sludge (IFAS) Systems (Contd)

SUBMERGED FIXED MEDIA IFAS (Contd)

AccuWeb® uses fixed media modules. The standard modules include AccuWeb™ fabric media assembled on structural frames with media supports and tensioning rods. The media is fabric mesh with small hexagonal openings of less than 2-cm diameter. The modules can be assembled in various dimensions to meet aeration basin size and joined for various capacities. AccuWeb™ was tested in a full-scale demonstration at the City of Greensboro, NC, in 1997. See the WERF 2000 publication entitled "Collection and Treatment Processes – Investigation of Hybrid Systems for Enhanced Nutrient Control."

BioMatrix™ is similar to RINGLACE® (see below) in that it is a looped cord media product in multisided shapes (RINGLACE® uses rings and loops in lace-like shapes). The concept is to hang this rope-like medium attached to metal brackets mounted into an overall metal frame. The frames are modular and are immersed in the aerobic zone of a bioreactor. The media is fabricated from polyvinyl chloridine (PVC) filaments woven into rope-like strands with protruding (5-mm) loops. This provides surfaces on which microorganisms can grow and effectively increase the SRT of an activated-sludge system. Trade names include RINGLACE® and BioMatrix™. Initially used in Japan and Germany, the technology was first applied in the United States in Annapolis, MD, in the early 1990s. It has since seen considerable research and development in the northeastern United States and southern Ontario, Canada.

HYBAS™ hybrid process is ideal in upgrading municipal treatment plants for nutrient removal. The HYBAS™ process needs less space because smaller tank volumes can be used because the biocarriers augment the overall amount of biomass in the activated sludge tank. The HYBAS™ process has in fact two separate biomasses: one with low sludge age (activated-sludge flocs), and one with high-sludge age (suspended biofilm). The HYBAS™ process can maintain a high overall biomass concentration with low loadings to the sedimentation basins. Even if the activated sludge is inhibited due to an influent toxicity event, nitrification will recover more quickly.

BioWeb™ was designed to optimize process considerations and remove integrity concerns. The BioWeb™ structure is extremely strong due to its interlocking "honeycomb" design with a break strength in excess of 1,000 pounds per square foot. It uses a proprietary knitting process that is self-tensioning during installation and prevents fraying and unraveling even if cut. It comes in manufactured-to-order continuous rolls that allow for simple frame designs and installation. It provides for excellent substrate and oxygen distribution and diffusion.

RINGLACE® is a flexible-strand medium formed as a linear laced material to support attached biomass. The medium can be attached to various frames to fit within specific aeration basin dimensions. RINGLACE® biomedium was developed in Japan in the 1970s and became available in the United States in 1990. Ringlace Products, Inc., has been the exclusive distributor for the Americas since 1992. They claim over 400 RINGLACE® installations worldwide.

Comparison to Established Technologies:

The advantage of IFAS over a conventional activated-sludge plant is that IFAS allows significant expansion without additional aeration basins, which is effective for Biological Nutrient Removal (BNR). The IFAS system also has increased resilience to shock loads and significantly increases capacity of existing clarifiers. The higher total biomass concentration of IFAS processes allows higher reactor volumetric organic loadings at biomass loadings, which is similar to the conventional air-activated-sludge process, and produces a treated effluent quality equal to or better than the conventional activated-sludge process.

Available Cost Information:

Approximate Capital Cost:	$0.10 to $0.60 per gallon/day of plant capacity (Hydroxyl). $0.30 to $0.50 per gallon treated (AGAR®). $300,000/MBD (LINPOR®).
Approximate O&M Costs:	Cost range depends on wastewater treatment process required, but it is similar to activated sludge process.

Technology Summary

Integrated fixed-Film Activated Sludge Systems (IFAS) (Contd)

Vendor Name(s):

AGAR®
US Filter, Zimpro Products
301 W. Military Rd.
Rothschild, WI
Telephone: 715-355-3206
Email: carrolj@usfilter.com

CLEARTEC®
EIMCO Water Technologies
2850 S. Decker Lake Drive
Salt Lake City, UT 84119-2300
Telephone: 801-526-2111
Email: info.ewt@glv.com or
jeff.mcbride@eimcowater.com

LINPOR® and AccuWeb®
Mixing and Mass Transfer Technologies
583 Greenhaven Road
Pawcatuck, CT 06379
Telephone: 860-599-5381
Web site: http://m2ttech.com/index.asp

AccuWeb™
Brentwood Industries
610 Morgantown Road, Reading, PA 19611
Telephone: 610-374-5109
Fax: 610-376-6022
Web site: www.brentw.com

HYBAS™
AnoxKaldnes Inc.
260 West Exchange Street
Suite 301
Providence, RI, 02903
Telephone: 401-270-3898
Email: usa@anoxkaldnes.com

BioWeb™
Entex Technologies, Inc.
1829 E. Franklin Street, Suite 600
Chapel Hill, NC
Telephone: 919-619-8862
E-mail: wayne.flournoy@entexinc.com

RINGLACE®
Ringlace Products, Inc.
P.O. Box 301157
Portland, OR 97294
Telephone: 503-618-0313
Fax: 503-771-9649
General Information: info@ringlace.com

Installation(s):

Lakeview Wastewater Treatment Facility
Region of Peel
Ontario, Canada

3.7 MGD HYDROXYL-iFAS™

North Buffalo Wastewater Treatment Plant
P.O. Box 3136
Greensboro, NC 27402
Telephone: 336-373-2055
Fax: 336-412-6305

Westerly, RI

City of Broomfield, CO

Technology Summary

Integrated fixed-Film Activated Sludge Systems (IFAS) (Contd)

Vendor Name(s) (Contd):

HYDROXYL-PAC Media
Hydroxyl Systems, Inc.
1100th Main Road
Westport, MA 02747
Telephone: 508-636-9289
Email: dturner@hydroxyl.com

Key Words for Internet Search:

IFAS, activated sludge, wastewater treatment, fixed film, Cleartec , LINPOR®, Hydroxyl-PAC, BioWeb, AGAR®

Data Sources:

Captor process, Water Science and Technology, Vol. 29, 10–11, pp 175–181, IWA publishing, 1994.

WERF Report, "Collection and Treatment Processes – Investigation of Hybrid Systems for Enhanced Nutrient Control," Final Report, 2000.

Communications with vendor contacts, including emails, web site, and telephone conversations.

Porous plastic foam cubes used as biomass carriers in LINPOR® process.

Technology Summary

Membrane BioReactor (MBR)

Objective:

Treatment by filtration of biomass for high-quality effluent in a smaller footprint.

State of Development:

Innovative. Various modules are being developed and improved. Some of the membrane modules are innovative while some modules are in established markets.

Description:

An MBR is a biological reactor that uses membranes for solid-liquid separation instead of conventional clarifiers. In an MBR the fine pores of membranes are used to filter water from the Mixed Liquor Suspended Solids (MLSS) process. This filtered water (permeate) leaves as secondary effluent while solids remain in the reactor as MLSS with some solids periodically withdrawn as waste solids. Using membranes instead of clarifiers enables an activated sludge system with high MLSS concentrations, thereby reducing the required bioreactor volume for a desired Solids Retention Time (SRT). MBR systems can operate with MLSS concentrations at 20,000 mg/L or higher. High SRTs allow the development of slow-growing microorganisms such as nitrifiers.

Membranes used in MBRs are comprised of two basic materials: (1) organic polymers and (2) inorganic materials such as ceramics. Organic polymer-based membranes are most widely used for municipal wastewater treatment and are formed from either modified natural cellulose acetate materials or synthetic materials. The membranes are modular units. The modules are of the following types: tubular, hollow-fiber, spiral-wound, plate-and-frame, and pleated cartridge filters, depending on the desired application.

Some MBR systems are designed for membranes, immersed in the reactors. Other applications locate the membranes in a separate stage or compartment. Any of the previously listed types of membranes can be used in either application.

Membrane fouling is the systematic accumulation of suspended solids, colloids, precipitates, and macromolecules on the membrane surface or inside the pores, causing a reduction in membrane permeability. Commonly used strategies to control fouling includes chemical washing and cleaning as well as air-scour and permeate back-pulsing to prevent cake-layer formation.

Comparison to Established Technologies:

The advantages of MBR systems over conventional biological systems include better effluent quality, smaller space requirements, and less sludge generation. Since the MBR acts as a filter and it separates water from the MLSS, it can achieve TSS less than 1.0 mg/L and BOD less than 1.5 mg/L. MBRs offer a small footprint; therefore, it is an excellent option for expanding existing plants with very limited space. MBR systems provide operational flexibility with respect to flow rates and the ability to readily add or subtract modular units as necessary. However, immersed membranes typically require that water be maintained a a reasonably constant level so that they remain wet. Throughput limits are required by the physical properties of the membrane resulting in the fact that peak design flows should be no more than 1.5 to 2 times the average design flow. MBRs have been used with Biological Nutrient Removal (BNR) systems and can achieve total nitrogen levels below 4.0 mg/L and total phosphorus levels less than 0.5 mg/L.

Available Cost Information:

Approximate Capital Cost: Capital costs vary with the size of plant as the economy of scale applies ($6 million/MGD for 4 MGD and $3.2 million/MGD for 12 MGD plant).

Approximate O&M Costs: Operating costs are mainly attributed to power due to high mixed liquor concentration in the reactor and membrane cleaning costs ($1.23/1,000 gal).

Technology Summary

Membrane BioReactor (MBR) (Contd)

Vendor Name(s):

Enviroquip, Inc.
2404 Rutland Drive, Suite 200
Austin, TX
Telephone: 512-834-6019
Email: dennis.livingston@enviroquip.com
Web site: http://www.enviroquip.com/

US Filter/MEMCOR
4116 Sorrento Valley Blvd.
San Diego, CA 92121

Zenon Environmental Services, Inc.
3239 Dundas Street West
Oakville, Ontario, Canada
Telephone: 905-465-3030
Fax: 905-465-3050
Email: rsccott@zenon.com
Web site: http://www.zenon.com/

Mitsubishi International Corporation
333 South Hope Street West, Suite 2500
Los Angeles, CA 90071
Telephone: 213-687-2853
Fax: 213-626-3739
Email: lei.ge@mitsubishicorp.com

Infilco Degremont Inc.,
P.O. Box 71390
Richmond, VA 23255-1390
8007 Discovery Drive
Richmond, VA 23229-8605
Telephone: 804-756-7600
Fax: 804-756-7643
Web site: http://www.infilcodegremont.com/index.html

Ḱeppel Seghers Engineering Singapore Pte Ltd./ Toray
31 Shipyard Road
Singapore 628130
Telephone: 32-0-3-880-7704
Fax: 32-0-3-880-7749
Web site: www.keppelsegners.com

Huber Technoogy Inc.
9805 North Cross Center Court, Suite H
Huntersville, NC 28078
Telephone: 704-949-1010
Fax: 704-949-1020
Web site: www.hubertechnology.com

Installation(s):

Chino Valley, AZ

Pumpkinvine, GA

Hamptons, GA

Hyrum City, UT

Traverse City WWTP – 17 MGD, Grand Traverse County, MI

Hampton Creek WWTP – 1.0 MGD, 5235 Hampton Golf Club Drive, Hampton, GA

Stevens Pass WWTP – 0.21 MGD

Cauley Creek – 5.0 MGD, 7225 Bell Road, Duluth, GA 30097

Broad Run Water Reclamation Facility,
Loudoun County Sanitation District, Ashburn,VA
Telephone:571-223-3855
Fax: 571-223-3866

Membrane BioReactor (MBR) (Contd)

Key Words for Internet Search:

Membrane bioreactor, wastewater, tubular, hollow-fiber, spiral wounds, plate and frame, pleated cartridge filters

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

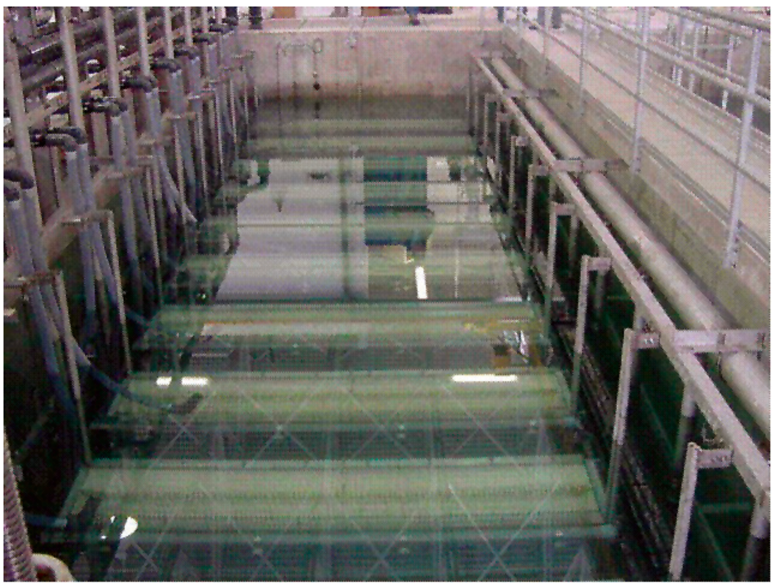
Web site data sources are as follows:

http://www.werf.org/products/MembraneTool/home/

http://www.zenon.com/

http://www.enviroquip.com/

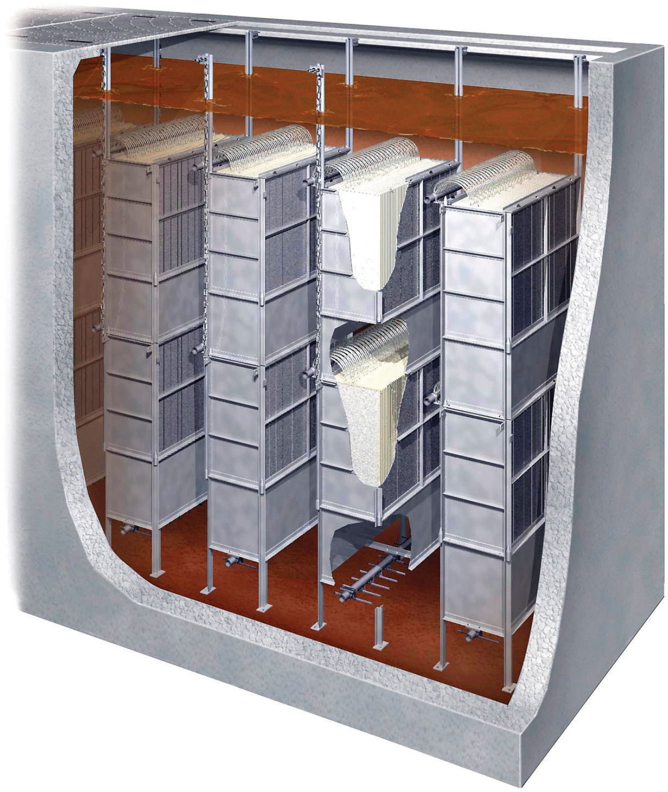
http://www.infilcodegremont.com/index.html



Picture of MBR Installations

Technology Summary

Membrane BioReactor (MBR) (Contd)



MBR Plate and Frame Modules
Pictures courtesy of Enviroquip, Inc. and Zenon Environmental Services, Inc.

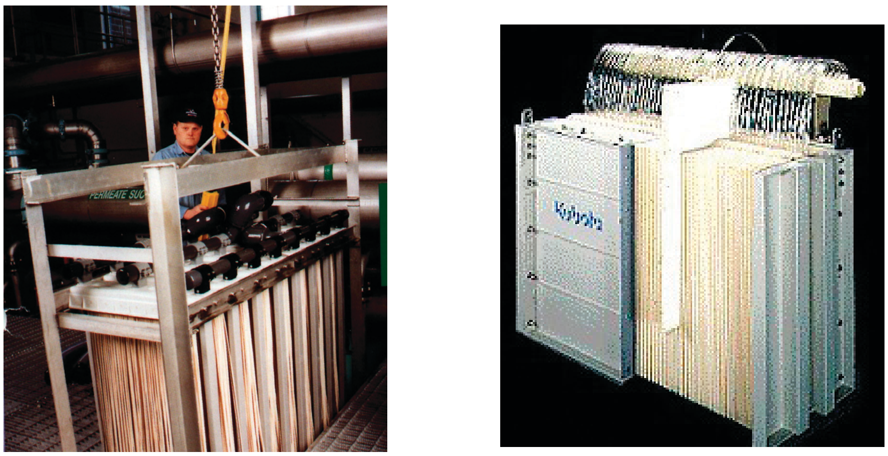
5-mgd Hollow Fiber Plant

Technology Summary

Membrane BioReactor (MBR) (Contd)

Immersed Membrane Suppliers

- Zenon Environmental Services, Inc.
- Kubota (Enviroquip, Inc.)
- Mitsubishi International Corporation (GE Water)
- US Filter/MEMCOR
- Seghers Keppel/Toray
- Huber Technology



Hollow Fiber MBR

Flat Sheet Plant

Technology Summary

Membrane BioReactor (MBR) (Contd)

Common MBR Characteristics

- Modular assemblies: Multiple parallel units
- Scouring air: Prevent solids deposition
- Fine screen pretreatment: 2 mm max solids
- Filterable sludge: DO > 0 and SRT > 12 days
- High recirculation Rates: Return > 4 x Influent flow
- Periodic relaxation: 1 min no flow every 10
- Periodic backflush: Weekly/monthly with NaOCl
- Periodic chemical clean: Semiannual/annual

MBR Design Considerations

- Membrane design flux: Avg, max, and peak
- Flow equalization: Inline or offline
- Target MLSS range: SRT > 12 days
- Hydraulic retention time (HRT): Adequate to avoid short circuit
- Air scour requirement: Low O_2 transfer
- Supplemental aeration: DO > 1 mg/L MBR
- Dentrification: Supplemental air reduction

Hollow Fiber versus Flat Sheet

Hollow Fiber

- Design flux: 8 to 12 gal/ft^2 x d avg,
  20 to 28 gal/ft^2 x d max, <36 gal/ft^2 x d peak
- Target MLSS: 10,000 to 15,000 mg/L
- Scouring air: 0.013 to 0.016 cfm/ft^2
- Piping: Above liquid, top access
- Trans Membrane Pressure (TMP) differential: 5 to 16 ft forward, 100 ft back

Flat Sheet

- Design flux: 12 to 16 gal/ft^2 x d avg,
  24 to 32 gal/ft^2 x d max, <40 gal/ft^2 x d peak
- Target MLSS: 15,000 to 20,000 mg/L
- Scouring air: 0.028 to 0.030 cfm/ft^2
- Piping: Submerged, piping gallery

Technology Summary

Mobile-Bed Reactor Technology (MBRT) Process

Objective:
BOD removal, nitrification and denitrification

State of Development:
Innovative.

Description:
The MBRT process consists of small cylindrical polyethylene carrier elements in aerated or nonaerated basins for biofilm growth. The mixers in the system continuously keep the elements circulated. A final clarifier is used to settle out the sloughed solids.

The process is defined as a hybrid system as it can be easily retrofitted into existing activated-sludge basins. While similar to IFAS systems, this technology is different because the process does not include an activated-sludge return. Kaldnes®-HYBAS™/ActiveCell™, Hyrdoxyl-F3R, GeoReactor® systems are examples of the MBRT process.

The moving-bed biofilm process combines the technologies of activated-sludge processes and biofilm processes. The moving-bed biofilm process is frequently used for upgrading an existing plant, especially when space is an issue, because of the retrofit aspects of this technology. High-rate biofilm systems, such as the ones listed, are highly efficient in removing the soluble organic and nitrogen loads.

Comparison to Established Technologies:
MBRTs do not recycle activated sludge in the reactor. The media in a reactor are constantly moving to provide better aeration.

