6th Water Arabia Conference and Exhibition, Saudi Arabia, February 11, 12 & 13, 2020

Sustainable Circular Economy Approach to Optimize Biological Nutrient Removal Using Glycerol (Bio-Diesel by-product) as a Carbon Substrate

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Introduction

sustainable approach for VFAs production, this study apply circular economy theories by using Biodiesel by-product (mainly glycerol) as an alternative carbon source in biological phosphorus and nitrogen removal in waste water treatment. This also in line with the Saudi “Vision 2030” of achieving environmental sustainability, since about 50% of all waste in Saudi Arabia is organic waste that has a great potential to be used to produce Biodiesel.

Introduction

- Biological nutrient removal (BNR)(EBPR and Denitrification) require a carbon source to be carried out.

- **VFAs**:

  - Are the major carbon source in wastewater That can drive EBPR.

  - Concentration and composition significantly affect efficiency .

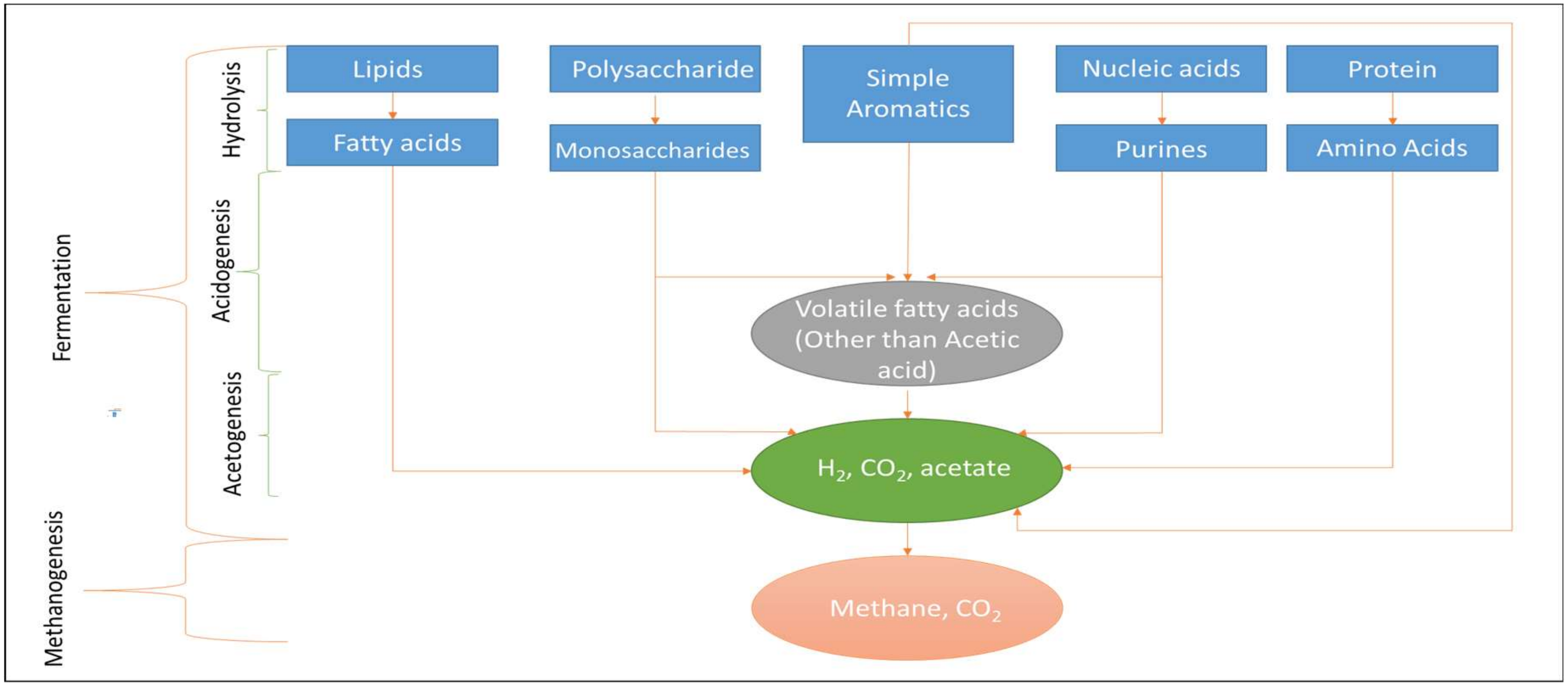
  - Can be produced through fermentation or external substrate fermentation.

