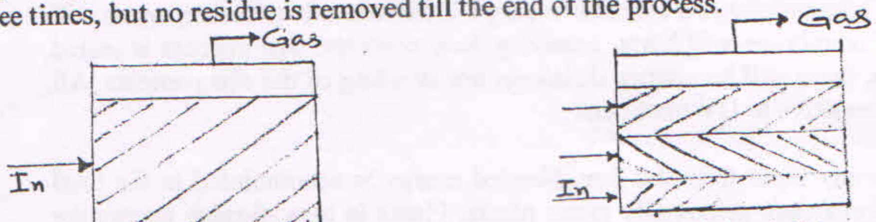
Technology of Bio-methanation (Anaerobic Digesters) Lecture-III&IV

There are many bio-methanation technologies available to translate methanogenesis into a process technology. We will review these in the current context of our multi-step mechanisms. First of all, a number of environmental requirements mentioned in the preceding lectures for the proper operation of these technologies can easily be met from a technical point of view : **Anaerobiosis** – temperatures around 35 or 60^{0}C, pH between 6.8 to 8 at least for the methanogenic phase, absence of toxin compounds, and C/N ratios between 20 and 25 for optimum performance. It must be noted that irrespective of the biological constraints and of the type of biomass substrate degraded, biomethanation technologies are optimized depending upon their objective – **Energy Production , De-pollution** or a combination of both ?

1. Batch or Continuous process :

Basically, the technologies for biomethanation can be divided into two major categories : Batch and continuous (fig 1). In the fist one, the substrate biomass is introduced at one time in the beginning of the process. In the fed-batch system, the substrate biomass is introduced at two or three times, but no residue is removed till the end of the process.



Batch (a) Fed-batch (b)

Fig. 1 Batch and Fed-batch anaerobic digesters.

A batch type digester is a simple digester in which organic matter is placed in a closed tank and allowed to be digested anaerobically over a period of two to six months, depending upon the feed material and other parameters like temperature, pH etc. If necessary, the digester may be heated o maintain the digester at the desired temperature. This type of digester is very simple to run and very little attention needed between starting up and emptying out. Maximum efficiency of digester can be obtained if the digester is carefully loaded to avoid wastage of space and pockets of air trapped in the sludge, because these inhibit the onset of methanogenesis.

Batch type of digesters have the drawback of waste handling problems and hence these are usually small, although many of the original form scale units consisted of two or more large batch tanks operated in series.

Batch digesters possess some advantages in the sense that they can be used, when the waste is only available at irregular intervals and even if it has a very high solid content (25%). If the waste is fibrous or difficult to digest, batch digestion may be more suitable than continuous flow types, because the digestion time can be increased easily. If several batch digesters are used in series, with each at a different stage in the digestion cycle, a continuous flow of gas is obtained (fig. 2).

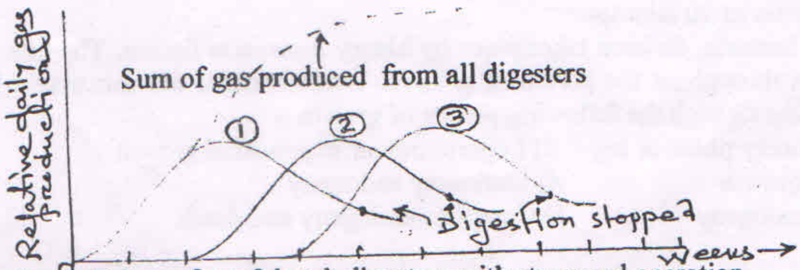


Fig. 2 A continuous flow of biogas from 3 batch digesters with staggered operation.

The digesters would be started up at regular intervals, so that when one is approaching the end of its run, a new one is beginning. When this idea is carried to its logical conclusion and all the batches are digesting in one large tank, then one conceives the displacement system, known as continuous plug flow.
In a varient fed-batch system (fig. 1b), the substrate biomass is introduced at two or three times, but no liquor is removed from the reactor till the end of the process.

Continuous process :
In the continuous process (fig.3), the substrate biomass is introduced continuously or intermittently: the total volume of the mixed liquor remains constant, the digested mixed liquor being removed continuously at the same flow rate, as the substrate biomass is introduced.