Available Cost Information:
Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):
Kaldnes MBBR
Kaldnes North America Inc.
58 Weybosset Street, 4th Floor
Providence, RI 02903
Telephone: 401-270-3898
Fax: 401-270-3908
Email: chj@anoxkaldnes.com
Web site: http://www.kaldness.com

Parkson Corporation
2727 NW 62nd Street
P.O. Box 408399
Fort Lauderdale, FL 33309-8399
Telephone: 800-553-5419 or 954-974-6610
Fax: 954-974-6182
Web site: http://www.parkson.com

Hydroxyl Systems Inc.
1100 S. Main Road
Westport, MA 02790
Telephone: 508-636-9289
Fax: 508-636-7823
Web site: http://www.hydroxyl.com/index.php

Installation(s):
AnoxKaldnes-HYBAS™
Broomfield Wastewater Reclamation
2985 West 124th Avenue
Broomfield, CO 80020

HYDROXYL-iMBR™

City of Moorehead, MN

Technology Summary

Mobile-Bed Reactor Technology (MBRT) Process (Contd)

Key Words for Internet Search:

Mobile-bed reactor, MBR, MBRT, wastewater, biofilm, activated sludge

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

http://www.hydroxyl.com/

WERF Report, "Collection and Treatment Processes – Investigation of Hybrid Systems for Enhanced Nutrient Control," Final Report, 2000.

http://www.kaldnes.com/process.html

Technology Summary

Bardenpho® (Three Stage) with Returned Activated Sludge (RAS) Denitrification

Objective:
Enhanced removal of phosphorus and nitrogen from wastewater.

State of Development:
Innovative Use of Established Technology.

Description:
The Three-Stage Bardenpho® with Returned Activated Sludge (RAS) denitrification provides phosphate and nitrogen removal efficiently. First, RAS is subjected to an anoxic stage to remove nitrates. While a fraction of the influent wastewater is sent to the anoxic reactor, the remaining portion is fed to the anaerobic reactor directly. There is also an internal recycle from the oxic reactor to the second-stage anoxic reactor.

Comparison to Established Technologies:
In the basic Three-Stage Bardenpho® process, the oxic reactor is in tandem with the anaerobic and anoxic reactors. RAS is returned to the anaerobic reactor and there is an internal recirculation from the oxic reactor to the anoxic reactor. The Three-Stage Bardenpho® with RAS denitrification process includes the anaerobic reactor sandwiched between the two anoxic reactors, with the oxic reactor downstream of the three stages.

Available Cost Information:
Approximate Capital and O&M Costs: Cost estimates are dependent upon local requirements and specific application and economy of scale applies. For example, uniform annual cost of a 100,000 GPD plant is estimated about $272,075 based on an interest rate of 6% for a 20-year period.

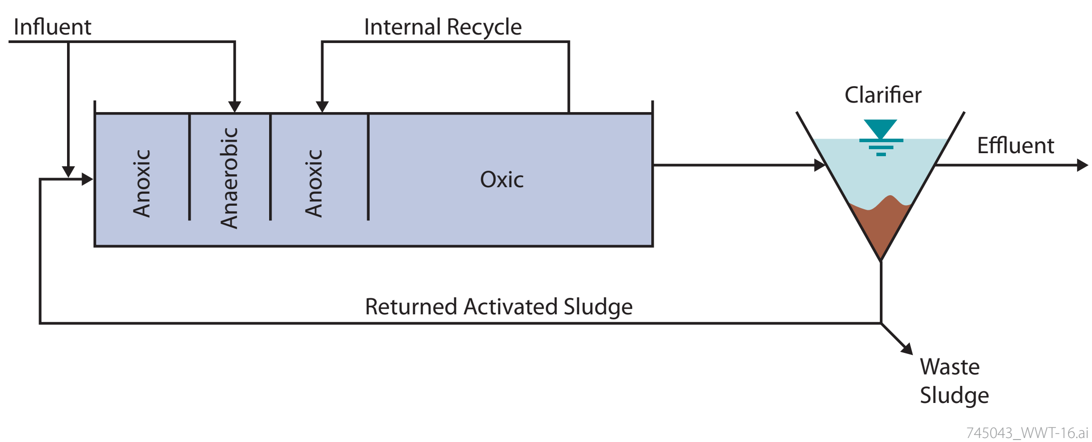
Vendor Name(s):
N/A

Installation(s):
Used in Kelowna WWTP, British Columbia, Canada

Key Words for Internet Search:
Modified Bardenpho®, three-stage RAS denitrification

Data Sources:
"Design and Retrofit of Wastewater Treatment Plants for Biological Nutrient Removal," Water Quality Management Library, Volume 5, Second Edition, 1998.

Principles and Practice of Nutrient Removal from Municipal Wastewater, Lewis Publishers, Second Edition, 1991.



Process Flow Diagram for Three-Stage Bardenpho® with RAS Denitrification Process

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Technology Summary

Biological-Chemical Phosphorus and Nitrogen Removal (BCFS) Process

Objective:

Enhanced nutrient removal (nitrogen and phosphorus).

State of Development:

Innovative Use of Established Technology.

Description:

The BCFS process has been developed to achieve low-nutrient effluent concentrations at relatively low Biochemical Oxygen Demand Ratio to Nitrogen (BOD/N) and Biochemical Oxygen Demand Ratio to Phosphorus (BOD/P) ratios in the influent. The process design is based on the University of Cape Town (UCT) process. In the process, the return sludge is introduced at the start of the anoxic zone to prevent the presence of nitrate in the anaerobic zone. Mixed liquor is recirculated from the end of the anoxic zone to the anaerobic zone. At the end of the anoxic zone, most of the nitrate is removed. In the anoxic zone, the phosphorus is taken up by phosphate-accumulating bacteria in the activated sludge. The anoxic phosphorus uptake results in a lower energy and BOD demand as well as lower sludge production.

Because of the different microorganisms involved in phosphorus and nitrogen removal, the retention times for both removal processes are different. For maximum nitrification and availability of COD for denitrification a long sludge-retention time is necessary. For biological phosphorus removal, usually shorter retention times are advantageous. In the BCFS process, long sludge-retention times that are favorable for the removal of nitrogen are preferred.

Comparison to Established Technologies:

The BCFS process achieves removal rates for BOD, nutrients, and suspended solids similar to other process designs based on the activated-sludge concept. With the BCFS process configuration, a stable and reliable operation is possible. It has been demonstrated that the biological phosphorus removal capacity is usually sufficient to comply with effluent standards. The settling characteristics of the activated sludge can be enhanced by implementing the BCFS process design. The compartmentalization of the process allows low and stable sludge volume index (SVI) to be achieved. At the Holten WWTP, SVI is reduced from 150 to 80 mL/mg. Chemical phosphorus removal is limited by kinetic factors as well as stoichiometric factors, and excessive inorganic precipitant requirements need to be reduced.

Available Cost Information:

Approximate Capital Cost: The capital costs for the implementation of a BCFS process in case of upgrading depend on the availability of existing tanks and equipment as well as local requirements and specific application. Actual costs are not disclosed.

Approximate O&M Costs: Not disclosed.

Vendor Name(s):

N/A

Installation(s):

Holten WWTP, The Netherlands

Technology Summary

Biological-Chemical Phosphorus and Nitrogen Removal (BCFS) Process (Contd)

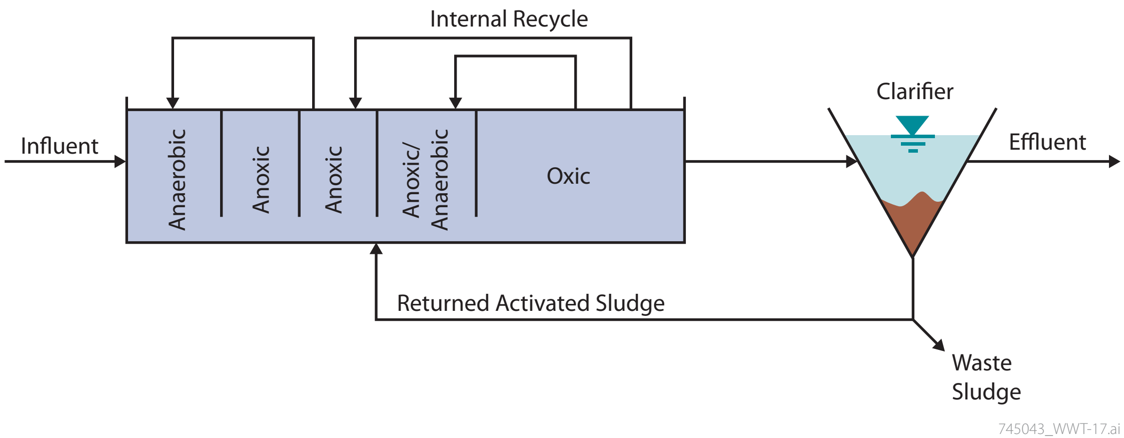
Key Words for Internet Search:

BCFS, nitrogen phosphorus nutrient removal

Data Sources:

Technical University of Delft,The Netherlands.

Waterboard Groot Salland, The Netherlands.



Process Flow Diagram for BCFS Process

Technology Summary

Modified University of Cape Town (MUCT) Process

Objective:

Enhanced removal of phosphorus and nitrogen from wastewater.

State of Development:

Innovative Use of Established Technology.

Description:

The Modified University of Cape Town (MUCT) process provides efficient nitrogen removal by sending the RAS to the anoxic zone. The anaerobic reactor, is located upstream of two anoxic reactors. RAS is subjected to the first anoxic reactor stage. There is an internal recycle from the first anoxic reactor to the anaerobic reactor, and another internal recycle from the oxic reactor to the second anoxic reactor.

Comparison to Established Technologies:

The MUCT process is different from the UCT process. MUCT includes two anoxic stages in series. Influent wastewater is fed to the anaerobic reactor, which is located upstream of the anoxic reactors. RAS is returned to the first anoxic reactor. There is an internal recirculation from the first anoxic reactor to the anaerobic reactor. Removal of nitrogen in the aeration basin may vary from 40 to 100 percent and the effluent nitrate should be sufficiently low so as not to interfere with the anaerobic contact zone. Plug flow configuration of the aeration basin allows the anoxic zones in the first section of the plant to be low, while the endogenous oxygen demand at the end of the aeration basin and the DO level will increase to allow for the required nitrification and phosphate uptake. Nitrates not removed in the aeration basin will be recycled to the anoxic zone. Therefore, efficient overall nitrogen removal is achieved more economically.

Available Cost Information:

Approximate Capital and O&M Costs: Cost estimates are dependent upon local requirements and specific application and economy of scale applies. For example, uniform annual cost of a 100,000 GPD plant is estimated to be about $272,075 based on an interest rate of 6 percent for a 20-year period.

Vendor Name(s):

N/A

Installation(s):

King County South AWTP, WA

Key Words for Internet Search:

Modified UCT process, RAS anaerobic reactor

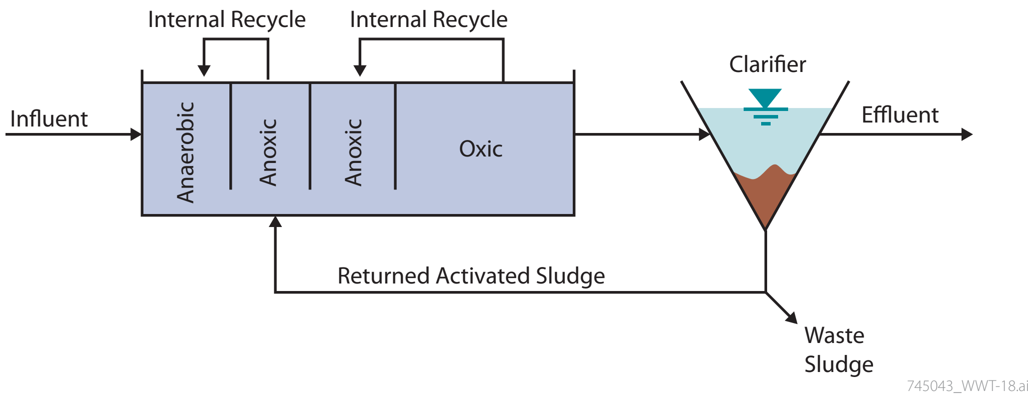
Data Sources:

"Design and Retrofit of Wastewater Treatment Plants for Biological Nutrient Removal," Water Quality Management Library, Volume 5, Second Edition, 1998.

Principles and Practice of Nutrient Removal from Municipal Wastewater, Lewis Publishers, Second Edition, 1991.

Technology Summary

Modified University of Cape Town (MUCT) Process (Contd)



Process Flow Diagram for Modified UCT Process

Technology Summary

Modified Anaerobic/Oxic (A/O) Process

Objective:

Enhanced removal of phosphorus and nitrogen from wastewater.

State of Development:

Innovative Use of Established Technology.

Description:

The modified A/O process provides phosphate and nitrogen removal. If nitrification is not required and the temperatures are not high, the simple two-stage, high-rate A/O process may be sufficient. However, with higher temperatures some nitrate formation can not be avoided. Therefore, RAS should be subjected to an anoxic stage to remove nitrates before mixing it with the influent wastewater.

Comparison to Established Technologies:

The simple high-rate A/O process uses an anaerobic reactor upstream of the oxic reactor. RAS is returned to the anaerobic reactor. The modified A/O process, however, includes an anoxic reactor downstream of the anaerobic reactor where only RAS is recycled. Influent wastewater is directly sent to the anaerobic reactor for phosphorus removal. There is an internal recirculation from the anoxic reactor to the anaerobic reactor.

Available Cost Information:

Approximate Capital Cost: Cost estimates are dependent upon local requirements and specific application and economy of scale applies. For example, uniform annual cost of a 100,000 GPD plant is estimated about $244,000 based on an interest rate of 6 percent for a 20-year period.

Approximate O&M Costs: Unknown.

Vendor Name(s):

N/A

Installation(s):

Fayetteville AWTP, AR

Key Words for Internet Search:

High-rate A/O with RAS dentrification

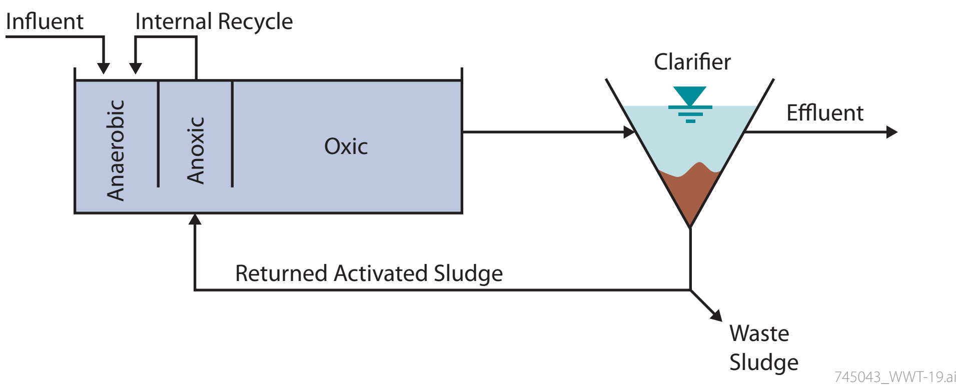
Data Sources:

"Design and Retrofit of Wastewater Treatment Plants for Biological Nutrient Removal," Water Quality Management Library, Volume 5, Second Edition, 1998.

Principles and Practice of Nutrient Removal from Municipal Wastewater, Lewis Publishers, Second Edition, 1991.

Technology Summary

Modified Anaerobic/Oxic (A/O) Process (Contd)



Process Flow Diagram for Modified Anaerobic/Oxic (A/O) Process

Technology Summary

Trickling Filter/Solids Contactor (TF/SC)

Objective:
Organics and nitrogen removal.

State of Development:
Innovative Use of Established Technology.

Description:
The TF/SC is comprised of a trickling filter, aerated-solids contact tanks, and a flocculation clarifier with RAS recycled back to the solids contact tanks. Final clarification of TF effluent is required. A portion of this treated effluent is recirculated for media wetting. This is a hybrid system that combines the low-energy consumption and simple operation of a trickling filter with the excellent settling characteristics of a suspended growth system. The benefits include organic removal and nitrification through the TF and superior solids flocculation and settling in the aeration component. The aeration component is referred to as solids contact tank since its retention time is relatively short (30 minutes or less). There are many important design considerations for the TF/SC process, including periodic media flushing, solids contact operation, flocculating clarifier design, and reduced hydraulic gradeline and floc disruption to the solids contactor.

Comparison to Established Technologies:
A number of advances have occurred since the introduction of the trickling filter that makes it a potential candidate for a secondary facility with the increasingly stringent effluent requirements. These advances include the development of better media and the discovery of new combined processes. The development of new media including vertical filter media, horizontal filter media, random media, and cross-flow media has increased the void area available compared to rock media. These new types of media provide increased air circulation, higher specific surface area for biological growth, and the ability to slough off growth without plugging.

Available Cost Information:
Approximate Capital Cost: Dependent upon local requirements and specific application.

Approximate O&M Costs: Not available.

Vendor Name(s):
N/A

Installation(s):
Annacis Island WWTP, Vancouver, Canada

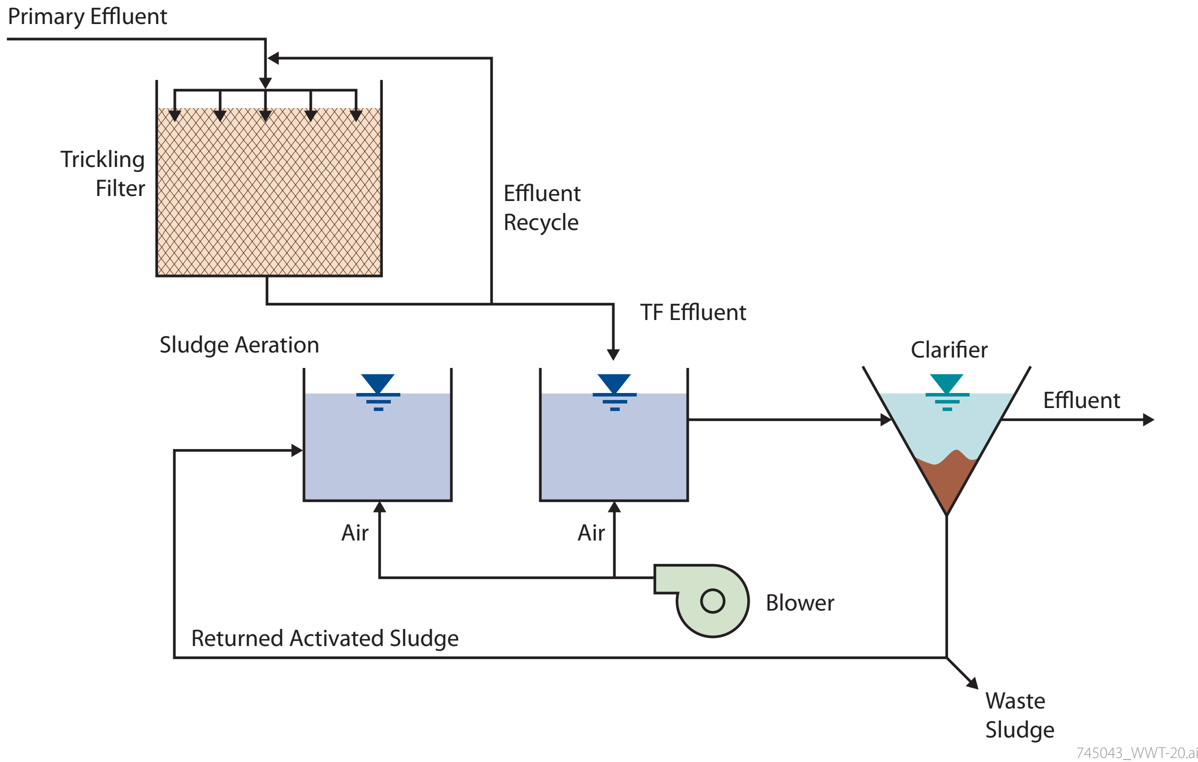
Key Words for Internet Search:
Trickling Filter/Solids Contactor

Data Sources:
Brookville Water Pollution Control Centre Upgrade, Class Environmental Assessment Report, Simcoe Engineering Group Limited, December 2004.

