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RESEARCHES ON THE DIGESTERS AND REACTORS WHICH CAN BE USED IN A FARM SCALE BIOGAS PLANT

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Abstract

In the general context of searching integrated system of renewable energy production, this paper present some researches on the reactors and the digesters, as a main part of a biogas plant at a farm scale. After we present the most used types of digesters, we also concentrated over the processes which take place into a digester, one of them being the removal of H2S from biogas (desulphurisation), which can be made by various methods, either biological or chemical, taking place inside or outside the digester. In the case of biological desulphurization outside the digester, we concentrate on the types of reactors which can be used in this case. Beside the well known types of reactors, we present the possibility of using an original self pressure membrane bioreactor. In this type of bioreactor, the metabolic activity of gas producing microorganisms, especially yeast, could obtain high pressure from gas produced in closed medium on the one hand, and separation of other products of metabolism through membrane on the other hand, using gas pressure as driving force. It is known that several strains of yeast resist on very high hydrostatic pressure heaving good activity. This fact give the possibility to use their energy for other purposes, such as producing mechanical work. Combination of both, gas pressure and alchool burning, increase the process efficiency.

Key words: *biogas plant, digester, modular membrane bioreactor, self pressurized membrane bioreactor*

INTRODUCTION

A farm scale biogas plants is named the plant attached to only one farm, digesting the feedstock produced on that farm. Many farm scale plants co-digest also small amounts of methane rich substrates (such as oily wastes from fish industries or vegetable oil residues), aiming to increase the biogas yield. It is also possible that a farm scale biogas plant receives and processes animal slurries from one or two neighbouring farms (e.g. via pipelines, connecting those farms to the respective anaerobe digestion unit).

There are many types and concepts of farm scale biogas plants around the world. In Europe, countries like Germany, Austria and Denmark are among the pioneers of farm scale biogas production. The interest of European farmers in anaerobe digestion applications is growing nowadays, not only because agricultural biogas production transforms waste products into valuable resources and produces high quality fertiliser, but also because it creates new business opportunities for the involved farmers and gives them a new status, as renewable energy providers.

The farm scale biogas plants have various sizes, designs and technologies. Some are very small and technologically simple, while others are rather large and complex, similar to the centralised co-digestion plants. Nevertheless, they all have a common principle layout: manure is collected in a pre-storage tank, close to the digester and pumped into the digester, which is a gas-tight tank, made of steel or concrete, insulated to maintain a constant process temperature. Digesters can be horizontal or vertical, usually with stirring systems, responsible for mixing and homogenising the substrate, and minimising risks of swimming-layers and sediment formation.

MATERIALS AND METHODS

The core of a biogas plant is the digester - an air proof reactor tank, where the decomposition of feedstock takes place, in absence of oxygen, and where biogas is produced. Common characteristics of all digesters, apart from being air proof, are that they have a system of feedstock feed-in as well as systems of biogas and digestate output [5]. In European climates anaerobic digesters have to be insulated and heated.

There are a various types of biogas digesters, operating in Europe and around the world. Digesters can be made of concrete, steel, brick or plastic, shaped like silos, troughs, basins or ponds, and they may be placed underground or on the surface. [1]. The size of digesters determine the scale of biogas plants and varies from few cubic meters in the case of small household installations to several thousands of cubic meters, like in the case of large commercial plants, often with several digesters (Figure 1).

The design of a biogas plant and the type of digestion are determined by the dry matter content of the digested substrate. As mentioned before, anaerobe digestion operates with two basic digestion systems: wet digestion, when the average dry matter content of the substrate is lower than 15 % and dry digestion, when the dry matter content of the substrate is above this value, usually between 20-40 %.

Wet digestion involves feedstock like manure and sewage sludge, while dry digestion is applied to biogas production from solid animal manure, with high straw content, household waste and solid municipal biowaste, green cuttings and grass from landscape maintenance or energy crops (fresh or ensiled). From the point of view of feedstock input and output, there are two basic digester types: batch and continuous.

Vertical digesters

In practice, most digesters are vertical digesters. Vertical digesters are generally built on-site round tanks of steel or reinforced concrete, often with a conic bottom, for easy stirring and removal of sand sediments. They are air proof, insulated, heated and outfitted with stirrers or pumps. The digesters are covered by a roof of concrete, steel or gas proof membrane and the produced biogas is piped and stored in an external storage facility, close to the digester or under the gas proof membrane. The membrane is inflated by the produced biogas or it can be fastened to a central mast

Horizontal digesters

Horizontal digesters have a horizontal axis and a cylindrical shape. This type of digesters are usually manufactured and transported to the biogas plant site in one piece, so they are limited in size and volume. [1]. The standard type for small scale solutions is a horizontal steel tank of 50-150 m^3, which is used as the main digester for smaller biogas plants or as pre-digesters for larger plants. There is also an alternative of concrete, the channel type digester, which allows a larger digester volume of up to 1 000 m^3.

