National Water and Wastewater Conference (NWWC 2023)

Applicability of Hydrothermal Pretreatment for Municipal Sludge: Anaerobic Digestibility and Dewaterability

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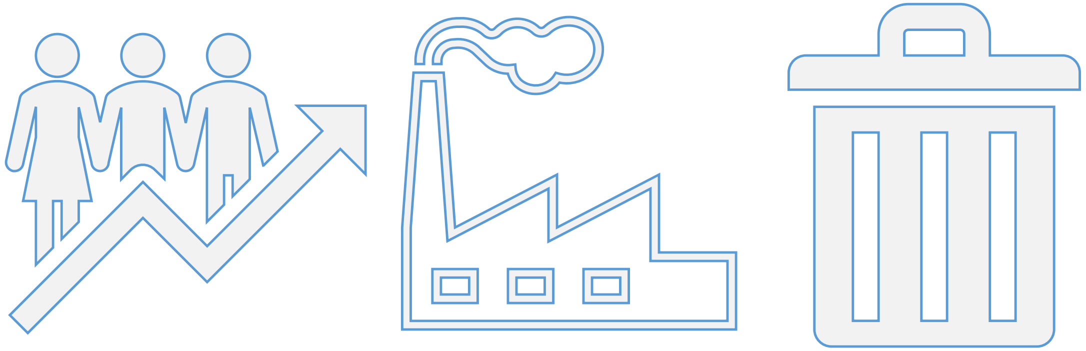
Water Research Resource Recovery WR3

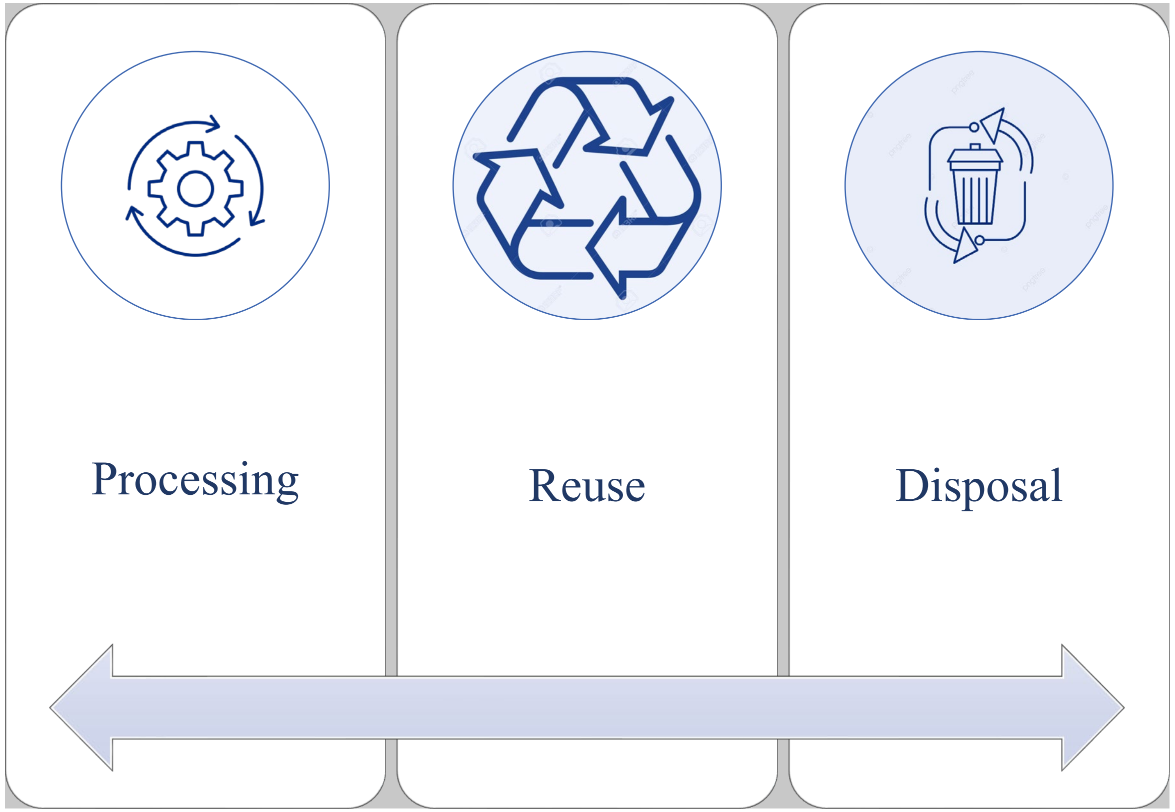
Presentation Outline

- ➢ Global MSW Problem
- ➢ Conventional Vs. Hydrothermal Pretreated Anaerobic Digestion
- ➢ Materials & Method
- ➢ Results
- ➢ Conclusions
- ➢ Q&A

Problem Statement

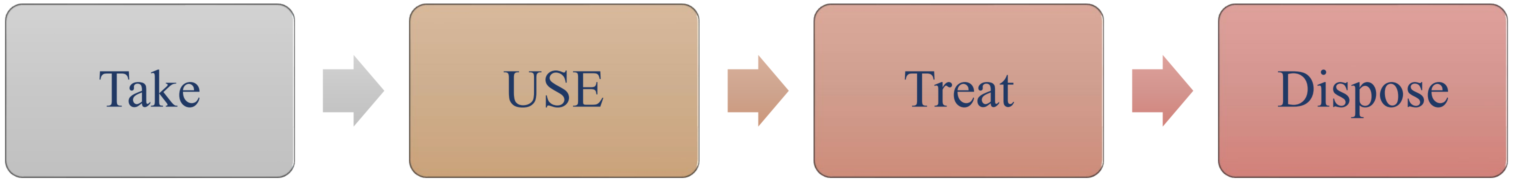


- 45 million tons of dry sludge per year



SLUDGE MANAGEMENT

Wastewater Treatment Plant (WWTP)