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

Technology Summary

Trickling Filter/Solids Contactor (TF/SC) (Contd)



Process Flow Diagram for TF/SC Process

Technology Summary

Aerobic Granular Sludge Process (AGSP)

Objective:

The AGSP has the ability to provide comparable treatment efficiency to conventional activated sludge at lower costs with the compact aerobic granular sludge technology.

State of Development:

Embryonic.

Description:

It has been demonstrated that granular sludge has improved settling characteristics facilitating efficient solid-liquid separation. With high biomass retention and biological activity, a granular sludge reactor can be operated at high-volume loading rates. The AGSP reactor is operated as a sequenced batch reactor (SBR), which is necessary to achieve process conditions for the formation of aerobic granular sludge. Similar to conventional applications of the SBR concept, one treatment cycle in the AGSP reactor has four well-defined phases. These are filling, mixing/aerating, settling, and decanting. Batch feeding of the reactor induces a high-substrate concentration at the beginning of a treatment cycle. Due to a high concentration gradient, substrate can diffuse deeply into the granules preventing starvation of bacteria within the granules. With insufficient feeding (diffusion gradient), the bacteria at the center of the granules will be starved and weakened which eventually leads to the disintegration of the granules. In general, the size of the granules will increase until the formation of stable granules is limited by substrate diffusion. Less stable granules are susceptible to shear forces and will be reduced in size or disintegrate. Weakened biomass in the granule center will also decrease the granule density and inhibit settling processes, causing washout. Thus, a dynamic equilibrium will eventually be reached between substrate concentration and the average diameter of granules. It has been observed that high-shear forces under turbulent flow conditions give selective advantage to the formation of stable granules. Research has shown that nitrogen removal rates of more than 80 percent seem feasible. While nitrification takes place in the outer, aerobic layer of the granules, denitrification will occur in the anoxic core of the granules with the necessary carbon source being supplied by substrate diffused into the granules.

Comparison to Established Technologies:

In the past, granular sludge was used as part of anaerobic treatment process design concepts. However, recent research has shown that granular sludge can also be obtained under aerobic process conditions. Unlike bacteria found in anaerobic granular sludge, aerobic bacteria, in general, do not naturally form granules. In order to achieve granulation under aerobic process conditions, short-settling times are used to introduce a strong selective advantage for well-settling sludge granules. Poor-settling biomass will be washed out under these conditions. Accordingly, appropriate settling and decanting times in each treatment cycle are chosen. In pilot trials, the AGSP reactor is operated at settling times that correspond to average settling velocities of about 10 to 15 mph. These relatively high settling velocities allow high-volume loadings of the reactor resulting in a compact reactor design.

Further development of the aerobic granular-sludge technology may result in the design of compact secondary and tertiary treatment units with small footprints, thereby providing cost savings because of reduced space requirements.

Available Cost Information:

Approximate Capital Cost: Not available.

Approximate O&M Costs: Not available.

Technology Summary

Aerobic Granular Sludge Process (AGSP) (Contd)

Vendor Name(s):

Delft University of Technology
Department of Biotechnology
Environmental Biotechnology Group
Delft, The Netherlands
Telephone: 31-15-278-1551
Email: m.dekreuk@tnw.tudelft.nl
Web site: www.bt.tudelft.nl

Installation(s):

There are no installations in the United States.

Key Words for Internet Search:

Aerobic granular sludge, aerobic granular reactor technology

Data Sources:

De Kreuk, M. K. and M. C. M. Van Loosdrecht, "Selection of Slow Growing Organisms as a Means for Improving Aerobic Granular Sludge Stability," Water Science Technology, 49, pp. 11–12 and 9–19, 2004.

Etterer, T. and P. A. Wilderer, "Generation and Properties of Aerobic Granular Sludge," Water Science Technology, pp. 3–43, 2001.

Morgenroth, E., T. Sherden, M. C. M. Van Loosdrecht, J. J. Heijnen, and P. A. Wilderer, "Aerobic Granular Sludge in a Sequencing Batch Reactor," Water Resources, Vol. 31, No. 12, 1997.

Technology Summary

ANaerobic Membrane BioReactor (AN-MBR)

Objective:

Anaerobic treatment by filtration of biomass for high-quality effluent in a smaller footprint.

State of Development:

Embryonic.

Description:

An AN-MBR is similar to an MBR facility except that the biological processes are done in anaerobic reactions. In the AN-MBR process, the mixed liquor of the anaerobic reactor passes through membranes for liquid-solids separation. The membranes can be internal, submerged modules or located in an external tank. Different types of membrane material can foul at different rates due to struvite formation and other factors. Review of recent information indicates that AN-MBR systems may be able to achieve treatment levels comparable to conventional activated sludge processes under moderate temperature conditions. Economics may favor an AN-MBR system located upstream of an existing wastewater treatment plant. The idea is to withdraw and pre-treat some of the incoming wastewater and reduce the organic loadings into the existing plant.

Comparison to Established Technologies:

Conditions in an AN-MBR are ideal for the formation of struvite, which is reported to contribute significantly to the fouling of membranes. Membrane materials, used for anaerobic applications, have hydrophobic characteristics that cause lower permeate flux than in aerobic applications.

The production of biogas with a high content of methane provides an additional benefit with about 22 to 26 megajoules (MJ) of energy per cubic meters depending on the carbon dioxide content. Gas in the headspace of an AN-MBR reactor can be used for continuously sparging an internal membrane system.

Available Cost Information:

Approximate Capital Cost: Not available.

Approximate O&M Costs: Not available.

Vendor Name(s):

Enviroquip, Inc.
2404 Rutland Drive, Suite 200
Austin, TX 78758
Telephone: 512-834-6019
Web site: http://www.enviroquip.com/

US Filter/MEMCOR
4116 Sorrento Valley Blvd.
San Diego, CA 92121

Zenon Environmental Services, Inc.
3239 Dundas Street West
Oakville, Ontario, Canada
Telephone: 905-465-3030
Fax: 905-465-3050
Email: rsccott@zenon.com
Web site: http://www.zenon.com/

Installation(s):

There are no known large, full-scale AN-MBR systems in operation that treat municipal wastewater.

Technology Summary

ANaerobic Membrane BioReactor (AN-MBR) (Contd)

Vendor Name(s) (Contd):

Infilco Degremont Inc.
P.O. Box 71390
Richmond, VA 23255-1390
8007 Discovery Drive
Richmond, VA 23229-8605
Telephone: 804-756-7600
Fax: 804-756-7643
Web site: http://www.infilcodegremont.com/index.html

Key Words for Internet Search:

ANaerobic Membrane BioReactor, AN-MBR, anaerobic treatment of lower strength wastewaters

Data Sources:

Membrane Bioreactors for Anaerobic Treatment of Wastewaters, WERF Project 02-CTS-4 Phase 1 Report, 2004.

Membrane Bioreactors for Anaerobic Treatment of Wastewaters, WERF, Phase 2 Report, 2004.

Preliminary Investigation of an Anaerobic Membrane Separation Process for Treatment of Low Strength Wastewaters, WERF, 2004.

Technology Summary

Anaerobic Migrating Blanket Reactor (AMBR®)

Objective:

Improve wastewater treatment efficiency.

State of Development:

Embryonic. Pilot-scale studies have been performed.

Description:

AMBR® is an anaerobic system like the AEBR with mixing to maintain sludge in the system. The AMBR® is a compartmentalized system where the flow of wastewater is reversed on a regular basis. In this process, the influent feed and the effluent withdrawal point is changed such that the sludge blanket remains uniform in the anaerobic reactor. This helps maintain the sludge in the system without the use of packing or settlers for solids capture.

Comparison to Established Technologies:

AMBR® is an anaerobic system with mixing to maintain sludge in the system without packing and settlers for solids capture. This technology improves process efficiency over conventional activated sludge. It has been applied overseas to treat high-strength food-processing wastewater to demonstrate this efficiency.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

Washington University
Hilltop Campus
Campus Box 1198, One Brooking Drive
St. Louis, MO 63130
Telephone: 314-935-5663
Fax: 314-935-5464
Email: angenent@seas.wustl.edu

Installation(s):

No installation in the United States at this time.

Key Words for Internet Search:

AMBR, migrating blanket reactors, wastewater treatment

Data Sources:

Angenent, Largus T. and Shihwu Sung, "Development of Anaerobic Migrating Blanket Reactor (AMBR), A Novel Anaerobic Treatment System," Water Research, Vol. 35, No. 7, pp. 1,739–1,747, 2001.

Telephone conversation with Lars Angenent, Washington University, St. Louis, MO, August 2004.

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Technology Summary

DEamMONification (DEMON)

Objective:

Biological ammonia removal from high-strength streams (e.g., sludge liquors, landfill leachate).

State of Development:

Embryonic. Full-scale system was operated in Austria and Switzerland for 3 years. A full-scale system was also operated in Swizerland for one year (article referenced below). Extensive research pilot-scale studies were performed in the United States (New York and Alexandria) and Europe. Technology is available commercially.

Description:

DEamMONication comprises two autotrophic reaction steps: (1) partial nitritation (aerobic oxidation of about 50 percent of ammonia to nitrite); and (2) anaerobic oxidation of residual ammonia by generated nitrite. The DEMON process is operated in a single-sludge SBR system where intermittent aeration is provided. Aeration control is based on the pH-signal that corresponds with the production of intermediate nitrite, and allows an optimum interaction of both process steps.

Comparison to Established Technologies:

DEMON, as an exclusively autotrophic process, requires no organic carbon and substantially less aeration energy as compared to conventional nitrification/denitrification systems. The patented control system provides stable process performance (90 percent ammonia removal) at varying influent loads. Suspended growth biomass of slowly growing anaerobic ammonia oxidizers can be easily transferred from one plant to the other to accelerate startup procedure.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

Grontmij Nederland BV
Infrastructure and Milieu
Afdeling Water and Reststoffen
Postbus 203, 3730 AE De Bilt
Handelsregister 30029428
The Netherlands
Telephone: 31-30-220-79-11
Fax: 31-30-220-01-74
Web site: http://www.grontmij.nl/site/nl-ni/

Cyklar-Stulz
CH-8737 Gommiswald Rietwiesstrasse 39
Switzerland
Email: info@cyklar.ch
Web site: http://www/cyklar.ch

Installation(s):

Full-scale DEMON systems in Strass, Austria and Glarnerland, Switzerland. Pilot systems are operated by Alexandria Sanitation Authority, Virginia, and by New York City Department of Environmental Protection, New York. There are no full-scale installations in the United States at this time.

Key Words for Internet Search:

Deammonification, DEMON process, sidestream treatment, ammonia

Data Sources:

Wett, B., "Development and Implementation of a Robust Deammonification Process," presentation at the Leading Edge Technologies Conference, Singapore, 2007.

Wett, B., S. Murthy, et al., "Key Parameters for Control of DEMON Deammonification Process," presentation at the Nutrient Removal Conference in Baltimore, MD, 2007.

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Technology Summary

Hydrogen-based hollow-Fiber Membrane Biofilm Reactor (HFMBfR)

Objective:
Treatment to remove oxidized contaminants.

State of Development:
Embryonic.

Description:
The process reactor consists of a hollow-fiber membrane bundle with an inner and outer microporous layer and a nonporous layer sandwiched in between. Hydrogen is introduced inside the fibers, which are sealed on one end to prevent escape and allowed to diffuse through the nonporous layer. The water in contact with the biofilm layer reacts to reduce the contaminant while hydrogen is oxidized. (U.S. Patent – 6,387,262)

The technology can be used for treating wastewater, groundwater, or drinking water. The process is effective in treating water with contaminants such as perchlorate, nitrates, chlorinated solvents, selenate, bromate, chromate, and radionuclides.

Comparison to Established Technologies:
Not comparable to any established technology.

Available Cost Information:
Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):
Biodesign Institute
Arizona State University
1001 South McAllister Avenue
P.O. Box 875701
Tempe, AZ 85287-5701
Telephone: 480-727-0434
Email: rittmann@asu.edu

Applied Process Technology, Inc.
3333 Vincent Road, Suite 222
Pleasant Hill, CA 94523
Telephone: 925-977-1811 or 1-888-307-2749
Fax: 925-977-1818
Email: info@aptwater.com
Web site: http://www.aptwater.com/

Installation(s):
There are no installations in the United States at this time.

Key Words for Internet Search:
HFMBfR, reducing oxidized contaminants

Data Sources:
http://www.aptwater.com

http://www.uspto.gov/

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Technology Summary

Membrane-Aerated BioReactor (MABR)

Objective:

Aeration of membranes to enable the treatment of wastewater.

State of Development:

Embryonic. Commercially not available; extensive research is currently being performed in the United States and Europe.

Description:

A Membrane-Aerated BioReactor (MABR) uses a gas-permeable membrane for oxygen transfer to wastewater and does not use bubble aeration as used in conventional systems for aeration. The ability to control the contact time between air and wastewater enables high-oxygen transfer efficiencies. The oxygen transfer at the membrane enables microbial colonization at the membrane surface. Oxygen transfer across the membrane increases due to microbial respiration. The biofilm formed on the membrane surface; therefore, the aerobic and anaerobic processes go on at the same time. The MABR can simultaneously remove BOD and nitrogen from the wastewater.

Comparison to Established Technologies:

The MABR, when compared to trickling filter and Membrane BioReactor (MBR), can have lower energy requirements and be a single-reactor treatment process.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

University of Minnesota
Department of Civil Engineering
500 Pillsbury Drive, SE
Minneapolis, MN 55455
Telephone: 612-625-9857
Email: semme001@amn.edu

Installation(s):

There are no installations in the United States at this time.

Key Words for Internet Search:

Membrane-Aerated BioReactor, MABR, wastewater, gas-permeable membrane

Data Sources:

WERF Report, Treatment Processes – Membrane Technology: Pilot Studies of Membrane-Aerated Bioreactors, Final Report, 2005.

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Technology Summary

Microbial Fuel Cell (MFC) Based Treatment System

Objective:

Generate electricity from wastewater treatment.

State of Development:

Embryonic. Not available commercially; however, extensive research underway.

Description:

The concept of the system is based on using bacteria in a conductive material in which the bacteria can grow. The microorganisms present in the wastewater oxidize compounds in the wastewater away from oxygen during the process. The electrons gained through oxidation are transferred towards an electrode (anode). The electrons depart through an electrical circuit towards a second electrode (cathode). At the cathode, the electrons are transferred towards a high-potential electron acceptor, preferably oxygen. As current flows over a potential difference, power is generated as a result of bacterial activity. The generation of electricity is based on the respiratory enzymes of the bacteria that span the outer membrane and transfer electrons to materials on the surface of the cell.

Comparison to Established Technologies:

Not comparable to any established technology.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

Research Projects at various universities including:

Pennsylvania State University
Hydrogen Energy Center
University Park, PA 16802
Telephone: 814-863-7908
Email: blogan@psu.edu

Washington University
Hilltop Campus
Campus Box 1198, One Brooking Drive
St. Louis, MO 63130
Telephone: 314-935-5663
Fax: 314-935-5464
Email: angenent@seas.wustl.edu

Installation(s):

There are no installations in the United States at this time.

Key Words for Internet Search:

Microbial fuel cell, MFC, wastewater treatment, energy conversion

Data Sources:

Logan, B.E., "Extracting Hydrogen and Electricity from Renewable Resources," Environmental Science Technology, 38, 160A–167A, 2004.

Logan, B.F., et al., "Microbial Fuel Cells: Methodology and Technology," Environmental Science Technology, 40 (7); 5,181–5,192, 2006.

http://www.engr.psu.edu/ce/enve/mfc-logan_files/mfc-logan.htm

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Technology Summary

Multi-Stage Activated Biological Process (MSABP™)

Objective:
Carbon oxidation, nitrification, and denitrification

State of Development:
Embryonic.

Description:
The Multi-Stage Activated Biological Process (MSABP™) is an embryonic method of domestic and industrial wastewater treatment based upon the spatial microorganisms' succession and the trophic hydrobiont chains. These spatially segregated trophic microorganism chains provide proper conditions at which bacteria are used as food source sequentially by first primary and then higher level microorganisms in the food chain. Apparently, the spatial microorganism succession provided treatment by aerobic and anaerobic microorganisms maintained at different stages of the biological reactor.

There are eight compartments in the biological reactor. The influent wastewater enters the first compartment and travels through the each compartment circulating via the flow pattern created by air diffusers located at the bottom of the tank. Wastewater flow is in a looping pattern so that short circuiting is reduced. Removal of organics and nitrification take place in the first four compartments. Fifth and sixth compartments are anoxic and denitrification occurs in these compartments. Usually 80 percent of the BOD is reduced in these compartments leaving about 20 percent available for nitrification and denitrification processes. The seventh and eighth compartments operate in endogenous phase and digest remaining volatile solids.

Comparison to Established Technologies:
The vendor claims that no waste-activated sludge is generated in this system. Total number of compartments and size are based on the influent wastewater characteristics and treatment goals.

Available Cost Information:
Approximate Capital Cost: Dependent upon local requirements and specific application.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):
Aquarius Technologies, Inc.
1103 Mineral Springs Drive, Suite 300
Port Washington, WI 53074
Telephone: 262-268-1500
Fax: 262-268-1515
Email: info@aquariustechnologies.com

BioScape Technologies, Inc.
Tim Bossard, Jack Akin
816 Bennett Avenue
Medford, OR 97504
Telephone: 541-858-5774
Fax: 541-858-2771
Email: info@bioscapetechnologies.com

Installation(s):
Beijing Eizen Lubao Oil Co., China
Johnson and Johnson Ltd., China
Salatey Shamir Foods, Israel
Pigs grow farm, Spain
Marugan WWTP, Spain
Delta Textile Factory, Israel
Shtrauss Dairy Foods, Israel

Key Words for Internet Search:
Multi-Stage Activated Biological Process, MAB, MSABP™, trophic hydrobiont chains

Data Sources:
http://www.aquariustechnologies.com/

http://www.bioscapetechnologies.com/index.html

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Technology Summary

Nereda™

Objective:

Treating domestic or industrial wastewater by means of aerobic pellets.

State of Development:

Embryonic.

Description:

The Nereda™ process is based upon cultivating aerobic bacteria in conditions that cause the bacteria to form an adhesive material that bonds the bacteria into concentrated "pellets." The adhesive material and the conditions that produce it are not disclosed by the vendor. Nereda's claim is that forming pellets allow large concentrations of bacteria to be contained in less space than conventional activated-sludge bacteria that are more dispersed and less concentrated. The pellets are also easier to settle in clarifiers because of their higher density. Bacteria in the pellets are as capable of decomposing the wastewater as dispersed bacteria in conventional activated sludge; however, the advantages of higher concentrations and better settling may be able to reduce the costs of aeration basins and clarifiers. The pellets may also be less prone to bulking and poor solids settling episodes.

Comparison to Established Technologies:

The Nereda™ process offers important advantages when compared to conventional water purification processes. All the processes can occur in one reactor; therefore, this process eliminates the need for a clarifier. This process needs only a quarter of the space required by conventional installations.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

Andreas Giesen
DHV Water BV
P.O. Box 1132
3800 AL Amersfoort
The Netherlands
Telephone: 0031-33-468-22 00
Fax : 0031-33-468-28 01
Email: andreas.giesen@dhv.nl
Web site: http://www.dhv.com

Installation(s):

There are no installations in the United States at this time.

Key Words for Internet Search:

Nereda™, DHV Water BV

Data Sources:

http://www.nereda.net

http://www.dhv.com

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Technology Summary

SHARON (Single reactor High-activity Ammonia Removal Over Nitrite)

Objective:

Nitrogen removals from digested-sludge-processing recycle flows.

