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Upgrade of Existing Water Resources Recovery Facilities (WRRFs) to Perform Co-Digestion Utilizing Plant Modeling, Energy Modeling and Life Cycle Assessment (LCA)

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Introduction

- Water resources recovery facilities (WRRFs) generate organic sludges that require stabilization.
- Anaerobic digestion of sewage sludge is a well known and often used method of solid stabilization.
- Biogas production rich in methane can be collected and used to reduce operating cost of WRRF.
- Co-digestion is the addition of organic substrates with the goal of increasing methane production during digestion.
- WRRF is being upgraded to perform co-digestion and a detailed evaluation of performance and environmental cost is required for its proper implementation.

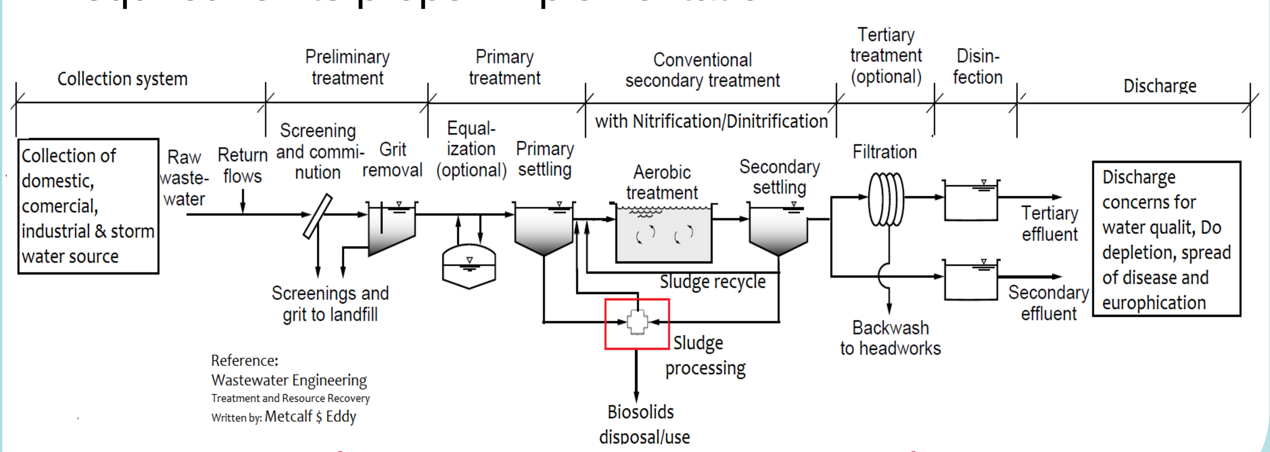

Fig.01. Typical Water Resource Recovery Facility (WRRF)

Objectives

To determine the conditions that optimize co-digestion performance and biogas production at different WRRFs, the following objectives have been identified:

- Perform 'biochemical methane production' (BMP) assays to determine the efficacy of various substrates (e.g. cheese whey, grease interceptor waste, food processing byproducts, pulped food waste, other types of food/organic waste)
- Operate two bench scale digesters to evaluate the effects (positive or negative) of the new substrates on digester operations and performance.
- Evaluate different ratios of substrates to determine the optimal mix for both digester performance and biogas production utilizing BioWin based plant modeling.
- Determine the impact of co-digestion & recuperative thickening on dewatering properties of digested sludge.
- Optimize digester performance and biogas production, energy utilization as well as life cycle costs (LCA) of WRRFs using BioWin software, Excel based Energy models & SIMAPRO software.

Materials & Methods

- Measurements of TS, VS, TSS, VSS were and will be performed according to *Standard Methods.*
- Total COD, soluble COD, ammonia, orthophosphate, alkalinity, and volatile acids were and will be determined using HACH kits.