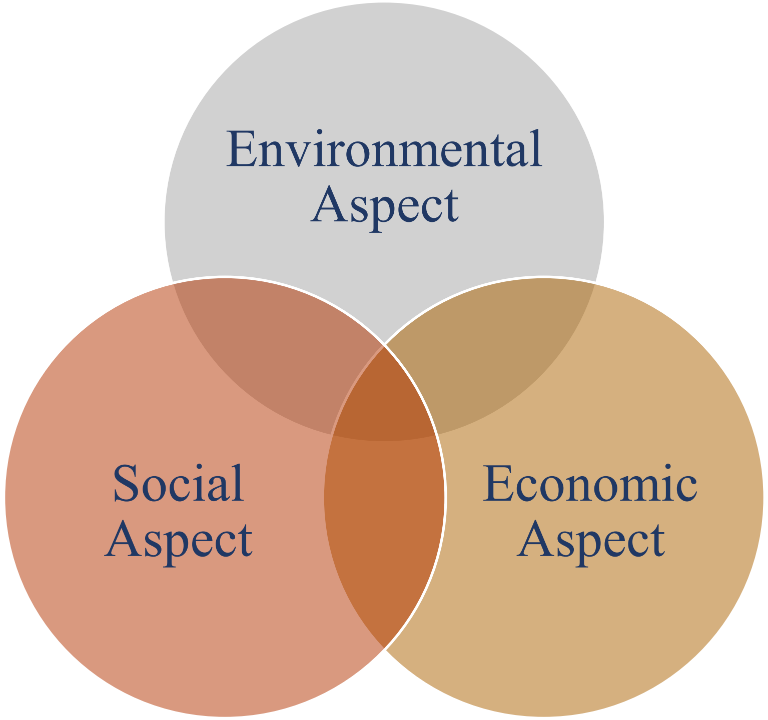
Linear Economy

Water Resource Recovery Facility (WRRF)

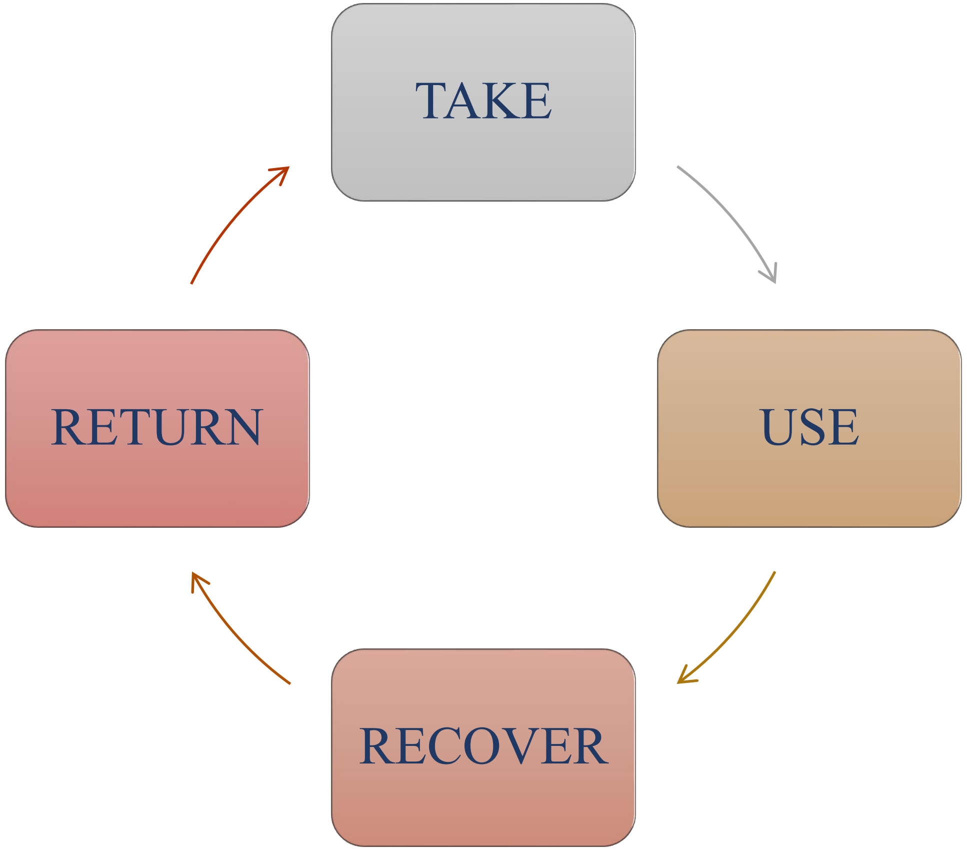
Circular Economy

Anaerobic Digestion

Water Resource Recovery Facility (WRRF)



Circular Economy



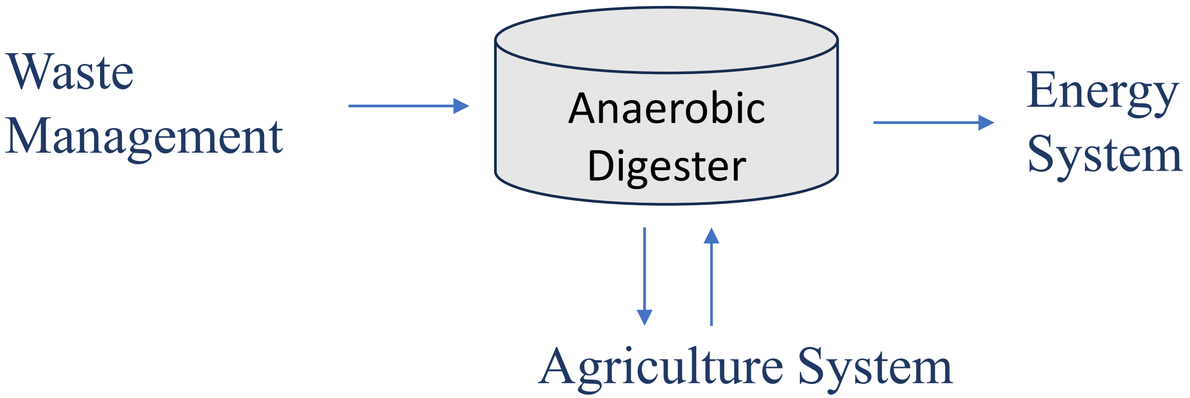
Wastewater Treatment Plant (WWTP)

Wastewater Resource Recovery Facility (WRRF)