State of Development:

Embryonic. One full-scale application is under construction in Wards Island, New York City, New York. Six facilities are in operation worldwide.

Description:

SHARON is a sidestream process that has been developed to remove nitrogen biologically from recycle flows of anaerobically digested solids. The SHARON process takes place in a simple, completely mixed reactor without biomass retention. Compared to the conventional conversion of ammonium via the nitrification/denitrification route, the SHARON process converts ammonia nitrogen to nitrite nitrogen, which is then converted to nitrogen gas. The oxidation of ammonia is stopped at nitrite by creating favorable process conditions for nitrifying bacteria. Further oxidation of the nitrite can be prevented since at higher temperatures the ammonia oxidizers, such as nitrosomonas, grow significantly faster than the nitrite oxidizing bacteria, such as nitrobacter. This is used in the SHARON process design, which is characterized by the absence of sludge retention. By choosing a sufficiently short hydraulic retention time, the slow-growing nitrite oxidizers are washed out of the system and ammonia oxidation is stopped at nitrite. The microbiological activity in the SHARON reactor results in significant heat production, which causes a temperature rise of about 5 to 8 degrees C. Due to high process temperature of between 30 to 40 degrees C, relatively short retention times can be realized. Since the inflowing reject water from dewatering can be expected to be relatively warm, additional heating is only required in winter time.

Comparison to Established Technologies:

The removal efficiency is strongly dependent on the ammonium influent concentration and the Hydraulic Retention Times (HRTs). Generally the removal efficiency increases with higher influent concentrations and longer HRT. Considerable savings in carbon source and aeration capacity are reported when the SHARON process is compared to the conventional nitrogen conversion within the context of overall nitrogen removal. Based on European data, average nitrogen removal efficiency is in the range of 80 to 90 percent. On average, 70 percent of the nitrogen load is converted via nitrite. The presence of suspended solids is not reported to have influence on the removal efficiencies and operation of the process as it operates without sludge retention. The pH has to be controlled carefully due to high concentrations and the high-reaction rates involved in the process. The bicarbonate in the sludge liquor and the denitrification process compensate the acidifying effect of the nitrification. In the process, the CO_2 stripping needs to be sufficient to allow for full use of the bicarbonate. The process is highly dynamic and has to be designed for rapid response.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Technology Summary

SHARON (Single Reactor High-activity Ammonia Removal Over Nitrite) (Contd)

Vendor Name(s):

Mixing and Mass Transfer Technologies
Southeastern Region
8833 North Congress Ave., Suite 818
Kansas City, MO 64153
Telephone: 816-854-1969
Email: arawakomski@m2ttech.com or
tgilligan@m2ttech.com
Website: http://www.m2ttech.com

Delft University of Technology
Prof. Dr. Ir. Mark van Loosdrecht
Department of Biotechnology
Julianalaan 67, 2628 BC Delft, The Netherlands
Telephone :31-15-278 1618
Email: mark.vanLoosdrecht@tnw.tudelft.nl

Installation(s):

There are no installations in the United States at this time.

Key Words for Internet Search:

SHARON process, wastewater treatment, sidestream process, biological treatment

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

Communication with Mixing and Mass Transfer Technologies, 23 May 2005.

Technology Summary

SHARON – ANAMMOX (ANaerobic AMMonia OXidation)

Objective:
Nitrification, denitrification, and ammonia removal.

State of Development:
Embryonic. Bench-scale and pilot-scale studies have been performed throughout the world. The United States and Europe are performing extensive research. The technology is not yet available commercially.

Description:
This process is a modification of the SHARON process. The process removes ammonia from the wastewater. The principle of these combined processes is that the NH_4-N in the sludge digester effluent is oxidized in the SHARON reactor to NO_2-N for only 50 percent of NH_4-N. The mixture of nitrite and ammonia is ideally suited as influent for the ANAMMOX process, and ammonium and nitrite are anaerobically converted to nitrogen gas and water.

Comparison to Established Technologies:
SHARON – ANAMMOX process allows a reduction of up to 60 percent of the oxygen and energy demand as compared to the traditional nitrification/denitrification route via nitrate. The process combination does not require the presence of organic COD for denitrification. It is considered to be more sustainable than conventional treatment because of the reduced CO_2 emissions associated with energy savings. An overall nitrogen removal efficiency of 90 to 95 percent can be achieved depending on process conditions and influent characteristics.

Available Cost Information:
Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):
Mixing and Mass Transfer Technologies
Southwestern Region
8833 North Congress Ave., Suite 818
Kansas City, MO 64153
Telephone: 816-854-1969
Email: arawakomski@m2ttech.com
Web site: http://www.m2ttech.com

Mixing and Mass Transfer Technologies
Northeast Region
583 Greenhaven Road
Pawcatuck, CT 06379
Telephone: 860-599-5381
Email: tgilligan@m2ttech.com
Web site: http://www.m2ttech.com

Installation(s):
There are no installations in the United States at this time.

Key Words for Internet Search:
ANAMMOX, SHARON process, wastewater treatment, ammonia

Data Sources:
Communication with Mixing and Mass Transfer Technologies.

http://www.bt.tudelft.nl/r_proj/mic/P_Dongen.htm

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Technology Summary

STRASS Process (Nitritation and Denitritation in SBR)

Objective:

Biological ammonia removal from high-strength streams (e.g., sludge liquors, landfill leachate).

State of Development:

Embryonic. Two full-scale systems in Strass and Salzburg, Austria, have been successfully implemented in 1997 and 1999 respectively. In 2004 it was transformed to the superior DEMON technology. In Salzburg, Austria, 1,000 kg N/d sidestream treatment is still in operation. Extensive pilot-scale studies performed in the United States at Alexandria Sanitation Authority, Virginia.

Description:

The STRASS process uses a high-sludge sequencing bench reactor to oxidize ammonia to nitrite (nitritation) followed by reduction of the produced nitrite to nitrogen gas (denitritation). A supplemental carbon source, such as primary sludge is used to drive the denitritation process. The key feature of the STRASS process is that the pH based control mechanism is highly effective to control the intermittent aeration system. During an aeration, interval acidification occurs because of nitritation. When the lower pH setpoint is reached, the aeration stops and alkalinity/pH recovers. At the upper pH setpoint, aeration is switched on again resulting in a characteristic sawtooth profile of the pH course. Following this control strategy, frequency and length of aeration intervals is self adjusting to the feed rate and concentration of sidestreams. Proper selection of pH setpoints helps to control Nitrite Oxidizing Bacteria (NOB) inhibition and inorganic carbon limitation.

Comparison to Established Technologies:

The STRASS process is an equivalent technology compared to the SHARON process, and it was developed in the same year. The main difference is that SHARON process is operated as a chemostat without sludge retention (to keep a short SRT to maintain inhibition of NOBs), while STRASS process is operated in an SBR with sludge retention. NOB inhibition is reliably maintained by pH-controlled intermittent aeration (aeration stops immediately after available ammonia has been transformed to nitrite and H^+), low Dissolved Oxygen (DO), and elevated temperature.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

Cyklar-Stulz
CH-8737 Gommiswald Rietwiesstrasse 39
Switzerland
Telephone: 41-55-290-11-41
Fax: 41-55-290-11-43
Email: info@cyklar.ch
Web site: http://www.cykar.ch

Installation(s):

Full-scale STRASS systems are in Strass and Salzburg, Austria. Pilot systems are operated by Alexandria Sanitation Authority, Virginia, United States. There are no full-scale installations in the United States at this time.

Key Words for Internet Search:

STRASS, sidestream treatment, ammonia, pH-control, Air Intercept Zone (AIZ)

Data Sources:

Wett, B., et al., “pH Controlled Reject Water Treatment,” Water Science Technology, 1998.

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Technology Summary

Vacuum Rotation Membrane (VRM®) System

Objective:

Filtration of biomass for high-quality effluent with smaller footprint, lower energy demand, and more effective scouring of the membrane surface.

State of Development:

Embryonic. Systems are in operation in Europe.

Description:

The new membrane system employs flat-sheet ultra-filtration membranes rotating around a horizontal shaft. Scouring air is introduced next to the shaft at about half the water depth, providing high-intensity scouring of a small section in the 12 o'clock position. The membranes rotate through this scouring section several times per minute. Operating results showed that neither back-pulsing nor regular cleaning is required to maintain an average flux of at least 10 gal/ft^2 with a suction head of less than 10 feet.

Comparison to Established Technologies:

The vendor claims that the VRM® system reduces aeration tank volume by 70 percent and energy consumption.

Available Cost Information:

Approximate Capital Cost: $1/gallon (based on overseas operations).

Approximate O&M Costs: $100,000/year/1 MGD (based on overseas operations).

Vendor Name(s):

Huber Technology, Inc.
9805 North Cross Center Court, Suite H
Huntersville, NC 28078
Telephone: 704-949-1010
Email: christian@hhusa.net
Web site: http://www.huber.technology.com or
http://www.huber.de

Installation(s):

There are no installations in the United States at this time.

Key Words for Internet Search:

VRM®, membrane bioreactor, wastewater, vacuum, rotation

Data Sources:

http://www.huber.de

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Chapter 4

In-Plant Wet Weather Management Processes

4.1 Introduction

Chapter 4 in-plant wet weather management processes include the storage and treatment of wastewater with infiltration/inflow entering a WWTP or storm-related flows in combined sewer systems entering a WWTP. This chapter focuses on storage and treatment technologies that can be used to manage the volume of wastewater during wet weather events.

4.2 Technology Assessment

Table 4.1 includes a categorized list of emerging and established technologies for wet weather management. The innovative wet weather management technologies are as follows: Continuous Deflection Separator (CDS), HYDROSELF® Flushing Gate, Tripping Flusher®, TRASHMASTER™ Net Capture System, and WWETCO Compressed Media Filtration® or WWETCO CMP® System. Alternative wet weather disinfection is the embryonic in-plant wet weather management embryonic technology, which is highlighted at the end of this chapter.

Wet weather flows can be better managed if the conveyance systems to a facility are well maintained. However, new technologies are needed to overcome the wet weather issues more efficiently. Emerging technologies used to rehabilitate conveyance systems to reduce wet weather flows are described in the U.S. EPA document "Emerging Technologies for Conveyance Systems – New Installations and Rehabilitation Methods" (EPA 832-R-06-004, July 2006). An evaluation of the innovative technologies identified for in-plant wet weather management processes is presented in Figure 4.1.

Table 4.1— In-Plant Wet Weather Management Processes – State of Development

Established Technologies
Dispersed Air Flotation
Dissolved Air Flotation (DAF)
Enhanced Clarification/High Rate Clarification (HRC)
▪ Ballasted Flocculation (Actiflo® and Microsep®)
▪ Lamella Plate Settlers
Screening
Vortex Separation

Innovative Technologies
Continuous Deflection Separator (CDS)
HYDROSELF® Flushing Gate
Tipping Flusher®
TRASHMASTER™ Net Capture System
WWETCO Compressed Media Filtration® or WWETCO CMF® System
Innovative Use of Established Technologies
None at this time
Embryonic Technologies
Alternative Wet Weather Disinfection

Figure 4.1—Evaluation of Innovative In-Plant Wet Weather Management Technologies

Process	Evaluation Criteria									
	Development	Applicability	Benefits	Impact on Processes	Complexity	Air/Odor Emissions	Reuse	Energy	Footprint	Retrofitting
Continuous Deflection Separator (CDS)	P, N	S, F	W	▲	▲	⊖	Dn	▲	⊖	▲
HYDROSELF® Flushing Gate	M, N	S, F	W	▲	⊖	⊖	Dn	▲	⊖	▲
Tipping Flusher®	M, N	S, F	W	▲	⊖	⊖	Dn	▲	⊖	▲
TRASHMASTER™ Net Capture System	M, N	S, F	W	▲	⊖	⊖	Dn	▲	⊖	▲
WWETCO Compressed Media Filtration® or WWETCO CMF® System	P, N	S, F	W	▲	▲	⊖	Dn	▲	⊖	▲

Key

Statement of Development
- B = Bench scale
- I = Full-scale industrial applications
- M = Full-scale municipal applications
- O = Full-scale operations overseas
- P = Pilot
- N = Full-scale operations in North America

Applicability
- F = Few plants
- I = Industrywide
- L = Primarily large plants
- S = Primarily small plants

Potential Benefits
- C = Capital savings
- I = Intense operational demand
- O = Operational/maintenance savings
- S = Shock load capacity
- W = Wet weather load capacity

Effluent Reuse
- Dp = Direct potable
- Dn = Direct nonpotable
- Ip = Indirect potable
- In = Indirect nonpotable

Comparative Criteria
- ▲ Positive feature
- ⊖ Neutral or mixed
- ▼ Negative feature

Technology Summary

Continuous Deflection Separator (CDS)

Objective:

Separates debris, sediments, oil, and grease from stormwater runoff.

State of Development:

Innovative.

Description:

CDS works by continuous deflection of the stormwater runoff. The CDS unit has a diversion chamber where the flow of water is diverted to the separation chamber. The flow and screening controls prevents the re-suspension and release of separated solids. During flow events, the diversion weir bypasses the separation chamber to avoid already trapped solids to be washed into the flow.

The CDS units are available either precast or cast- in-place, and offline units can treat flows from 1 to 300 cubic feet per minute (cfm). The inline units treat up to 6 cfm, and internally bypass flows in excess of 50 cfm.

Comparison to Established Technologies:

Operation of CDS is independent of flow for a wide treatment ranges.

Available Cost Information:

Approximate Capital Cost: Not disclosed by vendor.

Approximate O&M Costs: Not disclosed by vendor.

Vendor Name(s):

CONTECH® Construction Products Inc.
9025 Centre Pointe Drive, Suite 400
West Chester, OH 45069
Telephone: 800-338-1122 or 513-645-7000
Web site: http://www.contech-cpi.com/contract

Installation(s):

Cincinnati, OH

Key Words for Internet Search:

CONTECH®, Continuous Deflection Separation, CDS

Data Sources:

Vendor web site: http://www.contech-cpi.com/

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Technology Summary

HYDROSELF® Flushing Gate

Objective:
Wet weather management, cleaning of Combined Sewer Overflows (CSOs) and storage tanks.

State of Development:
Innovative.

Description:
The Hydroself® flushing gate system is a method of removal of accumulated sediments and debris in the combined sewer retention systems, stormwater runoff, and balancing tank. The operating principle for the Hydroself® flushing system is that the flush water is held in reserve and as released there is a high-energy wave. The wave removes the accumulated debris from the retention chamber and interceptors along the flushway lengths.

Comparison to Established Technologies:
The Hydroself® flushing gate system is not similar to established wastewater technology, but is similar to other innovative technologies that restore the capacity of collection systems. Removing accumulated sediment may be accomplished manually. The system lessens manpower needs and improves employee safety over manual cleaning.

Available Cost Information:
Approximate Capital Cost: Approximately $350,000.

Approximate O&M Costs: Approximately $250/event.

Cost information taken from the WERF Manual, Best Practices for Wet Weather Wastewater Flows, 2002.

Vendor Name(s):
Steinhardt GmbH Wassertechnik
Roderweb 8-10-D-65232
Taunusstein, Germany
Telephone: 49-6128-9165-0
Email: info@steinhardt.de
Web site: http://www.steinhardt.de/htm_en/fset_e.html

Installation(s):
Gabriel Novac and Associates, Inc.
3532 Ashby
Montreal, Quebec H4R 2C1, Canada
Telephone: 514-336-5454
Email: gnacso@gnacso.com

Clough Creek CSO Treatment Facility
Cincinnati, OH

Key Words for Internet Search:
Flushing gate system, wastewater, high-energy wave, Hydroself®

Data Sources:
WERF Manual, Best Practices for Wet Weather Wastewater Flows, 2002.

http://www.copa.co.uk

http://www.epa.gov/ednnrmrl/repository

http://www.steinhardt.de/htm_en/fset_e.html

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Technology Summary

Tipping Flusher®

Objective:

Wet weather management, cleaning of CSOs, and storage tanks.

State of Development:

Innovative.

Description:

The system generally includes filling pipes and valves, a pumping system, and wet well (where restricted by the site conditions), and the tipping flusher vessels. The tipping flusher is a cylindrical stainless steel vessel suspended above the maximum water level on the back wall of the storage tank. Just before overtopping the vessel with water, the center of gravity shifts and causes the unit to rotate and discharge its contents down the back wall of the tank. A curved fillet at the intersection of the wall and tank floor redirects the flushwater (with minimum energy loss) horizontally across the floor of the tank. The fillet size depends on the size of the flusher. The flushing force removes the sediment debris from the tank floor and transports it to a collection sump located at the opposite end of the tank.

Comparison to Established Technologies:

The Tipping Flusher® is not similar to established wastewater technology, but it is similar to other innovative technologies that restores the capacity of collection systems. Removing accumulated sediment may be accomplished manually. The system lessens manpower needs and it improves employee safety over manual cleaning.

Available Cost Information:

Approximate Capital Cost: Approximately $525,000

Approximate O&M Costs: Not disclosed by vendor.

Costs information taken from the WERF Manual, Best Practices for Wet Weather Wastewater Flows, 2002.

Vendor Name(s):

Steinhardt GmbH Wassertechnik
Roderweb 8-10-D-65232
Taunusstein, Germany
Telephone: 49-6128-9165-0
Email: info@steinhardt.de
Website: http://www.steinhardt.de/htm_en/fset_e.html

Installation(s):

Gabriel Novac and Associates, Inc.
3532 Ashby
Montreal, Quebec H4R 2C1, Canada
Telephone: 514-336-5454
Saginaw, MI

Key Words for Internet Search:

Sewer, tank, flushing tipping flusher, wet weather management, wet well

Data Sources:

WERF Manual, Best Practices for Wet Weather Wastewater Flows, 2002.

http://www.copa.co.uk

http://www.epa.gov/ednnrmrl/repository

http://www.steinhardt.de/htm_en/fset_e.html

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Technology Summary

TRASHMASTER™ Net Capture System

Objective:

Wet weather management of trash and debris removal from CSOs and stormwater systems.

State of Development:

Innovative.

Description:

The TRASHMASTER™ Net Capture System is a process that removes accumulated trash, sediments, and debris in a combined sewer system (CSS) or stormwater collection system. The operating principle of the TRASHMASTER™ Net Capture System is to capture trash, debris, and sediment in special removable nets as the water flows through the unit. No electrical connections are required. It is used in low-flow applications (5 cubic feet per second [cfs] or less) and inserts in-line on the outflow piping. It is a light weight, roto-molded, fiberglass unit that is very easy to install on pipes that are 24 inches or less in size by using onsite equipment. No special construction is necessary. The unit can be installed in two days or less to depths of ten feet. The unit can also accommodate special chemical feed systems to treat waterborne impurities.

Comparison to Established Technologies:

The TRASHMASTER™ Net Capture System is a unique solution to remove trash and debris in low flowing water. The vendor, Fresh Creek Technologies, produces similar, established technologies (e.g., Netting Trash Trap™ system). Other established technologies require extensive engineering, special installation equipment, a more expensive product, and a week or longer to install.

Available Cost Information:

Approximate Capital Cost: Approximately $40,000.

Approximate O&M Costs: Approximately $110 per event.