Horizontal digesters can also run in parallel, in order to achieve larger throughput quantities. Because of their shape, the plug-flow stream is automatically used. The feedstock flows slowly from the entry side to the discharge side, forming a plug-flow, streaming through the digester. The risk of discharging un-decomposed substrate is minimised through a minimum guaranteed retention time of the substrate inside the digester. Horizontal continuous flow digesters are usually used for feedstock like chicken manure, grass, maize silage or manure with a high straw content.

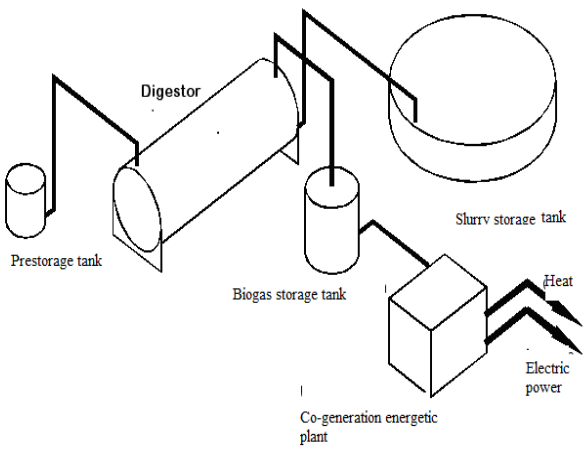

Fig. 1. Schematic representation of a farm scale biogas plant, with horizontal digester of steel [6]

Digestate is used as fertiliser on the farm and the surplus is sold to plant farms in the nearby area. The produced biogas is used in a gas engine, for electricity and heat production.

About 10 to 30% of the produced heat and electricity is used to operate the biogas plant and for domestic needs of the farmer, while the surplus is sold to power companies and respectively to neighbouring heat consumers.

Apart from the digester, equipped with stirring system, the plant can include pre-storage for fresh biomass, storage for digested biomass and for biogas, and even a Combined heat and power unit. The digester can also be vertical, with or without conic bottom, a so called 'two-in-one' slurry storage and digester tank, where the digester is build inside the storage tank for digestate. The two tanks are covered with a gas tight membrane, inflated by the emerging gas production and stirred by electric propeller. The plant can furthermore consist of a pre-storage tank for the co-substrate and a Combined Heat and Power unit.

A recent development of the farm scale biogas plant is the concept of energy-crop based plants. Their advantage is that the energy content of energy crops is much higher than of most of the organic waste materials. The major limitations of these kinds of biogas plants are related to operation costs, land use and availability.

Centralised (joint) co-digestion plants

Centralised co-digestion is a concept based on digesting animal manure and slurries, collected from several farms, in a biogas plant centrally located in the manure collection area. The central location of the biogas plant aims to reduce costs, time and manpower for the transport of biomass to and from the biogas plant. Centralised anaerobe digestion plants co-digest animal manure with a variety of other suitable co-substrates (e.g. digestible residues from agriculture, food- and fish industries, separately collected organic household wastes, sewage sludge).

Animal manure and slurries are collected from the pre-storage tanks or from the slurry channels at the farm and transported in special vacuum container trucks to the biogas plant, according to an established schedule [8]. At the biogas plant, manure is mixed with the other co-substrates, homogenised and pumped inside the digester tank. The transport of fresh manure from the farmers to the biogas plant and of digestate from the biogas plant to the farmer's storage facilities, placed close to the fields where digestate is applied as fertiliser, is the responsibility of the biogas plant. The storage facilities for digestate are sometimes shared by several farmers.

The digester feeding system is continuous, and biomass mixture is pumped in and out of the digesters in equal amounts through precise pump-sequences. Digestate, pumped out of the digester, is transferred by pipelines to temporary storage tanks. In many cases, these tanks are covered with a gas proof membrane, for the collection of the additional biogas production (up to 15% of the total), taking place at lower temperature. Before leaving the biogas plant, digestate is analysed and nutritionally defined. The manure suppliers can take back only that amount of digestate, which they are allowed by law to spread on their fields. The excess is sold as fertiliser to the crop farmers in the nearby area. In all cases, digestate is integrated in the fertilisation plan of the farm, replacing mineral fertilisers, closing the cycle of carbon and nutrient recycling (Figure 2). More and more biogas plants are also equipped with installations for separation of digestate in liquid and solid fractions.

