Annotated Bibliography

Do the readings which are assigned to you and write a couple of bullet points (or a paragraph) highlighting the key points of the reading. Include facts relevant to start up!

Name: Emily Liu

1. *Abbasi, T., Abbasi, S.A., 2012. Formation and impact of granules in fostering clean energy production and wastewater treatment in upflow anaerobic sludge blanket (UASB) reactors. RENEWABLE & SUSTAINABLE ENERGY REVIEWS 16, 1696–1708.* https://doi.org/10.1016/j.rser.2011.11.017
    a. Sludge granules provide anchorage to microflora that decompose the organic materials within the reactor.
    b. Granules supports active biofilms and also provide buoyancy and settleability necessary to enable granule-liquid contact within the reactor
    c. Granules are dense particles consisting of an intertwined mixture of symbiotic anaerobic microorganisms
    d. Factors that play a role in granule formation and granule characteristics:
        i. operating conditions
            1. Upflow velocity-- at UFV above 1 m/h can cause granules to disintegrate
        ii. Temperature
        iii. pH and alkalinity
            1. Stable pH value close to neutrality (6.3-7.8 required for methanogens) and a high partial pressure of hydrogen
            2. Alkalinity can provide buffer for sharp changes in pH. Levels ranging from 250-950 mg/L are ideal
        iv. strength and composition of wastewater, reactor hydrodynamics, presence of metal ions and trace metals, presence of polymers, and production of exo-cellular polymeric substances by anaerobic bacteria
            1. Substrate characteristics will affect granule composition
            2. Nitrogen and phosphorus might help the formation of granules during startup time
            3. Metals help facilitate flocculation and binding to exo-cellular polymers, but solubility is enhanced when pH drops below 5
            4. Ca^2+ assists in granulation, but need to be careful of creating granules too large
            5. Copper, manganese, zinc, cobalt, molybdenum and nickel, besides iron, have been shown to stimulate methane production in anaerobic digesters
            6. Adding vitamins? Increase in hydrogen production
2. *Abdelgadir, A., Chen, X., Liu, J., Xie, X., Zhang, J., Zhang, K., Wang, H., Liu, N., 2014. Characteristics, Process Parameters, and Inner Components of Anaerobic Bioreactors. BIOMED RESEARCH INTERNATIONAL.* https://doi.org/10.1155/2014/841573

   a. Faster upflow velocity fluidizes sludge bed and allows for more contact with sludge granules
   b. https://www.hindawi.com/journals/bmri/2014/841573/tab1/ Advantages and Disadvantages of UASB
   c. https://www.hindawi.com/journals/bmri/2014/841573/fig2/ key process stages of anaerobic digestion
   d. 5 important parameters: temperature, pH, hydraulic retention rate (HRT), Organic Loading Rate (OLR), sludge retention rate (SRT), upflow velocity, particle size distribution
   e. Temperature impacts microbial growth, nitrification, and BOD removal
   f. The pH range suitable for most organisms is 6.0–9.0 [30]; beyond this range, digestion can proceed, but with less efficiency.
   g. Increase in OLR will lead to operational problems like sludge bed flotation (accumulation of biogas) and excessive foaming at the gas-liquid interface, as well as accumulation of undigested ingredients.
   h. The SRT is determined by the loading rate, the fraction of suspended solids (SS) in the influent, the removal of SS in the sludge bed, removal rate of excess sludge, and the characteristics of the SS (biodegradability, composition, etc.), one of the most important parameters regarding the success of a UASB reactor
   i. Impact of introducing hanging baffles or changing bottom geometry to reduce the amount of poorly mixed zones
   j. Setting multiple 3-phase separator baffles may improve coagulation, granulation, and biological degradation. ahttps://www.hindawi.com/journals/bmri/2014/841573/fig5/
   k.

3. *Amani, T., Nosrati, M., Mousavi, S.M., 2012. Response surface methodology analysis of anaerobic syntrophic degradation of volatile fatty acids in an upflow anaerobic sludge bed reactor inoculated with enriched cultures. BIOTECHNOLOGY AND BIOPROCESS ENGINEERING 17, 133–144. https://doi.org/10.1007/s12257-011-0248-7*
   a. Study on the effect of Volatile Fatty Acids (VFAs) on the activity of syntrophic bacteria and methanogens in UASBs
   b. CH_4 content in biogas were determined with a model TGS 2611 methane sensor
   c. five microbiological and operating variables [propionate, butyrate, acetate, M/A and hydraulic retention time (HRT)]
   d. Results:
      i. The granules were less stable, less dense, and had irregular surfaces likely due to acidogenic products (VFAs) and low pH conditions
      ii. Table 2 shows when the M/A (methanogen to acetate-oxidizing syntrophs ratio) was increased from 1 to 2.1, the removal rates of propionate, butyrate and acetate were increased. However, when the M/A was 3.1, the removal rates were decreased.
      iii. Increasing the HRT led anaerobic microorganisms to adapt to the low pH conditions, and removal efficiencies improved

iv. M/A affected the biogas production rate significantly, i.e. higher M/A meant more biogas production
v. Presence of VFAs decreased pH
vi. All VFAs inhibit the VFA removal and the effect of butyrate on VFA removal is more significant
vii. Granular sludge provides more efficient spatial microbial proximity than suspended culture to enhance the flux of substrates and metabolites, thus enhancing syntrophic reactions.

Name: Cara

4. *Batstone, D.J., Puyol, D., Flores-Alsina, X., Rodriguez, J., 2015. Mathematical modelling of anaerobic digestion processes: applications and future needs. REVIEWS IN ENVIRONMENTAL SCIENCE AND BIO-TECHNOLOGY 14, 595–613.* *https://doi.org/10.1007/s11157-015-9376-4*
5. *.Buzzini, A.P., Pires, E.C., 2007. Evaluation of a upflow anaerobic sludge blanket reactor with partial recirculation of effluent used to treat wastewaters from pulp and paper plants. Bioresource Technology 98, Issue 9,1838-1848*

   https://doi.org/10.1007/s11157-015-9377-3
    - Studies in Latin America have found that stabilization ponds, activated sludge processes and UASBs are the most common wastewater treatment technologies (in that order)
        - 34% of these facilities have design flows of less than 5L/s
        - Ponds work well in rural areas where the demand for land is lower than in urban areas
- BOD and COD removal efficiencies in UASBs in India and Brazil vary widely, ranging from 41% to 84%
- Brazillian UASB costs are about $15-$25 per person for construction and $1-$2/yr for upkeep costs (so lower costs are very possible)
- Mentions common paired secondary treatments with UASBs (mentions trickling filter!)
- **"Gravity flow sewer systems require minimum flow conditions to prevent sewer clogging. In (semi) arid climate countries, which suffer from limited tap water supply, minimum flows are not guaranteed."**
- Anaerobic systems present good biodegradable organic matter removal, but the concentrations of N and P in the effluent might even be higher than in the influent.
    - Nitrogen removal should be a huge priority of secondary treatment
    - Phosphorus removal in places using anaerobic reactors is only effective if chemical products are used (iron or aluminum salts).
- UASBs are, as noted, not great at removing pathogens (again, trickling filter is mentioned as a way for removal)
    - If a trickling filter successfully meets WHO guidelines for pathogen removal, post-treatment wastewater can be used in agriculture

- Keeping the flow of wastewater somewhat constant seems to be a main priority for UASBs to work well
- Talks about the many problems associated with biogas collection (many familiar to us already) but does not offer ideas or solutions. Does say the high energy potential of the biogas makes it worth it to try to collect it.
    - 30-40% of methane is stuck in the liquid effluent (methods to lower this percentage are available but are very expensive)
    - This was written in 2007 - see if anything's changed?
    - Can use leftover sludge as energy source(???)