Vendor Name(s):

Fresh Creek Technologies, Inc.
1425 Pompton Avenue
Suite 1–2
Cedar Grove, NJ 07009
Telephone: 973-237-9099
Fax: 973-237-0744
Web site: www.freshcreek.com

Installation(s):

Kingston, Ontario, Canada
Harrington, WA

Key Words for Internet Search:

TRASHMASTER™ Net Capture System, netting systems, Fresh Creek Technologies, freshcreek

Data Sources:

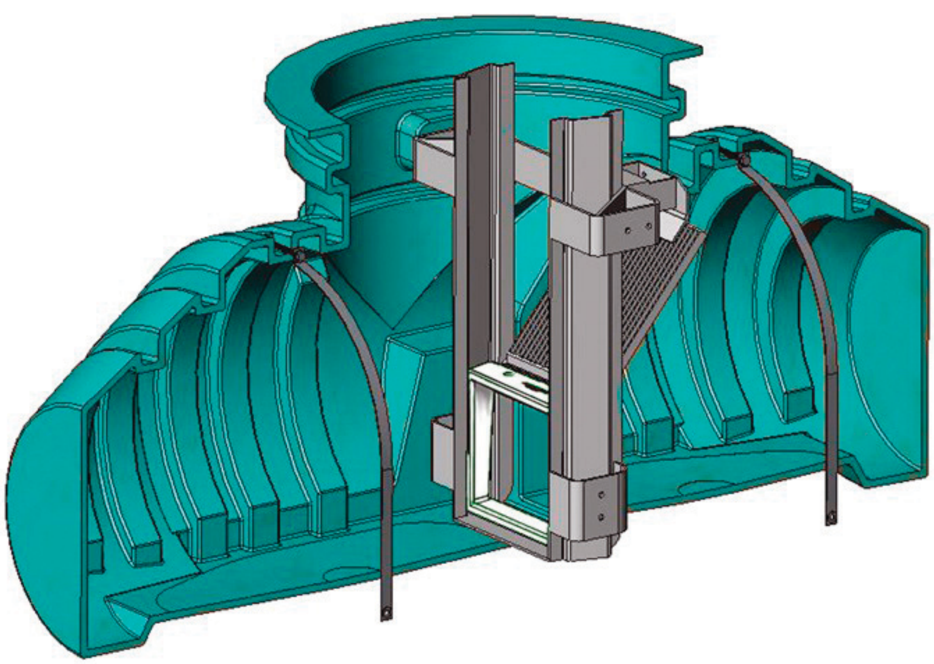
Email and telephone conversations with vendor.

http://www.freshcreek.com

Technology Summary

TRASHMASTER™ Net Capture System (Contd)

TRASHMASTER™ Net Capture System from Fresh Creek Technologies



Cross Section of a TRASHMASTER™ Net Capture System

Technology Summary

WWETCO Compressed Media Filtration® or WWETCO CMF® System

Objective:

Wet weather management.

State of Development:

Innovative.

Description:

The patent pending WWETCO Compressed Media Filtration®, also known as WWETCO CMF® System, consists of detached fibrous lump media that is hydraulically compressed by a flexible housing with the fluid filtered in a lateral direction, which provides a porosity gradient from uncompressed highly permeable media zone to an adjustable lesser porous media zone in the direction of flow. The result allows the removal of larger particles in the upper zone and the penetration and removal of smaller particles in the lower zones. This flexibility allows the application of the WWETCO CMF® at publicly owned treatment works (POTW) in a dual-use mode as a dry weather tertiary filter, then as a wet weather filter to treat either excess primary clarifier flows or excess screened and degritted flows.

Filter TSS removals are adjustable with compression provided. Up to 95 percent TSS removal can be achieved as a tertiary filter with effluent TSS consistently less than 1 mg/L and turbidities consistently under 1 ntu. Filter performance when treating screened and degritted wet weather flow can be 75 to 90 percent TSS removal. Hydraulic loadings in this application are typically 8 to 10 gpm/ft^2 with backwash quantities in the range of 5 to 10 percent of the filtered water volume. Filter performance when treating primary effluent flows during wet weather can generally be 65 to 75 percent. Pilot plant test results indicate that WWETCO CMF® proved to be effective in removing solids at various ranges of primary effluent flow. Typically, as hydraulic and solids loading rates increased, filter run times decreased requiring a balance of run time and loading rates for optimum performance. One pilot study indicated that 64 percent removal of solids at loading rates of 12 to 15 gpm per ft^2 is achievable for a primary effluent flow of 182 MGD with 100 mg/L solids concentration.

The WWETCO CMF® System incorporates a patent pending backwash method that uses low head air (10 standard cubic feet per minute [SCFM] per ft^2 at 7 ft Total Dynamic Head [TDH]) to circulate and scrub the filter media and lift the backwash water and solids to be wasted. The backwash method maximizes the use of the air and minimizes the amount of water to clean the filter. Backwashing is accomplished within a 20-minute period cleaning a filter cell was used to treat raw sewage or secondary clarifier effluent. Backwash solids are typically sent to biological treatment or directly to solids processing facilities.

No mechanical equipment is required to provide the filter compression, and this makes the system ideal for passive operation, which is often needed in wet weather treatment systems. The filter is left dry and can sit idle for extended periods with no odor or operational issues. When excess wet weather flows occur, the filter is immediately brought online and has no ramp-up requirements. Chemicals are not required. The filter can tolerate moderate screenings and grit loadings without impacting performance or cleaning operations.

Comparison to Established Technologies:

The WWETCO CMF® technology is comparable in performance with the ballasted flocculation systems being marketed for use at POTW to treat excess wet weather flows. Ballasted flocculation systems can typically achieve 85 percent TSS removals, but they require flocculation chemicals and ramp-up time (15 to 30 minutes) to achieve performance objectives. The WWETCO CMF® can meet similar or better removals, it requires no chemicals, and it immediately achieves performance objectives. The WWETCO CMF® starts dry and ends dry without odor issues, without special startup protocols, and without special attention to mechanical Equipment.

The ballasted flocculation systems generally require a footprint of approximately 40 to 80 ft per MGD of capacity and are generally 23- to 29-ft deep. This footprint does not include chemicals and sludge handling and processing requirements. The WWETCO CMF® requires a total footprint of approximately 150 ft^2 per MGD for treating primary clarifier effluent. The WWETCO CMF® for POTW application is 12-ft deep.

Technology Summary

WWETCO Compressed Media Filtration® or WWETCO CMF® System (Contd)

Available Cost Information:

Approximate Capital Cost: The capital cost is a function of hydraulic and solids loading rate. Higher solids wastewaters require lower hydraulic loading rates, shorter run times, thus more filters. General capital costs are as follows for complete systems including filter, appurtenant equipment, and concrete structures:

Application	Capital Cost Estimate ($ per gallon capacity)
Tertiary Filter	$0.05 to $0.06
Primary Effluent Filtration	$0.06 to $0.08
Wastewater and CSO Filtration	$0.10 to $0.15

Approximate O&M Costs: O&M costs include power for low-head blower air for backwashing. As the filter requires no other equipment other than valving, no chemicals and no additional solids handling, and it comes online passively, with little personnel attention required. Power costs are as follows:

Application	Power Cost (per million gallons treated)
Tertiary Filter	$0.30
Primary Effluent Filtration	$2.93
Wastewater and CSO Filtration	$12.80

Vendor Name(s):

WWETCO, LLC
800 Lambert Drive, Suite F
Atlanta, GA 30324
Telephone: 404-307-5731
Email: mark@wwetco.com
Website: http:/www.wetco.com

Installation(s):

Atlanta, GA

Columbus, GA

Key Words for Internet Search:

Compressed media filtration, WWETCO, Advanced Demonstration Facility at Columbus, Georgia, CSO filter, tertiary filter, wet weather filter

Data Sources:

ARCADIS, "Water Pollution Control Station Secondary By Pass Treatability Study Phase III," City of Akron, OH, February 2006.

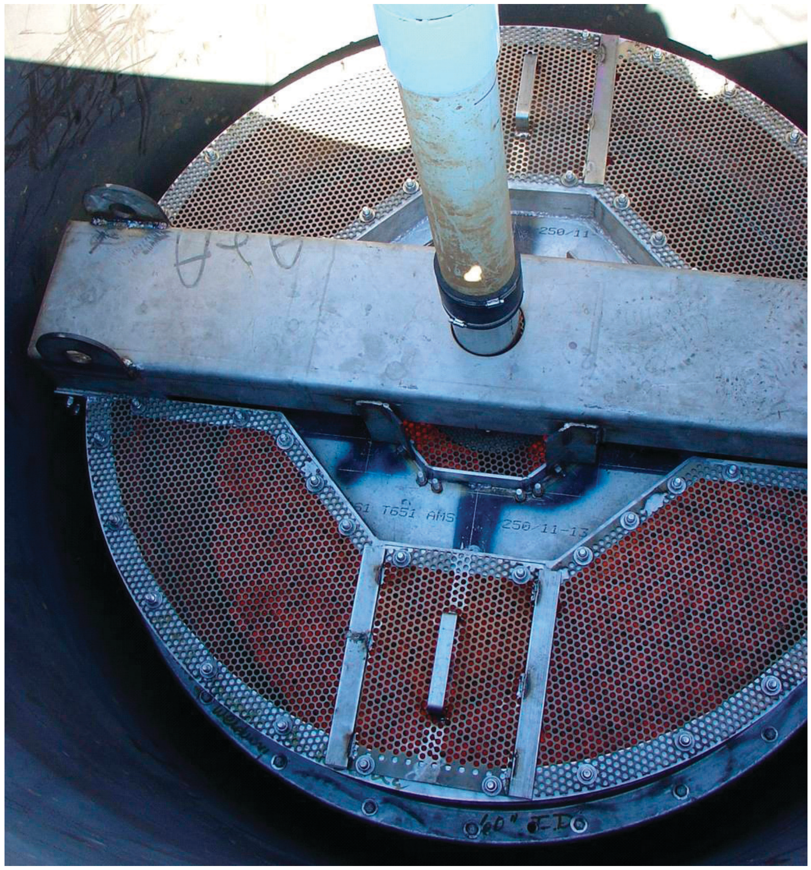
Arnett, C.A., M. Boner and J. Bowman, "Bacteria TMDL Solution To Protect Public Health And Delisting Process In Columbus, GA," WEFTEC, 2006.

Boner, M. et al., "Atlanta CSO Pilot Plant Performance Results," WEFTEC, 2004.

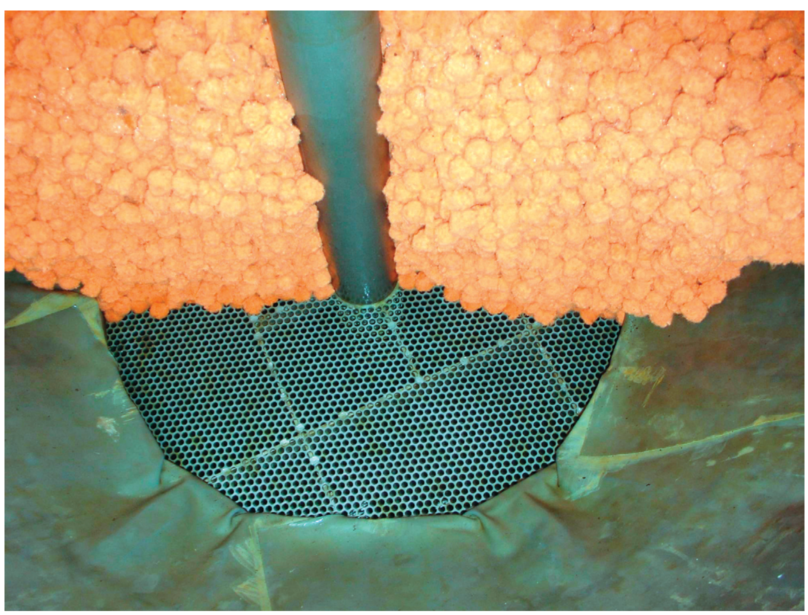
Frank, D. A. and T. F. Smith III, "Side by Side by Side, The Evaluation of Three High Rate Process Technologies for Wet Weather Treatment," WEFTEC, 2006.

WERF, Peer Review: Wet Weather Demonstration Project in Columbus, Georgia, Co-published: Water Environment Research Foundation, Alexandria, VA, and IWA Publishing, London, UK, 2003.

WWETCO Compressed Media Filtration® or WWETCO CMF® System (Contd)



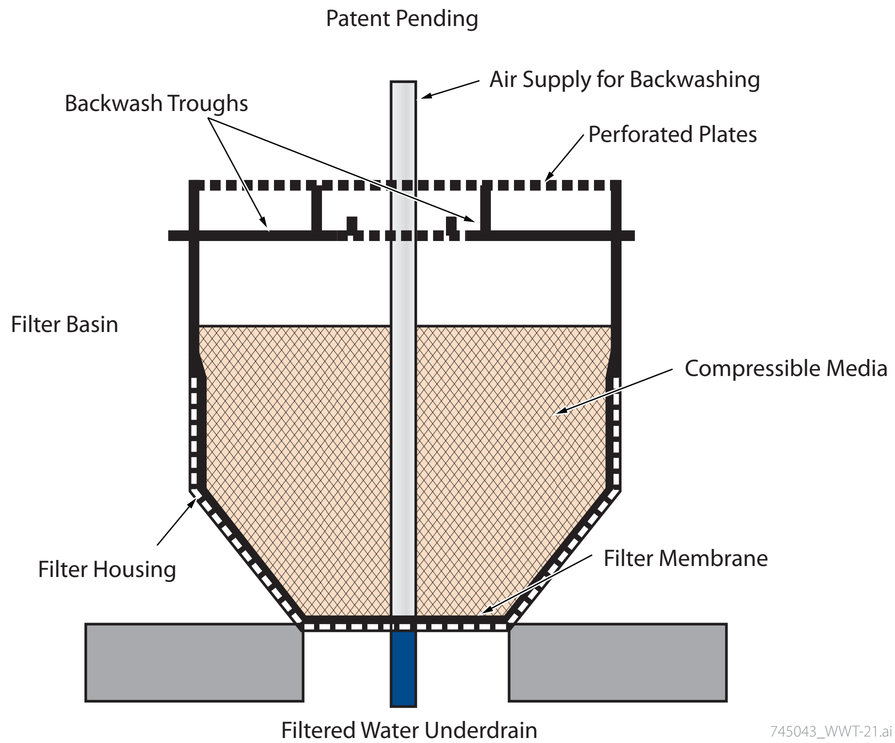
WWETCO CMF® Patents Pending



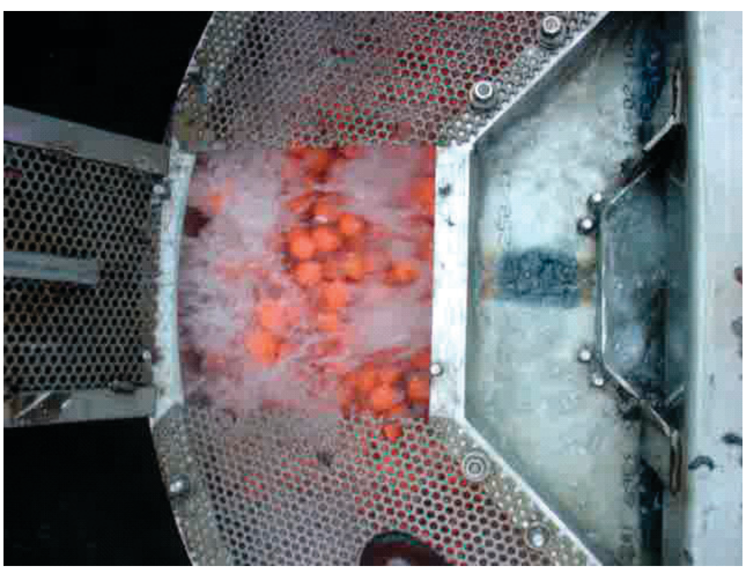
Synthetic Filter Media with Air Supply (Center) and Flexible Membrane

Technology Summary

WWETCO Compressed Media Filtration® or WWETCO CMF® System (Contd)



WWETCO CMF® Drained of Liquid at Ready Position (Patent Pending)



Filter in Backwash Mode

Technology Summary

Alternative Wet Weather Disinfection

Objective:

High-rate alternative to wet weather disinfection flows by using disinfection products such as peracetic acid, ferrite, or Bromo Chloro Dimethylhydantoin (1-Bromo-3-Chloro-5,5 Dimethylhydantoin [BCDMH]).

State of Development:

Embryonic. A pilot-scale test was performed in Akron, Ohio, on three wet weather test events. BCDMH was found to be an effective disinfectant at doses of 3 mg/L, 6 mg/L, and 12 mg/L.

Description:

Alternative disinfectants are being applied to wet weather flows because of their ability to act as high-rate disinfectant. Although not yet approved by the U.S. EPA specifically as a wastewater disinfectant, peroxyacetic acid (peracetic acid [CH_3CO_3H]) is an oxidizing agent that can be used as a disinfectant. Peracetic acid is produced 5, 15, and 35 percent solutions and is widely used in the food industry.

BCDMH is a chemical disinfectant used in treating drinking water. It is a crystalline substance, insoluble in water, but soluble in acetone. It reacts slowly with water releasing hypochlorous acid and hypobromous acid. EBARA has devised a system to liquefy the BCDMH powder in a mixer with an injection device. The solution is injected directly into the wastewater and it relies on the turbulence of the process to mix into the disinfection process.

Comparison to Established Technologies:

As compared to disinfection with chlorine compounds, peracetic acid does not form harmful byproducts after reacting with wastewater. However, a residual of acetic acid will be present and will exert an oxygen demand. The concentration used for disinfection of secondary effluent depends on the target organism, the water quality, and the level of inactivation required. For example, a concentration of 5 mg/L peracetic acid, with contact time of 20 minutes, was able to reduce fecal and total coliform by 4 to 5 logs in secondary effluent (Morris, 1993).

BCDMH has a small footprint and is easier to store than chlorine disinfection products. BCDMH is comparable to sodium hypochlorite, but it acts in contact a shorter amount of time. The shorter contact time is typically 3 minutes instead of 5 minutes for sodium hypochlorite, and it reduces the size of the contact chamber and may result in capital cost savings of about 54 percent.

Available Cost Information:

Approximate Capital Cost: Unknown.

Approximate O&M Costs: The cost of peracetic acid is about 3 to 5 times the cost of sodium hypochlorite.

Vendor Name(s):

Peracetic Acid
Microbial Control
FMC Corporation
1735 Market Street
Philadelphia, PA 19103
Telephone: 609-951-3180
Web site: http://www.microbialcontrol.fmc.com

BCDMH
EBARA Engineering Service Corporation
Shinagawa, NSS-11 Building
2-13-34 Konan, Minato-Ku, Tokyo, Japan
Telephone: 81-3-5461-6111 (switchboard)
Web site: http://www.ebara.co.jp/en/

Installation(s):

Columbus Water Works, Columbus, GA

Water Pollution Control Station, City of Akron, OH

Key Words for Internet Search:

Alternative disinfectant, wet weather, peracetic acid, PAA, BCDMH

Alternative Wet Weather Disinfection (Contd)

Data Sources:

Columbus Georgia Water Works, CSO Technology Testing web site: http://www.cwwga.org/NationalPrograms/Index.htm

Combined Sewer Overflow Technology Fact Sheet Alternative Disinfection Methods web site: www.epa.gov/owmitnet/mtb/altdis.pdf

Gehr, R., Wagner, M., P. Veerasubramanian, and Payment, P. "Disinfection Efficiency of Peracetic Acid, UV and Ozone After Enhanced Primary Treatment of Municipal Wastewater," Water Research, 37, 19, pp.4,573–4586, 2003.

Moffa, Peter E., Daniel P. Davis, Chris Somerlot, Dan Sharek, Brian Gresser and Tom Smith. "Alternative Disinfection Technology Demonstrates Advantages for Wet Weather Applications," Water Environment and Technology, January 2007.

Morris, R., "Reduction of Microbial Levels in Sewage Effluents using Chlorine and Peracetic Acid Disinfectants," Water Science and Technology, Vol. 27, 1993.

WERF, Wet Weather Demonstration Project in Columbus, Georgia, 98-WWR1P.

Rossi, S., et al., "Peracetic Acid Disinfection: A Feasible Alternative to Wastewater Chlorination," Water Environment Research, 79 (4): 341–350, 2007.

Kitis, M., "Disinfection of Wastewater with Peracetic Acid: A Review," Environment International, 30:47–55, 2004.

