Fundamentals of the (Anaerobic) Biogas Process

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The biogas generation basically takes place in four successive phases by decomposition of organic substances to water and biogas.
The degradation takes place in aqueous ambient by mixed bacteria culture of facultative anaerobic (living in both with and without oxygen) and strictly anaerobic (living only without oxygen) microorganisms like bacteria, molds and protozoa. For each step of degradation different microorganisms are involved. The respective group of microbes can only utilize the intermediate goods which are produced from the microbes before.

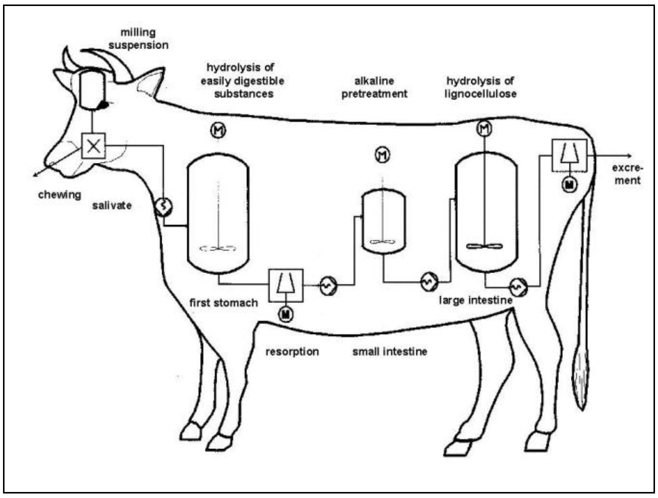

Figure 1 - Hydrolysis analog to ruminant digestive

The Technical University Munich Weihenstephan, Faculty of Energy and Environmental Technologies of the Food Industry has shown this procedures very demonstrative with its “Weihenstephan`s Cow”.
The procedure in a biogas plant is comparable with the digestive principle of ruminant animals. Only with the different for the animal rather the production of propionic acid (C-3) is essential but for the methanogenics all organic has to be reduced down to acetic acid (C-2).

Also the degradation rate of the biomass which has fed would not be maximal on animal digestive. In fact it must not be maximal instead of the “transport system” at the intestine will be not working well. If the biogas plant shall functioning in the same perfect way like the digestive of ruminants we have to have a well knowledge of the most important process steps and we have to design according to it. This is an essential basic for a high efficient, well degradation and biogas capacity and therefor an indispensable part of our biogas plants.
Basically for the biogas generation the group of content like raw-fat (lipids), protein and carbohydrates are suitable whereas lignin is not anaerobic degradable. Therefore it won’t be possible to generate biogas from raw fiber if the lignin wrapping is stabile enough.

Temperature	Mesophile Thermophile	35 - 40 °C 52 - 55 °C
pH - Value	Hydrolysis / Acidification Acetogenesis / Methanogenesis	4 (5) - 6 6,8 - 7,5
Nutrient Proportion C:N:P:S: = 2000:15:5:3		
preferably high Substrate stability		
preferably high Substrate homogeneity		
laminar flow conditions		
No wash-out of microorganism		

Table 1 – the optimal conditions for the Biogas process

Beside carbon the microorganism needs also some other nutrients and trace elements for their metabolism which are normally containing in sufficient quantity in the most of biomass to come to fermentation. In case it comes nevertheless to deficiency symptoms for example at mono fermentation, it would be easy to thwart by selective addition of the absence matter.
The metabolite of the bacteria at the anaerobic process is the wished biogas – a mixture from mainly methane (for example at digestion on crops ca. 60 – 70 % CH_4) and carbon dioxide (ca. 30 – 40 % CO_2). The part of trace gases are low (< 1 %) and may be neglected.

The gas generation and the content of CH_4 (biogas quality) depends stringently to the material composition. If the composition is known, it is possible to calculate the theoretical achievable amount of biogas and its content of CH_4 and CO_2 by using the Buswell-formula. To simplify matter the possible biogas yield and methane generation is shown in following table.