Circular Economy

Anaerobic Digestion

- Technological Aspects
- Socio-environmental Aspects
- Economical Aspects



Anaerobic Digestion

Organic matter: Carbohydrates, Protein, Fats

⇩

Hydrolysis

⇩

Acidogenesis

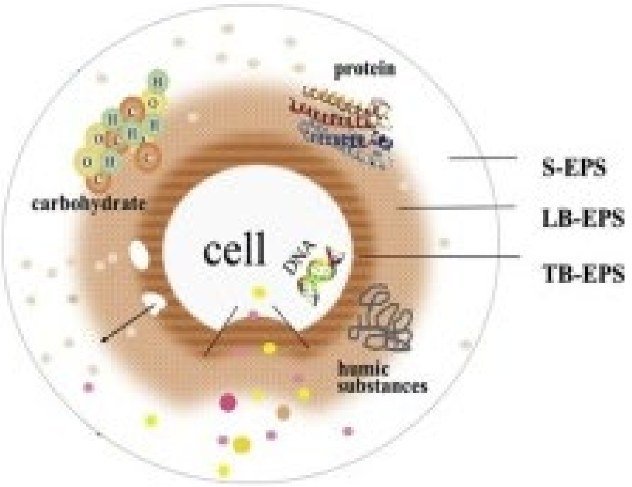
⇩

Acetogenesis

⇩

Methanogenesis

Compounds/ products	Enzymes	Microorganisms
Sugars Amino Acids Fatty Acids	Amylase, Proteases, Depolymerases, Lipases, Pectinases	Hydrolytic Bacteria
Acetate, Butyrate, Propionate, valerate, CO_2, NH_3	Hydrolases	Acidogenic Bacteria
Acetic Acid, Formate, Alcohols, CO_2, H_2	Dehydrogenases, Transferases, Oxidoreductases	Acetogenic Bacteria
CH_4, CO_2, H_2S	Methyl-coenzyme, M reductase, Transferases, Transacetylase, Dehydrogenases	Methanogens: Acetoclastic Hydrogenotrophic



- Relatively long HRT (risk of instability)
- Low overall hydrolysis efficiency

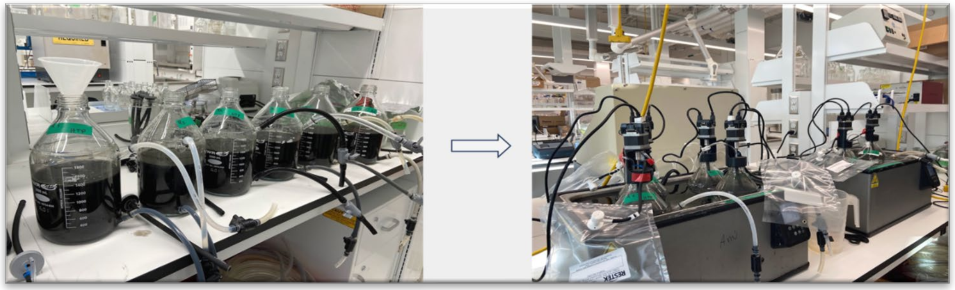
Anaerobic Digestion

Multifunctional Process:

- Treating waste streams
- Generating bioenergy
- Mitigating GHG emissions
- Recycle nutrients
- Produce value-added products