Table 1. Substrate characteristics used in anaerobic digester and BMP experiments

Reactor	Substrate	TS mg/L	VS mg/L	TCOD mg/L	SCOD mg/L	Alkalinity mg/L	Ammonia mgN/L	Volatile Acids mg/L	Reactive Phosphorous mgP/L	COD/VS gCOD/gVS
Anaerobic Digester	Primary Sludge (PS)	26769	22630	59973	2682	413	95	1315	22	2.65
	Waste Activated Sludge (WAS)	26089	20139	52448	71	68	8.2	25	55	2.60
	Cheese Whey (CW)	112959	102841	218870	146233	501	212	4190	1879	2.13
BMP assay	Waste Activated Sludge (WAS)	9.55	7.42	4.80	29.7	B.D	1.09	18.55	7.88	0.65
	Primary Sludge (PS)	41.39	31.83	80.70	7840.0	592.50	9.57	3984.00	23.15	2.54
	Cheese Whey (CW)	115.65	106.75	201.07	113700.0	2240.00	122.84	3735.00	-	1.88
	Digestate/Seed	28.13	19.23	35.12	302.0	1335.00	557.50	139.15	11.15	1.83

Note: B.D-Below detection limit

- Characterization of other food waste will be performed accordingly (e.g. biodegradable plastics, green waste, manure, sewage, paper waste, slaughterhouse waste, food waste, coffee ground waste, vegetable waste etc.).

BMP Experiment

- The bottles were/will be flushed with nitrogen gas and sealed before they were placed in an incubator at 35°C.
- The methane production were/will be measured periodically by passing the gas through a 2N NaOH solution to capture the CO_2 and H_2S which are also produced during the process.
- All bottles were/will be seeded by digestate acclimated to primary sludge.

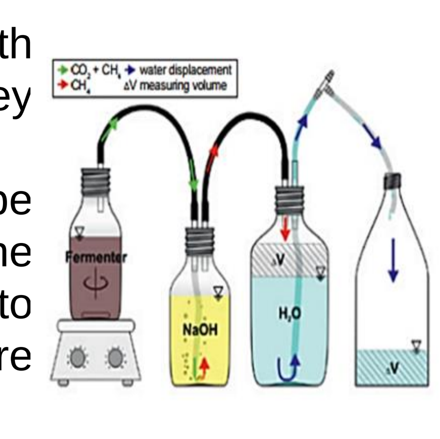

Fig.02. BMP setup

Previous BMP Results

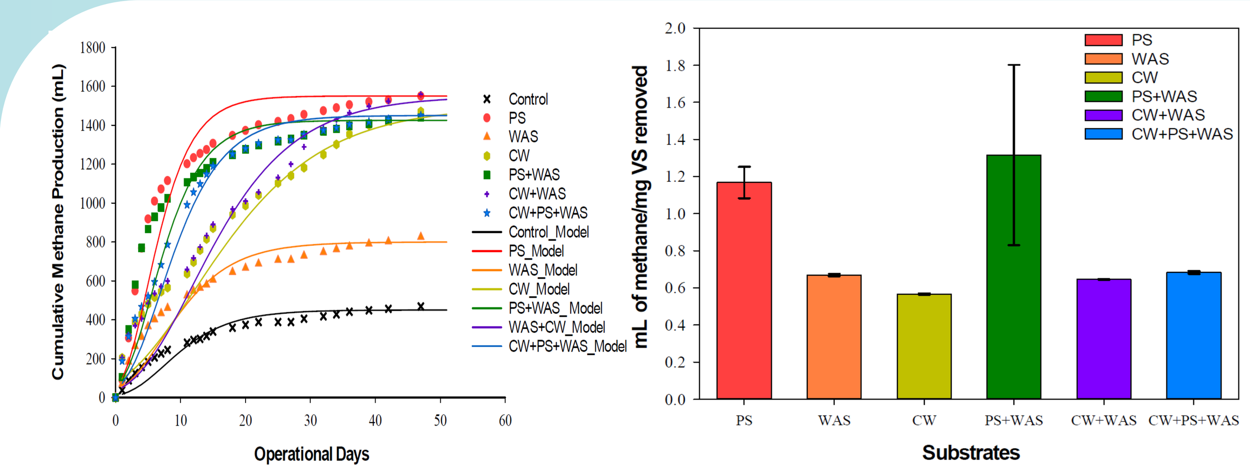

Fig.03. Graphical Representation of BMP Results

- Methane production over time shows the kinetics for the bio-degradability of different substrates as well as the specific methane yield.
- Microorganisms need more time to break down certain organic matter, as shown by the substrates containing cheese whey.

Digester Experiment

- Each digester has the produced gas travel through a Wet Tip Gas Meter.
- Each tip is calibrated to 100ml of gas produced.
- Tips are recorded by HOBO ware pendants.