Ingredients / basic substances	**stoichiometrical Biogas yield (Liter Biogas / kg ODM decomposed)**	**ca. Methan content of Biogas (% of Biogas)**
Fat (Lipids)	1.400 l/kg (1,4 m³/kg)	80 .. 90 %
Proteins	600 .. 900 l/kg (0,6 .. 0,9 m³/kg)	75 .. 80 %
Carbohydrates	700 .. 800 l/kg (0,7 .. 0,8 m³/kg)	50 .. 60 %

Table 2 – specific Biogas yields of substrates main components

On the basic of these data and of the known composition of the fermenting substrates, the Biogas amount and thus the achievable energy quantity can be estimated.

At the hydrolysis also some gas occurs as metabolite of the microorganism. Primarily it is CO_2 and most notably at this step the main part of hydrogen sulfide H_2S occurs. This so-called hydrolysis gas is energetic worthless but contains a very strong malodor.

By using a two-phase digesting system it is possible to collect the hydrolysis gas separately and lead it into a biofilter. In such unit the hydrolysis / exhaust gas mixture could be cleaned in a way that no unpleasant odor will disturb the neighborhood.
Due to the separate collecting of the hydrolysis gas the biogas quality of two-phase biogas plants is always better than with single-phase system. Precisely because in a single-step Fermentor we get a compulsory mixing of all emerging gases those who are accrue at the hydrolysis steps and those who are accrue at the methanisation steps.

The two-phase process provides as well formidable advantages concerning more stability of the biology and consequently of the degradation process.
A view on the following illustration of the anaerobic degradation phases makes plain that in a single step biogas fermenter all degradation steps, which must be coordinated in spite of its different environmental conditions, has to be run well balanced in the same room.

This means in a general rule for single-step biogas plants much more retention time for getting the same degradation efficiency as if a two-phase plant is used.
Is for example a single-phase biogas plant fed with easily and fast hydrolyzing substrate, this could disturb the methanisation caused by lowering the pH-value and it could easily come to complete disrupt of the biology. One speaks then of “acidity of the Fermentor”.

With other words into a single-step biogas plant one may feed fresh biomass in the same room only as much as the hydrolysis and the methanisation could take place in a well balance.

If however the two main phases are spatial separated (we call it then as two-phase fermentation), each phase now could run in its ideal condition and the two-phase biogas plant achieves the highest capacity at shorter retention time.
However if mainly and predominantly cattle (cow) manure has to be digested a two-step processing makes no sense, because the hydrolysis process was already happened into the digestive system of the animal.

The better the microorganism are adapted to the used substratum and the better the optimum environmental conditions will be achieved, as faster as more complete and as more reliable the process will take place.

At the first two steps, means the hydrolysis and the acidification, the complex polymers will be broken down to its monomers.
The different participated microbes will cut the chain of carbon atoms into more and more short-warp compounds. The particles become smaller. Because the substrate is going to be more liquid, this phase is called as the hydrolysis.

The intermediates of the acidification are in the first line volatile short-chained fatty acids, alcohols, CO_2 and H_2.

At the beginning of all processes the hydrolyzing bacteria and microbes are facultative anaerobic and are living in a closed symbiosis with the acidifying bacteria and therefor one can put together this two degradation phases in one room, like it is done at two-phase biogas plants.

The hydrolysis is the limiting factor of biogas production.