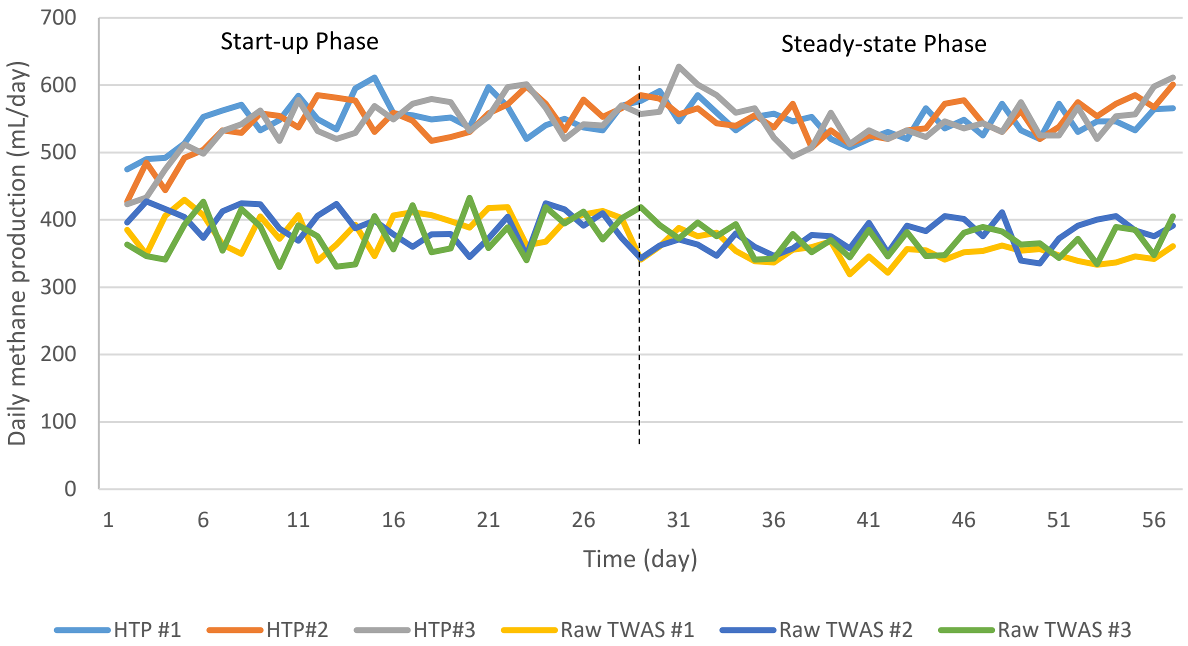
HTP| Semi-continuous for sludge AD

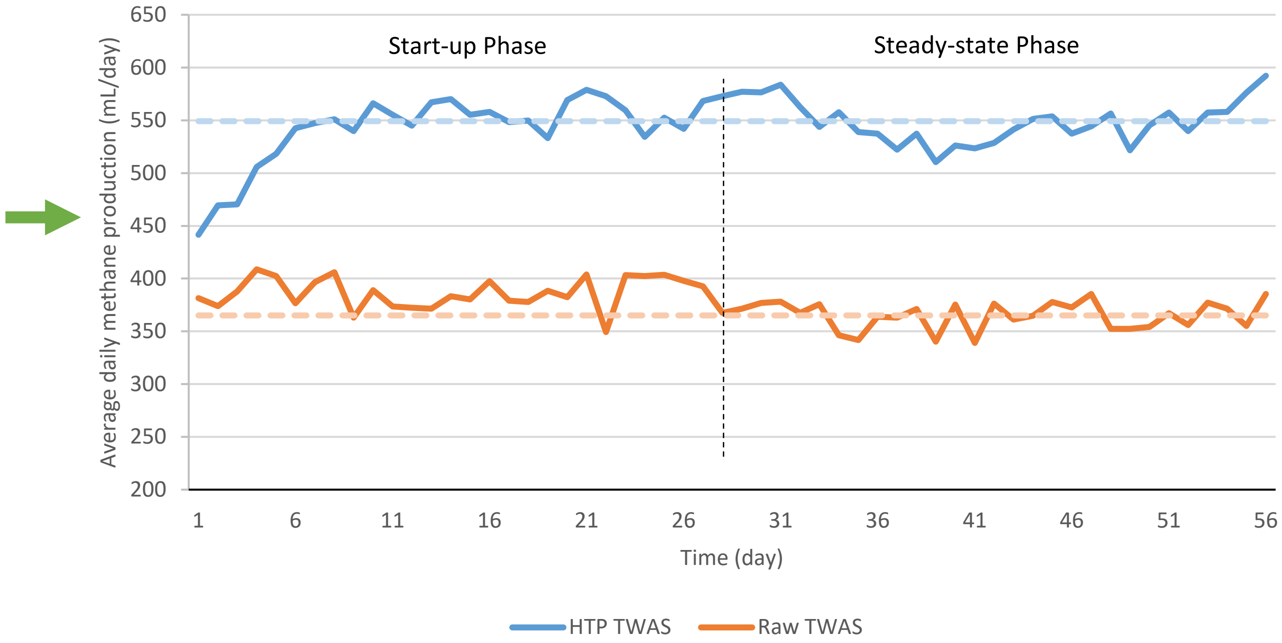
Experimental Conditions & Set-up
TWAS from ABTP
HTP conditions: T=170 °C, P= 3 bars, t= 30 min
6 bioreactors (1800 mL)
HRT= SRT= 15 days
Working Volume= 1500 mL
Mesophilic Conditions
All analyses performed in duplicates or triplicates



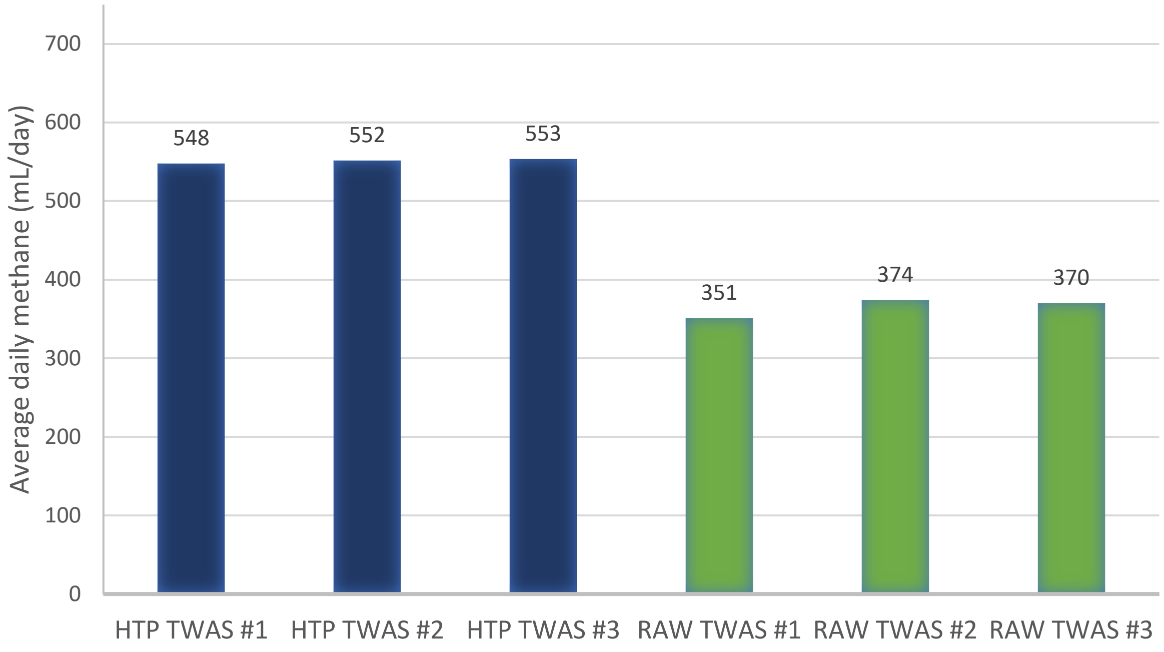
		Raw TWAS		HTP TWAS	
Parameter	Units	Ave ± standard deviation	Range	Ave ± standard deviation	Range
TCOD	g/L	33 ± 4	30.6 – 45	32 ± 3	29 – 44
SCOD	mg/L	213 ± 31	184 – 270	14679 ± 2442	12444 – 19973
TS	g/L	38 ± 5.7	32 – 48.5	31.5 ± 5	26.5 – 40.5
TSS	g/L	32 ± 5	27 – 41	19.5 ± 2.5	16.8 – 24
VS	g/L	33 ± 5	27.5 – 43	26.5 ± 4	22.5 – 34
VSS	g/L	25 ± 4	21 – 32	12.0 ± 1.5	10.5 – 15
VFA	mg HAc/L	41 ± 6.5	35 – 53	1256 ± 194.5	1078 – 1644
Viscosity	cP	509 ± 57	425 – 603	18 ± 3	14 – 20
pH		6.6 ± 0.2	6.3 – 6.8	5.8 ± 0.03	5.8 – 5.9