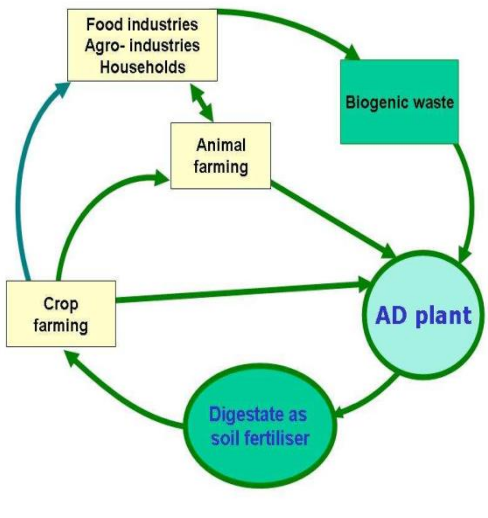

Fig. 2. Schematic representation of the closed cycle of centralised anaerobe digestion [2]

This way, centralised co-digestion represents an integrated system of renewable energy production, organic waste treatment and nutrient recycling.

Experience shows that the system (Fig. 2) is capable to generate agricultural, environmental and economic benefits for the farmers involved and for the overall society such as:

Renewable energy production

- Cheap and environmentally safe recycling of manure and organic wastes
- Reduction of greenhouse gas emission
- Improved veterinary safety through sanitation of digestate
- Improved fertilisation efficiency
- Less nuisance from odours and flies
- Economical benefits for the farmers

Desulphurization

Removal of H2S from biogas (desulphurisation) can be done by various methods, either biological or chemical, taking place inside or outside the digester. Desulphurisation depends on the content of HS and the throughput rate throughout the desulphurization equipment.

The throughput rate can fluctuate significantly, depending on the process. Higher biogas production and thus high throughput rates can be observed after insertion of new feedstock into the digester and during stirring. Throughput rates up to 50% higher than normal can occur for short time intervals. For this reason and in order to ensure complete desulphurization, it is necessary to use over-dimensioned desulphurization equipment, compared to average throughput rate.

Biological desulphurization

Biological oxidation is one of the most used methods of desulphurisation, based on injection of a small amount of air (2-8 %) into the raw biogas (fig.3). This way, the hydrogen sulphide is biologically oxidised either to solid free sulphur or to liquid sulphurous acid (H2SO3):

2H2S + O2 -> 2HO + 2S2H2S + 3O2 -> 2H2SO.

In practice, the produced sulphur precipitate is collected and added to the storage tanks where it is mixed with digestate, in order to improve fertiliser properties of digestate. Biological desulphurization is frequently carried out inside the digester, as a cost-effective method. The oxygen is provided by injection of air in the top of the digester, done with the help of a very small compressor. The air injection pipes inside the digester should be positioned on the opposite side of the biogas output, in order to avoid blockage of the output pipe.

Fig. 3. Elementary sulphur resulted from biological desulphurization inside the digester [9]

The air is injected directly in the headspace of the digester and the reactions occur in the reactor headspace, on the floating layer (if existing) and on reactor walls.

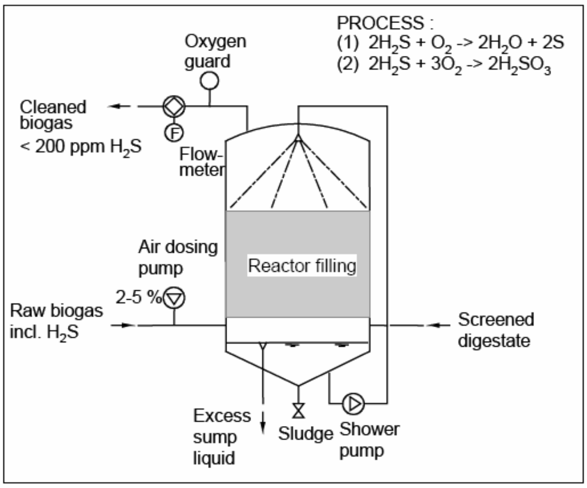

Fig. 4. Schematic diagram of system for biological H $_2$S oxidation [3]

Due to the acidic nature of the products there is the risk of corrosion. The process is dependent of the existence of a stable floating layer inside the digester. For these reasons, the process is often taking place in a separate reactor as shown in figure 4.

Biological desulphurization can take place outside the digester in desulphurization tanks or desulphurization columns. This method facilitates the control of desulphurization process and the precise adjustment of oxygen addition.

RESULTS AND DISCUSSIONS

The reactor is similar to a scrubber, consisting of a porous filling (randomly packed plastic elements or similar) where micro-organisms can grow, a sump, a pump and nozzle arrangement, allowing regular showering of the filling. The H2S is oxidized through a biological process to acidic products or free sulphur, by upstream injection of a small amount of atmospheric air.

Showering has the function of washing out acidic products and supplying nutrients to the micro-organisms. The sump must therefore contain a liquid with high alkalinity, rich in essential nutrients for the micro-organisms. Digestate, preferably screened, is in this case the ideal and available choice.