Name: Shania

6. *Chong, S., Sen, T.K., Kayaalp, A., Ang, H.M., 2012. The performance enhancements of upflow anaerobic sludge blanket (UASB) reactors for domestic sludge treatment - A State-of-the-art review. WATER RESEARCH 46, 3434–3470.* https://doi.org/10.1016/j.watres.2012.03.066
    - Aim of start-up is to develop active biofilm and reach nominal organic loading rate → takes 3 months or more than a year for steady state
    - Steps it can be shortened and optimized:
        - Inoculation period: carrier is put in close contact with innoculating sludge (ex of carrier material: Cloisonyl)
        - Increase organic loading rate: main parameters to change is to have a short HRT → flow rate is increased. Biofilm is much higher when HRT is increased
    - Hydrodynamic conditions are successful to control biofilm characteristics → implementation of low hydrodynamic strengths during start-up made it possible to treat more pollution quickly
    - There are three phases of biofilm formation: At the beginning Y_{CH4} is slow , the value of it increases to a stable level close to a theoretical value corresponding to how much wastewater is put into the system,
    - To maintain biofilm: when reactor performance is stable → biofilm still grows
        - This can lead to excess biomass and accumulation → clogging of bed→ limits reactor volume to treat water → BUT our reactor has a sludge weir to maintain growth
7. *Donoso-Bravo, A., Mailier, J., Martin, C., Rodriguez, J., Aceves-Lara, C.A., Vande Wouwer, A., 2011. Model selection, identification and validation in anaerobic digestion: A review. WATER RESEARCH 45, 5347–5364.* https://doi.org/10.1016/j.watres.2011.08.059
    - Anaerobic digestion is a multistep process where one slower steps controls the global rate
    - The model "AdM1" was developed to reach a common basis to describe the dynamic of 24 species and 19 bioconversion processes

- Batch tests helps with kinetic parameter determination in AD, such as: (1) the possibility to easily record the time evolution of several variables (2) the relatively short time span as compared to continuous operations and (3) simplicity and popularity as reflected in a wide acceptance
    - But batch tests lack input excitation
- Continuous system tests: more time consuming than batch test
- This article mainly outlines the different systems that can be used for anaerobic digestion such as batch, continuous, and fed-batch operations. I don't think this article is much helpful in determining what we need to know

8. *Escudie, R., Cresson, R., Delgenes, J.-P., Bernet, N., 2011. Control of start-up and operation of anaerobic biofilm reactors: An overview of 15 years of research. WATER RESEARCH 45, 1–10.* https://doi.org/10.1016/j.watres.2010.07.081
    - Effectiveness and stability of UASB reactor depends on initial start-up → affected by numerous physical, chemical and biological parameters.
    - initial development of granules can be divided into four steps: (1) Transport of cells to a substratum (i.e. an uncolonized inert material or other cells); (2) Initial reversible adsorption to the substratum by physicochemical forces; (3) Irreversible adhesion of cells to the substratum by microbial appendages and/or polymers; (4) Multiplication of the cells and development of granules.
    - Granule formation during start-up lends a decided advantage for ability to provide high COD removal efficiency within a shorter time
    - Presence of divalent and trivalent cations exert positive impact on granulation by neutralizing negative charges on the bacteria surfaces
    - Found that higher Fe^{2+}(300-450 mg/L) and Ca^{2+} (150-300mg/L)helped deteriorate bacteria specific activity → accelerates adsorption, adhesion and multiplication and granulation process
        - Adding Al^{3+} negatively affected granulation at high concentrations but not low concentrations
    - Adding organic-inorganic hybrid polymers also showed promising effects: water extract of Moringa Oleifera seeds, Chitosan and Reetha extract, Commercial cationic polymer AA180H, Organic-inorganic hybrid polymers
        - All either helped in granule formation, decreasing wash-out of methanogens, increased COD removal efficiency, or shortened start-up period
    - Zero-valent iron (ZVI) bed: When a voltage of 1.4 V was supplied to the ZVI bed → COD removal efficiency increasedover 90% → electric field helps maintain low oxidation reduction potential
    - At 35degC methanogenic bacteria generates within 3 days, at 10degC generation time can take 50 days.
        - Higher temperature enhances methanogenesis but also lowers effluent quality due to sludge washout

- General optimal conditions are: pH 7.2-7.6, temperature of 33-37degC(mesophilic) or 50-55 degC(thermophilic)

Table 5 – Recent studies and comparison of various coupled systems at low temperatures.

Ref.[a]	T (°C)	Digester type	Size (m^3)	HRT (h)	Influent COD (mg/L)	Concentration in final effluent (mg/L) [Average removal efficiency (%)][b]					COD removal efficiency[c]
						COD_t	COD_{ss}	TSS	NH_4–N	EC	
With a fixed-bed reactor:											
[1]	15–35	UASB + AF (×2)	0.416 + 0.204	5 + (1.5 – 24)	640	84 [86]		31 [85]			+
[2]	13	AF + AH	0.06 + 0.65	4 + 8	506	147 [71]	18 [91]		50 [−7]	2.2×10^6 [0.48]	+
				3 + 6		187 [63]	43 [79]				−
				2 + 4		207 [59]	59 [71]				−
[3]	10–28	UASB-AF	0.0053	3 – 24	200–1300	201 [63]		68 [70]			−
[4]	15–21	AF + UASB	56.5 + 113	4 + 8	962–1627	545 [58]	152 [81]				0
[5]	15–35	UAFB	0.0059	3.4	272	139 [49]					0
With a continuous-stirred-tank reactor:											
[6]	15, 35	UASB + CSTR	0.14 + 0.106	6 h + 21.2 d (SRT)	460	151 [66]	32 [87]		[−18]		+
[7]	29–34	UASB + CSTR	0.14 + 0.106	10 h + 20 d (SRT)	1186	332 [72]					+
Two-stage UASB:											
[8]	18–25	UASB + UASB	60 + 33	5–6, 8–10	1531	55					0
[9]	14	HUSB + UASB	25.5 + 20.36	5.7 + 11.6	118	142 [65]		31 [87]			0
	17			5 + 9.3	201	103 [64]		21 [89]			+
	18.5			2.8 + 6.5	281	102 [49]		18 [86]			+
	20.6			3 + 13.9	401	55 [53]		19 [81]			+
With a septic tank:											
[10]	24	UASB + Septic tank	0.8	48	1189	523 [56]	[87]				+
				96		499 [58]	[90]				
[11]	17.3	UASB + Septic tank	0.8	48	905	433 [51]	[83]	89 [74]	36 [12]		+
				96		408 [54]	[87]	73 [78]	36 [13]		
With a lamella settler:											
[12]	16.4	UASB-ESR1	3	23 h	1447	897 [38]	271 [61]				++
		UASB-ESR2		24 h		854 [41]	550 [62]				

a References: [1] Chernicharo and Machado (1998); [2] Elmitwalli et al. (2001), Elmitwalli et al. (2002); [3] Lew et al. (2003), Lew et al. (2004); [4] Sawajneh et al. (2010); [5] Gao et al. (2011); [6] Mahmoud et al. (2004), Mahmoud et al. (2008); [7] Mahmoud (2008); [8] Halalsheh et al., 2005a,b; [9] Álvarez et al. (2008); [10] Al-Shayah and Mahmoud (2008); [11] Al-Jamal and Mahmoud (2009); [12] Halalsheh et al. (2010).
b All concentrations are given in mg/L, except EC (in org/100 mL); average removal efficiencies are given in percentage, except EC (in log units).
c COD removal efficiency compared to UASB reactors at the particular operating condition: − Unfavourable, + Favourable, ++ Very favourable, 0 no effect/no direct correlation.