HTP| Semi-continuous for sludge AD





HTP| Semi-continuous for sludge AD



	RAW TWAS	HTP TWAS
Average daily methane (mL/day)	365	551
Biogas production rate (L/L/d)	0.65	0.85
Methane % in biogas	55	65
VSD (%)	50	63
Methane yield (mL/g $TCOD_{added}$)	116	176
Methane yield (mL/g VSS_{added})	169	255
TCOD removal (%)	40	50

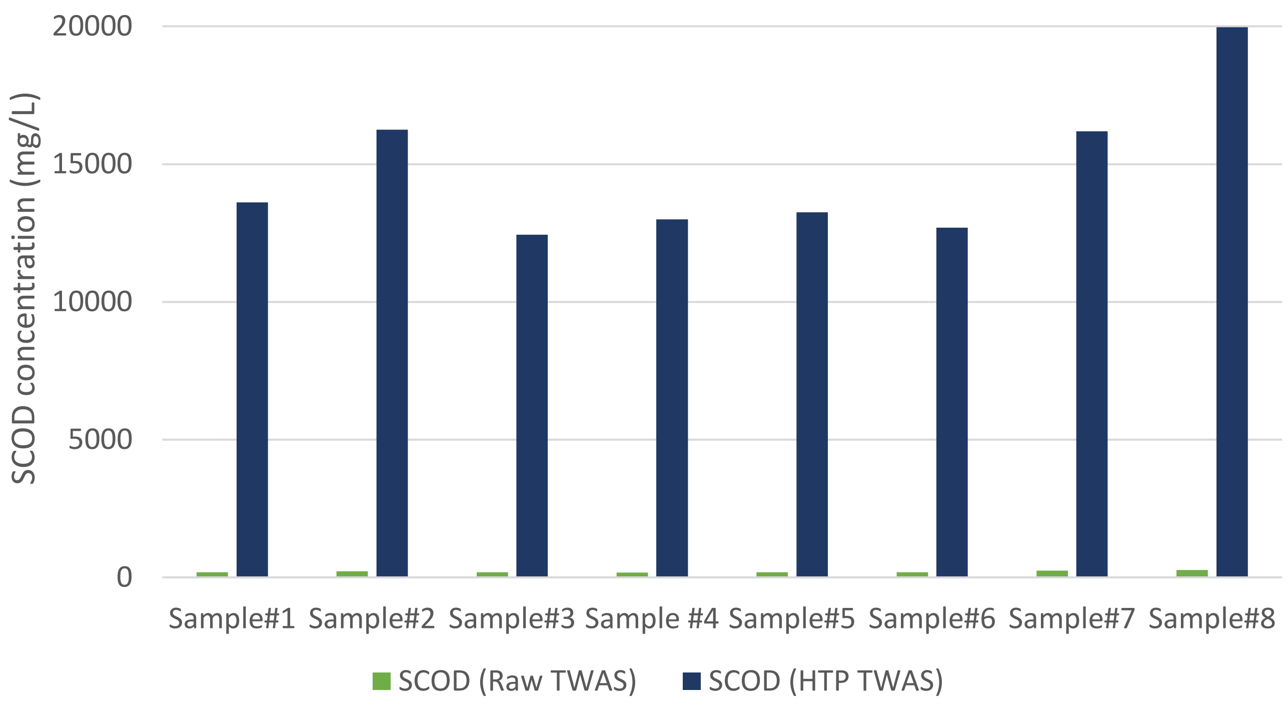
-Yield enhancement 51%
-Biodegradability increase 30%

- **Degree of Solubilization**
- **Solids Solubilization**
- **Particle size distribution**
- **TAN**
- **Viscosity**
- **Stability of the system**

HTP| Semi-continuous for sludge AD

Degree of Solubilization

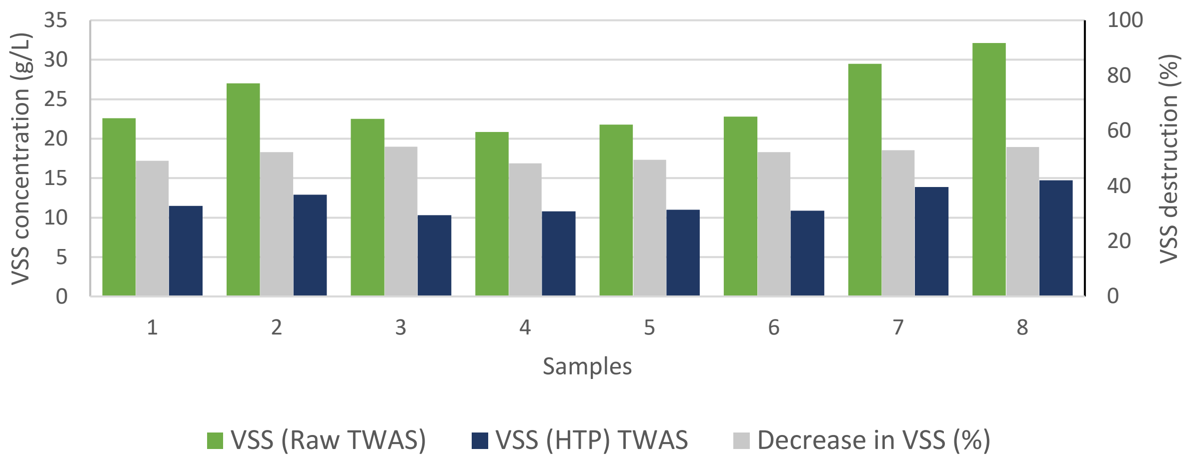
- HTP increased the solubilization level to 41%
- SCOD increased from an average value of 213 mg/L in Raw TWAS to about 15000 mg/L in HTP TWAS → particulate organics has been solubilized