  - production of VFAs for full-scale use is cost prohibitive.

(Chen, Randall, & McCue, 2004; Shen & Zhou, 2016; Wu, Peng, Li, & Wang, 2010)

Introduction

Fermentation



Fermentation

Methanogenesis

Hydrolysis

Acidogenesis

Acetogenesis

Lipids

Fatty acids

Polysaccharide

Monosaccharides

Simple Aromatics

Nucleic acids

Purines

Protein

Amino Acids

Volatile fatty acids (Other than Acetic acid)

H_2, CO_2, acetate

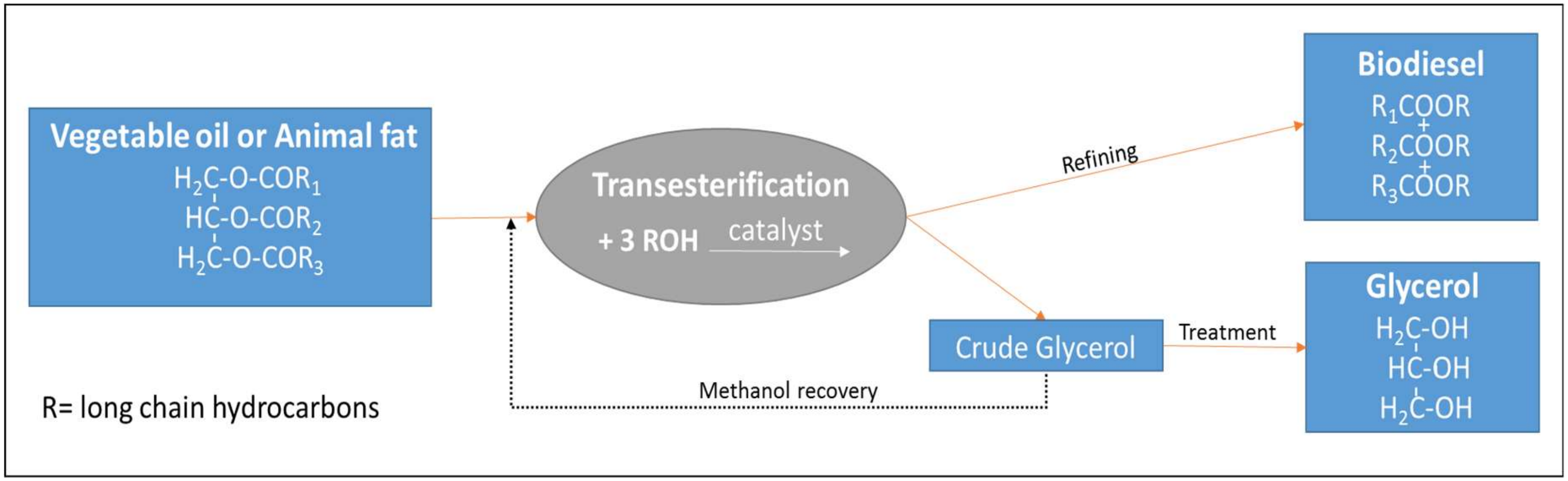
Methane, CO_2

(Metcalf & Eddy, 2014)

Introduction

Biodiesel

- Is a fuel produced from vegetable oils or animal fats (in the presence of a catalyst) through a transesterification reaction
- Results in glycerol as a by-product.
- Typical biodiesel waste mixtures contain 56% to 60% crude glycerol



Vegetable oil or Animal fat

$H_2C\text{-}O\text{-}COR_1$
$HC\text{-}O\text{-}COR_2$
$H_2C\text{-}O\text{-}COR_3$

Transesterification

+ 3 ROH $\xrightarrow{\text{catalyst}}$

Refining

Biodiesel

R_1COOR
+
R_2COOR
+
R_3COOR

Crude Glycerol

Treatment

Glycerol

$H_2C\text{-}OH$
$HC\text{-}OH$
$H_2C\text{-}OH$

Methanol recovery

R= long chain hydrocarbons

(Correa & Arbilla, 2008; Demirbas, 2008; Eguchi, Kagawa, & Okamoto, 2015; Hoekman & Robbins, 2012; Leoneti, Aragao-Leoneti, & De Oliveira, 2012; Usta et al., 2005).