Name: Emily Wood

9. *Ghaniyari-Benis, S., Borja, R., Monemian, S.A., Goodarzi, V., 2009. Anaerobic treatment of synthetic medium-strength wastewater using a multistage biofilm reactor. BIORESOURCE TECHNOLOGY 100, 1740–1745. https://doi.org/10.1016/j.biortech.2008.09.046*

- "The aim of this study was to evaluate the performance and practicability of a multistage anaerobic biofilm reactor composed of three sequential compartments treating synthetic wastewaters containing molasses as a carbon source to evaluate COD removal for different influent conditions."
- Sampling ports were used to draw liquid and a water jacket maintained the temperature at 35 degC
- Start-up was conducted in 3 phases, each lasting 45 days: first with batch additions of wastewater, then continuous flow, and finally with an addition of $CaCO_3$.
- "A decrease in HRT from 24 to 16 h had no effect on COD removal efficiency. When HRT decreased to 8 h, COD removal efficiency was still 84.9%."

- “The relatively poor performance observed at a HRT of 8 h was attributed principally to the instability created by the sudden doubling of the influent loading rate.”

Compartments	HRT (h)	Parameters		
		COD removal (%)	VFA concentration (mg/L)	Total percentage of COD removed (%)
1	24	81.5	913	81.5
	16	78.6	1154	78.6
	8	73.7	1258	73.7
2	24	88.3	371	6.8
	16	87.2	458	8.6
	8	79.2	959	5.5
3	24	91.6	223	3.3
	16	91.6	228	4.3
	8	84.9	458	5.7

10. *Jimenez, J., Latrille, E., Harmand, J., Robles, A., Ferrer, J., Gaida, D., Wolf, C., Mairet, F., Bernard, O., Alcaraz-Gonzalez, V., Mendez-Acosta, H., Zitomer, D., Totzke, D., Spanjers, H., Jacobi, F., Guwy, A., Dinsdale, R., Premier, G., Mazhegrane, S., Ruiz-Filippi, G., Seco, A., Ribeiro, T., Pauss, A., Steyer, J.-P., 2015. Instrumentation and control of anaerobic digestion processes: a review and some research challenges. REVIEWS IN ENVIRONMENTAL SCIENCE AND BIO-TECHNOLOGY 14, 615–648. https://doi.org/10.1007/s11157-015-9382-6*
    - This article outlines many modern technologies and control strategies used to measure the performance of an anaerobic digester. The vast majority involve expensive technologies that would not be suitable for an AguaClara wastewater plant.
    - The rate limiting steps of anaerobic digestion are methanogenesis and acetogenesis
    - Resistance thermometers, thermo-elements, and thermistors are typically used to monitor the temperature
    - The pH of an anaerobic digester must be controlled to avoid ‘acidification and process failure’
    - Volatile Fatty Acid (VFA) accumulation leads to an ‘imbalance in anaerobic digestion’ and is sometimes used as a measurement of reactor performance
    - “methane produced per unit of total solid (TS) or volatile solids (VS) of any given substrate” is a common measure of reactor performance
    - Anaerobic co-digestion can aid biogas production: (ex. Co-digesting manure and organic waste, also varying the C/N ratio) [pg 633]
    - This article also mentions ways to deal with sulfide gas [pg. 634]

11. *Kassab, G., Halalsheh, M., Klapwijk, A., Fayyad, M., van Lier, J.B., 2010. Sequential anaerobic-aerobic treatment for domestic wastewater - A review. BIORESOURCE TECHNOLOGY 101, 3299–3310.* *https://doi.org/10.1016/j.biortech.2009.12.039*
    - This article suggests that sequential anaerobic-aerobic wastewater treatment is a more efficient and viable option for 'low-income' communities, especially when wastes are concentrated. The anaerobic pre-treatment consumes less energy and produces less excess sludge, but post-treatment is needed.
    - Anaerobic systems are good at removing helminth (parasitic worms) eggs, but not great at removing fecal coliforms. They produce primarily methane and CO2 biogas, but also ammonium and hydrogen sulfide.
    - References another study in which a UASB reactor (at HRT = 4 hrs) was used in succession with an aerobic system. The UASB reactor was responsible for 81-94% of the total COD removed by the system.
    - Decreasing upflow velocity and increasing HRT (from 2 to 3 hrs) led to better performance of the UASB reactor.
    - Synthetic wastewater has been created using "meat extract (50%), sucrose and starch (32%), cellulose (8%) and vegetable oil (10%), in addition to the SBR excess sludge."
    - Apparently "suspended solids in the raw wastewater can be detrimental to the maintenance of the good characteristics of granular sludge"

Domestic sewage treatment in a pilot system composed of UASB and SBR reactors P. Torres* and E. Foresti**

- The following table describes 'the scale and operational conditions' or a UASB-Tricking FIlter combination

System configuration	Scale and operational conditions								Ove Per
	Anaerobic unit				Aerobic unit				Rer effi (%)
	Temp. (°C)	Vol. (l)	HRT (h)[b]	OLR[c]	Temp. (°C)	Vol.[b] (l)	HRT (h)	Load	Tot COI
Sequential anaerobic-non-submerged attached growth aerobic processes									
UASB–TF	26	416	4	3.8	26	60	2–12	SuLR[d]: 17.1–6.8	80–
UASB–TF	26	416	5.6	1.9	26	106	1.5	SuLR: 25	81

●

Name: Dominic

12. *Ketheesan, B., Stuckey, D.C., 2015. Effects of Hydraulic/Organic Shock/Transient Loads in Anaerobic Wastewater Treatment: A Review. CRITICAL REVIEWS IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY 45, 2693–2727. https://doi.org/10.1080/10643389.2015.1046771*

Limitations of anaerobic digestion (in comparison to aerobic systems):

- There is a very delicate balance between the acidogenesis (metabolic conversion of monomers to Volatile Fatty Acids), acetogenesis (acetate production from CO2 and electron donor reactants), and methanogenesis. Any imbalances may affect the stability of the anaerobic and result in:
  - deterioration in COD removal
  - reduced biogas production
  - poor effluent quality
- Aerobic systems are much more resilient, but do not produce useful products.

Significance of shock loading:

- Shock loading = instantaneous changes in organic loading rate
  - Controlling variables: hydraulic retention time AND organic feed strength
- It is important to evaluate and understand how the system can regain stability before the adverse effects become irreversible!