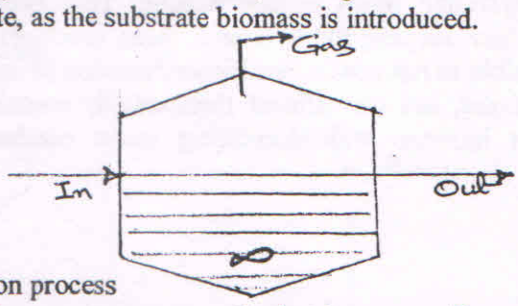


Fig. 3 Continuous biomethanation process

Nearly all factors favour the continuous process over the batch process. From a biological point of view, batch processes are always in a transient state in which the proper balance between the various microbial sub-communities in the overall methanogenic ecosystem remains problematic at all times. On the contrary, continuous processes are in a pseudo-stationery state, where the proper balance between the various steps is easier to maintain.
From the point of view of a physical state of the substrate biomass, as long as the mixed liquor remains "liquid", that is of the slurry type, continuous systems are easy to handle. The simplest varient includes the manual semi-continuous (daily for example) loading of the biogas digester. Even when the substrate biomass is a solid and remains so in the mixed liquor, giving rise to what is known as dry fermentation, the continuous processes are to be preferred to batch processes. Indeed, and specially for urban solid wastes, continuous technologies are reaching the demonstration stage. Only when a very simple technology is warranted, as in the case of agricultural residues in rural areas, can the batch process be preferred to the continuous process. Even then, some form of fed-batch process should be considered, namely the progressive addition of the solid substrate biomass or conversely the progressive addition of water or liquid to the solid substrate biomass. An interesting batch process is the extraction of biogas from landfills. Huge amount of domestic waste are disposed off in landfills. Economically interesting quantities of biogas can be simply collected over periods of years from these landfills from pipes penetrating deep into them.
From a performance point of view, the total biogas production, for the same amount of substrate is comparable in batch and continuous processes, yet in batch processes it is not constant. In continuous systems, on the contrary, the biogas production remains almost the same over indefinite periods of time. Production of biogas, adapted to the energy demands can be modulated by regulating the loading rate.

Active Biomass recycle :
Whenever the substrate biomass is a slurry 7-10% (by weight of dry biomass) containing a large portion of insoluble material, the most appropriate biomethanation system remains the continuous completely mixed methane digester without active biomass (bacteria) recycle. The slurry rheology remains Newtonian up to 7-10% concentration. At higher concentraion, the mixed liquor becomes essentially non-Newtonian. This means a completely different set of physico-

chemical laws for mass and heat transfer and it is difficult to have a homogeneous reaction medium. This results in increasing difficulties in obtaining a reliable biomethanation process. However, when the substrate biomass is more dilute and contains essentially soluble material, the situation is different. One of the limiting factors as far as mean residence times are concerned in continuous methane digesters, is the bacterial specific growth rate (mew). In most cases of biomethanaion, hydrogen – otrophic methanogenic archaebacteria have mew= 4-7 days, acetielastic methanogenic archaebacteria have mew= 7-10 days, but obligate hydrogen – producing acetogenic bacteria may have longer mew values up to 12-14 days.
In the absence of active biomass recycle (fig. 4), the mean residence time of the active biomass is necessarily equal to the hydraulic mean residence time. This explains why in continuous biomethanation systems without recycle, the hydraulic mean residence time usually maintained around 12-14 days. It is possible to run continuous biomethanation ystms without recycle at lower hydraulic mean residence times, but the effluent then usually contains significant amount of volatile fatty acids, which increase with decreasing mean residence time, thus reducing conversion efficiency.

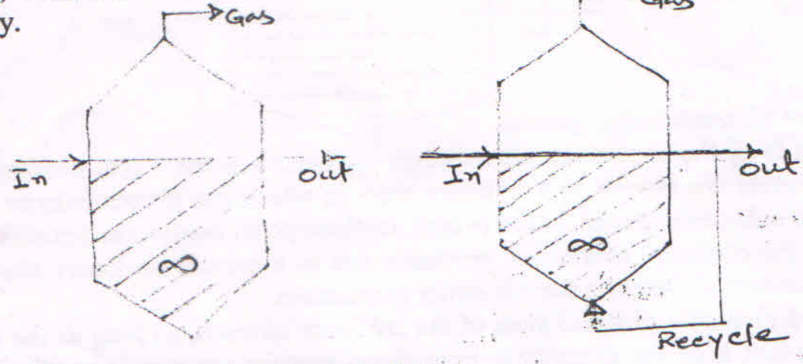


Fig. 4 Biomethanation with (a) and without recycle (b)
The only way to overcome these limitations is to differentiate the mean hydraulic retention time (Θ_h) from the mean retention time for the active biomass in the methane digester by recycling it after a sedimentation (clarification – thickening step).

Trapping or Recycle of active biomass
Contact processes where the substrate biomass is put into contact with large quantities of active biomass (bacteria) in a continuous, completely mixed reactor, and the active biomass subsequently decanted in a separate decanter, are well known and most generally used for the aerobic treatment of wastewaters. It was thus quite normal that type of contact process was among the first to be tested when the anaerobic treatment of wastewater appeared more economical. They have performance in practice about twice as large as the simple completely mixed continuous process without recycle.