Literature Review:

- Glycerol can be fermented to VFAs (Yin, Yu, Wang, & Shen, 2016).
- Prefermenter production of VFAs can be optimized by manipulating the mixing intensity (Banister & Pretorius, 1998; Danesh & Oleszkiewicz, 1997).
- Propionic acid was found to be more effective for BNR systems (Chen et al., 2004; Shen & Zhou, 2016; Wu et al., 2010).
- H_2 could inhibit Acetogenesis if H_2 exceeds 10^{-4} atm (Fukuzaki, Nishio, Shobayashi, & Nagai, 1990; Metcalf&Eddy, 2014).

Introduction

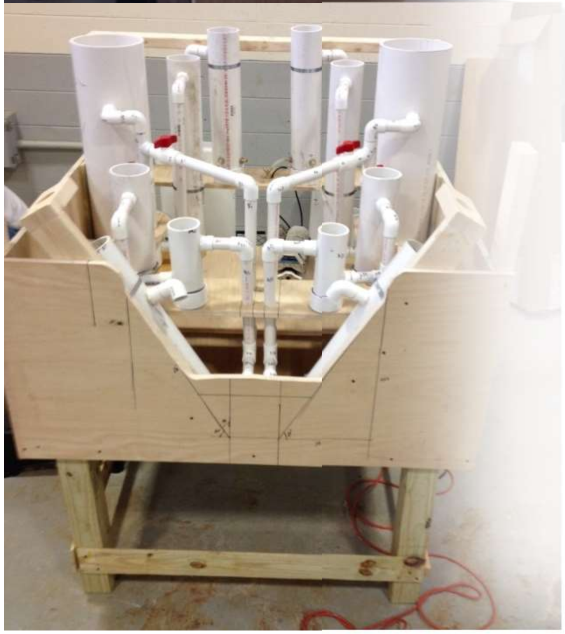
Objective:

- **Is to apply circular economy theory to optimize activated sludge system nutrient removal using fermented and direct addition of glycerol (biodiesel by-product) in a pilot scale A^2O experiment.**

Aim of the study:

- Compare the biological nutrient removal with and without prefermentation.
- Study the effect of glycerol adding location on the overall biological nutrient removal.
- Study the effect of prefermenter mixing intensity on the production of VFAs.

Sustainable Circular Economy Approach to Optimize Biological Nutrient Removal Using Glycerol (Bio-Diesel by-product) as a Carbon Substrate



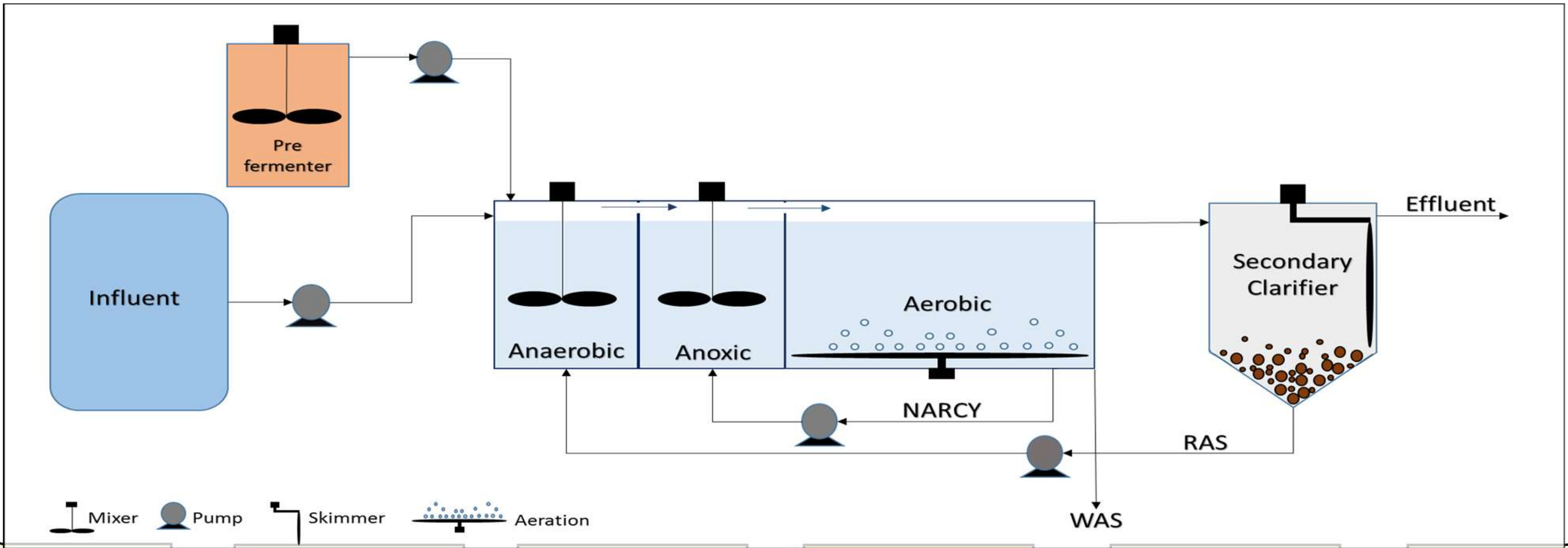
Sustainable Circular Economy Approach to Optimize Biological Nutrient Removal Using Glycerol (Bio-Diesel by-product) as a Carbon Substrate