Chapter 5

Process Monitoring Technologies

5.1 Introduction

Process monitoring technologies are now a critical component in the improvement of wastewater treatment. Those included in this report as process monitoring technologies, not only help prevent upsets in treatment systems and help facilities stay within the compliance limits during upset conditions, but also could potentially save energy and chemicals used by maximizing process efficiency.

5.2 Technology Assessment

Table 5.1 includes a categorized listing of emerging and established technologies for process monitoring. An evaluation of the innovative technologies identified for process monitoring is presented in Figure 5.1. Summary sheets for each innovative technology are provided at the end of this chapter.

The innovative monitoring technologies listed in this chapter are focused on online monitoring in wastewater treatment systems, which help to prevent any upset to the system. These monitoring systems usually are probes or sensors that can detect change in physical, chemical and biological activity, and they can be installed at the influent, effluent, or in the main basin or the process tank. These monitoring devices are also helpful in saving energy and reducing operation and maintenance cost. These monitoring devices are also helpful in saving energy and reducing operation and maintenance cost. The innovative process monitoring technologies are as follows: Ammonia and Nitrate Probes (ChemScan N-4000, Hach Evita In Situ 5100, Myratek Sentry C-2, Hach NITRATAX, NitraVis® System, and Royce 8500 Series Multi-Parameter), Fluorescence In Situ Hybridization (FISH) for Filamentous and Nitrifying Bacteria, Microwave Density Analyzer, Microtox®/Online Microtox®, SymBio™ – Nicotinamide Adenine Dinucleotide (NADH) Probes, Online Respirometry, and NITROX™ – Oxidation Reduction Potential (ORP) Probe. The embryonic process monitoring technologies are as follows: Biological Micro-Electro-Mechanical Systems (BioMEMS), FISH for Phosphorus Accumulating Organisms (PAOs), Handheld Advanced Nucleic Acid Analyzer (HANNA), Immunosensors and Immunoassays, and Photo-electro Chemical Oxygen Demand (PeCOD™). The innovative and embryonic process monitoring technologies follow at the end of summarized in the technology summary sheets.

Table 5.1—Process Monitoring Technologies – State of Development

Established Technologies
Ammonia and Nitrate Process
▪ ChemScan
▪ Myratek
▪ Hach Evita
▪ Hach NITRATAX
▪ NitraVis® System
Dissolved Oxygen Analyzer
Online Cl_2 Residual
pH Probes
Sludge Blanket Level Detector
Solids Retention Time (SRT) Controller
Total Suspended Solids Analyzer
Innovative Technologies
Ammonia-Nitrate Probes
▪ ChemScan N-4000
▪ Hach Evita In Situ 5100
▪ Myratek Sentry C-2

Innovative Technologies (Contd)
▪ Hach NITRATAX
▪ NitraVis® System
▪ Royce 8500 Series Multi-Parameter
Fluorescence In Situ Hybridization (FISH) for Filamentous and Nitrifiying Bacteria
Microwave Density Analyzer
Microtox®/Online Microtox®
SymBio™ – Nicotinamide Adenine Dinucleotide (NADH) Probes
Online Respirometry
NITROX™ – Oxidation Reduction Potential (ORP) Probe
Innovative Use of Established Technologies
None At This Time
Embryonic Technologies
Biological Micro-Electro-Mechanical Systems (BioMEMS)
FISH for Phosphorus Accumulating Organisms (PAOs)
Handheld Advanced Nucleic Acid Analyzer (HANNA)
Immunosensors and Immunoassays
Photo-electro Chemical Oxygen Demand (PeCOD™)

Figure 5.1—Evaluation of Innovative Process Monitoring Technologies

Process	Evaluation Criteria: Development	Applicability	Benefits	Impact on Processes	Complexity	Air/Odor Emissions	Reuse	Energy	Footprint	Retrofitting
Ammonia and Nitrate Probes	I, M, N	I, F	C, O, S	▲	▲	⊖	⊖	▲	⊖	▲
Fluorescence In Situ Hybridization (FISH) for Filamentous and Nitrifying Bacteria	I, M, N	I, F	C, O, S	▲	▲	⊖	⊖	⊖	⊖	▲
Microwave Density Analyzer	I, M, N	F	C, O, S	▲	▲	⊖	⊖	⊖	⊖	▲
Microtox®/Online Microtox®	I, M, N	I, F	C, O, S	▲	⊖	⊖	⊖	⊖	⊖	⊖
SymBio™ – Nicotinamide Adenine Dinucleotide (NADH) Probes	I, M, N	I, F	C, O	▲	▲	⊖	⊖	▲	⊖	
Online Respirometry	I, M, N	F	C, O, S	▲	▲	⊖	⊖	▲	⊖	▲
NITROX™ – Oxidation Reduction Potential (ORP) Probe	M, N	I, F	C, O, S	▲	▲	⊖	⊖	▲	⊖	▲

Key

Statement of Development
- B = Bench scale
- I = Full-scale industrial applications
- M = Full-scale municipal applications
- O = Full-scale operations overseas
- P = Pilot
- N = Full-scale operations in North America

Applicability
- F = Few plants
- I = Industrywide
- L = Primarily large plants
- S = Primarily small plants

Potential Benefits
- C = Capital savings
- I = Intense operational demand
- O = Operational/maintenance savings
- S = Shock load capacity
- W = Wet weather load capacity

Effluent Reuse
- Dp = Direct potable
- Dn = Direct nonpotable
- Ip = Indirect potable
- In = Indirect nonpotable

Comparative Criteria
- ▲ Positive feature
- ⊖ Neutral or mixed
- ▼ Negative feature

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Technology Summary

Ammonia and Nitrate Probes

Objective:

Automatic online analysis of dissolved nutrients and halogens for water and wastewater process monitoring and control, including nitrification, denitrification, phosphorus removal, disinfection, dechlorination, and choramination. In situ, real-time measurement of ammonia and/or nitrate concentration.

State of Development:

Innovative.

Description:

ChemScan N-4000: Online multiple parameter analyzer using full-spectrum UV-visible detection with chemometric analysis of spectral data. The analyzer is script driven and has the capability of performing rapid sequential analysis with or without the assistance of chemical reagents. Nitrate analysis and/or a separate analysis of nitrite are performed based on the direct analysis of spectra from the sample. Ammonia analysis is reagent-assisted using bleach and hydroxide reagents. The analyzer contains an internal manifold to provide automatic zeroing, cleaning, and managing multiple sample lines. A variety of accessories are available, including sample pumps, filters, and external controllers.

Hach Evita In Situ 5100: Nitrate analyzer using UV absorption to measure nitrate concentration. Probe is immersed in wastewater and the ion specific membrane allows the appropriate ions to be transferred to the carrier solution so no sample preparation is necessary and interference from bacteria and particles is virtually eliminated. Uses deionized water that needs to be refilled every 10 weeks. Measuring range is 2 to 50 mg/L NO_3-N with accuracy of ±10 percent. Readings approximately every 13 minutes are possible.

Myratek Sentry C-2: Based on Ion Selective Electrode (ISE) technology. A sample is isolated in the measuring chamber and ammonia and nitrate values established. Calibration using the standard addition method is performed automatically at user-set intervals. Installation takes less than 1 hour; maintenance less than 15 minutes per week.

Hach NITRATAX: Probe-style analyzer based on UV light absorption. Photometer measures primary UV 210 beam while a second beam at 350 nm provides a reference standard. Measuring range is 0.1 to 50 mg/L NO_3-N.

NitraVis® System: In situ, real-time spectral measurement (UV and Visibility [VIS] range of 200 to 750 nm) of nitrate concentration without filtering. Interferences, such as those caused by turbidity, are detected and compensated for. Operates in media at temperatures of at least 32°F, with a pH between 4 and 9, and contains less then 5,000 mg/L chloride. Automatic cleaning with compressed air prior to each measurement. Measuring range is 0.1 to 100 mg/L NO_3-N with accuracy of ±3 percent.

Royce 8500 Series Multi-Parameter: Patented, in situ xenon-based optical sensor allows virtually continuous monitoring. Automatic cleaning system available. Individual models address varying combinations of the following parameters: turbidity, total suspended solids, COD, TOC, BOD, nitrate, nitrite, color, phenols, and hydrocarbons.

Comparison to Established Technologies:

Traditionally monitoring was performed by taking samples and analyzing them for various parameters in laboratories. Performing lab analyses are time-consuming steps that do not resolve a problem until the results are gathered. These monitoring technologies provide real-time or near real-time conditions in the treatment system through continuous monitoring. Immediate feedback helps operators take corrective action in the event of a shock or toxic load immediately.

Technology Summary

Technology Summary

Ammonia and Nitrate Probes (Contd)

Available Cost Information:

Approximate Capital Cost: $25,000 to $45,000 (ChemScan and Myratek); $11,000 for Hach Evita In situ 5100 (probe only; USC Controller and Communications add $3,100).

Approximate O&M Costs: $2,800 to $4,000 annually; Costs vary with frequency of calibration. Includes O&M time. Replace electrodes every 6 months. WTW claims no O&M cost for NitraVis® as there are no chemicals or other consumables use.

Vendor Name(s):

ASA/ChemScan
2325 Parklawn Drive
Waukesha, WI 53186
Telephone: 262-717-9500
Email: info@chemscan.com
Web site: http://www.chemscan.com

Myratek, Inc. – BioChem Technology, Inc.
100 Ross Road, Suite 201
King of Prussia, PA 19406-2110
Telephone: 610-265-8620
Email: rick@myratek.com
Web site: http://www.biochemtech.com

WTW Inc.
6E Gill Street
Woburn, MA 08801
Telephone: 800-645-5999
Email: info@wtw-inc.com
Web site: http://www.wtw.com

Royce Technologies
14125 South Bridge Circle
Charlotte, NC 28273
Telephone: 800-347-3505
Email: royce@itt.com
Web site: www.roycetechnologies.com

Hach Company
P.O. Box 389
Loveland, CO 80539-0389
Telephone: 800-227-4224
Web site: www.hach.com

Installation(s):

South Cross Bayou WRF
St. Petersburg, FL
Telephone: 727-582-7015

Wastewater Treatment Plant
Enfield, CT
Telephone: 860-253-6450

Wastewater Treatment Plant
Abington, PA
Telephone: 215-884-8329

Key Words for Internet Search:

Water monitoring, wastewater, ammonia, nitrates, probe, online analysis

Technology Summary

Ammonia and Nitrate Probes (Contd)

Data Sources:

Misiti, John Hach, "UV Spectrum Based NOx Monitors," paper.

Web site sources are as follows:

http://www.chemscan.com

http://www.myratek.com

http://biochemtech.com

http://www.hach.com

http://www.wtw.com

http://www.roycetechnologies.com

Vendor-supplied information.

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Technology Summary

Fluorescence In Situ Hybridization (FISH) for Filamentous and Nitrifying Bacteria

Objective:
Identify and quantify specific microorganisms in wastewater.

State of Development:
Innovative.

Description:
Bacteria in activated sludge contains DNA as unique genetic material. DNA sequences unique to individual groups of microorganisms can be used to identify specific microorganisms in a sample containing a mixture of many different types of microorganisms. The process of identifying specific microorganisms is part of the full-cycle 16S Ribosomal Ribonucleic Acid (rRNA) approach by using FISH. Fluorescently labeled 16S rRNA probes are hybridized, stained, and observed under an epifluorescent microscope.

Comparison to Established Technologies:
The microbial detection process is able to positively identify specific microorganisms in a mixed culture. Previously, microbiological tests performed in a laboratory were necessary to identify and enumerate bacteria. This process provides real-time feedback, over laboratory tests that take hours or even days for results.

Available Cost Information:
Approximate Capital Cost: Unknown.

Approximate O&M Costs: Unknown.

Vendor Name(s):
Department of Civil and Environmental Engineering at the following universities:
University of Illinois, Urbana-Champaign
University of Cincinnati
North Carolina State University

Installation(s):
There are no known installations.

Key Words for Internet Search:
Fluorescence In Situ Hybridization, FISH, 16S rRNA, full-cycle 16S rRNA approach, phylogeny

Data Sources:
Department of Civil and Environmental Engineering, University of Illinois, Urbana-Champaign, University of Cincinnati, and North Carolina State University.

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Technology Summary

Microwave Density Analyzer

Objective:
Solids measurement.

State of Development:
Innovative.

Description:
The microwave sludge density transmitter uses microwave-phase difference measurements to determine the density of solids flowing through pipes. This method exploits the way that fluid density affects the propagation of microwaves when they pass through it. The Microwave Density Analyzer allows reliable measurement of the sludge density and monitors the difference in microwave phase between the original wave and one wave that passed through the measured fluid. Unlike the method of monitoring the attenuation of a transmitted wave, measuring flow density by observing a wave's phase difference is not affected by flow velocity and is resistant to the effects of contamination, scaling, fouling, and gas bubbles. It uses no moving mechanical parts or mechanism that is often used in other measuring methods for cleaning, sampling, or defoaming. It permits continuous measurement. The density meter measures density in electric current, which is suitable for an application in a process for monitoring and controlling.

Comparison to Established Technologies:
This density meter has adapted a new measuring method called "phase difference method by microwaves." When microwaves go through a substance and come out of it, This density measures the phase lag of the waves and obtains a certain physical property of the substance that is proportional to the density.

Available Cost Information:
Approximate Capital Cost: 8-inch density meter is about $75,000 to $100,000 depending upon the specific application.

Approximate O&M Costs: Not disclosed.

Vendor Name(s):
Toshiba
Instrumentation Marketing Logistics Services
9740 Irvine Blvd.
Irvine, CA 92618-1697
Telephone: 800-231-1412, x3693 or 949-461-4400
Fax: 949-859-1298
E-mail: instrument@tic.toshiba.com
Web site: http://www.toshiba/com/ind/product_display

Installation(s):
Blue Plains AWTP, Washington, D.C.

Key Words for Internet Search:
Microwave Density Analyzer, LQ500, LQ300, LQ510

Data Sources:
Engineering Program Management Consultancy Services, CH2M HILL, Parsons, "Evaluation of the Test Results for the Microwave Sludge Density Meter at the Gravity Sludge Thickener (GST) No. 7," Blue Plains AWTP, Interoffice Memorandum, 2006.

Toshiba web site: http://www.toshiba.com/ind/product_display

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Technology Summary

Microtox®/Online Microtox®

Objective:
Acute toxicity analysis for wastewater, water, soil, and other hazardous waste applications.

State of Development:
Innovative.

Description:
The toxicity test is based on indigenous bioluminescence of a marine bacterium (*Photobacterium phosphoreum* to *Vibrio fischeri* strain, NRRL B-11177). The aqueous samples are incubated for controlled time and luminators are used to compare the reduction in light of the sample with a control culture of the bacterium. The proportional reduction in bioluminescence is indicative of toxicity of the sample. The Microtox® instrumentation systems are available for online and offline toxicity analysis.

Comparison to Established Technologies:
Microtox® monitoring is a biosensor based on a toxicity measurement system. The Microtox® process can provide near real-time monitoring of water and wastewater and is much faster than other laboratory based analysis.

Available Cost Information:
Approximate Capital Cost: $17,895.

Approximate O&M Costs: $2.50 to $7 per test.
Cost information includes the cost for the software for the unit. The O&M cost varies depending on the dilution range of toxicity tests.

Vendor Name(s):
Strategic Diagnostics, Inc.
111 Pencader Drive
Newark, DE 19702
Telephone: 302-456-6789 or 800-544-8881
Email: sales@sdix.com
Web site: http://www.sdix.com

Installation(s):
Petersburg, VA

Key Words for Internet Search:
Microtox®, toxicity test, wastewater, online

Data Sources:
WERF Report, Collection and Treatment – A Review and Needs Survey of Upset Early Warning Devices, Final Report, 2000.

Web site sources are as follows:

http://www.sdix.com/

http://www.azurenv.com/

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SymBio™ – Nicotinamide Adenine Dinucleotide (NADH) Probes

Objective:

SymBio™ process probe is used for simultaneous nitrification and denitrification in the same basin. The nicotinamide adenine dinucleotide and dissolved oxygen (NADH/DO) monitoring probe provides an effective tool for strict aeration control to maintain simultaneous nitrification and denitrification conditions.

State of Development:

Innovative.

Description:

The SymBio™ process monitors the NADH level in the biomass along with the dissolved oxygen level in the wastewater to precisely predict the changes in the biological oxygen demand. Based on the results of the NADH levels, the aeration is controlled to maintain low dissolved oxygen (<1.0 parts per million [ppm]) for Simultaneous Nitrification and deNitrification (SNdN) in the same basin.

Comparison to Established Technologies:

The SymBio™ Process monitors are newly available sensors that can measure NADH in wastewater in real-time. Based on the reading, aeration in the tank can be adjusted to enhance nitrification or denitrification processes. This maximizes aeration efficiency and reduces energy for aeration.

Available Cost Information:

Approximate Capital Cost: About $100,000 for one sensor with monitoring and process control setup.

Approximate O&M Costs: No additional cost for O&M incurred (energy consumption reduced 20 to 25 percent).

The cost for the SymBio™ system is based on the setup of the NADH sensor and the monitoring system. (The cost reflects the estimate for the year 2005.)

Vendor Name(s):

Enviroquip, Inc.
2404 Rutland Drive, Suite 200
Austin, TX 78758
Telephone: 512-834-6015
Email: hiren.trivedi@enviroquip.com
Web site: http://www.enviroquip.com

Installation(s):

Big Bear, CA
Rochelle, IL
Lake Elsinore, CA
Pflugerville, TX
Stonington, CT
Perris, CA
Bend, OR
New Philadelphia, OH

Key Words for Internet Search:

Aeration, NADH, fluorescence, nitrification, BOD

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

Enviroquip, Inc., Email, brochures, and telephone conversation, July 8, 2005.

Enviroquip, Inc. web site is as follows: http://www.enviroquip.com

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Technology Summary

Online Respirometry

Objective:
Measures cellular respiration or oxygen uptake rate.

State of Development:
Innovative.

Description:
Respirometry devices are used for biotreatment process control. The device can be set up and operated in different modes. For oxygen uptake-based respirometers, oxygen is measured either in closed headspace gas or liquid phases. The respirometry rate measurement can also determine the shock-load measurement and toxicity in a system when the baseline respirometry rate has been set for a system.

Respirometer's sensors can also be calibrated to measure other gases of concern like carbon monoxide, hydrogen sulfide, and methane.

Comparison to Established Technologies:
Traditionally, respirometric studies or kinetic parameters for wastewater treatment have been performed in laboratories with use of dissolved oxygen probes. During the stabilization of probes in the laboratory, sensitive information was lost, which was critical for measuring oxygen uptake rates and dissolved oxygen rates. The real-time feedback using the probes provides more reliable information on oxygen uptake.

Available Cost Information:
Approximate Capital Cost: 1 unit of the respirometer Respicond V for about $60,000 U.S.

Approximate O&M Costs: Unknown.

Cost based on the published cost for the Respicond V on the web site of A. Nordgren Innovations AB, Sweden.

Vendor Name(s):
A. Nordgren Innovations AB
Djakneboda 99
SE915 97 Bygdea, Sweden
Telephone: 46-934-31260
Email: a.nordgren@respicond.com
Web site: http://www.respicond.com

Columbus Instruments
950 N. Hague Avenue
Columbus, OH 43204
Telephone: 614-276-0861 or 800-669-5011
Email: sales@colinst.com
Web site: http://www.colinst.com

Respirometry Plus, LLC
P.O. Box 1236, Fond du Lac, WI 54935-1236
Telephone: 800-328-7518
Email: operations@respirometryplus.com
Web site: http://www.respirometryplus.com

Installation(s):
There are no known installations.

Key Words for Internet Search:
Cellular respiration, online respirometry, biotreatment process control, oxygen respirometer

Data Sources:
WERF web site and publications.

Research journals and publications.