A reactor loading of approx. 10 m3/h of biogas per m3 of reactor filling and a process temperature around 35°C can normally be chosen. The process has proven very efficient, provided sufficient air is injected (slightly more than stoichiometrically needed). The sump pH must be maintained at 6,0 ppm or higher. A washing procedure, where the filling elements are showered through with an air/water mixture, has to be carried out at regular intervals in order to prevent free sulphur deposits from closing the reactor filling.

In some cases, when biogas is stored or passing a digestate storage take HS reactor is omitted and only air is injected. Biogas cleaning is, in such case, relying on the formation of a floating layer in the storage tank, on which the micro-organisms can grow and perform the oxidation. A floating layer can usually be maintained with the choice of a low mixing intensity, without too many problems in operating the tank as buffer storage. This solution is more cost effective, but more unreliable as well, as floating layers are rather unstable, i.e. sinking overnight without notice and resurfacing some days later. Periods with low efficiency of H_2S removal are therefore likely to occur.

Desulphurisation can also be done by adding a chemical substance to the feedstock mixture, inside the digester. This way, the sulphur is chemically bounded during the AD process, preventing the release of hydrogen sulphide into biogas. Thereby, sulphur is not lost, but remains in the digestate.

Chemical biogas desulphurisation can take place outside of digester, using e.g. a base (usually sodium hydroxide). The method needs special equipment.

Another chemical method to reduce the content of hydrogen sulphide is to add commercial ferrous solution to the feedstock. Ferrous compounds bind sulphur in an insoluble compound in the liquid phase, preventing the production of gaseous hydrogen sulphide. The method is rather expensive, as the consumption of ferrous material on a stoichiometric basis has proven to be 2-3 times the desired reduction in gaseous hydrogen sulphide. A cheaper alternative is thus to supply co-substrates (organic wastes) containing ferrous materials and to use the ferrous addition only as a back up.

The possibility of using a self pressurized membrane bioreactor

In our studies, we researched the possibility of using a self pressured membrane bioreactor, which use of metabolic activity of micro-organisms for getting a high pressure generator [4]. This is possible through the accumulation of gas resulting from metabolism in a closed environment. As a result, the pressure created can be used both as a driving force in membrane separation of the product of metabolism and as a potential energy gained for other processes that use pressure (fig.5). The yeasts have been extensively studied over time, being involved in important branches of food industry based on fermentation and wine-making technology, beer and bakery technology. The same principles that are based on fermentation, production of ethanol as bio-fuel is another area whose importance increases with the price of crude oil through alternative energy and environmentally friendly that it offers.

In closed environment, can be easily obtained as the limit pressure, metabolic activity is not affected by the condition to eliminate the constant-products of metabolism and nutrient medium composition remains constant. Certainly one factor is the strength of the membranes involved in limiting the accumulation of pressure separation to the nominal level required by the manufacturer.

We aim to obtain practically useful for both separation pressure product of metabolism found in the biomass - ethanol - and in order to build upon mechanical excess gas accumulated at the top of the bioreactor. Constant supply of nutrient media and culture, the culture of constant discharge and the separation constant dead maintain constant ethanol production of carbon dioxide and thus obtain the entire system working pressure. Also, always maintaining the optimal level of nutrient concentrations, metabolic activity during which a culture of micro-organisms is used will be constant at the value obtained previously in the literature or by testing and allows adjustment of the exhaust flow yeast culture.

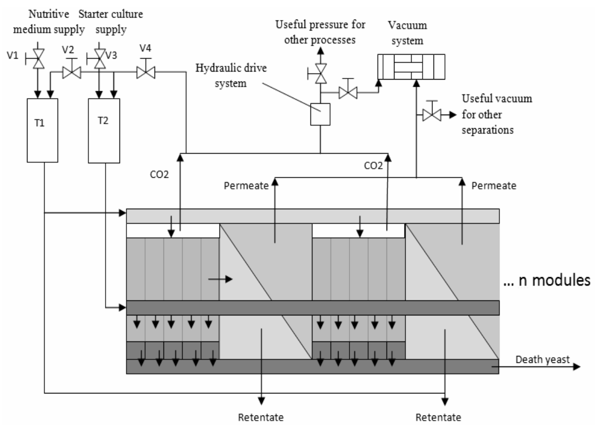

Fig.5. Block diagram for obtaining hydraulic pressure using biotechnological methods [7]

CONCLUSIONS

In this paper, we concentrated over the reactors and digesters which can be used in a farm scale biogas plant. We presented the most used digesters over the world, but we also proposed a self pressured membrane bioreactor, which can use the metabolic activity of micro-organisms for getting a high pressure generator.

We also presented the most used methods of desulphurisation, biological or chemical, which take place inside the digesters.

In the world context of searching new alternatives for new sources of energy, the use of biogas is one of the viable solutions for the future, both for rural communities and for urban sites.

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