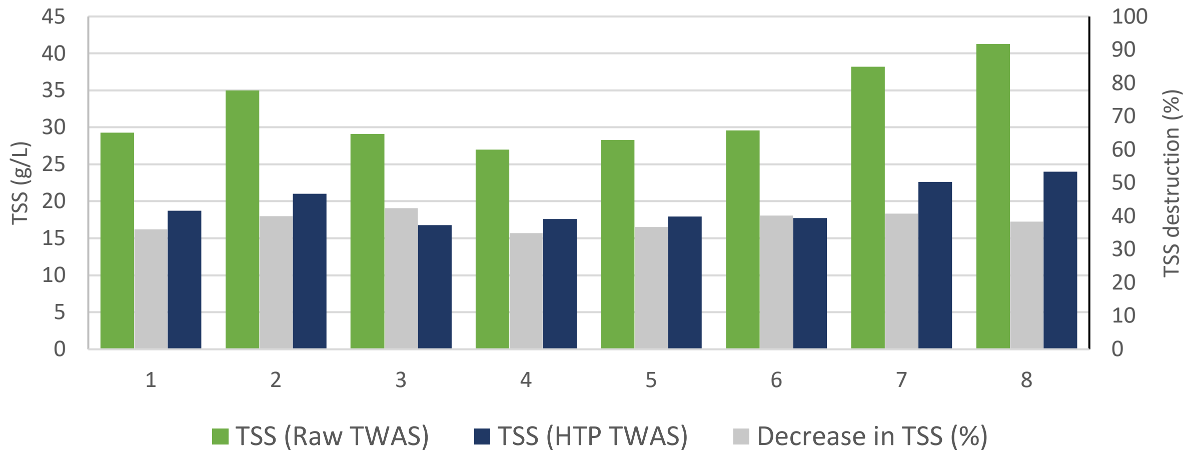


Solids Solubilization

- VSS/VS ratios decreased from 0.75 to 0.45
- TSS/TS ratios decreased from 0.85 to 0.62

→ HTP enhances the mineralization of organic solids

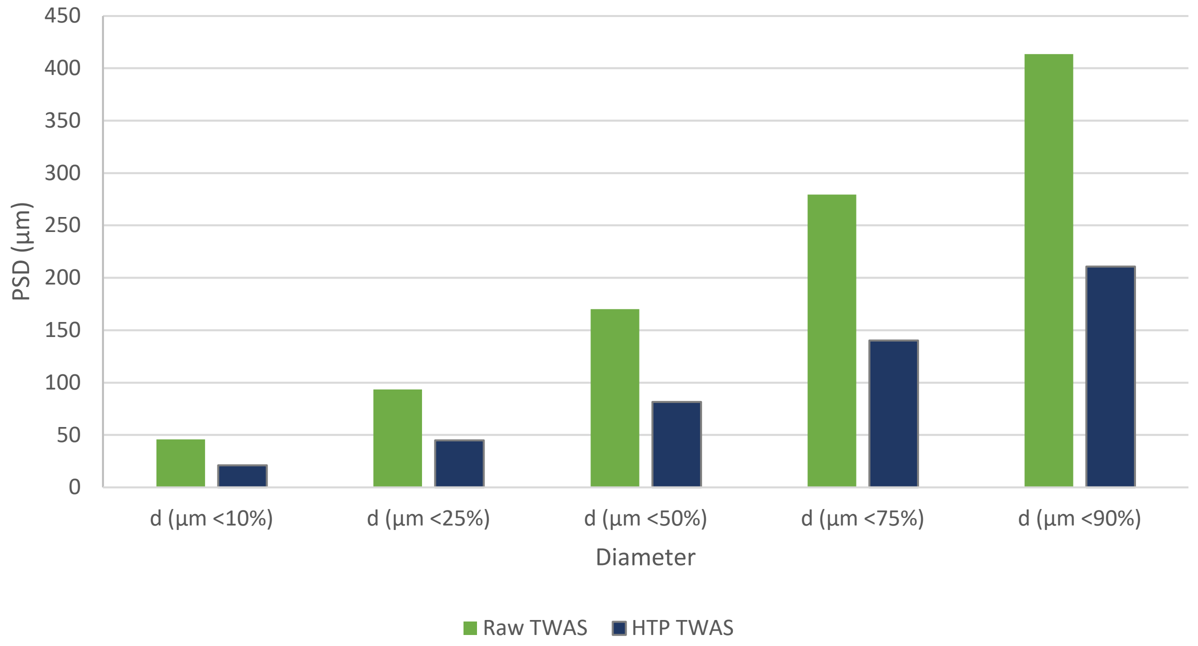




HTP| Semi-continuous for sludge AD

Particle size distribution

- The mean diameter of particles shifted from 206 to 104 µm
- Anaerobic microorganisms' maximum substrate utilization rate is inversely proportional to the particle size



TAN

- A noticeable increase in total ammonia nitrogen (TAN) was observed from 51 mg/L to 261 mg/L

→ HTP enhances the hydrolysis of nitrogen-enriched organics (such as proteins)

Viscosity

- HTP decreased viscosity from 510 cP to 18 cP (equivalent to a 96% drop)

→ **Polyacrylamide** (PAM) sludge floccules were destroyed, allowing extracellular and intracellular organic matter to be released in the aqueous phase

Stability of the system

- pH of HTP bioreactors ranges between 7.7 and 7.9

pH of Raw TWAS ranges between 7.5-7.7

VFA/Alk ratios of 0.19 (RAW TWAS) and 0.26 (HTP TWAS)

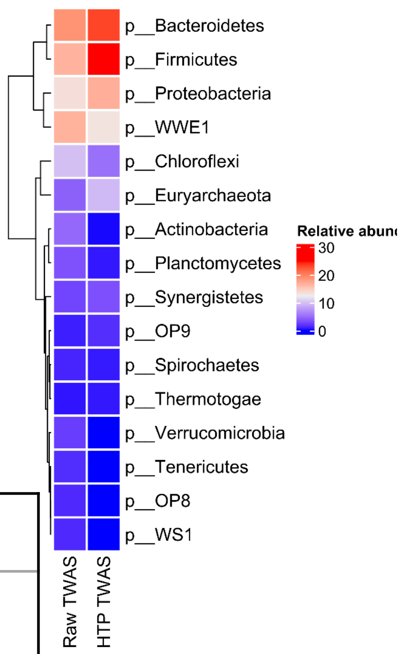
(FAN) was 22 and 35 mg/L for raw and HTP TWAS

