

## The microbial world of biogas production: obligate limits for engineering

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### 1/ Volta: 1776 on Lake Maggiore

- inflammable air from marshlands.*
- Called nowadays methane.

### 2/ Biogas plant Sizing Depends on:

- Process & goals
- Flow and mass loading
- Reaction kinetics
- Biomass growth
- Temperature
- Concentration of reactants
- Planning (future industrial or urban development)

### 3/ Operating efficiency of the utilization of the produced biogas Net amount of the energy recovered:

- if only heat is produced  $\Rightarrow > 90 \%$
- if both electricity and heat are produced  
 $\Rightarrow 85 \%$  (35 % electricity and 50 % heat)
- if only electricity is produced:  $\Rightarrow < 35 \%$

### 4/ The biological process of biogas production

- A unit of biogas production appears as tanks, pipes, pumps, steel, concrete.....
- However, the active part, the **anaerobic sludge**, is not an inert and dirty matter: there are **living microorganisms**

### 5/ How the microorganisms are working ?

### 6/ How the microorganisms are working ?

### 7/ How they look like ?

### 8/ In some cases, granules or biofilms

### 9/ Hydrolytic and fermentative bacteria

### 10/ Syntrophic degradation of acidic intermediates

### 11/ Hydrogenophilic methanogens: *Methanobrevibacter sp.*

### 12/ Acetoclastic methanogens: *Methanosarcina sp* and *Methanosaeta (Methanotherix)*

### 13/ Temperature and methanogenesis

### 14/ pH and methanogenesis

### 15/ Environmental factors: pH

- Low pH: reduction of the activity of methanogens causing accumulation of VFA and H<sub>2</sub>.
- At higher partial pressure of H<sub>2</sub>: inhibition of propionic acid-degrading bacteria inducing accumulation of other VFAs and the pH drops further.
- If the situation is left uncorrected, the process may eventually fail.
- pH decrease due to overloading

## 16/ Other environmental factors

### Nutrients and trace metals

- macro (N, P and S) and micro (trace metals) nutrients in sufficient concentration to support biomass synthesis.
- methanogens have **specific requirements** of trace metals such as Ni, Co, Fe, Mo, Se, W etc.
- nutrients and trace metals requirements for anaerobic process are much lower as only 4 - 10% of the COD removed is converted biomass.

### Inhibition/Toxicity

- influent waste: Ammonia, heavy metals, antibiotics, halogenated compounds, cyanide etc
- byproducts of the metabolic activities: ammonia, sulfide, VFAs

## 17/ Variability of methane content

☞ *CO<sub>2</sub> soluble, CH<sub>4</sub> insoluble*

☞ *Influence of hydraulic retention time*

☞ *Influence of pH*

**From 40 to 85 % CH<sub>4</sub> in the biogas**

☞ **Depends not only on the process and environmental conditions**

☞ **But also on the substrate**

## 18/ Most important parameters of anaerobic processes

### Biomass yield:

- Low biomass yield: 0.05-0.15 kg VSS/kg COD
- depends on types of substrates metabolized

### Specific substrate utilization rate:

- **High rate in laboratory:** 0.6-1.5 kg COD/kg VSS-day
- depends on types of substrates metabolized

### • At industrial scale:

- less than 0.55 kg COD/kg VSS/day
- Vary with substrates
- Maximum with starch and sugars
- 0.24 - 0.3 for cellulosic waste materials

## 19/ Some other parameters of anaerobic processes

### Organic loading rate:

- High loading rates for wastewaters: 10-40 kg COD/m<sup>3</sup>-day (only for high rate reactors, e.g. AF, UASB, FBR)
- For CSTR: 3 to 4 kg COD/m<sup>3</sup>-day

### Start-up time:

- Long start-up: 9-18 months for mesophilic digesters

### SRT and HRT:

- Long SRT is essential to retain the slow growing methanogens within the reactor
- Doubling time of 5- 6 months in AF with easily degradable substrate.
- In CSTR, SRT = HRT (20 to 30 days)

### methanogenic potential of the substrate

## 20/ Bioengineering limits: Substrates

## 21/ Bioengineering limits: System design

## 22/ Impact of Specific substrate utilization rate

quantity of pollution degraded by unit of sludge mass and by unit of time

**maximum load:**

•F/M. max: 0,6 à 1,2 kg COD/kg VSS/day *for easily degradable substrate*

•Paper industry: max = # 0,25 to 0,35

importance of measurement and of increasing the quantity of sludge:

•*adaptation of process*

•*loss of sludge*

start up as a fonction of sludge quantity:

•*Choice of initial inoculum (quality and quantity)*

•*constant monitoring of reactor sludge quantity*

## 23/ Consequences: Bioengineering of anaerobic processes

### 24/ Example of sludge loss: overloading and Va

### 25/ Total sulfide and methanogenesis ( $H_2S$ , $HS^-$ and $S^{2-}$ )

### 26/ Sulfur, sulfide and corrosion

### 27 / Sulfur, sulfide and corrosion

•Due to inappropriate materials for seals, oxidation of  $H_2S$  into  $S_0$  and later  $H_2SO_4$  is possible

•Corrosion of:

•enameled steel digesters (starch and soft-drink industries)

•Polyurethane coated steel (starch industry)

•Concrete digester (paper industry)

### 28/ Sulfur, sulfide and corrosion

### 29/ The anaerobic digestion, often a source of various problems....

**Delicate, but economical, its control depends on the stakeholders:**

☞ inexact definition of goals and inaccurate terms

and conditions of the designing and building contract (original data, liabilities, etc...)

☞ deficiency in concepts and engineering

☞ unadapted microbial inoculum (quality/ quantity)

☞ standard parameters, but non calculated:

• *overloading, microorganism losses, chronic unbalance*

☞ nutritional deficiencies and toxicities

☞ scientific and technical training deficient

### 30/ Conclusions

Anaerobic digesters, like other biological treatment plants, are not simple chemical reactors, but are a complex ecosystem.

Anaerobic digestion must involved biological engineering

Anaerobic digestion is an operational process to decrease organic carbon content in wastewaters and to produce energy from wastes and crops.

When applied, its mastery depends on knowledge of operating employees.

The future: **ICA in anaerobic installations for improvement of start-up and for optimization**