UTILIZATION OF BIOGAS IN AGRICULTURAL AND INDUSTRIAL PLANTS

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Abstract - *The production of biogas from anaerobic digestion (AD) is widely used by modern society for the treatment of livestock manure and slurries. The aim is to produce renewable energy and to improve their fertilizer quality. In countries with significant agricultural production, the strengthening of environmental legislation and regulation of manure and vegetable wastes recycling increased the interest for AD as a cheap and environmental friendly solution. Latest developments in Europe, USA and other parts of the world have shown increasing interest among farmers to cultivate energy crops, used as feedstock for biogas production. AD is today standard technology for stabilization of primary and secondary sewage sludge, for treatment of organic industrial waste from food- processing and fermentation industries as well as for the treatment of the organic fraction of municipal solid waste. A special application is biogas recovery from existing landfills.*

Key Words: *Agricultural plants, waste water, solid waste, industrial plants, landfill recovery plants*

1. INTRODUCTION

Organic wastes also generate large amounts of methane as they decompose. Methane is a powerful greenhouse gas that traps heat in the atmosphere more efficiently than carbon dioxide. Given equal amounts of methane and carbon dioxide, methane will absorb 86 times more heat in 20 years than carbon dioxide [1]. To reduce greenhouse gas emissions and the risk of pollution to waterways, organic waste can be removed and used to produce biogas, a renewable source of energy. When displacing fossil fuels, biogas creates further emission reductions, sometimes resulting in carbon negative systems. Despite the numerous potential benefits of organic waste utilization, including environmental protection, investment and job creation, the United States currently only has 2,200 operating biogas systems, representing less than 20 percent of the total potential [2].

Biogas is produced after organic materials (plant and animal products) are broken down by bacteria in an oxygen-free environment, a process called anaerobic digestion. Biogas systems use anaerobic digestion to recycle these organic materials, turning them into biogas, which contains both energy (gas), and valuable soil products (liquids and solids). Anaerobic digestion already occurs in nature, landfills, and some livestock manure management systems, but can be optimized, controlled, and contained using an anaerobic digester. Biogas contains roughly 50-70 percent methane, 30-40 percent carbon dioxide, and trace amounts of other gases [3]. The liquid and solid digested material, called digestive, is frequently used as a soil amendment.

Some organic wastes are more difficult to break down in a digester than others. Food waste, fats, oils, and greases are the easiest organic wastes to break down, while livestock waste tends to be the most difficult. Mixing multiple wastes in the same digester, referred to as co-digestion, can help increase biogas yields. Warmer digesters, typically kept between 30 to 38 degrees Celsius (86-100 Fahrenheit), can also help wastes break down more quickly [4].

2. AGRICULTURAL BIOGAS PLANTS

The agricultural biogas plants are considered those plants which are processing feedstock of agricultural origin. The most common feedstock types for this kind of plants are animal manure and slurries, vegetable residues and vegetable by products, dedicated energy crops (DEC), but also various residues from food and fishing industries etc. Animal manure and slurries, from cattle and pig production, are the basic feedstock for most agricultural biogas plants in Europe, although the number of plants running on DEC was increasing the last years. AD of animal manure and slurries is considered to improve their fertilizer value for the reasons listed below:

I. Manure and slurries from different animals (cattle, pig, poultry etc.) are mixed and co-digested, providing a more balanced content of nutrients.

II. AD breaks down complex organic material such as organic nitrogen compounds, increasing the amount of plant-available nutrients.

III. Co-digestion of manure with other substrates adds various amounts of nutrients to the feedstock mixture.

The design and technology of biogas plants differ from country to country, depending on climatic conditions and national frameworks (legislation and energy policies), energy availability and affordability. Based on their relative size, function and location, agricultural AD plants can be classified as: family scale biogas plants (very small scale), farm scale biogas plants (small or medium to large scale), and centralized/ joint co-digestion plants (medium to large scale).

2.1 Family Scale Biogas Plants

In countries like Nepal, China or India operate millions of family scale biogas plants, utilizing very simple technologies. The AD feedstock used in these biogas plants originate from the household and/or their small farming activity and the produced biogas is used for the family cooking and lighting needs.

The digesters are simple, cheap, robust, easy to operate and maintain, and can be constructed with local produced materials. Usually, there are no control instruments and no process heating (psychrophilic or mesophilic operation temperatures), as many of these digesters operate in warmer climates and have long HRT.

2.1.1 The Chinese type (Fig. 1a) is an underground reactor of typically 6 to 8 m^3. It is supplied with household sewage, animal manure and organic household waste. The reactor is operated in a semi-continuous mode, where new substrate is added once a day and a similar amount of decanted mixed liquid is removed once a day. The reactor is not stirred, so the sedimentation of suspended solids must be removed 2-3 times per year, occasion when a large portion of the substrate is removed and a small part (about one fifth of the reactor content) is left as inoculum.

2.1.2 The Indian type (Fig. 1b) is similar to the Chinese type as it is a simple underground reactor for domestic and small farming waste. The difference is that the effluent is collected at the bottom of the reactor and a floating gas bell functions as a biogas reservoir.

2.1.3 Another small scale biogas plant is the displacement type, which consists of a horizontal cylindrical reactor. The substrate is fed at one end and the digestive is collected at the opposite end. The substrate moves through the reactor as a plug flow, and a fraction of the outlet is re-circulated to dilute the new input and to provide inoculation [5].