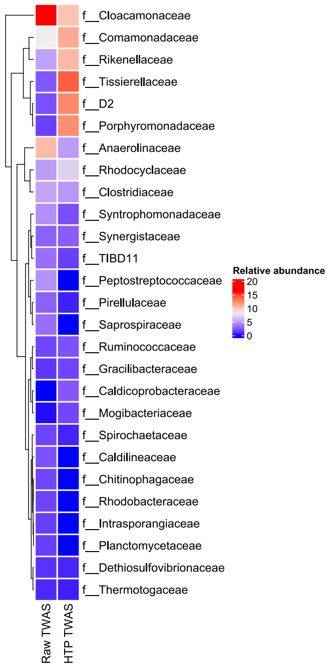
HTP| Microbial Community

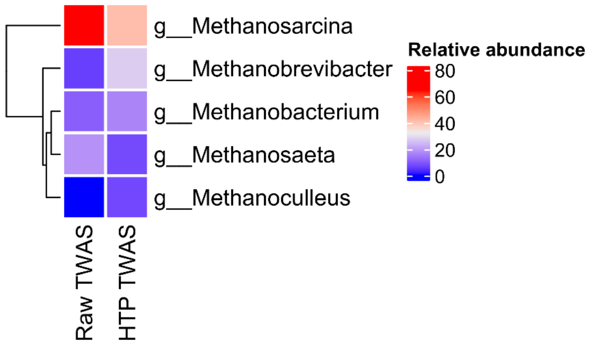
HTP led to increased microbial diversity and richness

	Chao1	Pielou evenness	Faith Phylogenetic distance	OTUs	Shannon
Raw TWAS	120	0.84	10.3	105	5.9
HTP TWAS	224	0.89	19.8	210	6.9

	RAW TWAS	HTP TWAS
Bacterial Community	- Chloroflexi (hydrolyze carbohydrates) was higher - VFAs oxidizers , potential roles in hydrolysis and acidogenesis	- Abundance of fermenters and hydrolytic bacteria ↑ (Firmicutes (25%), Bacteroidetes (23%), Proteobacteria (17%), and Synergistetes (3.3%)) -Degrade various organics (cellulose & proteins) -Tissierellaceae & Porphyromonadaceae (positively correlated with high methane production)
Archaeal Community	- genus *Methanosarcina* (65%), genera *Methanosaeta* (19%), *Methanobacterium* (11%) & *Methanobrevibacter* (6%)	Euryarchaeota phylum ↑ (methanogens ↑) - acetoclastic Methanosaeta was reduced - hydrogenotrophic methanogens (Methanobrevibacter (27%), Methanobacterium (16%) & Methanoculleus (7%) significantly increase Hydrogenotrophic methanogens generally exhibit greater resistance to environmental changes (e.g., high ammonia levels) than acetoclastic methanogens

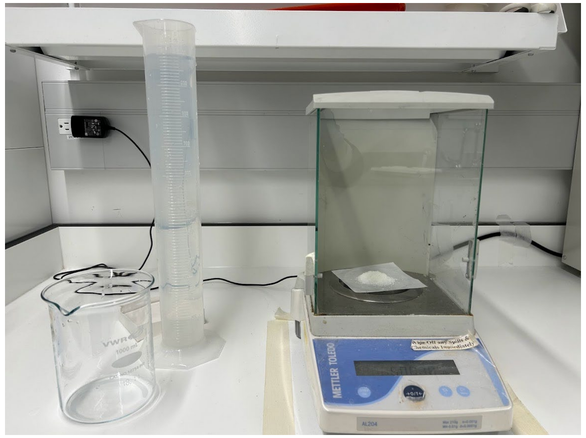






HTP + AD Impact on Dewaterability

- Inefficient dewatering increases the costs of sludge disposal



Preparation of cationic powder polymer
- 0.5%weight:Volume

→

Determination of optimum Doses for RAW and HTP ADS
- Raw TWAS: 21.6 mL
- HTP TWAS: 25 mL