Materials and Methods:

- Two A_2O BNR system
- Real wastewater
- SRT = 10 days

Reactor	Volume (L)	Diameter (inches)	Liquid Height (inches)
Anaerobic	3.59	4.00	17.43
Anoxic	5.90	4.00	28.65
Aerobic	17.95	8.00	21.79

- Glycerol dose 68.5 (phase1) and 78.8 (phase 2) mg-COD/L influent
- All comparisons were tested statistically using paired sample t-test



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Average Influent characteristics for all phases (both receive same influent)

		Flowrate	TN	NH3	TP	SOP	TSS	s-COD	TCOD	PH	DO
		L/day	mg/l as N	mg/l as N	mg/l as P	mg/l as P	mg/L	mg/L	mg/L		mg/L
Pre-Phase	Train A, B	54.1	39.2	37.8	5.0	5.0	74.4	193.2	319.1	7.6	0.2
Phase One	Train A, B	54.2	41.5	29.6	5.3	3.6	64.3	153.0	247.6	7.5	0.1
Phase two	Train A, B	51.7	52.3	33.9	4.4	3.4	52.8	120.5	208.8	7.7	0.1

Results and discussion: *Acclimation of the biomass (preliminary Phase)*

- No experimental variable
- No glycerol or prefermenters
- Does not have sufficient carbon source to drive biological nutrient removal
- Used as an acclimation period for the biomas

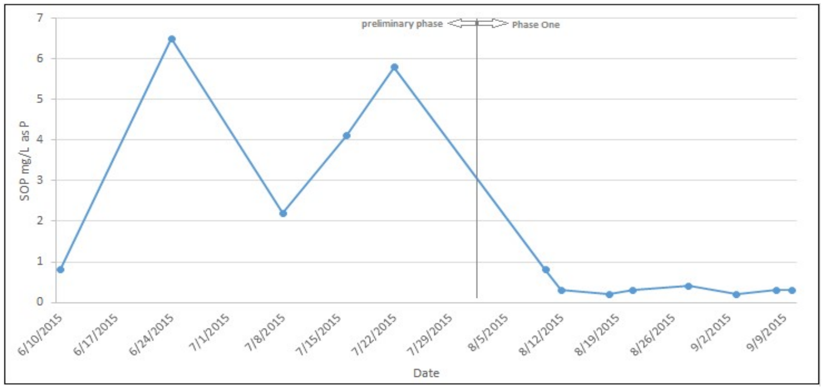
Sustainable Circular Economy Approach to Optimize Biological Nutrient Removal Using Glycerol (Bio-Diesel by-product) as a Carbon Substrate