Causes of Instability:

- *Accumulation of Volatile Fatty Acids (VFAs)*:
  Acidogens- which create VFAs from monomers) have a bacterial yield (g VSS/ g COD) five times higher than methanogens; therefore, a sudden increase in OLR during shock loading may result in the accumulation of VFAs.
    - Can inhibit methanogenesis
    - Can result in a drop in pH
    - Acetogenesis pathway becomes thermodynamically unfavorable
- Biomass Washout
    - Stability is very important! Another cause of concern in our system

Monitoring:

- VFAs and pH are important in monitoring systems - too high of a concentration may result in desired reaction being thermodynamically unfavorable.
- Acetoclastic methanogens are slow growing microorganisms with a minimum doubling time of 2–3 days, while hydrogenotrophic methanogens exhibit faster growth with minimum doubling times of 6 hours. Acetoclastic methanogens are responsible for almost 70% of the total methane production (creates long startup)

Regaining Stability: The table below is very important! It provides papers which detail appropriate measures to take when trying to control microbial populations within the reactor (based on parameters which gauge the effectiveness of the system)

Table 1 of 1

Table 1 Summary of literature on control/recovery strategies for anaerobic reactors during hydraulic/organic shock/transient loading

Study by	Control strategy	Effectiveness
Graef and Andrews (1974)	Removal of produced CO_2 in the headspace of reactors with dilute alkali	pH control
Schmidt and Ahring (1993)	Addition of either hydrogen-utilizing methanogen that does not use formate, or a hydrogen- and formate-utilizing methanogens to disintegrated granules	Improved degradation rate of propionate and butyrate
Espinosa et al. (1995)	Regulate the supply of trace metals such as Fe, Ni, Co, and Mo	Improved degradation rate of propionate and butyrate
Mitra et al. (1998)	Use of a polymeric composite ion exchanger (CIX) to dissipate any build-up of hydrogen ions	pH control
Voolapalli and Stuckey (1998)	Use of submerged silicone membrane extraction to remove the CO_2 and H_2	pH control and improved acetate degradation
Voolapalli and Stuckey (1999)	Addition of acetate utilizing cultures and formate/H_2 utilizers to improve butyrate, propionate degradation	Improved degradation rate of acetate
Akram and Stuckey (2008)	Addition of PAC to adsorb low and high molecular weight soluble organics during a hydraulic step overload	Improve effluent COD and flux in a membrane bioreactor
Steinberg and Regan (2011)	Use of an acido tolerant methanogenic community to overcome digester failure due to pH drop	Enhanced tolerance to pH drop during organic shock loading
Tale et al. (2011)	Bioaugmentation of propionate degrading cultures	Improved propionate degradation and system recovery
Tale et al. (2015)	Bioaugmentation of aerotolerant methanogenic, propionate enrichment cultures	Improved propionate degradation and faster system recovery
Acharya et al. (2015)	Bioaugmentation of propionate, butyrate, and acetate degrading cultures	Low VFA levels and faster system recovery

13. *Khan, A.A., Gaur, R.Z., Tyagi, V.K., Khursheed, A., Lew, B., Mehrotra, I., Kazmi, A.A., 2011. Sustainable options of post treatment of UASB effluent treating sewage: A review. RESOURCES CONSERVATION AND RECYCLING 55, 1232–1251. https://doi.org/10.1016/j.resconrec.2011.05.017*

Projected Efficiencies for UASBs (General Conditions):

- UASB process can achieve up to 70% chemical oxygen demand (COD) removal in warm-climate countries; however, the treatment efficiency decreases with the decrease in temperature, reaching a 50% COD removal at 15 °C.
- The UASB reactor performance at low temperatures can be improved by changing its configuration like incorporating settler above the GLSS (gas–liquid–solid separator), or adding the AF at the top of the UASB reactor

Proposed Post Treatment Systems:

- Trickling Filter
- Duckweed Pond
- Etc. (We are working with string digester team on this)

14. *Latif, M.A., Ghufran, R., Wahid, Z.A., Ahmad, A., 2011. Integrated application of upflow anaerobic sludge blanket reactor for the treatment of wastewaters. WATER RESEARCH 45, 4683–4699. https://doi.org/10.1016/j.watres.2011.05.049*

- Discusses treatment for different types of wastewater (fishery, piggery, distillery, black water, etc.) I do not believe this article contains much useful information for our research.
- methanogenesis is strongly affected by pH. As such, methanogenic activity will decrease when pH in the digester deviates from the optimum value. Optimum pH for most microbial growth is between 6.8 and 7.2 while the pH values less than 4 and more than 9.5 are not tolerable (Gerardi, 2006). Several cases of reactor failure have been reported in various studies of wastewater treatment due to accumulation of high concentrations of volatile fatty acid, causing a drop in pH which inhibited methanogenesis
- It is generally assumed that a transition from mesophilic to thermophilic conditions is accompanied by a significant (over 80%) and lengthy (over 4 days) decrease in methane production due to adaptation of methanogens to thermophilic temperatures

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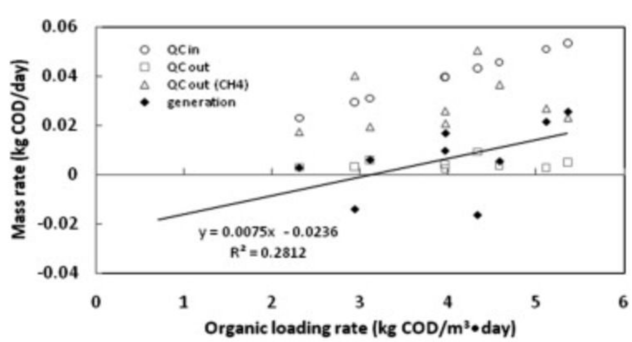
Name: Valentine

15. *Li, W.-W., Yu, H.-Q., 2013. Anaerobic Granule Technologies for Hydrogen Recovery from Wastes: The Way Forward. CRITICAL REVIEWS IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY 43, 1246–1280. https://doi.org/10.1080/10643389.2011.644218*
    - “recent development of **sludge granulation technologies** has significantly improved the biomass retention and raised the hydrogen productivity and operation stability”

- HPG= hydrogen producing granule
    - is a special type of anaerobic granule that aims at hydrogen production from wastewater
- HPG possesses more compact structure, better settleability, and thus **higher adaptability to harsh environments and operational fluctuations**
- hydrogen might have the greatest opportunity to realize large-scale production and utilization as a renewable energy in the near future, because it has a **higher application value than methane, better separation than biochemicals and superior scalability**
- HPG technologies still face significant technological and economical challenges at the present stage, such as low HY, limited mass transfer, and a narrow range of feedstock
- Physical enhancement—> electric, sonic and magnetic fields can be used to eliminate methanogens yet preserve HBP
- Chemical Enhancement —> multivalent cations such as Ca2+ have been conventionally dosed in hydrogen-production systems to neutralize the negative charge and facilitate a fast granulation
- Biological Enhancement —> direct metabolic pathway regulation, and creation of microbial consortia with high hydrogen productivity