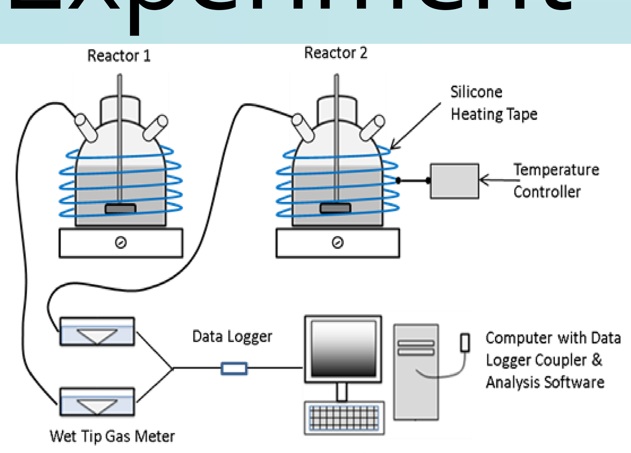

Fig.04. Digester Set-up

- Digesters are run at a solids retention time (SRT) of 30 days and will be run at other SRTs.
- All substrates fed are at total solid's concentration of 2.5-3%.
- Operating temperature maintained at 36°C.
- Operated and will be operated at volatile acid to alkalinity ratio between 0.2 and 0.05.

Previous Digester Results

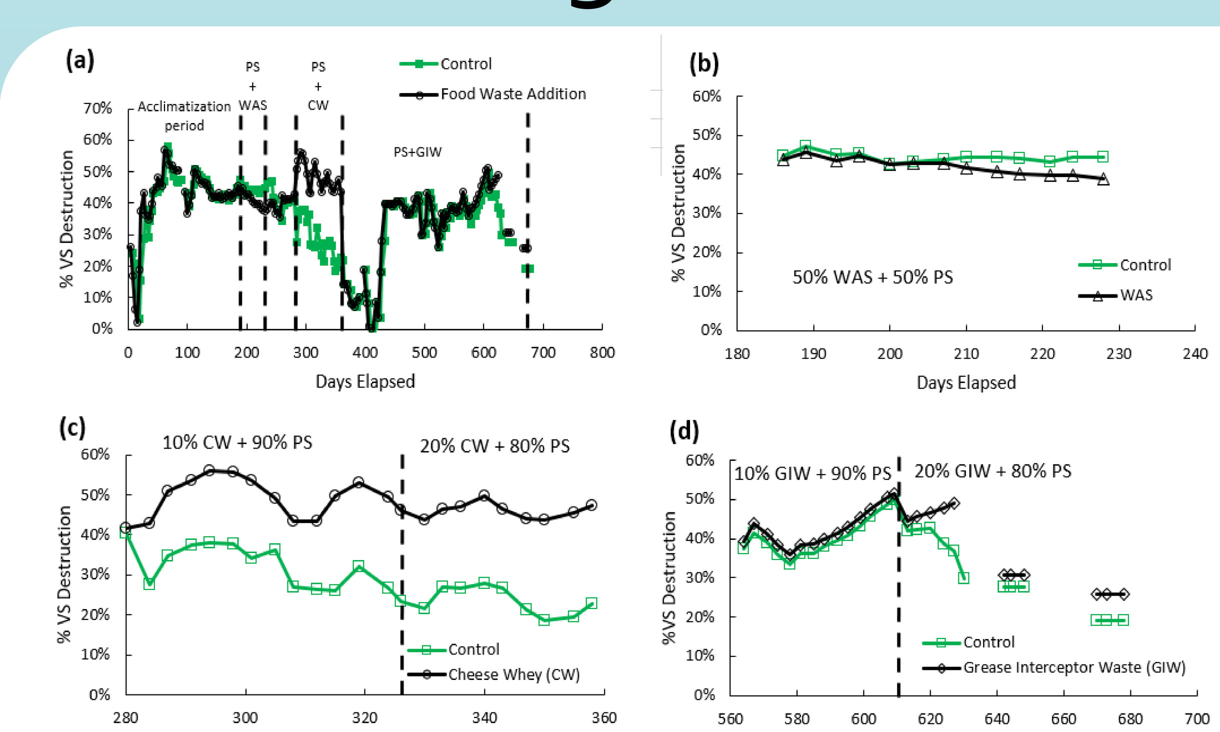

Fig. 5. Percent volatile solids destruction profile a) over the total experimental period b) during waste activated sludge (WAS) feed c) during cheese whey (CW) feed, and d) during grease interceptor waste (GIW) feed.