↓

Flocculation

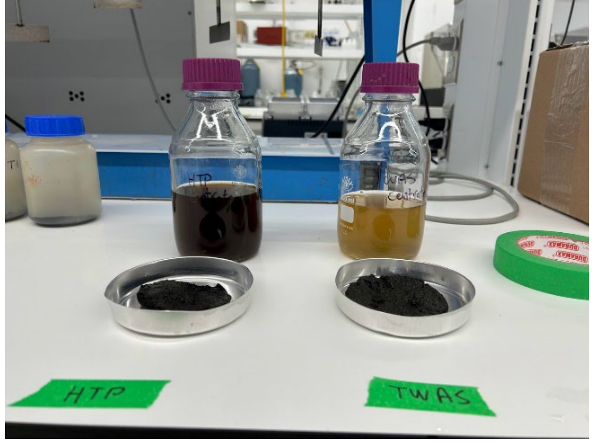
→

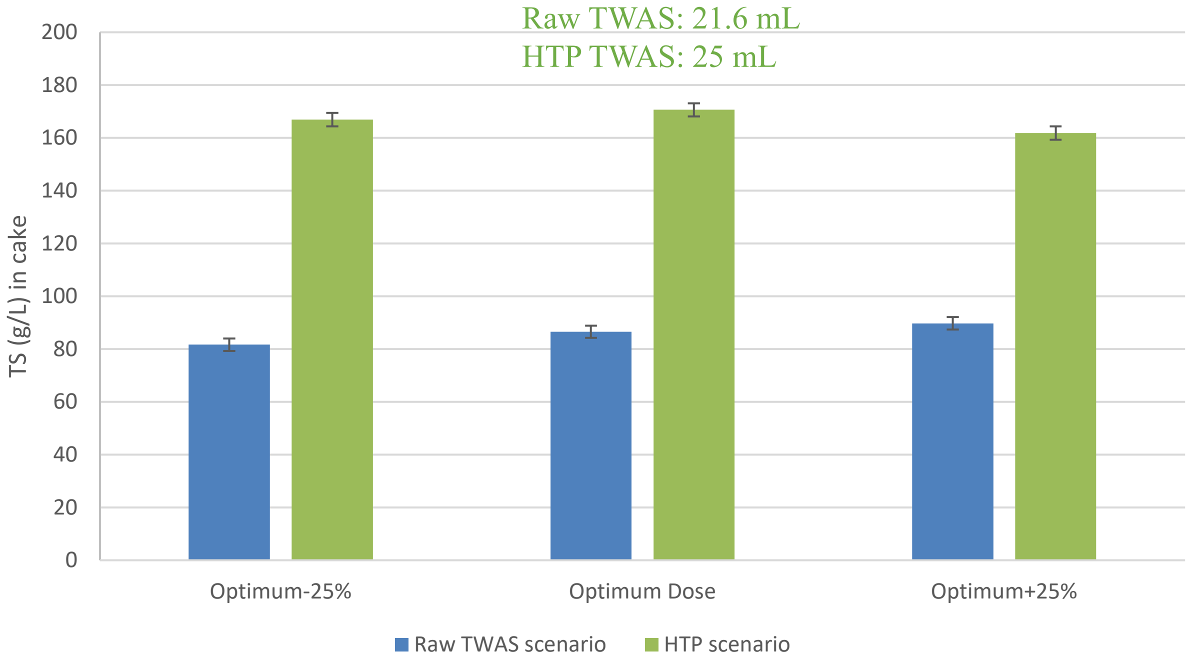
Centrifuge
- 4000 rpm for 10 min

↓

TS of supernatant and cake are determined

HTP + AD Impact on Dewaterability





- Solids content in the cake increased from 82 g/L to 164 g/L in the ADS HTP TWAS digesters (2-fold increase)
- Capillary suction time (CST) decreased from 1180 s to 270 s

HTP modifies sludge characteristics (filterability & viscosity) through the breakdown of gel structure and release of intracellular-bound water

➢ No other technology competes with HTP in the production of Class A biosolids:
  - Highest quality classification of treated sewage sludge (USEPA)
  - Free from harmful pathogens & odors
  - Suitable for land application as fertilizers, soil conditioners, certain landscaping & land reclamation purposes

Conclusions: HTP

Hydrothermal pretreatment aligns with the circular economy principles by efficiently converting organic waste into both energy and valuable resources "Waste-to-energy Strategy"

- Enhances Biogas Production
- Improves dewaterability of ADS
- The nutrient-rich digestate can be repurposed as a valuable fertilizer, closing nutrient cycles and supporting sustainable agriculture
- The process reduces the overall carbon footprint by capturing and utilizing methane, a potent greenhouse gas, for energy production
- Microbial community mitigates and minimizes the toxic effects of emerging contaminants such as PFAS compounds

Acknowledgment

Supervisor: Dr. Elsayed Elbeshbishy

Co-supervisor: Dr. Bipro Dhar

NSERC

Colleagues: WR³ Group

Water Research Resource Recovery WR³

NSERC CRSNG

TRADEWORKS ENVIRONMENTAL

Toronto Metropolitan University

DHAR LAB @ UALBERTA

Publications

1- Abir Hamze; Mohamed Sherif Zaghloul; Basem Zakaria; Bipro Dhar; Elsayed Elbeshbishy. Hydrothermal pretreatment for semi-continuous sludge anaerobic digestion: Impact on digester performance, sludge dewaterability and microbial community. *To be submitted to Waste Management Journal*

***2*- Abir Hamze;** Mohamed Sherif Zaghloul; Bipro Dhar; Basem Zakaria; Roxana Suehring, Rania Hamza; Elsayed Elbeshbishy. Fate of Per - and polyfluoroalkyl substances (PFAS) in Anaerobic Digestion with Hydrothermal Pretreatment of Sludge. *To be submitted to Waste Management Journal*

***3*- Abir Hamze;** Mohamed Sherif Zaghloul; Bipro Dhar; Elsayed Elbeshbishy. *Effects of Ydro Process Biotechnology on Dark Fermentation and Anaerobic Digestion. To be submitted to Bioresource Technologies*

Conferences

1.**Abir Hamze**; Mohamed Sherif Zaghloul; Bipro Dhar; Elsayed Elbeshbishy (2023). The Impact of Hydrothermal Pretreatment on Municipal Sludge Dewaterability. 2nd Canadian IWA YWP Conference - June 2023

2. **Abir Hamze**; Mohamed Sherif Zaghloul; Basem Zakaria; Bipro Dhar; Elsayed Elbeshbishy (2023). Microbial Community changes due to Hydrothermal Pretreatment of the Thickened Waste Activated Sludge prior to Anaerobic Digestion. 2nd Canadian IWA YWP Conference - June 2023

3. Mohamed S. Zaghloul, **Abir Hamze**, Reza Malekzadeh, Dimitrios Chrysochoou, Rania Ahmed Hamza, Elsayed, Elbeshbishy. Bioaugmentation – A Novel Biological Pre-treatment of Biosolids to Improve Resource Recovery in Anaerobic Digestion and Fermentation. 2023 National Water and Wastewater Conference, Niagara Falls- November 2023

4. **Abir Hamze**; Mohamed Sherif Zaghloul; Bipro Dhar; Elsayed Elbeshbishy. Applicability of Hydrothermal Pretreatment for Municipal Sludge: Anaerobic Digestibility and Dewaterability. 2023 National Water and Wastewater Conference, Niagara Falls- November 2023

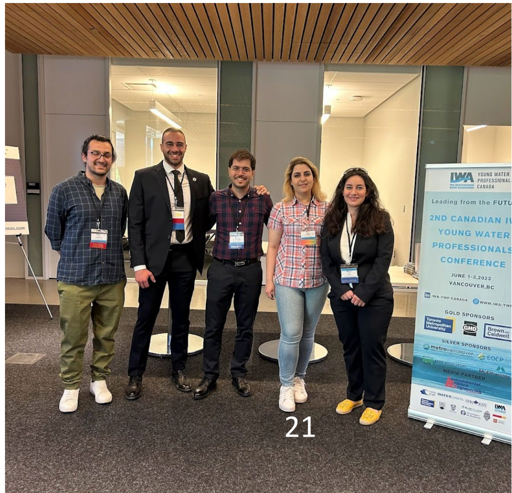
Book Chapter

Chapter 12: Decentralized Sanitation Implementation in Different Countries

Mohamed S. Zaghloul, Abir Hamze, Farokh Laqa Kakar, Rania A. Hamza, Elsayed Elbeshbishy


IMPLEMENT THE RECOMMENDATIONS OF THE TRUTH AND RECONCILIATION COMMISSION
CESAR
can hockey
match the correct batch
jeopardy
WASTE WIZARDS



Thank you