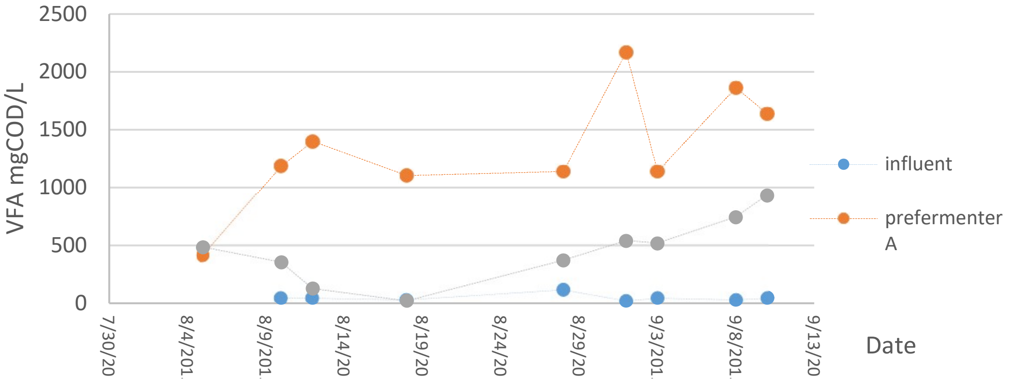
Results and discussion: Location of the Glycerol Dose (Phase 1)

- A produced 2.4 more total VFAs than prefermenter B
- EBPR functions showed a considerable improvement in phosphorus removal after attaching the prefermenters
- SOP removal efficiency for train A and B were 92.2% and 85.6% respectively
- both trains removed 100% ammonia

	SOP mg-P/L	TN mg-N/l	NH_3 mg-N/l	NO_x mg-N/l	s-COD mg/L	T-COD mg/L	TSS mg/L	DO mg/l	pH
Pilot A	0.4	10.8	0.0	6.3	28.9	33.0	7.7	0.1	7.9
Pilot B	0.6	11.8	0.0	8.1	31.9	30.9	6.3	0.8	7.6

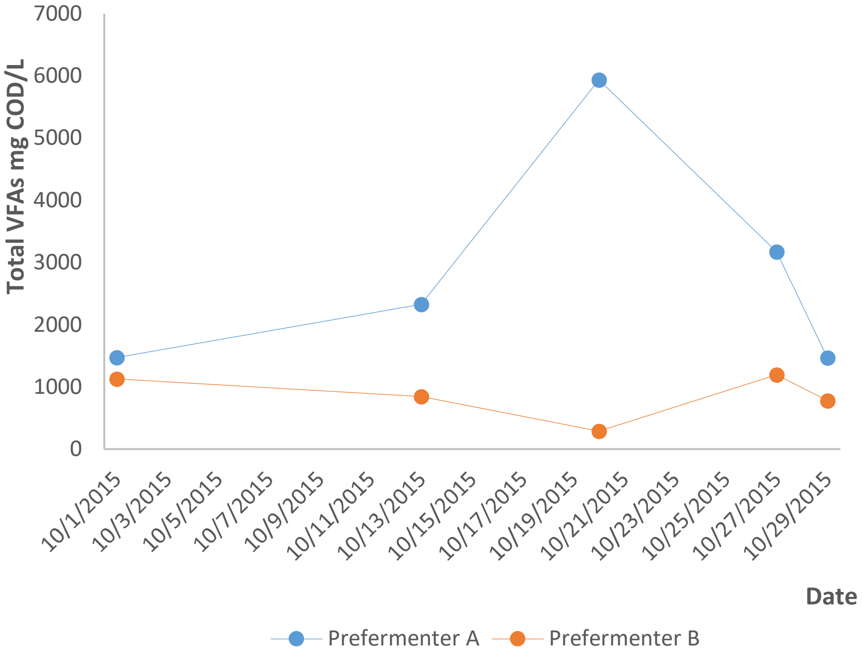
***Effluent samples were taken from the clarifier supernatant**





Results and discussion: Mixing Intensity (Phase 2)

- PF-A (7rpm) & PF-B (50rpm)
- VFA production had an inverse correlation with mixing intensity similar to a lab scale testing [12]
- Reducing the PF mixing to 7 rpm resulted in about 250% increase in the VFAs production and increased the propionic to acetic acid ratio about 50%.
- Better VFA production was observed with lower mixing intensity



	SOP mg-P/L	TN mg-N/l	NH_3 mg-N/l	NO_x mg-N/l	s-COD mg/L	T-COD mg/L	TSS mg/L	DO mg/l	pH
Pilot A	0.7	10.8	1.5	5.7	30.2	30.7	9.3	0.4	7.8
Pilot B	0.4	8.4	1.1	7.1	31.6	36.3	10.0	0.7	7.8

***Effluent samples were taken from the clarifier supernatant**

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Conclusion:

- Both location of glycerol addition had beneficial effects on the A_2O with no significant difference in the effluent quality with respect to both P and N.