Previous Digester Results

- Changing reactor 2's feed to be 50% primary sludge & 50% WAS reduced the biogas yield by as much as 30%.
- With the addition of WAS, reactor 2 achieved 40% reduction.
- The addition of cheese whey to the digesters resulted in an increase in volatile solids destruction of over 50%, while at the same time the control reactor decreased to 30%.
- Even with a primary sludge that did not digest well the cheese whey was able to significantly increase digester performance.
- Grease interceptor waste consistently lead to an improved VS destruction.
- Biogas yield during the 10% GI waste addition was on average 46% greater.
- If the GI waste could be thickened, the GI waste could provide a more significant benefit.
- Cheese whey could still provide a large benefit in net gas production, even if the per mass gas production is low.

BioWin Modeling

- BioWin wastewater process simulation software ties together biological, chemical, and physical process models to provide insight into the whole plant.
- BioWin simulations help engineers and operators make decisions that reduce capital and operating costs and ensure treatment objectives are met.
- BioWin is a recognized leader in the simulation field for 25 years and can be effective to model co-digestion.

BioWin Applications

- BioWin is used around the world by Consulting engineers, Infrastructure owners, equipment manufacturers or suppliers, WRRFs, operations companies and academic institutions.

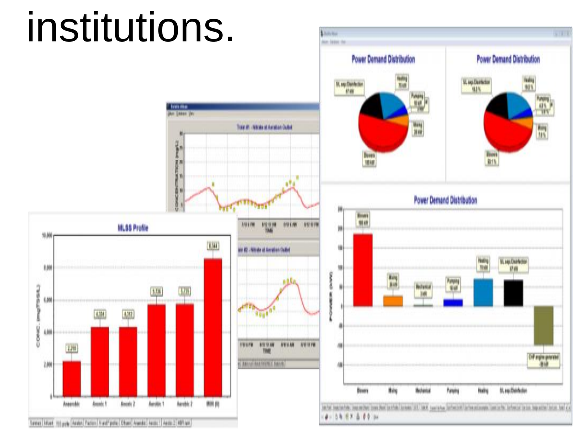

Fig.06. BioWin Graph

BioWin is used to:

- Explore strategies to reduce water resource recovery facilities energy consumption and operating costs.
- Select optimal treatment processes.
- Reduce capital investment.
- fundamental wastewater treatment concepts.
- Build model extensions and conduct research into emerging technologies.
- Evaluate expansion of existing recovery facilities.

- BIOWIN modeling will be utilized to use parameters determined in this study from Anaerobic Digestion and BMP assays to predict plant performance for different food/organic wastes to optimize co-digestion systems.

Energy Modeling

- Energy modeling is a process of building computer models/excel models of energy systems in order to analyze units of WRRFs. Such models often employ scenario analysis to investigate different assumptions about the technical and economic conditions at play.
- Outputs may include the system feasibility, greenhouse gas emissions, cumulative financial costs, natural resource use, and energy efficiency of the system under investigation.
- Mathematical optimization is often used to determine the least-cost. Methane production is modeled using Gompertz equation:

$$M = P.exp\left\{-exp\left[\frac{R_{max}.e}{P}(\lambda - t) + 1\right]\right\}$$

M = cumulative methane yield for a given time, mL CH_4/g VS
P = maximum methane potential during a BMP experiment, L CH_4/kg VS
R_{max} = maximum methane production rate, L CH_4/kg VS/d
e = mathematical constant equal to 2.7183
λ = the lag phase for methane production to begin, days
t = time, days

Energy Modeling

- Co-digestion of food waste is utilized to enhance production of biogas at WRRFs.
- Biogas production from food waste resolves concerns of waste management.