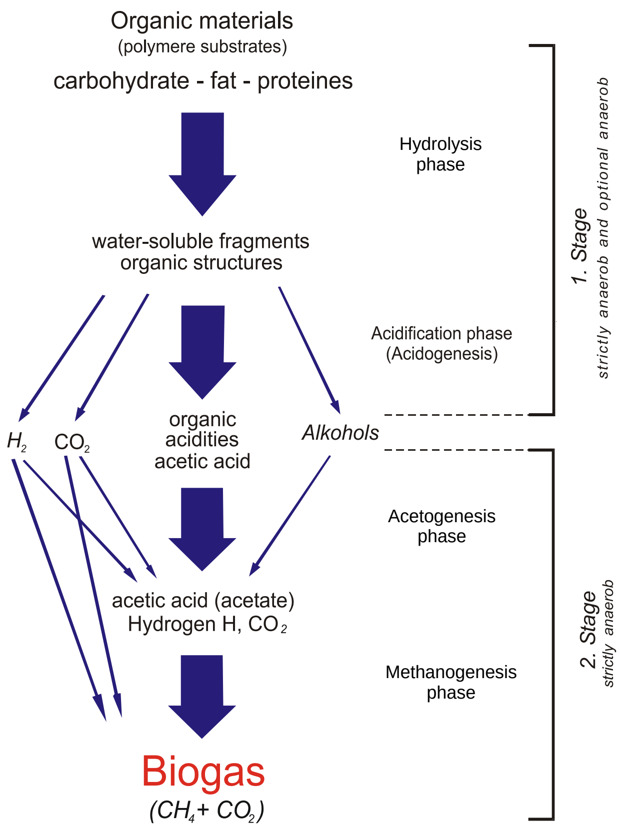

Figure 2 – The anaerobic degradation phases

The optimal temperature for hydrolysis and acidification process is 30 – 40 °C.

The sufficient and well done pre-acidified substrate may now going to the next two process steps, called as acetogenesis and methanogenesis and will be there disintegrated further. Also at these two phases it is like the first step that the involved microbes are living in a closed symbiosis and by this reason it must be centralized in the strictly anaerobic methanisation step.

The methane-forming bacteria are among the oldest living creatures of the earth (archaen species) and have a very specialized metabolism. They grow very slowly and are extremely sensitive to changes in environmental circumstances, such as temperature and pH value.

The methanisation step (2nd stage) has its optimal pH-value between 35 °C and 40 °C (in case the pH-value is more than 8 one should analyze the process because this could be caused by an increased accumulation of ammonia and could affect toxic to the process).

The methanisation step could be operated generally at mesophilic temperature, i.e. between 35 – 40 °C, however as well at thermophilic temperature with 52 – 55 °C. <u>But</u>: “either ... or”, an “as well as” is not possible.

We prefer the mesophilic temperature range because of the considerably steady and less disturbance-susceptibly (it’s also the blood heat of all endothermic organism) than the thermophilic range.

The advantage of a thermophilic process would be the same degradation takes place in some shorter time. It <u>cannot be generated more biogas</u> than carbon is available and also not sufficiently hydrolyzed material cannot be more decomposed in that short time.

Another advantage of the thermophilic process could be seen in a better pasteurization of the digested substrate. But for many biogas plants e.g. the digestion of renewable crops, this is not of importance.

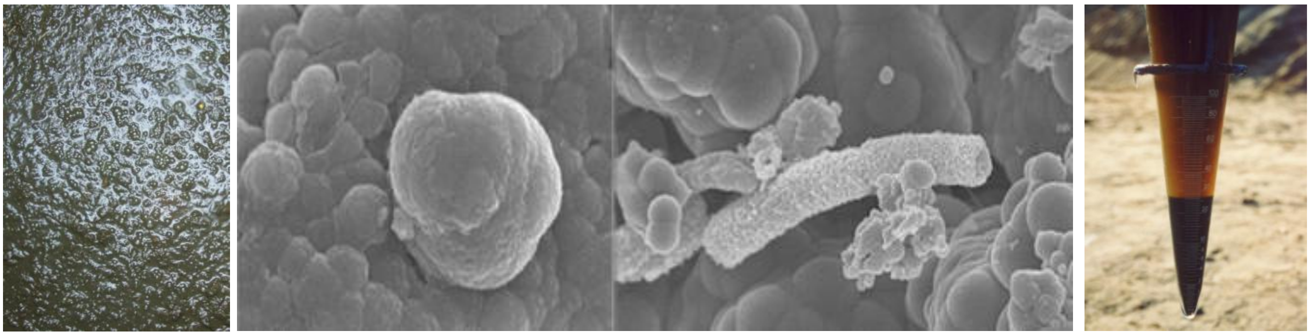

Figure 3 - The archaen are spherical and rod-shaped. A well designed biogas plant achieved degradation rates of >85 %

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