Anaerobic Digestion for Organic Waste Treatment

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History

- Ancient technology
- First Anaerobic Digestion plant in Bombay in 1859
- In 1895 Methane produced by AD was used to light street lamps in Exeter, England

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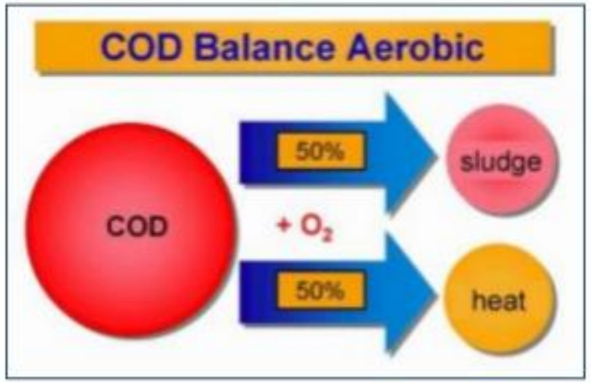
Introduction

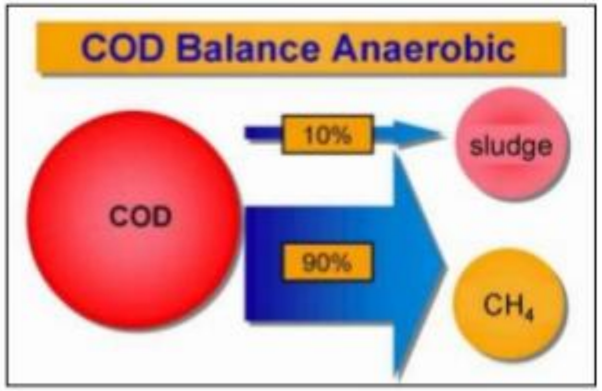
- Anaerobic digestion (AD) is the method of organic wastes treatment aimed at decomposition of complex organic substances into simple, chemically stabilized compounds, mainly methane and CO_2 and digestate (biofertilizer a.k.a Compost).
- This conversion of complex organic compounds to methane and CO_2 is possible due to the cooperation of four different groups of microorganisms: fermentative, syntrophic, acetogenic, and methanogenic bacteria.
- The main process steps of anaerobic digestion of organic wastes are: hydrolysis, acid formation, acetogenesis, and methanogenesis.
- Microbes adopt various pathways to evade the unfavourable conditions in the anaerobic digester like competition between sulphate reducing bacteria (SRB) and methane forming bacteria for the same substrate.

AD Compared to Aerobic WW Treatment

COD Balance Aerobic Biodegradation

COD Balance Anaerobic Biodegradation





Disadvantage of AD compared to Aerobic Biodegradation is that the start up time of an AD reactor can be up to 3 months compared to 2 weeks for aerobic reactor.

Hydrolysis

- During hydrolysis of the polymerized, mostly insoluble organic compounds, like carbohydrates, proteins and fats, these large molecules are decomposed into soluble monomers and dimers, that is, monosaccharides, amino acids, fatty acids and alcohols.
- This is accomplished through enzymes from the group of hydrolases (amylases, proteases, and lipases) produced by appropriate strains of hydrolytic bacteria.
- Hydrolysis is carried out by bacteria from the group of relative anaerobes of genera like Streptococcus and Entero bacterium

Acidogenesis

- During this stage, acidifying bacteria convert water-soluble chemical substances, including hydrolysis products, to short-chain organic acids (formic, acetic, propionic, butyric, and pentanoic), amino acids and peptides, alcohols (methanol, ethanol), aldehydes, carbon dioxide, and hydrogen.
- Among the by-products of acidogenesis, ammonia and hydrogen sulphide by-products give an intense unpleasant smell to this phase of the process.
- The acid phase bacteria belonging to facultative anaerobes use oxygen accidentally introduced into the process, creating favourable conditions for the development of obligatory anaerobes of the following genera: Pseudomonas, Bacillus, Clostridium, Micrococcus, or Flavobacterium.