16. *Lim, S.J., Fox, P., 2011. Evaluation of a static granular bed reactor using a chemical oxygen demand balance and mathematical modeling. BIORESOURCE TECHNOLOGY 102, 6399–6404. https://doi.org/10.1016/j.biortech.2011.03.031*
    - Chemical oxygen demand (COD) balance was used along with a mathematical model
        - Used to evaluate the static granular bed reactor (SGBR)
    - The SGBR was modeled using the general transport equation considering advection, diffusion, and degradation by microorganisms, and the first-order reaction rate constant was 0.0166/day.
    - SGBR model provided mechanistic insight into why the **COD removal efficiency in the SGBR is proportional to an organic loading rate.**
    - Various wastewaters such as non-fat dry milk, slaughterhouse wastewater, high-strength sulfate wastewater, and domestic wastewater were treated
    - The COD removal efficiency was between 77.2% and 94.5% (Ave.: 87.4 ± 4.4%) and COD removal increased as the OLR increased



    - df

17. *Lim, S.J., Kim, T.-H., 2014. Applicability and trends of anaerobic granular sludge treatment processes. BIOMASS & BIOENERGY 60, 189–202. https://doi.org/10.1016/j.biombioe.2013.11.011*

- UASB = upflow anaerobic sludge blanket
  - able to treat various high-strength wastewaters / municipal wastewater
- EGSB = expanded granule sludge blanket
  - developed to increase contact between wastewater and the granules
  - Dispersed sludge is separated from mature granules using the rapid upward velocity in this reactor.
  - treats low and/or high-strength especially under low temperatures.
- SGBR = static granular bed reactor
  - Used for various wastewaters at a broad range of organic loading rate in lab-, pilot-scale tests.
- The UASB reactor:
  - does not require any mixing device and is equipped with a set of Gas Liquid Solid Separator (GSS) to separate solids (granules) from the effluent
  - easy to withdraw gas out of the reactor
  - usually designed to treat high-strength organic wastewaters with an organic loading rate (OLR)

Advantage	**Disadvantage**
•Excellent performance -Long solids retention time -Even at high loadings and low temperatures •Low energy consumption -Energy consumption is very low, especially electricity -Low sludge production -The sludge production is low when compared to aerobic processes •Low macro/micro nutrient requirement -Anaerobic sludge requires lower nutrient •Production of valuable by product – Biogas -Produced methane reduces the operating costs •Low hydraulic retention time -High-rate anaerobic digestion process	• Long start-up period -Takes long start-up period before the reactor reaches the steady-state •Low performance at very low loadings -The activity of granules is lower •Post treatment for discharge standards -Organic matter, solids, nutrient, and pathogens are treated after the UASB process for discharge standards •Low pathogen removal -Pathogen removal is very low in anaerobic digestion treatment under mesophillic conditions •Odor problems -Hydrogen sulfide can be problem under anaerobic digestion •Low nutrient removal

•Improved sludge dewaterability -Smaller volume of stabilized sludge •Simple reactor construction -Construction is very simple -Low requirement of operating and maintaining reactors	- Nutrient removal is very low in anaerobic digestion treatment

Name: Franny

18. *Liotta, F., Chatellier, P., Esposito, G., Fabbricino, M., Van Hullebusch, E.D., Lens, P.N.L., Pirozzi, F., 2015a. Current Views on Hydrodynamic Models of Nonideal Flow Anaerobic Reactors. CRITICAL REVIEWS IN ENVIRONMENTAL SCIENCE AND TECHNOLOGY 45, 2175–2207. https://doi.org/10.1080/10643389.2015.1010426*
    - This article describes mathematical modeling of uasb reactors
    - Exact mixing patterns cannot be generalized; have to examine it case by case
    - Difficult to come up w equations since there are a lot of components related to uasb reactors
        - Simple ones and easy to apply don't consider biogas production, sludge bed blanket expansion & contraction, and the granulation process
        - Model below simulates vertical velocity of sludge aggregates

$$u(z,t) = \frac{V_R}{T \cdot C_S} - W_S \quad (14)$$

where V_R = reactor liquid volume [L^3]; T = retention time [T]; C_S = reactor cross section

and W_S = settling velocity for sludge solids [LT^{-1}].

$$V\frac{dC}{dt} = V \cdot C_0(t) - Q \cdot C(t) \quad (9)$$

$$\frac{\partial C}{\partial t} = \frac{D}{L}\frac{\partial^2 C}{\partial z^2} - \frac{u}{L}\frac{\partial C}{\partial z} \quad (10)$$

- Model above describes hydrodynamic behavior of uasb reactor (advective diffusive equation)
- Many models in text w different pros and cons… I can report on if we are looking to optimize a specific component but it's difficult bc all have at least 1 component missing

- Models differ mainly by the numerical techniques and boundary conditions

19. *Lopez, I., Borzacconi, L., 2010. UASB reactor hydrodynamics: residence time distribution and proposed modelling tools. ENVIRONMENTAL TECHNOLOGY 31, 591–600. https://doi.org/10.1080/09593331003646638*
    - Reactors must account for rates of fluid composition and how fluid flows through reactor (hydrodynamic behavior)
    - Can perform tracer tests to determine flow of uasb reactor
        - Proves that deviations from ideal cstr are negligible so cstr behavior was assumed; almost all hydraulic models reported in literature are close to cstr models
    - Fluid is usually characterized using residence time distribution (RTD)
        - Need RTD of fluid particles inside and age distribution in exit flow
        - Doesn't account for micro mixing phenomena but gives sufficient information nonetheless
    - Enough evidence to say that the reactor behavior is very close to a complete mixing (cstr) and bc of this, can assume an ETIS model
    - Extended tank in series (ETIS) model can be used for the whole reactor (reaction zone and not the settler zone)

    The ETIS distribution can produce results similar to other models. For example, for the Van der Meer model, an N value can be found that yields a virtually identical RTD. Working in the Laplace domain instead of the time domain is a powerful way to verify these findings. The Laplace transform of a function $f(t)$ is:

    $$L\{f(t)\} = F(s) = \int_0^{\infty} f(t) e^{-st} dt. \qquad (3) \quad (3)$$

    The Laplace transform of the E curve can be obtained from the dynamic balance equations of an inert tracer if the ideal reactor network is known. Denoting $G(s)$ as this transform, the Van der Meer model is represented as:

    $$G_{VdM}(s) = \frac{[(1-\alpha)a\tau]s + \alpha\gamma}{[a(1-a)\tau^2]s^2 + [\alpha\gamma + a - \alpha a]\tau s + \alpha\gamma} \qquad (4) \quad (4)$$

    - where α is the flow fraction that enters the first compartment, $\alpha\gamma$ is the flow fraction that exits the first compartment and a is the fraction of total volume occupied by the first compartment.

    - Most cited models in literature fit the ETIS model

    - Transfer model:

$$G_{ETIS}(s) = \left(\frac{1}{1 + \frac{\tau}{N} s} \right)^N . \qquad (5) \ (5)$$

-

- Then can use ETIS model to find RTD by finding the parameter N

Name: Lydia

20. *Ma, X. (Cissy), Xue, X., Gonzalez-Meija, A., Garland, J., Cashdollar, J., 2015. Sustainable Water Systems for the City of Tomorrow-A Conceptual Framework. SUSTAINABILITY 7, 12071–12105. https://doi.org/10.3390/su70912071*

SUMMARY:

To be more efficient and sustainable in the long run, human society should mimic natural processes.