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Technology Summary

NITROX™ – Oxidation Reduction Potential (ORP) Probe

Objective:

NITROX™ process is used to achieve denitrification of wastewater in an oxidation ditch by continuously monitoring the Oxidation Reduction Potential (ORP) of the wastewater.

State of Development:

Innovative.

Description:

This monitoring technology uses an ORP probe that constantly monitors and controls aeration to achieve anoxic and anaerobic conditions for Simultaneous Nitrification-deNitrification (SNdN). Nitrogen removal levels, from this unique process, are equivalent to systems that use anoxic tanks in front of the aeration basins. Effluent total inorganic nitrogen concentrations of less than 10 mg/L are common, and do not require preanoxic tanks and internal recycle pumps. Denitrification process involves the cycling of a single oxidation ditch through anoxic and aerobic periods. At selected intervals, the aeration system is turned off and the mixer(s) are turned on. Denitrification system consists of an ORP converter and a NITROX™ controller.

Comparison to Established Technologies:

ORP probes have not been traditionally used in the wastewater to regulate the nitrification and denitrification processes. The use of the ORP probe provides better process control over previous options. This maximizes aeration efficiency and reduces energy for aeration.

Available Cost Information:

Approximate Capital Cost: Approximately $100,000/MGD.

Approximate O&M Costs: 20 percent reduction in O&M.

Vendor Name(s):

United Industries
2380 O'Neal Lane, Suite 1
Baton Rouge, LA 70816
Telephone: 225-755-0724
Email: info@ui-inc.com
Web sites: http://www.ui-inc.com/ or
http://www.ui-inc.com/nitrox.htm

Installation(s):

Grand Coulee, WA

Diamondhead, MS

Key Words for Internet Search:

NITROX™, nitrification, wastewater, Oxidation Reduction Potential, ORP, monitoring

Data Sources:

Metcalf and Eddy, Wastewater Engineering Treatment and Reuse, 4th Edition, 2003.

Telephone conversation with United Industries.

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Technology Summary

Biological Micro-Electro-Mechanical Systems (BioMEMS)

Objective:
Biological Micro-Electro-Mechanical Systems (BioMEMS) are aimed at rapid testing of biomolecules that are indicative of an upset process.

State of Development:
Embryonic.

Description:
BioMEMS are being developed for the faster detection of upset signs in a bioprocess by using microchips or integrated circuits that can detect and quantify the biomolecules that cause process upsets. The systems aim at detecting the changes in the microbial activities that are caused by a shock load or toxicity. BioMEMS can be a very useful in predicting operational problems before they occur, such as bulking, foaming, and detecting, which cause operational problems because of changes to microbial population.

Comparison to Established Technologies:
Not similar to any established technology.

Available Cost Information:
Approximate Capital Cost: Unknown.

Approximate O&M Costs: Unknown.

Vendor Name(s):
University of Cincinnati
Water Quality Biotechnology Program
Room 765, Baldwin Hall, Box 210071
Cincinnati, OH 45221-0071
Telephone: 513-556-3670
Email: daniel.oerther@uc.edu or chong.ahn@uc.edu
Web sites: www.wqb.uc.edu or www.biomems.uc.edu

Installation(s):
There are no installations in the United States at this time.

Key Words for Internet Search:
BioMEMS, wastewater, biomechanics, biological micro-electro-mechanical systems

Data Sources:
Web site sources are as follows:

www.biomems.uc.edu

www.memsnet.org

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Technology Summary

Fluorescence In Situ Hybridization (FISH) for Phosphorus Accumulating Organisms (PAOs)

Objective:
Identify specific microorganisms in wastewater.

State of Development:
Embryonic.

Description:
Bacteria in activated sludge contain DNA as unique genetic material. DNA sequences unique to individual groups of microorganisms can be used to identify specific microorganisms in samples that contain a mixture of many different types of microorganisms. The process of identifying specific PAOs is part of the full-cycle 16S rRNA approach using FISH. Fluorescently labeled 16S rRNA probes are hybridized, stained, and observed under an epifluorescent microscope.

Comparison to Established Technologies:
The FISH for PAOs microbial detection process is able to positively identify specific microorganisms in a mixed culture. Previously, microbiological tests performed in a laboratory were necessary to identify and enumerate bacteria. This process provides real-time feedback, over laboratory tests that take hours or even days for results.

Available Cost Information:
Approximate Capital Cost: Unknown.

Approximate O&M Costs: Unknown.

Vendor Name(s):
Department of Civil and Environmental Engineering at the following universities:
University of Illinois at Urbana-Champaign
University of Cincinnati
North Carolina State University

Installation(s):
There are no known installations.

Key Words for Internet Search:
Fluorescence In Situ Hybridization (FISH), 16S rRNA, full-cycle 16S rRNA approach, phylogeny

Data Sources:

Amann, R. I., L. Krumholz, and D. A. Stahl, "Fluorescent-Oligonucleotide Probing of Whole Cells for Determinative, Phylogenetic, and Environmental Studies in Microbiology," Department of Veterinary Pathobiology, University of Illinois, Urbana, IL 61801, Journal of Bacteriology, 172(2), pp. 762–770, February 1990.

Amann, Rudolf, "Monitoring the Community Structure of Wastewater Treatment Plants: A Comparison of Old and New Techniques," Max-Planck Institut für Marine Mikrobiologie, Arbeitsgruppe Molekulare Ökologie, Celsiusstr. 1, D-28359 Bremen, Germany, FEMS Microbiology Ecology, Volume 25, Issue 3, p. 205, March 1998.

Daims, Holger, Niels B. Ramsing, Karl-Heinz Schleifer, and Michael Wagner, "Cultivation-Independent, Semiautomatic Determination of Absolute Bacterial Cell Numbers in Environmental Samples by Fluorescence In Situ Hybridization," Lehrstuhl für Mikrobiologie, Technische Universität München, 85350 Freising, Germany, and Department of Microbial Ecology, Institute of Biological Sciences, University of Aarhus, 8000 Aarhus, Denmark, Applied and Environmental Microbiology, pp. 5,810–5,818, Vol. 67, No. 12, December 2001.

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Technology Summary

Handheld Advanced Nucleic Acid Analyzer (HANAA)

Objective:
Real-time detection of pathogens in water and wastewater.

State of Development:
Embryonic.

Description:
HANAA uses the genetic material of microorganisms in wastewater by performing a Polymerase Chain Reaction (PCR) to detect pathogens. PCR is a technique for enzymatically replicating DNA without using a living organism, such as *E. coli* or yeast. Like amplification using living organisms, this technique allows for a small amount of DNA to be amplified exponentially. The HANAA is miniature thermal cycler, which can perform PCR in real time.

Commercially these products are available as Bio-Seeq™ and RAZOR®, although they are mostly being used for bioterrorism monitoring purposes.

Comparison to Established Technologies:
HANAA can be compared to a thermal cycler that is used in laboratories performing extensive molecular biology work. HANAA is a portable version of the thermal cycler and therefore, has the benefit of being used in field where monitoring needs to be performed, without extensive sampling and laboratory analysis time.

Available Cost Information:
Approximate Capital Cost: Unknown.

Approximate O&M Costs: Unknown.

Vendor Name(s):
Smiths Detection

Telephone: 1-908-222-9100

Web site: www.smithsdetection.com/

Idaho Technology Inc.
390 Wakara Way
Salt Lake City, UT 84108
Telephone: 801-736-6354 or 800-735-6544
Fax: 801-588-0507
Email: it@idahotech.com
Web site: www.idahotech.com/

Installation(s):
Information not available about the installations.

Key Words for Internet Search:
Bio-Seeq™, Smiths Detection, Handheld Advanced Nuclei Acid Analyzer, HANNA

Data Sources:
Higgins, James, "Handheld Advanced Nucleic Acid Analyzer (HANAA) for Waterborne Pathogen Detection," WERF publication, USDA, 2001.

www.smithsdetection.com

Telephone conversation with the vendor.

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Technology Summary

Immunosensors and Immunoassays

Objective:

Use antigen- antibody interaction to identify the presence of toxins in wastewater.

State of Development:

Embryonic.

Description:

Immunosensors and immunoassays involve antibodies that bind to a specific antigen noncovalently. Sensors and assays are designed to detect these interactions through a range of transducer options. The most popular immunoassay system in use is the Enzyme-Linked ImmunoSorbent Assay (ELISA). Environmental application includes analyzing selected contaminants such as pesticides and polyaromatic hydrocarbons. ELISAs include an antibody or antigen bound on a titer plate and an unbound reagent labeled with an enzyme that produces a signal in the presence of a specified substrate.

Comparison to Established Technologies:

This is not similar to any established technology.

Available Cost Information:

Approximate Capital Cost: Unknown.

Approximate O&M Costs: Unknown.

Vendor Name(s):

Not available commercially for wastewater applications.

Installation(s):

There are no known installations.

Key Words for Internet Search:

ELISA, antibody-antigen, immunosensors, and immunoassays

Data Sources:

Love, Nancy and Charles Bott, "A Review and Needs Survey of Upset Early Warning Devices," WERF publication, 2000.

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Technology Summary

Photo-electro Chemical Oxygen Demand (PeCOD™)

Objective:

Determine Chemical Oxygen Demand (COD) of wastewater without extensive laboratory process.

State of Development:

Embryonic.

Description:

Photo-electro Chemical Oxygen Demand (PeCOD™) technology can measure photo-current charge originating from the oxidization of organic species contained in a sample. The PeCOD™ technology is able to photo-electrochemically generate an electrical signal that directly correlates, via mass balance, with the oxidizable organic species contained in wastewater samples. The core of the technology is the ability of the UV-activated nano-particulate photocatalyst semi-conductive electrode to create a high-oxidation potential that ensures complete oxidation of all oxidizable organic species. This technology has the ability to capture and measure the resultant photo-current. The PeCOD™ online analyzer has been used to monitor COD in municipal wastewater treatment plants. Real-time COD event-monitoring enables efficient secondary treatment and reduces operational and discharge costs in regional plants vulnerable to COD surges from industrial sources.

Comparison to Established Technologies:

The photoelectric COD sensor has short analysis time, is simple to use, has low impact to the environment, and has a long sensor life. It provides real-time results in as low as 30 seconds to overcome the problems of time delay encountered by chemical oxidation methods. High sensitivity and wide linear range is obtained by direct signal acquisition.

Available Cost Information:

Approximate Capital Cost: Not available.

Approximate O&M Costs: Not available.

Vendor Name(s):

Aqua Diagnostic Pty Ltd.
Level 1, 159 Dorcas Street
South Melbourne, Victoria 3205
Australia
Telephone: 61 3 8606 3424
Fax: 61 3 9686 9866
Email: info@aquadiagnostic.com
Web site: http://www.aquadiagnostic.com

East China Normal University
Litong Jin
Department of Chemistry
Shanghai 200062
People's Republic of China

Installation(s):

There are no installations.

Key Words for Internet Search:

Photo-electro Chemical Oxygen Demand, PeCOD™, Aqua Diagnostic

Data Sources:

Aqua Diagnostic, "PeCOD™ COD Analyzer Delivers Rapid, Reliable and Accurate On-Line COD Monitoring, Technology."

Journal Abstract, "Ti/TiO_2 Electrode Preparation Using Laser Anneal and its' Application to Determination of Chemical Oxygen Demand," Electroanalysis, Volume 18, Issue 10, pp. 1,014–1,018.

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Chapter 6

Research Needs

6.1 Introduction

In order to develop new technologies or process improvements for any technology that is considered to be innovative or embryonic, additional research and field demonstration projects are necessary. This chapter focuses on specific technologies that may have a significant impact on wastewater treatment and wet weather management, and the relevant research needs in these areas.

6.2 Research Needs

Wastewater treatment technologies have shown tremendous growth in the past decade and continue to grow. The focus of treatment technologies is to achieve higher levels of pollutant removal while minimizing the operation and maintenance costs of the treatment system.

Emerging technologies can provide more cost-efficient solutions to the problems associated with deteriorating wastewater treatment and collection systems, growing population and urbanization, conservation of non-renewable resources and approaches toward cheap and green technology. Emerging technologies may also improve the performance of processes and systems. Research and technical issues can be grouped into the following areas: (1) upgrading older WWTPs; (2) nutrient removal and recovery; (3) use of smart technologies; (4) research and development to solve emerging problems in treatment facilities; and (5) security and emergency preparedness of WWTPs in United States.

6.2.1 Upgrading Old WWTPs

Most of the treatment plants in the United States were constructed more than two decades ago. Many of these treatment facilities need to be upgraded to improve capacity and treatment efficiency. The upgraded treatment processes that can best fit the existing technologies at Publicly Owned Treatment Works (POTWs) are chosen based upon permit requirements and their cost-effectiveness techniques used to achieve water quality and protect public health. Such upgrades are often opportunities to employ emerging technologies or established technologies in newer and better ways.

Some of the areas of current and future interest are as follows:

- Determine of the long-term performance and life-cycle cost effectiveness of system rehabilitation techniques, including new and existing materials.
- Identify emerging and innovative asset inspection technologies and demonstrate of these technologies in field settings to improve understanding of cost-effectiveness, performance, and reliability.
- Use technologies that are energy-efficient and conserve energy expenditures by wastewater utilities.
- Use physical adaptation for emerging and innovative technologies within the existing constraints of wastewater facilities.

6.2.2 Removal of Nutrients and Other Contaminants

Nutrients in wastewater effluent can stimulate excessive algae growth and ammonia is toxic to aquatic life. Increasingly more stringent nutrient discharge limits are promoting research into technologies that are capable of improved nutrient removal.

Compounds that can alter the endocrine system of animals are known as Endocrine Disrupting Compounds (EDCs) and have been linked to a variety of adverse effects in both humans and wildlife. Pharmaceutical compounds and their metabolites have been detected as Pharmaceutically Active Compounds (PhACs). Some PhACs are highly persistent and can function as EDCs.

Some of the areas of current and future interest are as follows:

- Processes to achieve low total nitrogen and total phosphorus levels.
- Recycle streams for bioaugmentation and enhanced nutrient removal.
- Use MBR technology for anaerobic wastewater treatment.
- Use Aerobic Granular Sludge Process (AGSP) for aerobic wastewater treatment.
- Evaluate availability and effectiveness of new carbon sources for denitrification.
- Identify refractory Dissolved Organic Nitrogen (rDON) and determine rDON bioavailability.
- Evaluate new processes and process modifications that can effectively remove rDON.
- Improve online nutrient and toxic monitoring techniques.
- Improve analytical methods for measuring very low levels of nitrogen and phosphorus.
- Improve disinfection technologies for control of emerging pathogens of concern (*Cryptosporidium, Giardia, e-Coli*-0157, etc.) without disinfection byproduct issues.

- Recover P, N, and ammonia from wastewater streams (e.g., Struvite precipitation and calcium phosphate formation) and study the feasibility of these processes in the United States.
- Evaluate new technologies for cost-effective removal of EDCs, PhACs, PBDEs, Prions, PPCPs, etc.

6.2.3 Use of Smart Technologies

Real-time information through monitors and automated process controls provide improved process performance and treatment response. These recent advances can be further developed to yield even greater advances. Some of the smart-technologies are as follows:

- Biological process modeling and control by using process-modeling tools to control plant operations and optimize treatment.
- Process automation, improved efficiency, space needs, reduced O&M costs, and reduced energy usage.
- Sensors and early warning devices to predict system upset.
- Microbiology and molecular tools to better understand and resolve biological wastewater treatment issues.
- Monitoring technologies development using the molecular approach to achieve real-time monitoring.
- Microbial ecology study of reactors, metabolic pathways, and bioengineered systems.
- Energy recovery improvement.

6.2.4 Security of Water Systems

With treatment and collection systems valued at more than $2 trillion, the wastewater infrastructure of the United States is one of the nation's most valuable resources. Large-scale damage to this national asset would require extensive rebuilding under very challenging conditions. While loss of life resulting from this damage might not be significant, the discharge of millions of gallons of untreated or partially treated sewage into the nation's rivers and lakes could cause catastrophic damage to aquatic ecosystems and the economy. While much attention has been given to the security of the nation's drinking water systems, there has been less emphasis on wastewater security. Research for security of wastewater systems includes the following:

- Emergency preparedness of WWTPs to deal with pandemics, new strains of viruses and bacteria, or spill incidents.
- Mitigation strategies for treatment plants after natural calamities (i.e., Katrina).
- Prevention and preparedness for bioterrorism.

6.2.5 Other Research Focus and Developments

There are many additional areas for further research in the wastewater treatment arena, specifically concerning the development of new technologies or in approaches to extend the life of wastewater infrastructure and investments in treatment technologies, including the following.

- Contact-stabilization and/or quick stabilization of storm water.
- Compounds of emerging concern such as EDCs, PPCPs, PBDEs, Prions, etc.
- Pathogens and antibiotic-resistant pathogens in water reclamation processes.
- Fate of specific organic pollutants.
- Sustainable wastewater conveyance and treatment.
- Novel advanced treatment processes that enable water reuse.
- Odor control and aerosol emission from the wastewater treatment facility.
- Disinfection alternatives to chlorination.
- Prevention of membrane fouling through changes in membrane system design, materials, and operation.
- Kinetic and stoichiometric parameter estimation of biological processes.
- Degradation of xenobiotics and destruction-resistant strains of microorganisms.
- Biohydrogen (as fuel-cells for electricity production) and bioethanol production through wastewater processes.

Some technologies can be used in certain regions depending on the climatic conditions. These technologies need to be made available to the WWTPs in those regions. One such example is the solar disinfection system that can be used in sunnier parts of the United States.

6.2.6 Research Needs and Prioritization per Water Environment Research Foundation (WERF)

The Water Environment Research Foundation (WERF) held a workshop in March of 2006 for an informed discussion on nitrogen and phosphorus removal at wastewater treatment plants. They have since produced the report entitled “WERF Workshop of Nutrient Removal: How Low Can We Go and What is Stopping Us from Going Lower?,” 05-CTS-1W. The report identifies research needs and prioritizes the results from that workshop; see Exhibit 6-1 (report is included with the permission from the WERF).

6.3 Chapter References

Institute of Environment and Resources – Wastewater Technology University of Denmark; web site: http://www.er.dtu.dk/English/

Water Environment Research Foundation (WERF), 2002; web site: www.werf.org/funding/researchplan.cfm

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal

05-CTS-1W

WERF WORKSHOP ON NUTRIENT REMOVAL:

HOW LOW CAN WE GO & WHAT IS STOPPING US FROM GOING LOWER?

by:

Charles B. Bott, Ph.D., P.E.
Virginia Military Institute

Sudhir N. Murthy, Ph.D., P.E.
District of Columbia Water and Sewer Authority, D.C.

Tanya T. Spano, P.E.
Metropolitan Washington Council of Governments, D.C.

Clifford W. Randall, Ph.D.
Virginia Tech

2007

WERF

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

Abstract:

Based on an expert stakeholder workshop convened in March 2006, this report provides a summary of discussions on the state of knowledge on the removal of nutrients (nitrogen and phosphorus) from wastewater and their limits of technology (LOT), and to help address the questions "how low can we go" and "what is stopping us from going lower". The panelists and participants included many of the key water quality professionals from consulting, academia, government, and utilities that have been working in this arena for several years and/or decades. The report includes an accompanying CD-ROM with the speaker presentations, documents distributed at the workshop, research needs and prioritization, as well as the list of participants and results from the workshop survey.

Benefits:

- Provides a summary of the state of knowledge through presentations and discussions by key experts and practitioners on limits of technology, removal strategies, etc., for nitrogen and phosphorus in wastewater
- Identifies key questions and research needs
- Informs WERF current nutrient removal challenge (06-NUTR-1)

Keywords: Nitrification, denitrification, boundary conditions, nitrogen, phosphorus, EBPR, BNR

PRIORITY RESEARCH NEEDS IDENTIFIED AT WORKSHOP

The following three categories of program-based research needs were identified:

A. Policy and Information Based Research
B. Experimental Research Targeting LOT Permitting Policy (short-term research)
C. Experimental Research Targeting LOT Design and Operation

Within these three categories, there are four priorities established ("Highest", "High", "Moderate", and "Long-Range"). See Appendix A for the detailed research needs and prioritization.