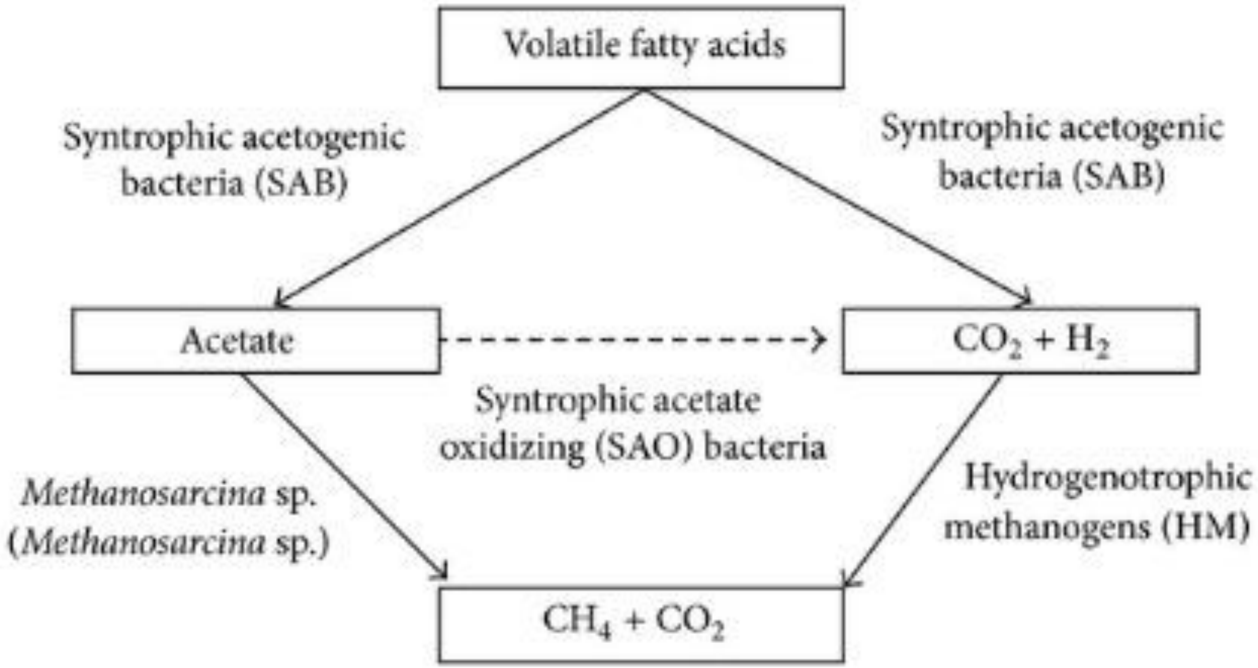
Acetogenesis

- In this process, the acetate bacteria including those of the genera of Syntrophomonas and Syntrophobacter convert the acid phase products into acetates and hydrogen which may be used by methanogenic bacteria.
- As a result of acetogenesis, hydrogen is released, which exhibits toxic effects on the microorganisms which carry out this process. Therefore, a symbiosis is necessary for acetogenic bacteria with autotrophic methane bacteria using hydrogen, hereinafter referred to as syntrophy
- Acetogenesis is a phase which determines the efficiency of biogas production, because approximately 70% of methane arises from the process of acetate reduction.

Methanogenesis

- In this phase the production of methane by methanogenic bacteria occurs.
- Methanogens as absolutely anaerobic microorganisms inhabit anaerobic environment ecosystems, such as tundras, marshlands, rice fields, bottom deposit, swamps, sandy lagoons, tanks where wastewater is decomposed, sewage sludge, solid wastes landfills, and ruminants' stomachs (in the rumen).
- These microorganisms are particularly sensitive to changes in temperature and pH, and their development is inhibited by high levels of volatile fatty acids and other compounds, such as hydrogen, ammonia, and H_2S in the environment
- Among methanogenic microorganisms, we can distinguish psychro-, meso- (35 °C) and thermophilic microorganisms (55 °C).
- The methanogenic Archaea are responsible for the final and critical step of anaerobic digestion, as they produce valuable methane.