- 1.4 hour anaerobic HRT was enough to ferment the glycerol and make it available for EBPR.

- Direct addition of glycerol to the anaerobic zone in PP2, resulted in the lowest Y_{obs} in the whole study.

- Co-fermentation of glycerol and primary sludge resulted in a significant VFAs increase even beyond the theoretical estimated additional VFAs from the glycerol addition.

Sustainable Circular Economy Approach to Optimize Biological Nutrient Removal Using Glycerol (Bio-Diesel by-product) as a Carbon Substrate

Conclusion (continued**):**

- Lower prefermenter mixing increased the VFAs production significantly (especially propionic acid) but did not correlate with superior EBPR effluent quality.
- In general, adding prefermentation reactor with glycerol dosage at low mixing energy should maximize the efficiency of the activated sludge system.
- Preliminary economic screening suggest that appling this optimization could save up to 20% of the BNR operational costs.

Questions & Comments

All welcome!

Thank you

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Emanon Photography, The background picture was retrieved from http://emanonphoto.blogspot.com/2011/03/ucf-knight_27.html

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Supporting Material

Introduction

- High nutrient concentration in municipal wastewater could cause significant environmental problems and health risks if discharged to receiving water without proper treatment (Walsh, 2012; Wanielista et al., 2008; Xuan, Chang, Daranpob, & Wanielista, 2009).
- Wastewater Nutrient can be removed chemically through precipitation or biologically through biological nutrient removal (BNR) (Metcalf&Eddy, 2014).
- A^2O, University of Cape Town (UCT), and 5-stage Bardenpho$^{\text{TM}}$ (Metcalf&Eddy, 2014).
- Biological Nutrient removal is the nitrogen removal and enhanced biological phosphorus removal (EBPR).

Introduction

Biological Nitrogen Removal (Nitrification/Denitrification)

Nitrification

Carried out by chemoautotrophic bacteria known as nitrifying bacteria in a two step process.

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O$$ ***Nitrosomonas Europea***

$$2NO_2^- + 2O_2 \rightarrow 2NO_3^-$$ ***Nitrobacter***

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$ ***Net equation***

Introduction

Biological Nitrogen Removal (Nitrification/Denitrification)

Denitrification

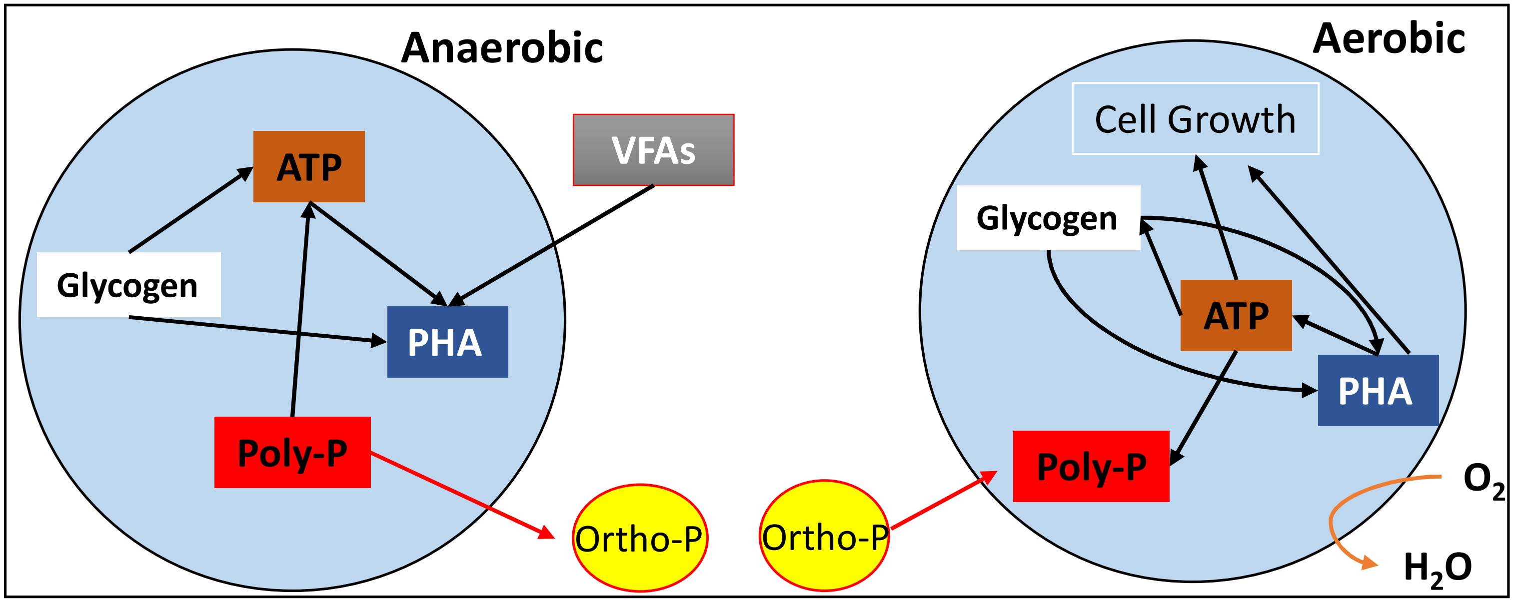
Denitrification is carried out as a dissimilation process by a broad range of heterotrophic groups of bacteria.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N$$