Table 1: Priority Research Needs Identified at Workshop.

		Program-Based Research Needs Identified	Priority
A		**Policy and Information Based Research**	
		This focuses on a forum for LOT policy development and disseminating information among WERF industry, utility, consulting and regulatory subscriber groups	
	1	Information Exchange and Technology Transfer – methods to improve sharing of operational and design experience at or near the LOT	Highest
	2	LOT Permitting Policy – need to develop consensus on achievable, realistic, and sustainable nutrient limits	Highest

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

	3	Long Range Sustainability for Water Reuse and Nutrient Recovery – need to understand and measure sustainable approaches to LOT nutrient removal	Long-range
B		**Research Targeting LOT Permitting Policy**	*Short-Term Research*
		Several topics of experimental research that should be considered to support the LOT permitting approach	
	1	Refractory Dissolved Organic Nitrogen (rDON) – need to better understand the production and sources of rDON, removal of rDON in various treatment schemes, and the significance of rDON in the environment	Highest
	2	Standard Methods for Low Level P Analysis – develop standard methods for LOT phosphorus measurement and understand / characterize residual and refractory phosphorus fractions	Highest
	3	Update Nitrification Inhibition EPA List – list of chemicals that represent threshold nitrification inhibition dosages was developed about 20 years ago; it has not been updated since and is incorrect / incomplete. Updated list is needed as part of local municipality pre-treatment program.	Highest
	4	Modeling Tools and Procedures – develop forum for modeling LOT nutrient removal	Highest
C		**Research Targeting LOT Design and Operation**	*Long-Term Research*
		Focus research targeted at improving the technology and design procedures for LOT nutrient removal processes based on differing plant size and discharge limits. Better understand the impact of LOT nutrient removal on sludge treatment and reuse, and the related implications for volume and mass of solids created.	
	1	Better Instrumentation and Application / Implementation / Use of Online Instruments – develop online instrumentation and control for LOT nutrient removal including nitrogen control, phosphorus control and supplemental carbon addition and control	Highest
	2	Substrates for Denitrification and Biological Phosphorus Removal – a majority of plants building LOT nitrogen and phosphorus removal processes will consider supplemental carbon for treatment; much work is needed to understand the appropriate use of supplemental carbon	Highest
	3	Methods to achieve Low P Levels – develop novel technologies for LOT phosphorus control, while simultaneously understand capabilities of current simultaneous precipitation, tertiary clarification and/or	High

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

		filtration technologies	
	4	Nitrification Process Control, Inhibition and Bioaugmentation - develop and refine understanding of nitrification impacts on LOT treatment, including impacts of chemical and substrate inhibition, cold temperature and cold shock, high temperature inhibition, BOD/TKN ratios, process anaerobic/anoxic/aerobic cycling, etc.	High
	5	P Limitations of Post-Secondary Denitrification Processes – as utilities consider simultaneous low TN and TP, phosphorus deficiency becomes an important issue for plants. Research is needed to understand phosphorus bioavailability in chemically removed material versus suspended solids from Bio-P processes	High
	6	Enhanced Biological Phosphorus Removal – continued research needed in several areas for cost-effective application of EBPR, e.g., P uptake and release kinetics, pre-fermenters, VFA, PAO, GAO, etc.	High
	7	Simultaneous Nitrification-Denitrification (SND) – better design and implementation information and methodologies to evaluate the amount of “nutrient removal credit” that can be expected with a SND process for small to medium sized plants	High
	8	Side Stream Treatment – research on reduction in influent loading, bioaugmentation, etc.	High
	9	Activated Sludge Settling, Selectors, Bulking – clarifiers are usually hydraulic bottlenecks for LOT nutrient removal; develop protocols for process and clarifier operations for LOT treatment	Highest

RESEARCH NEEDS AND PRIORITIZATION

Overall Goals

A research program that will provide utility, industrial, consultant and regulator subscribers a battery of tools to help insure that water quality-based nutrient limits are achievable, sustainable and cost effective. These tools will address design, operational control, measurement and regulatory compliance issues for limit of technology (LOT) nutrient removal. A well-defined and standardized approach to identify LOT effluent quality based on site-specific influent and receiving water characteristics, operating realities and treatability of various nutrient components, and other parameters, is a most critical need.

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

Overview

Several categories of program-based research needs were identified at the 2005 Nutrient Removal Workshop. These include:

A. Policy and Information Based Research
B. Experimental Research Targeting LOT Permitting Policy (short-term research)
C. Experimental Research Targeting LOT Design and Operation

Within these three categories, there are four priorities established. These are "Highest", "High", "Moderate", and "Long-Range". It is expected that funding would be established for the "Highest" priority research. WERF should first evaluate existing projects in these categories. Successful, existing WERF or Subscriber projects should be leveraged when possible to minimize WERF costs by providing program oversight, peer review or simply by disseminating results through information exchange on a case-by-case basis.

A. POLICY AND INFORMATION-BASED RESEARCH

This sub-program area focuses on a forum for LOT policy development and disseminating information among WERF industry, utility, consulting and regulatory subscriber groups.

1. Information Exchange and Technology Transfer

Priority – Highest

Methods are needed to improve the sharing of operational and design experiences at or near the LOT. This could be in the form of design methodologies, regulatory toolkits, standards for influent wastewater characterization, and web-based information sharing tools.

- A significant amount of institutional knowledge is available within process simulation models that are currently available. There is a need for educational enhancement within our field on the understanding, use and application of these models. These models represent a platform for sharing design and operational experiences. (also see modeling below–Part B-4)
- There is a need to translate the real world experience of LOT facilities, such as effluent variability, operation challenges, back into the design tools and operating strategies to test the ability of the toolkits to predict performance.
- There is a need to better understand what skills are required to operate LOT nutrient removal facilities and whether current training/certification programs are adequate. Also, to determine specific services and training needs for start-up and debugging of a new facility or a renovated facility.
- There is a need to better understand the costs and benefits of designing and operating plants to achieve LOT nutrient removal.
- This information-based research could be a reasonable forum to follow the development and application of membrane bioreactor processes and membrane treatment for very low levels of phosphorus removal and possibly the removal of refractory nitrogen.

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

- Although other forums could be used, there is a need to update and expand the well-known *EPA Nitrogen Control Manual (EPA/625/R-93/010, 1993)* to include current information and to include both LOT nitrogen and phosphorus removal and the improvements in instrumentation, controls and real time analytical measurement.

2. LOT Permitting Policy
Priority – Highest

There is an important need to develop consensus among municipalities, industry, regulators and consultants on what are achievable, realistic and sustainable limits for nutrients. Under what conditions can we achieve near perfection? How close to ideal can we permit? This suggests a need for permits that include "Boundary Conditions" or "Terms and Conditions" under which discharge limits can and should be reliably met. There is a need for policies and regulatory framework to develop these permitting strategies. Examples such as excluding refractory dissolved organic nitrogen from mass-based limits, accounting for higher influent levels due to industrial sources, water saving or conservation measures, statistically-based limits rather than absolute values (such as 90% of the time), and variances for wet weather flows and inhibition from unusual occurrences. WERF should pursue an understanding of environmental benefit and cost from different regulatory approaches and the costs and benefits associated with the risk mitigation of noncompliance.

- Assuming that effluent limits are being set based on the LOT, can we develop a methodology that will allow designers, operators and regulators to agree to site specific LOTs effluent limits?
- Do we need to develop a "CMOM" (capacity, management, operations and maintenance, similar to EPA's program for collection systems) or "EMS" (environmental management systems, similar to the EPA/WEF/NACWA program for biosolids) approach to our NPDES limits that incorporate LOT limits? If the system were designed to standards that all agree should be able to achieve LOT, the plant continuously monitors, operates and maintains the system but LOT limit is not achieved, can this provide a defense against monetary violations? Would an exceedance cause an action plan similar to a toxicity reduction evaluation, without onerous fines and penalties?
- Can an approach be developed that would define the range in effluent quality produced from various treatment technologies, i.e., denitrification filters (0 to 0.x mg/l Nitrate)?
- Evaluate why certain plants may sometimes not be able to meet specific limits
- There is a need to explore alternate permit limits such as a 12-month rolling average for a mass based limit over a strict LOT concentration limit. Trading programs will allow flexibility with a LOT limit. This may serve to bridge the operational performance deficiencies during process upset or wet weather conditions.
- There are wet and cold weather conditions that are not practical for wastewater treatment plant design that may occur infrequently and would need boundary conditions.
    - Consider permitting with Boundary Condition
    - Interpretation of blending regulations

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

3. Long Range Sustainability—Water Reuse and Nutrient Recovery Priority—Long Range

There is a need to understand and measure sustainable approaches to LOT nutrient removal. This includes developing a sustainability index and understanding the additional energy and chemicals requirements to attain LOT treatment. Metrics for value produced from treatment for reuse and reclamation is needed. Other approaches for sustainability include decentralized treatment, nutrient recovery, integrated water treatment and reclamation, and solids volume reduction.

B. EXPERIMENTAL RESEARCH TARGETING LOT PERMITTING POLICY (SHORT-TERM RESEARCH)

There are several topics of experimental research that should be considered to support the LOT permitting approach. These projects should receive highest priority for WERF funding.

1. Refractory Dissolved Organic Nitrogen (rDON)

Priority – Highest

For a plant achieving LOT nitrogen removal, 30-50% of the effluent N is in the form of rDON. There is a need to better understand the production and sources of rDON, removal of rDON in various treatment schemes, and the significance of rDON in the environment.

- Do non-biodegradable forms of nitrogen exist in wastewater and if so how can they be measured? Should they be excluded from nitrogen discharge mass limits?
- Occurrence – Removal – Significance?
- Source? Influent or biological process? Humics? EPS? SMP?
- Effect of treatment process design/operation on production/removal?
- Methods to remove – maybe a survey of different treatment systems in place now?
- Novel methods for removal?
- Production in suspended growth versus fixed film systems
- Production in separate stage nitrification/denitrification systems vs. combined systems.
- Differences in production between plug flow combined systems (e.g. Bardenpho) vs. those that approach complete mix (e.g. Carrousel systems) vs. "mixed flow" processes like Step Feed BNR
- Borrow from the field of drinking water NOM removal?
- Fate – bioavailability in the environment (including an assessment of the time scale of availability)?

2. Standard Methods for Low Level P Analysis

Priority – Highest

Develop standard methods for LOT phosphorus measurement and understand/characterize residual and refractory phosphorus fractions.

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

3. Update Nitrification Inhibition EPA List

Priority – Highest

U.S. EPA developed a list of chemicals that represent threshold nitrification inhibition dosages about 20 years ago and it has not been updated since. This list has proven to be incorrect and incomplete. Localities need an updated list that can be used as part of their pre-treatment program.

4. Modeling Tools and Procedures

Priority – Highest

Develop a forum for modeling LOT nutrient removal as well-developed models essentially represent current collective knowledge. This forum would evaluate reactor staging, wet weather, cold weather, inhibition, sidestream treatment, partial nitrification, denitrification and deammonification reaction, biological-P and chemical P removal to understand capabilities of plants to achieve LOT. Available data would be reviewed that show complete mix systems develop nitrifying bacteria with significantly lower growth rates than in plug flow systems; similar data are available comparing "mixed flow" systems (Step BNR) and plug flow systems. Also, given the importance of rDON, models need to updated to reflect current research results on bioflocculation of colloidal materials and to account for rDON removal/transformation and rDON production/end product formation during biological treatment. Models will be a primary tool in demonstrating LOT limits to regulators and, thus, these models must be "fine-tuned" when it comes to LOT limits. Small anomalies, such as reaction time to turn on additional aeration or turn off aeration, during the day could, in the case of nitrogen, add 0.1 to 0.5 mg/l TN to the effluent.

C. EXPERIMENTAL RESEARCH TARGETING LOT DESIGN AND OPERATION (LONG-TERM RESEARCH)

There is a need to focus research targeted at improving the technology and design procedures for LOT nutrient removal processes based on differing plant size and discharge limits. Plants that have very low TP limits without TN limits require different strategies as compared to plants that have combined low TN (3-4 mg/L) and moderately low TP (0.1-1 mg/L) limits. Research priorities in this category generally depend on the size of the plant being considered. Small plants typically have high SRT and HRT and large clarifiers, and thus there is a need to understand how to "extract" additional nutrient removal from "available volume." This suggests better information transfer and experimental research targeting these design modifications (do more nutrient removal with the tank volume available). Large plants already have low available safety factor in terms of SRT and HRT. New cost-effective technologies should be considered to further extract additional nutrient removal (e.g. breakpoint chlorination, bioaugmentation, side stream treatment, etc.) without large capital expenditures. There is also a need to better understand the impact of LOT nutrient removal on sludge treatment and reuse, and the related implications for volume and mass of solids created. *(Note: to be coordinated with the concurrent ET challenge on solids volume reduction)*.

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

1. Better Instrumentation and Application/Implementation/Use of Online Instrument
Priority – Highest

Develop online instrumentation and control for LOT nutrient removal including nitrogen control, phosphorus control and supplemental carbon addition and control. Leverage existing WERF projects including 03-CTS-8 and expand it to phosphorus removal and carbon control technologies. This will also improve efficiency and energy management at treatment facilities. This one area as with all instrumentation and controls has changed dramatically since the 1993 EPA manual was published and needs updating to current technology.

2. Substrates for Denitrification and Biological Phosphorus Removal
Priority – Highest

A majority of plants that will build LOT nitrogen and phosphorus removal processes will be considering supplemental carbon for treatment. Much work needs to be done to understand the appropriate use of supplemental carbon:

- Improve understanding of methanol utilization kinetics, microbiology, and stoichiometry both in suspended and attached growth systems – and temperature dependency
- Glycerol (unrefined byproduct of biodiesel production coupled with possible increase in methanol cost with consumption to produce biodiesel)
- Better understanding of benefit of acetate, ethanol, sugar solutions and other viable carbon sources compared to methanol – better understand kinetics, microbiology (ability of native organisms to use these substrates), and stoichiometry
- Evaluate the potential for insitu methanol production using methane derived from anaerobic digestion.
- Improve understanding and application of fermentation processes (using various sludge sources) for VFA production and Bio-P versus fermentation for high COD/TKN ratio for denitrification
- Better understanding of capability of denitrification in single-sludge second anoxic zone with and without carbon addition

3. Methods to Achieve Low P Levels
Priority – High

Develop novel technologies for LOT phosphorus control, while simultaneously understand capabilities of current simultaneous precipitation, tertiary clarification and/or filtration technologies (how well are we doing?). Two areas of research should be considered:

- Chemistry at low P concentrations (high Me/P dose ratio)
- Improvement of solids removal (membranes, filtration, or other)

4. Nitrification Process Control, Inhibition and Bioaugmentation
Priority – High

There is an important need to develop and refine our understanding of nitrification impacts on LOT treatment, including impacts of chemical and substrate inhibition, cold temperature and cold shock, high temperature inhibition, BOD/TKN ratios, process

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

anaerobic/anoxic/aerobic cycling. Develop molecular techniques to monitor and diagnose inhibition. Develop and refine novel techniques to enhance nitrification including bioaugmentation and heterotrophic wasting. Leverage existing WERF projects. Develop a user friendly system of analysis and evaluation for the end users for trouble shooting guide to nitrification inhibition.

5. P Limitations of Post-Secondary Denitrification Processes
Priority – High

As utilities consider simultaneous low TN and TP, phosphorus deficiency becomes an important issue for plants. Therefore, research is needed to understand phosphorus bioavailability in chemically removed material versus suspended solids from Bio-P processes.

6. Enhanced Biological Phosphorus Removal – Continued Research
Priority – High

Several areas of research remain for the cost-effective application of the enhanced biological phosphorus removal process at the LOT:

- P uptake and release kinetics – staging, P concentration and P storage, relationship between release and uptake specifically under dynamic loading conditions?
- Operation and control of pre-fermenters for VFA production? How much does fermenter operation affect the production of the different VFA forms, particularly acetic and propionic?
- PAO starvation with diurnal feeding? Need improved understanding of COD uptake and stabilization under anaerobic conditions - biochemical mechanisms involved.
- Improved understanding of secondary P release in anoxic zones and clarifiers?
- Better understanding of competition between PAOs and GAOs, particularly as related to influent wastewater characteristics such as the acetic/propionic acid ratio. Also, temperature effects on the competition over the range from 5-40^{o}C and the biochemical mechanisms involved.
- Better understanding of the interactions of EBPR and chemicals, which can develop a tool that will help identify when EBPR versus chemicals should be used to achieve LOT.

7. Simultaneous Nitrification-Denitrification (SND)
Priority – High

SND represents a good opportunity for small to medium size plants with available safety factor to maximize nutrient removal (both denitrification and potentially bio-P), likely as a component of more conventional nutrient removal processes. It seems likely that SND alone would not be used to meet LOT permit limits, but it could be part of a cost-effective solution for nutrient removal. There is a need for better design and implementation information and methodologies for evaluating the amount of "nutrient removal credit" that can be expected with a SND process. Several research areas should be addressed including nitrification to NO_2, improved online instrumentation for process control, potential bio-P considerations, nitrification kinetics, and modeling.

Exhibit 6.1—Paper from WERF Workshop on Nutrient Removal (Contd)

8. Sidestream Treatment – Reduction in Influent Loading and Bioaugmentation

Priority – High

Sidestream treatment is a cost effective method to reduce the use of supplemental carbon and aeration energy. An added benefit is the bioaugmentation of nitrifying bacteria to the main-stream treatment process. Research areas include:

- Further develop the Anammox and related processes for autotrophic denitrification.
- Use molecular methods to evaluate mainstream bioaugmentation efficiency of nitrifiers produced in side-stream treatment. Need thorough documentation of full-scale demonstrations.

9. Activated Sludge Settling, Selectors, Bulking

Priority – Highest (but should be addressed outside the WERF LOT Nutrient Removal Program)

Clarifiers are usually hydraulic bottlenecks for LOT nutrient removal. Develop protocols for process and clarifier operations for LOT treatment, including understanding benefits/ drawbacks of anoxic zones, IFAS and phosphorus deficiency from low TP co-precipitation. Given the sporadic performance of anoxic and anaerobic selectors, conduct research to understand and improve performance. Through additional surveys and experimentation, assess whether some BNR processes, influent compositions, and environmental conditions produce mixed liquor qualities that have superior settling and compaction characteristics. Building on previous WERF research, there is a need to develop a fundamental understanding of the factors leading to or favoring improved settling and compaction.

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Appendix

A

Trade Associations

A.1 Introduction

This chapter lists professional and trade associations that may have significant information. These professional and trade associations may provide relevant research assistance on wastewater treatment and in-plant wet weather management technologies within their respective areas of expertise.

A.2 Trade Associations

American Society of Civil Engineers (ASCE)
1801 Alexander Bell Drive Reston, VA 20191-4400
Telephone: 800-548-2723
Web site: http://www.asce.org

National Association of Clean Water Agencies (NACWA)
1816 Jefferson Place, NW, Washington D.C. 20036
Telephone: 202-833-2672
Web site: http://www.nacwa.org/

Water and Wastewater Equipment Manufacturers Association (WWEMA)
P.O. Box 17402, Washington, D.C. 20041
Telephone: 703-444-1777
Web site: http://www.wwema.org

Water Environment Federation (WEF)
601 Wythe Street, Alexandria, VA 22314-1994
Telephone: 703-684-2452
Web site: http://www.wef.org

Water Environment Research Foundation (WERF)
635 Slaters Lane, Suite 300, Alexandria, VA 22314
Telephone: 703-684-2470
Web site: http://www.werf.org

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