Methanogenic Pathways



The SAB consist mostly of Clostridium sp. at both mesophilic and thermophilic conditions. The hydrogenotrophic methanogens in both mesophilic and thermophilic anaerobic digesters belong to the two orders of Methanobacteriales and Methanomicrobiales

Factors Influencing AD

- Retention Time
- pH
- C:N Ratio
- Mixing
- Temperature
- F/M Ratio or Organic Loading Rate (OLR)
- Alkalinity
- Trace Metals (Micronutrients)
- Concentration of Sulphate (SRB's favouring)
- Pollutants

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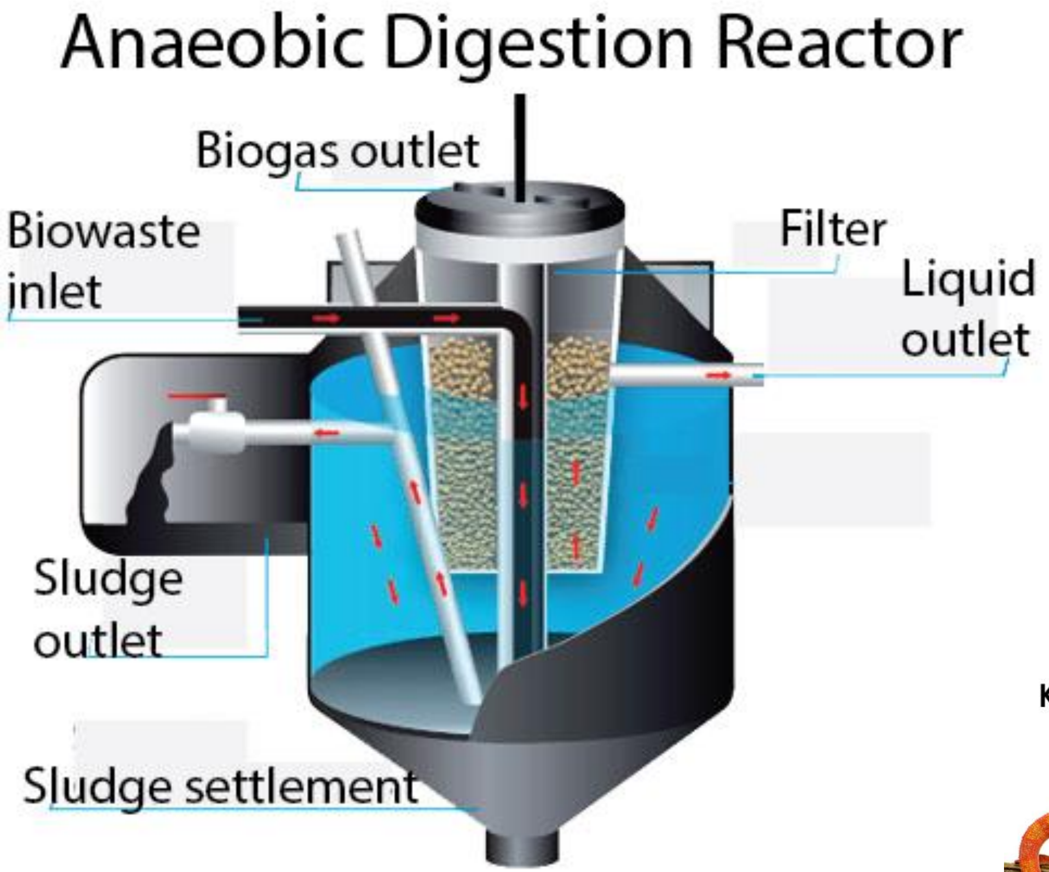
Technologically Five Process Stages

- Pre-treatment
- Anaerobic Digestion
- Gas Treatment (scrubbing H_2S and CO_2)
- Digestate treatment (sterilization) - Dewatering
- Supernatant Aerobic/ANNAMOX Treatment (digester supernatant is high in P and Ammonia-N)

Large AD Vertical Reactor Schematic (Municipal AD)



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Large Egg Shaped Digesters (Municipal)