Introduction

Enhanced Biological Phosphorus Removal (EBPR)

- Phosphorus removal from wastewater takes place in two main environments: anaerobic and aerobic.
- Anaerobic:
  - $\text{PAO} + \text{Poly-P} + \text{VFAs} \xrightarrow{\text{ATP}} \text{Ortho-P} + \text{PHA}$
- Aerobic:
  - $\text{Ortho-P} + \text{PHA} \xrightarrow[\text{O2}]{\text{ATP}} \text{PAOs} + CO_2 + H_2O$



Introduction

Composition of Crude Glycerol (w/w): 30% **glycerol**, 50% methanol, 13% soap, 2% moisture, approximately 2-3% salts (primarily sodium and potassium), and 2-3% other impurities

Introduction

VFAs were measured using a Shimadzu (Columbia, Maryland) gas chromatograph equipped with a Supelco (St Louis, Missouri) Nukol column, and flame ionization detector (FID). The injection port and the detector were maintained at 220°C. Column initial temperature was 110°C and then ramped up at 5°C/min to reach a final temperature of 190°C which was held for 10 minutes. The carrier gas was helium at a flow rate of 20 cm/min, and a 10 mM volatile free acid mix was used to develop the standard curve

Introduction

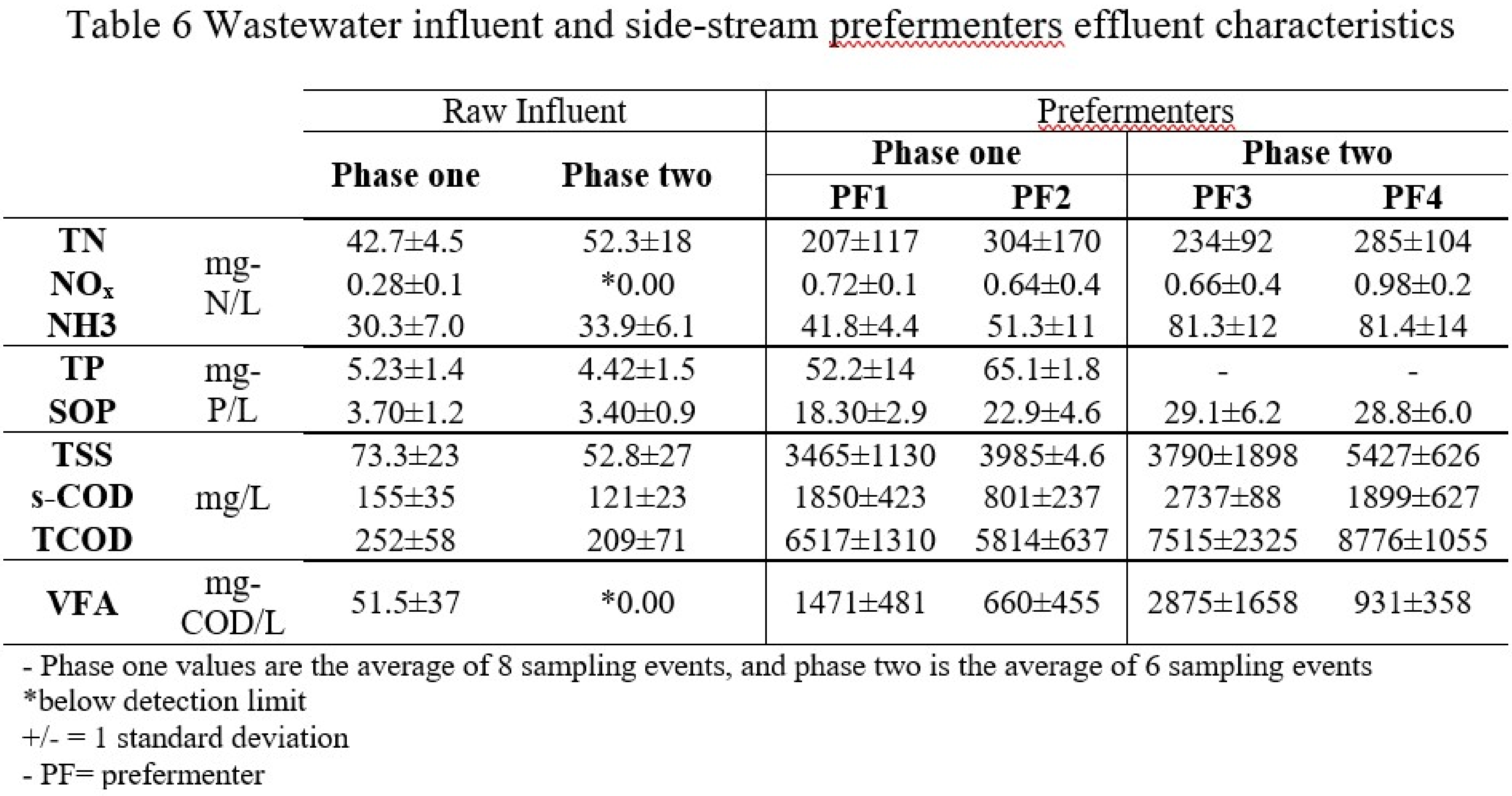


Table 6 Wastewater influent and side-stream prefermenters effluent characteristics

		Raw Influent		Prefermenters			
		Phase one	**Phase two**	**Phase one**		**Phase two**	
				PF1	**PF2**	**PF3**	**PF4**
TN	mg-N/L	42.7±4.5	52.3±18	207±117	304±170	234±92	285±104
NO$_x$		0.28±0.1	*0.00	0.72±0.1	0.64±0.4	0.66±0.4	0.98±0.2