* The higher the organic content, the more biogas.
* diversion (separation of fecal matter and urine)
    * improves efficiency of biodegration of organics
    * reduces hydraulic and solid retention time, in usb reactors.
    * also could double biogas production.
* wastewater has thermal energy.. could be used for building heating
* “In fact, there is no such thing as waste in nature, only wasted resources.”

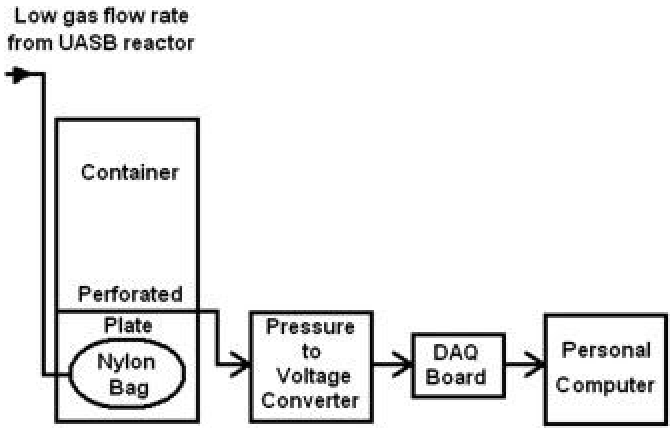
21. *Martinez-Sibaja, A., Alvarado-Lassman, A., Astorga-Zaragoza, C.M., Adam-Medina, M., Posada-Gomez, R., Rodriguez-Jarquin, J.P., 2011. Volumetric gas meter for laboratory-scale anaerobic bioreactors. MEASUREMENT 44, 1801–1805. https://doi.org/10.1016/j.measurement.2011.08.018*

SUMMARY:

The proposed measuring device was used to measure the biogas production of a UASB reactor.
Advantages:

- Biogas measured is collected in a removable nylon bag
- Evaluated to obtain the concentrations of methane and carbon dioxide

- Pressure calculates biogas production rates



22. *Mendes, C., Magalhes, R. da S., Esquerre, K., Queiroz, L.M., 2015. Artificial Neural Network Modeling for Predicting Organic Matter in a Full-Scale Up-Flow Anaerobic Sludge Blanket (UASB) Reactor. ENVIRONMENTAL MODELING & ASSESSMENT 20, 625–635. https://doi.org/10.1007/s10666-015-9450-x*

SUMMARY:
ANN (artificial neural Network) models are used and applied to predict the COD concentration in the effluent. Anaerobic digestion processes in UASB reactors involve a complex and nonlinear system that is known to be unstable.
Works best in:

- warm climates high application
- rates of organic loads
- short hydraulic retention times

23. *Montalvo, S., Guerrero, L., Borja, R., Sanchez, E., Milan, Z., Cortes, I., Angeles de la la Rubia, M., 2012. Application of natural zeolites in anaerobic digestion processes: A review. APPLIED CLAY SCIENCE 58, 125–133. https://doi.org/10.1016/j.clay.2012.01.013*

SUMMARY:
Zeolites are porous materials characterized by their ability to lose and gain water reversibly, adsorb molecules of appropriate cross-sectional diameter, and exchange their cations without a change in their structure. The use of a porous support such as zeolite enables the anaerobic reactor to retain high biomass concentrations and thereby operate at significantly reduced hydraulic retention times.

- ideal for use in biological purification wastewater processes
- With increases, there is a greater change of cross-feeding
- co-metabolism and interspecies hydrogen and proton transfer, **which may further stimulate the growth of microcolonies**
- Addition of zeolites resulted in significant ammonium removals from the organic sludge.

Name: Ahad

24. *Mungray, A.K., Murthy, Z.V.P., Tirpude, A.J., 2010. Post treatment of up-flow anaerobic sludge blanket based sewage treatment plant effluents: A review. DESALINATION AND WATER TREATMENT 22, 220–237. https://doi.org/10.5004/dwt.2010.1788*
    Summary: Cornell University does not provide access to this article
25. *Perez, J., Aldana, G., Cardenas, C., 2012. Upflow anaerobic sludge blanket reactor (UASB) performance through sludge age load and kinetic coefficients. REVISTA TECNICA DE LA FACULTAD DE INGENIERIA UNIVERSIDAD DEL ZULIA 35, 98–108.*
    Summary: This article is in Spanish
26. *Ramirez, I., 2012. ADM1 applications for a hybrid up-flow anaerobic sludge-filter bed reactor performance and for a batch thermophilic anaerobic digestion of thermally pretreated waste activated sludge. REVISTA FACULTAD DE INGENIERIA-UNIVERSIDAD DE ANTIOQUIA 167–179.*
    Summary:
    - *Granule structure and bacterial composition depends on the type of effluent being treated*
    - *A number of conversion processes active in anaerobic digestion of municipal sludge can be inhibited by accumulation of intermediate products like H2, NH3, or by extreme pH*
    - *In a UASB reactor, very low flow rate liquid superficial velocity may cause channeling of wastewater through the bed*
    - *In fully packed anaerobic filters, long term operation may result in excessive biomass entrapment in the interstitial cavities*

27. *Saliba, P.D., von Sperling, M., 2017. Performance evaluation of a large sewage treatment plant in Brazil, consisting of an upflow anaerobic sludge blanket reactor followed by activated sludge. Water Science and Technology 76, 2003–2014. https://doi.org/10.2166/wst.2017.284*

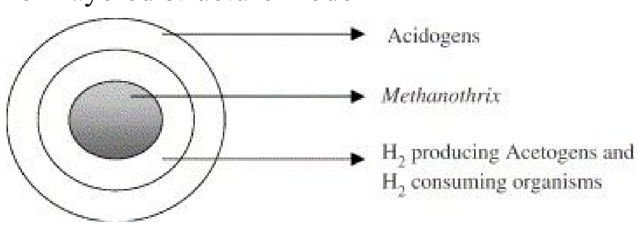
    ***Summary**:*
    - *UASB reactors are able to remove organic matter by 65-80% but have little effect on the removal of nitrogen and phosphorus and can increase ammonia concentration*
    - *UASB reactors often followed by aerobic treatment of effluent to meet regulatory guidelines*
    - *System composed of UASB reactor, followed with activated sludge was very effective for the treatment of domestic wastewater. (94% BOD removed, 91% COD removed)*
    - *These UASB followed by activated sludge systems are more efficient in warmer climates*

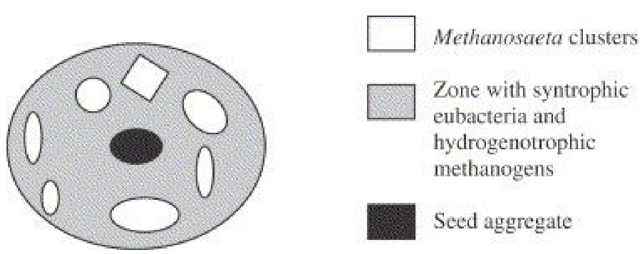
Name: Katrina

28. *Saravanan, V., Sreekrishnan, T.R., 2006. Modelling anaerobic biofilm reactors - A review. JOURNAL OF ENVIRONMENTAL MANAGEMENT 81, 1–18.* [*https://doi.org/10.1016/j.jenvman.2005.10.002*](https://doi.org/10.1016/j.jenvman.2005.10.002)