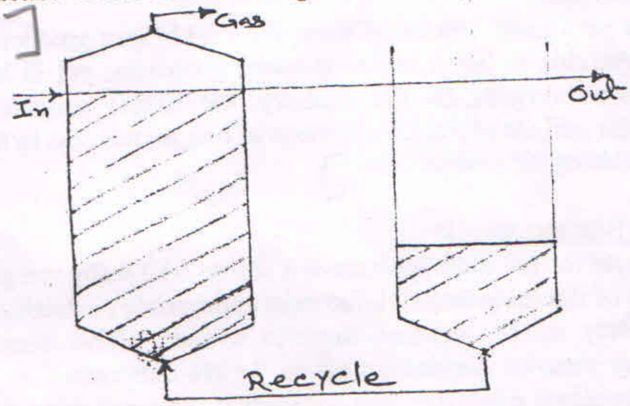


Fig. 5 Anaerobic contact process

Anaerobic Filter Reactor

The type of digester shown in fig. 6 was developed in the 1950s to use relatively dilute and soluble wastewaters with low levels of suspended solids. It consists of primarily a column or chamber filled with a packing medium and are not carried out of the digesters are also known as fixed film or retained film digesters. The matrix (packing medium) granulometry can be of all sizes from a few centimeters to large blocks. They can be of all forms, some of them particularly intended to channel the liquid flow. They are made of various materials. The important characteristics of these materials are their hydrophilicity or hydrophobicity, their internal porosity, their absorbing potential. Plastic, clay and active carbon are typical examples of materials used as matrices for fixed beds. Fixed beds can be operated with an up or a down liquid flow in the reactor.

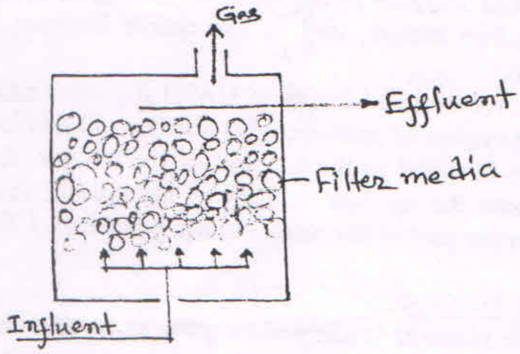


Fig. 6 Anaerobic Filter Reactor

In up-flow reactor, the liquid enters at the bottom and flows up through the packing medium; as the organic substances in the liquid pass over the bacterial film, they are converted into biogas. Due to high concentration of bacteria, the gas production rates in these digesters are much higher than in conventional digesters. The systems usually have COD loading rates which range from 8-16 kg/m^3/day and retention times ranging from 5 to 12 days.

Up-flow Anaerobic Sludge Blanket Reactor

The up-flow anaerobic sludge blanket (UASB) process shown in fig. 7. It is similar to the anaerobic filter, in which it involves a high concentration of immobilized bacteria within the reactor. However, the UASB contains no packing medium.

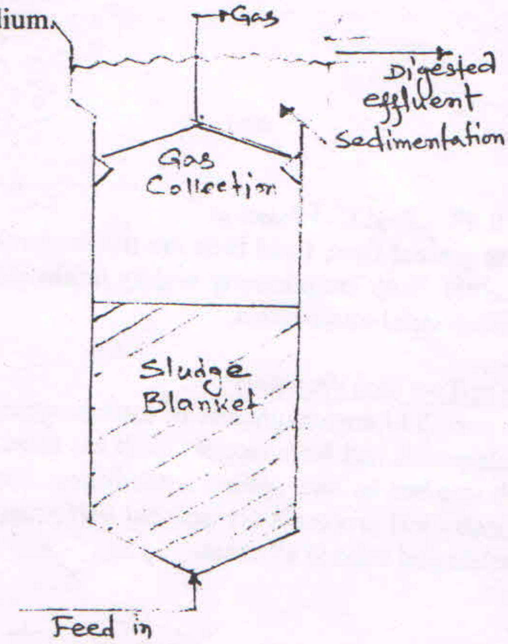


Fig.7 Up-flow anaerobic sludge blanket reactor.

The methane forming bacteria are concentrated in the dense granules of the sludge blanket which covers the lower part of the reactor. The feed liquid enters at the sludge blanket. The upward movement of the gas bubbles keeps the sludge fully mixed. The bacteria are retained in the reactor for very long periods throughout the operation of gas collection devices resembling inverted funnels. They allow the gas to escape, but encourage the settling of the suspended solids which contain the bacteria. Very high gas production rates have been reported with UASB process. UASB system allows very high loading rates of the order of 50kg COD/ m^3/day, though not in a regular and reproducible way. The relative instability of the dense active biomass granules still remains the weak point of the UASB process. The transportation of granules into flocks is accompanied by a 5-10 fold increase in the specific volume of the active biomass. As a result, whenever this transformation occurs, most of the active biomass usually leaves the digester entrained with the effluent.