A Plug Flow AD Horizontal Reactor for Farms

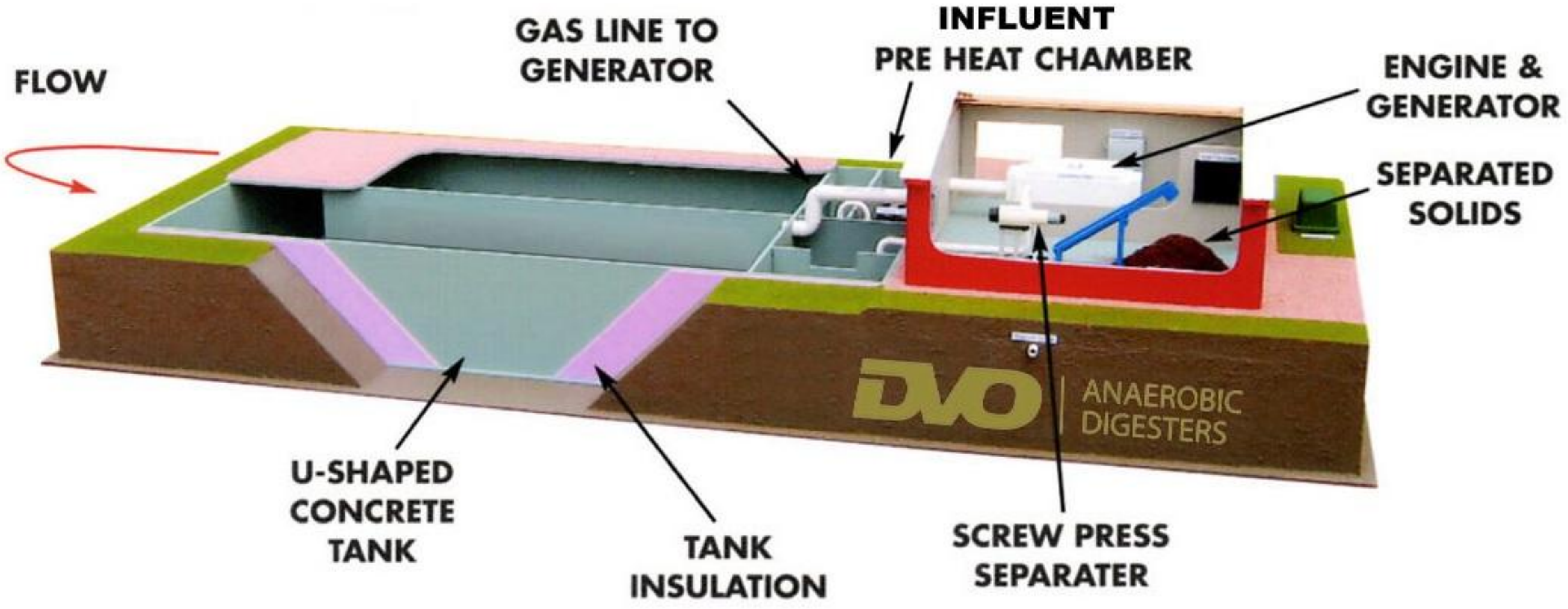

Photo of Farm Horizontal AD – 750 kW

Types of Digesters

- Five main types of Anaerobic Digesters: Complete Stir Tank Reactor, Plug-Flow, Packed Bed Biofilm AD, Covered AD Lagoon, UASB (upflow anaerobic granules sludge bed reactor)
- Excellent e-Learning Video on Types of Anaerobic Digesters: https://www.youtube.com/watch?v=u_ArD9jemaE

Upflow (Granular) Anaerobic Sludge Blanket Process - UASB

- Developed in Holland by Dr. Gatze Lettinga in the 1970s
- High Rate
- Positive Energy Footprint
- Low sludge production
- Popular - 72% of all AD plants are based on UASB
- Up to 90% Removal efficiency of Biodegradable COD
- Up flow encourages formation of heavier granules and washes out suspended bacteria
- The four top applications of high rate anaerobic reactor systems are for:
  - Breweries and beverage industry
  - Distilleries and fermentation industry
  - Food Industry
  - Pulp and paper.