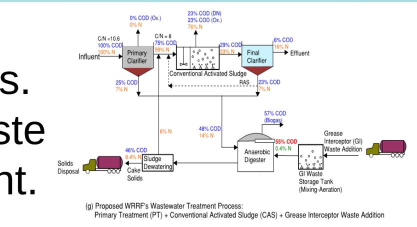

Fig. 7. Energy Balance

Table 2. Energy Consumption

Process Technology	Process Components of WRRF	COD removal in Carbon Removal Process	COD removal in nitrogen removal stages	Nitrogen removal from mainstream processes	Energy Consumption Due to Electrical Pumping and Mixing	Energy Consumption Due to Solids Dewatering	Total Energy Consumption, EC	Energy Production from Anaerobic Digestion, EP	Net energy Gain	ENI= EP/EC
Existing WRRF	PT + CAS	0.0	-0.1	-1.5	-0.4	-0.2	-2.2	1.7	-0.6	0.74
Advanced Carbon and Nutrient Removal Technology Addition to WRRF	CEPT + NI/DNI	0.0	-0.5	-1.1	-0.5	-0.2	-2.3	2.5	0.2	1.08
	A-stage + NI/DNI	-0.4	-0.2	-1.1	-0.5	-0.2	-2.4	2.1	-0.3	0.87
	HR-CS + NI/DNI	-0.4	-0.3	-1.1	-0.5	-0.2	-2.5	2.1	-0.4	0.83
	PT + HR-CS + DEM	-0.3	-0.1	-1.1	-0.4	-0.2	-2.1	2.2	-0.4	1.02
	CEPT + HR-CS + DEM	-0.2	-0.4	-0.6	-0.3	-0.2	-1.7	2.9	1.2	1.66
Existing WRRF + Co-Digestion (GI Waste Addition)	PT +CAS + GI	0.0	-1.5	-1.5	-0.4	-0.1	-3.8	4.3	0.5	1.13

- Energy modeling will be utilized to determine the efficacy of co-digestion systems with and without different traditional digestion and innovative N/P removal/recovery techniques.

Life Cycle Assessment

- LCA is a method for evaluating a range of environmental impacts across the full life cycle of a product system(cradle to grave).

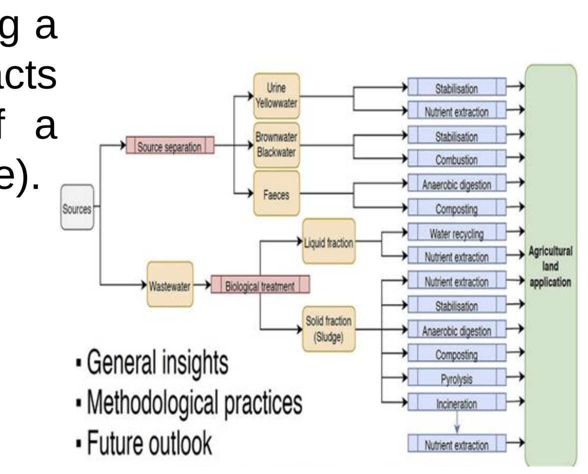
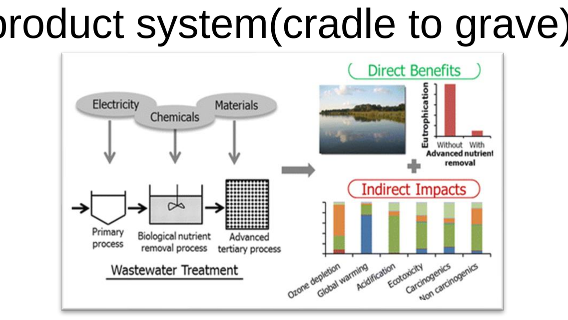

Fig. 8. Life Cycle Assessment (LCA)

- LCA will be utilized to estimate the total life cycle costs (e.g. global warming potential-GWP; Eutrophication potential-EP etc) of WRRFs after incorporating co-digestion systems.

Conclusion

- The addition of WAS as a co-digestive substrate has a negative impact on both gas production and VS reduction.

Conclusion of Digesters

- Addition of cheese whey increased volatile solids destruction and decreased the specific yield of the reactor. GI waste increased both VS destruction & specific yield.

Conclusion of BMP Assay

- Primary sludge produces more CH_4 than any other substrate or mixture, likely due to the digesters preexisting acclimation to primary sludge.
- Given the time to acclimate to the new substrate, it appears several mixtures could outperform the primary sludge.
- Better understanding why the grease interceptor waste requires so much time to begin producing methane could allow it to be a very successful substrate.
- Mixing grease interceptor waste with primary sludge increased methane production while decreasing the acclimation time – will be further investigated in the reactors.

Future Work

- Continue performing BMP assays with additional substrates, and mixtures.
- Operate digesters with more substrates and mixtures of substrates to validate BMP results.
- Continue to collect and analyze molecular samples to determine the make up of the microbial community.
- Make additional modifications to the digester systems to more accurately model the future conditions at the treatment plant.
- Perform recuperative thickening, dewaterability tests, different SRTs & digester solids concentrations.
- Utilize BioWin models, Energy models and LCA to assess the performance of co-digestion systems with organic wastes.