    Summary:

    - Rate of substrate conversion limited be rate of transport of substrate into biofilm and the pH inside the anaerobic granules
    - “Because of the high biomass concentration, it was demonstrated that volumetric organic loading rates as high as 50 kg chemical oxygen demand (COD) per m3 per day could be employed (Hulshoff Pol, 1989). The liquid velocity inside the reactor is usually in the range of 0.5–1.0 m/h.”
    - Has a lot of equations in this article (equation of flow model, partial differential equation for flow reactor for an inert tracer, anaerobic granules, boundary conditions, more…)
    - Lists different models but possible improvements include: Incorporation of the variation of density within the biofilm/granule, kinetic expressions, which include inhibition terms and the non-uniform pH profile inside the biofilm, and diversity in the bacterial population distribution inside the granule in terms of the predominant species/groups.
    - Multilayer model of granules or granule cluster structure (two below) or non-layered structure model

    - 

29. *Shoener, B.D., Bradley, I.M., Cusick, R.D., Guest, J.S., 2014a. Energy positive domestic wastewater treatment: the roles of anaerobic and phototrophic technologies. ENVIRONMENTAL SCIENCE-PROCESSES & IMPACTS 16, 1204–1222.* [*https://doi.org/10.1039/c3em00711a*](https://doi.org/10.1039/c3em00711a)

    Summary:

    - Briefly summarizes a bunch of different anaerobic systems including UASB

- Also talks about a lot of phototrophic systems that use algae and/or phototrophic bacteria
- “The average percent energy recovery (as methane, hydrogen, or electricity) from degraded COD [for UASB was] 24.0 ± 11.4%”
- “converting biogas to electricity requires expensive auxiliary equipment (i.e., gas conditioning, storage, prime movers or fuel cells) and is currently only feasible at high flow wastewater treatment facilities”
- Loss of dissolved methane (although relatively insoluble, Henry's constant = 776 bar•L/mol) in wastewater effluent is a challenge because it removed much of the potential for anaerobic processes to be energy positive. There is increased energy loss because of higher methane solubility at lower temperatures.

30. *Shoener, B.D., Bradley, I.M., Cusick, R.D., Guest, J.S., 2014b. Energy positive domestic wastewater treatment: the roles of anaerobic and phototrophic technologies. ENVIRONMENTAL SCIENCE-PROCESSES & IMPACTS 16, 1204–1222. https://doi.org/10.1039/c3em00711a*

    Summary:

    - Same article ^

31. *Singh, N.K., Kazmi, A.A., Starkl, M., 2015. A review on full-scale decentralized wastewater treatment systems: techno-economical approach. WATER SCIENCE AND TECHNOLOGY 71, 468–478. https://doi.org/10.2166/wst.2014.413*

    Summary:

    - Anaerobic “systems achieve only poor to moderate effluent quality and take a long time to start up (around 3–4 months), while aerobic systems have much shorter start-up time (around 2–4 weeks)”
        - Because of this, many anaerobic systems are pairs with aerobic systems
    - **Table 3**
      Performance inventory of full-scale anaerobic and combined treatment systems

			Removal (%)								
Treatment process	Capacity	Unit	BOD	COD	TSS	TN	TKN	NH_3-N	TP	TC/FC	Country
UASB[a]	250–500	p.e.	67	60	78	–	–	–	–	–	Brazil
	–	–	72	59	67	−13	–	–	−1	0.6 log FC	Brazil
	35	m^3	80	66	69	–	–	–	–	–	Colombia

- “Aerobic systems are efficient to produce treated effluents which can meet the discharge standards, and anaerobic processes are energy providers but less efficient than aerobic and advanced aerobic processes.”

Name: Kyra

32. *Subramanyam, R., 2013. Physicochemical and Morphological Characteristics of Granular Sludge in Upflow Anaerobic Sludge Blanket Reactors. ENVIRONMENTAL ENGINEERING SCIENCE 30, 201–212. https://doi.org/10.1089/ees.2012.0347*

SUMMARY: This article is more useful prior to startup to adjust sludge characteristics desirable within the reactor.

\This article provides an up-to-date review of physicochemical and morphological characteristics of granular sludge with regard to granule size, settling velocity, specific gravity, sludge volume index, volatile suspended solids–to–suspended solids ratio, ash content, inorganic chemical content, crystalline structure, molecular functional groups, microbial structure and composition, microbial communities, and methanogenic activity.

- **Enhance Characteristics of granular sludge:** Addition of external additives such as synthetic and natural polymers and vitamins may enhance the characteristics of granular sludge.
- **Reduce length of start-up periods:** Bioaugmentation might be a useful tool for improving the stability and significantly reducing the length of start-up periods.
    - Granulation technology has some drawbacks, such as a long start-up period—generally 3–8 months required for the development of granules (Zhou et al., 2007) and wash out of biomaatrss (Vlyssides et al., 2008)
    - Addition of synthetic (Percol 763 as a cationic synthetic acrylamide polymer and poly acrylamide 8265) and natural polymers (chitosan and reetha), and vitamins (C, B3, and B12) exhibits positive effects on granulation, start-up, and reactor performance (El-Mamouni et al., 1998; Show et al., 2004; Tiwari et al., 2005; Fermoso et al., 2010; Abbasi et al., 2012; Hudayah et al., 2012) in a UASB operation
    - Bartrolı´et al. (2011) found that bioaugmentation is a useful tool for improving stability and significantly reduced the length of the start-up period to achieve partial nitrification in a biofilm airlift reactor.
    - Addition of vitamins and polymers exhibits a positive effect on granulation, start-up, and reactor performance.

TABLE 1. PHYSICOCHEMICAL CHARACTERISTICS OF GRANULAR METHANOGENIC SLUDGES GROWN ON VARIOUS CARBON SOURCES IN UPFLOW ANAEROBIC SLUDGE BLANKET REACTORS

Sl. no.	*Carbon source*	*Granule size (mean dia., mm)*	*Settling velocity (m/h)*	*Specific gravity*	*Sludge volume index (mL/g)*	*Ash (%)*	*Operation period (days)*	*Remarks*	*Source*
1	Lactate	0.2–6	—	—	—	44–53	180	—	Fukuzaki *et al.* (1991a)
2	Propionate	0.3–0.6	—	1.355	—	48.2	178		Fukuzaki *et al.* (1991b)
3	Glucose	0.4–0.5	—	0.97–1.19	—	11–13	240	—	Chang *et al.* (1993)
4	Starch	2.1	81	1.065	—	34–40	470		Fukuzaki *et al.* (1995)
	Sucrose	1.82	92	1.063	—	29–35			
	Ethanol	0.87	59	1.058	—	24–29			
	Butyrate-propionate	0.55	41	1.223	—	56–63			
5	Phenol	0.61–0.77	—	1.11	—	8.7–11.9	300	—	Chang *et al.* (1995)
6	Glucose + peptone + meat extract	0.05–6	—	—	9.5	—	180	—	Yan and Tay (1997)
7	Phenol + glucose	1.5–4 (2.8)	—	—	12	—	320	—	Tay *et al.* (2001)
	Phenol	1–3 (1.8)	—	—	14	—		—	
8	Glucose + peptone +	—	47		22		127	—	Show *et al.* (2004)
	meat extract	—	64	—	30	—	131	Cationic polymer 80 mg/L added	
9	Sucrose	1.7–2	—	—	—	—	210	—	Chou and Huang (2005)
	Phenol	1.5–1.9	—		—		210	—	
10	Spent wash	1.35	51	1.012	—	—	60	—	Gupta and Gupta (2005)
11	Sucrose	—	94	1.0386	10–40		90	—	Ghangrekar *et al.* (2005)
12	Sucrose	4–5 (0.15)	—	—	—	—	250	Added chitosan	Tiwari *et al.* (2005)
		4–5 (0.144)	—	—	—	—	—	Cationic fraction of Reetha extract	
		4–5 (0.139)	—	—	—	—	—	Anionic fraction of Reetha extract	
		2 (0.128)	—		—			—	
13	Synthetic	<2	70	—	—	—	—	—	Abbasi *et al.* (2012)
	wastewater	>2	90	—	—	—	—	Added 0.5 mg/L vitamin C	
14	Glucose	0.5–2.5	23–68	1.003–1.008	20–25	16	120	—	Subramanyam and Mishra (2013b)