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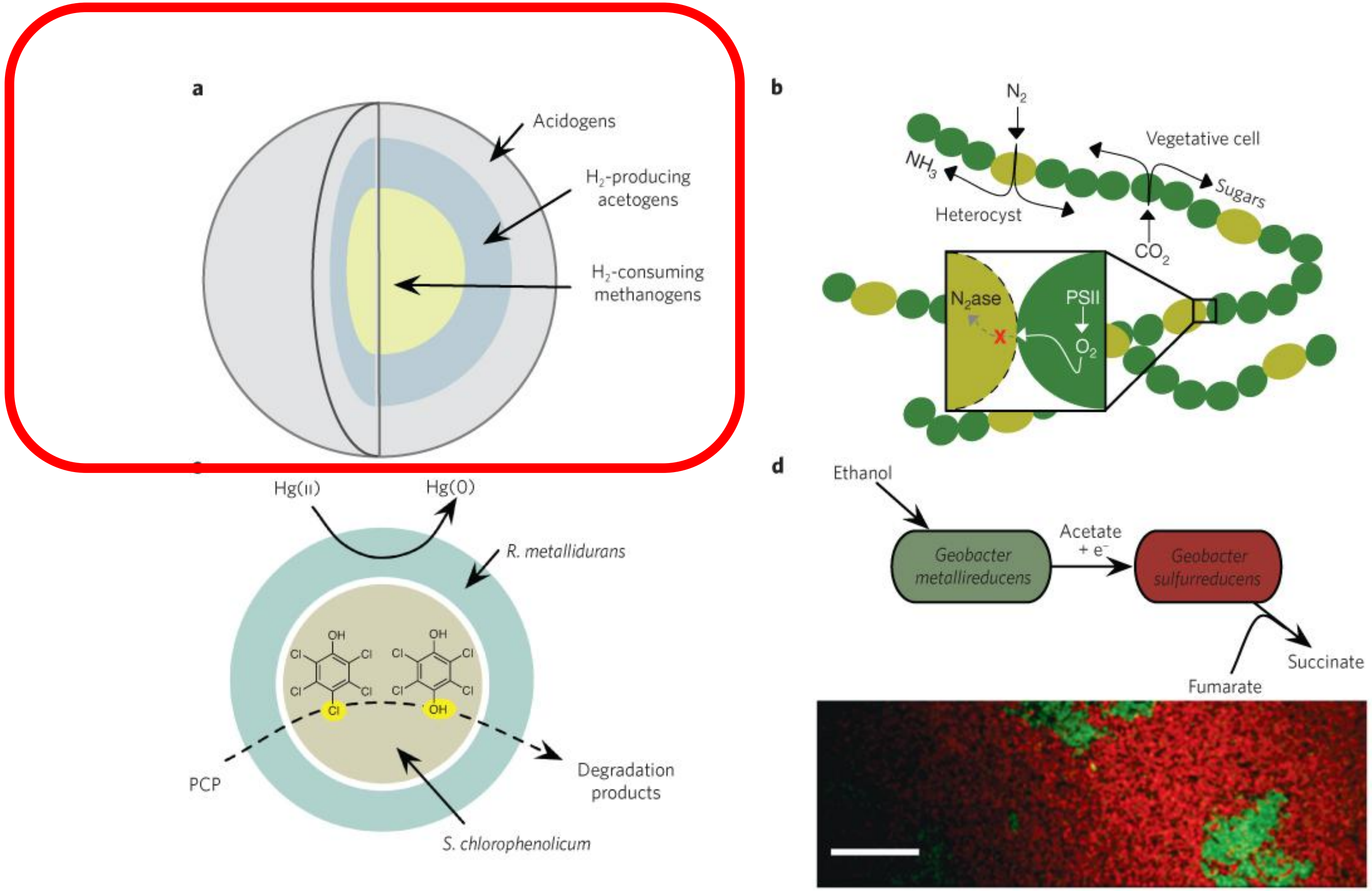
Granular Anaerobic Sludge

AD Sludge Granule Structure



Biogas Scrubbing and Drying

- Water vapor in biogas needs to be removed usually by condensing on cold surface
- H_2S in biogas is corrosive to engines and needs to be removed in caustic scrubber
- CO_2 can also removed in the same process
- Product is nearly pure CH_4 (methane)

Biogas Storage

Video of Anaerobic Digester Operation On Dairy Farm

- **Anaerobic Digester - Bellingham Technical College**

https://www.youtube.com/watch?v=7LPfno2KPcg

Suppliers of AD Technology

- Marches Biogas (http://marchesbiogas.com for farms - UK)
- DVO Inc USA (http://www.dvoinc.com for farms - USA)
- Bioconstruct Germany (http://www.bioconstruct.com/ for farms)
- OVIVO Water UK – AD for Municipals WWTWs (http://www.ovivowater.com/)
- Waterleau Belgium (http://www.waterleau.com) AD
- Degremont (http://www.degremont-industry.com/) for Municipal AD

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