The drawbacks due to active biomass losses in UASB digesters can be seriously reduced if the reactor incorporates some system of solid-liquid separation. The following systems are proposed. First, a decanting zone is installed in the top part of the reactor. It is characterized by a larger cross section which reduces the up-flow velocity of the liquid ; the biogas is withdrawn below this area. Secondly, the upper part of the reactor is equipped with a fine mesh sieve.

Fluidized Bed Anaerobic Reactor :

In this process, the active biomass is allowed to grow as a thin film around heavy particles like sand of 0.1 to 1 mm. average diameter. Other materials such as active carbon have been proposed. In order to allow these active biomass grains to function properly, the up-flow velocity of the liquid in the reactor must be increased, eventually with the aid of an additional recycle, until the fixed bed expands or fluidizes.

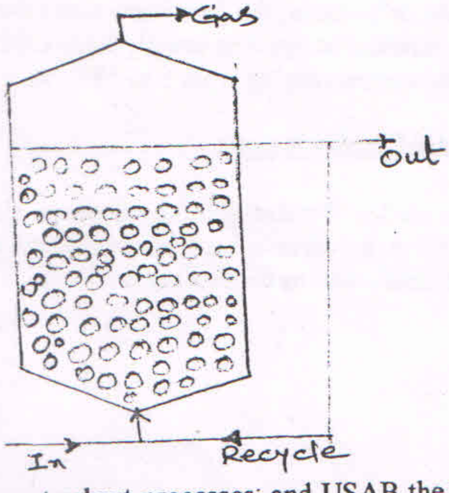


Fig. 8 Fluidized Bed Reactor

At the present time, fixed beds are the most robust processes; and USAB the highest performing processes. Both are presently widely implemented throughout the world, essentially for treating agro-industrial wastewaters.

One or Two Step Processes :

The overall biological process of methanogenesis consists of two main biological sub-processes : Acidogenesis and Methanogenesis. It has therefore often been proposed as an absolute rule that as each step has its own optimum conditions, biomethanation should be separated into two distinct technological processes for optimal performance. It is erroneous to consider this concept as an absolute and valid in all cases.

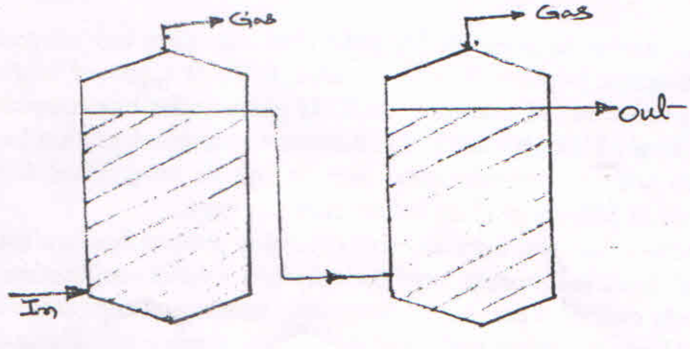
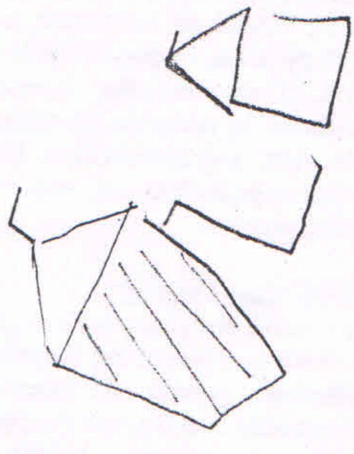


Fig. 8 Two Step Anaerobic Process.

However, there is a number of cases where a two – step process offers advantages over a one-step process. First, when the substrate biomass is a solid , it may be advantageous to organize the first step to transform the solid into a liquid or to extract a liquid from the solid. In these cases, the first step will often be a purely physical step or a combined physical – biological step. In this category, the handling and operation of the solid portion of the biomass may differ from the handling and operation of the liquid portion. Percolation of solid urban waste is a classical example.

Secondly, a simple first step is often incorporated for technical reasons. Whenever the supply of the waste e.g. wastewater, varies with time, both in flow-rate or in quality, then a equalizing pond offers a "buffer" and allows a more steady loading of the reactor. In this equalizing pond, not only does the biological process of fermentation occur, but solid material may sediment and be collected for treatment separately.



(End of Lecture III & IV)