Sl. no, sludge number.

-

33. *Verbyla, M.E., Oakley, S.M., Mihelcic, J.R., 2013. Wastewater Infrastructure for Small Cities in an Urbanizing World: Integrating Protection of Human Health and the Environment with Resource Recovery and Food Security. ENVIRONMENTAL SCIENCE & TECHNOLOGY 47, 3598–3605. https://doi.org/10.1021/es3050955*

SUMMARY: This article examines wastewater treatment systems and evaluates them for use in developing countries in small cities. It recommends that UASBs must provide sufficient nutrient removal prior to implementation in developing communities and that the advantages of biogas production should be subservient to risks of human health implications.
Interestingly, the study suggests that wastewater reuse may provide a greater energy savings than biogas recovery alone. This should be considered by AguaClara at large but is irrelevant to the current scope of work conducted by UASB. UASBs exhibit limited nutrient removal such as nitrogen and phosphorus. We should be testing our reactor for this as it is essential for controlling eutrophication in receiving water bodies. UASBs could be utilized in land watering systems as excess nutrients could offset agricultural fertilizing needs to augment production capacity. Should pathogens be present int eh system effluents, risks to human health offset advantages of nutrient, water and biogas recovery. IF helminth eggs are present (high risk when ingested), the UASB is ineffective at removing them and prior proposed uses of UASBs for irrigation could present health risks

34. *Wang, Y., Yan, L., Li, J., Shen, H., Zhang, C., Qu, T., 2016. A REVIEW OF TECHNOLOGY FOR SMALL SEWAGE TREATMENT: THE CHINESE PERSPECTIVE. OXIDATION COMMUNICATIONS 39, 275–284.*

SUMMARY:

35. *Zheng, M.X., Wang, K.J., Zuo, J.E., Yan, Z., Fang, H., Yu, J.W., 2012. Flow pattern analysis of a full-scale expanded granular sludge bed-type reactor under different organic loading rates. BIORESOURCE TECHNOLOGY 107, 33–40. https://doi.org/10.1016/j.biortech.2011.11.102*

BACKGROUND ON EGSB: An Expanded Granular Sludge Bed (EGSB) reactor is a variant of the UASB concept for anaerobic wastewater treatment. The distinguishing feature is that a faster rate of upward flow velocity is designed to facilitate partial expansion (fluidisation) of the granular sludge bed to impovoe wastewater-sludge contact as well as enhancing segregation of small inactive suspended particle form the sludge bed. THe increased flow velocity is either accomplished by utilizing tall reactors or by incorporating an effluent recycle. It is only appropriate for low strength soluble wastewaters (>2g soluble COD/L) or wastewaters that contain inert or poorly biodegradable suspended particles which should not be allowed to accumulate in the sludge bed
SUMMARY: This article is irrelevant tothe scope of work on UASB. Should wastewaters in the anticipated community be determined to have low COD levels then the EGSB reacor should be considered. It does however provide insight into how to model fluid flow within a reactor which may have use in analysis of our UASB

36. Impact of temperature on performance, microbiological, and hydrodynamic aspects of UASB reactors treating municipal wastewater
https://pdfs.semanticscholar.org/7733/9af3c815a2095b802c8626839561470778l1.pdf

SUMMARY:

The UASB reactor used could not achieve the desired COD, BOD and SS removal efficiency (70-90%) below 11°C. At an HRT of 6hrs:

Temperatures	*COD Reduction*	*BOD Removal*	*Methane Yield (mL-CH4/g-COD removed)*
32 (90°F)	*87%*	*88%*	*150*
20 (68°F)	*84%*	*86%*	*166*
15 (59°F)	*81%*	*79%*	*182*
11 (51.8°F)	*79%*	*75%*	*199*
6 (42.8°F)	*60%*	*58%*	

When HRT is reduced, the decrease in removal efficiency of COD and BOD observed was more severe.

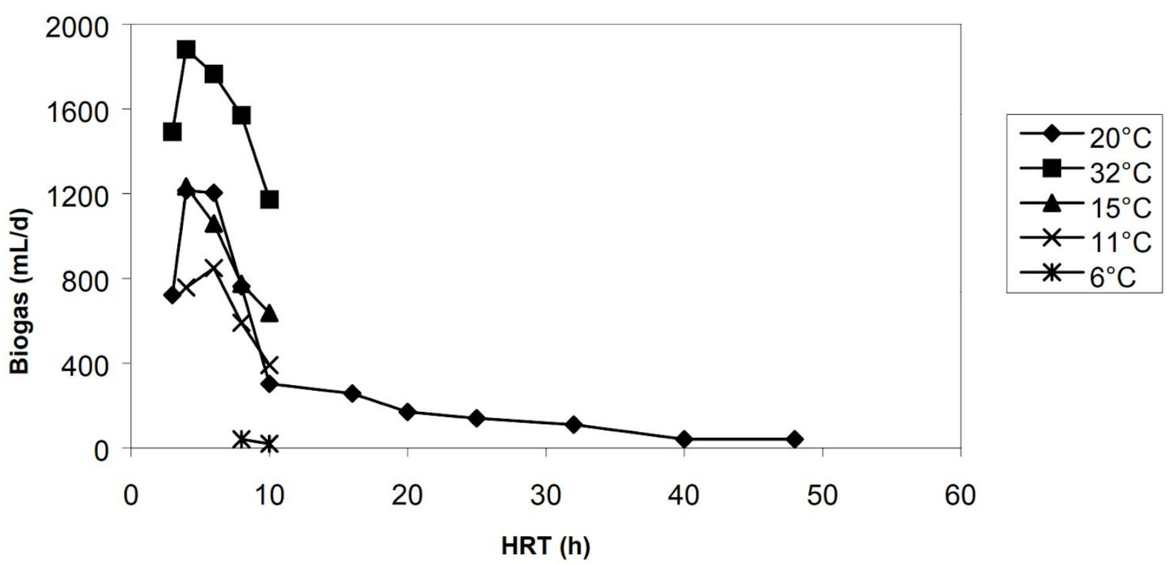


Figure above shows that the gas production increased with a decrease in HRT and decreased with a decrease in temperature