NH3		30.3±7.0	33.9±6.1	41.8±4.4	51.3±11	81.3±12	81.4±14
TP	mg-P/L	5.23±1.4	4.42±1.5	52.2±14	65.1±1.8	-	-
SOP		3.70±1.2	3.40±0.9	18.30±2.9	22.9±4.6	29.1±6.2	28.8±6.0
TSS	mg/L	73.3±23	52.8±27	3465±1130	3985±4.6	3790±1898	5427±626
s-COD		155±35	121±23	1850±423	801±237	2737±88	1899±627
TCOD		252±58	209±71	6517±1310	5814±637	7515±2325	8776±1055
VFA	mg-COD/L	51.5±37	*0.00	1471±481	660±455	2875±1658	931±358

- Phase one values are the average of 8 sampling events, and phase two is the average of 6 sampling events
*below detection limit
+/- = 1 standard deviation
- PF= prefermenter

Introduction

Analytical Techniques

Samples were collected from the anaerobic, anoxic, aerobic, and secondary clarifier as well as influent and effluent reservoirs in two sample containers. One of the sample containers was filtered immediately on site with a glass fiber filter (Whatman™, 1827-025, Pittsburgh, Pennsylvania) before transporting to the lab. The measurements of chemical oxygen demand (COD), e.g. TCOD and s-COD, ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), total nitrogen (TN), total phosphorus (TP), soluble ortho-phosphate (SOP), total suspended solids (TSS), and volatile suspended solids (VSS) were performed according to the procedures published in Standard Methods (APHA, 2005).

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Analytical Techniques

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