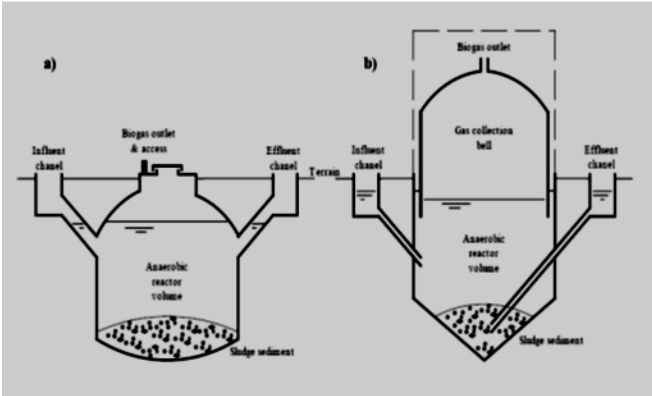

Fig -1: Principles of rural biogas reactor types: a) Chinese type; b) Indian type

2.2 Farm Scale Biogas Plants

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 (e.g. 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 neighboring farms (e.g. via pipelines, connecting those farms to the respective AD 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 AD applications is growing nowadays, not only because agricultural biogas production transforms waste products into valuable resources and produces high quality fertilizer 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 centralized 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 (Figs. 2 and 3) or vertical, usually with stirring systems, responsible for mixing and homogenizing the substrate, and minimizing risks of swimming-layers and sediment formation. The average HRT is commonly of 20 to 40 days, depending on the type of substrate and digestion temperature.

Digestive is used as fertilizer 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 neighboring heat consumers.

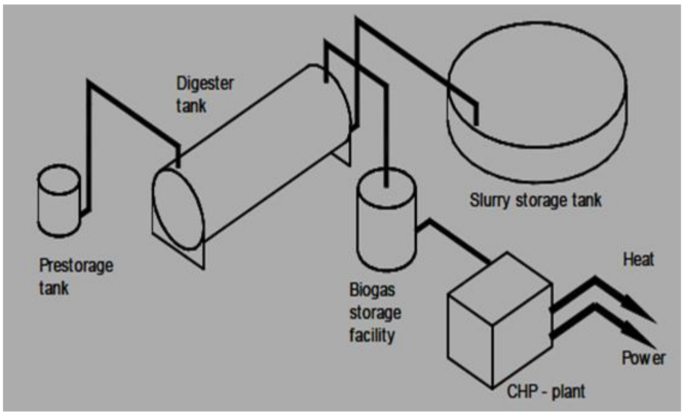

Fig -2: Schematic representation of a farm scale biogas plant, with horizontal digester of steel.

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 CHP unit.

Fig -3: Horizontal digester, built in Denmark

The digester can also be vertical, with or without conic bottom (Figs. 4, 5, 6 and 7), a so-called two-in-one slurry storage and digester tank, where the digester is build inside the storage tank for digestive. 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 CHP unit [6].

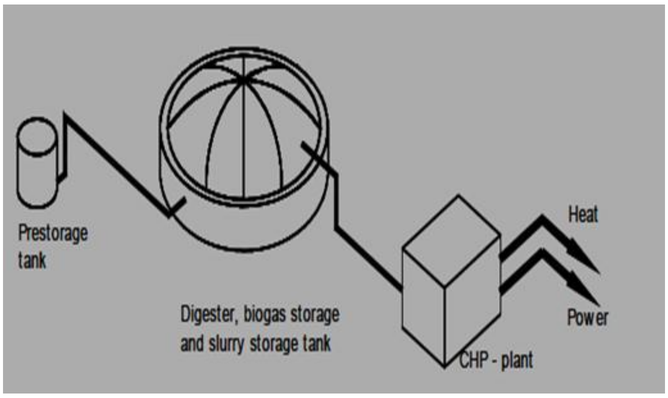

Fig -4: Schematic representation of the 'two–in-one' farm scale plant, with soft membrane cover

Fig -5: Picture of farm scale biogas plant in Denmark, co-digesting animal slurries and energy crops

(GROENGAS A/S)

Fig -6: Vertical digester in Germany, processing pig and poultry manure and crop silage

Fig -7: Vertical digester in Germany, built in 2005 for digestion of energy crops

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.

2.3 Centralized Co-Digestion Plants

Centralized 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. Centralized AD 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, and sewage sludge). The centralized co-digestion plants (also named joint co-digestion plants) were developed and are largely applied in Denmark (Fig. 8), but also in other regions of the world, with intensive animal farming.

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. At the biogas plant, manure is mixed with the other co-substrates, homogenized and pumped inside the digester tank. The transport of fresh manure from the farmers to the biogas plant and of digestive from the biogas plant to the farmer's storage facilities, placed close to the fields where digestive is applied as fertilizer, is the responsibility of the biogas plant. The storage facilities for digestive are sometimes shared by several farmers.

Like in the case of farm plants, the digestion process can be mesophilic or thermophilic. The HRT is of 12-25 days. According to European legislation, a controlled sanitation process of certain types of substrates of animal origin must be performed prior accessing the digester, which provides effective reduction of pathogens and weed seeds and ensures safe recycling of digestive.

Fig -8: Picture of centralized co-digestion plant in Denmark (LEMVIG BIOGAS)

The digester feeding system is continuous, and biomass mixture is pumped in and out of the digesters in equal amounts through precise pump-sequences. Digestive, 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, digestive is analyzed and nutritionally defined (DM, VS, N, P, K, and pH). The manure suppliers can take back only that amount of digestive, which they are allowed by law to spread on their fields. The excess is sold as fertilizer to the crop farmers in the nearby area. In all cases, digestive is integrated in the fertilization plan of the farm, replacing mineral fertilizers, closing the cycle of carbon and nutrient recycling (Fig. 9). More and more biogas plants are also equipped with installations for separation of digestive in liquid and solid fractions [7].

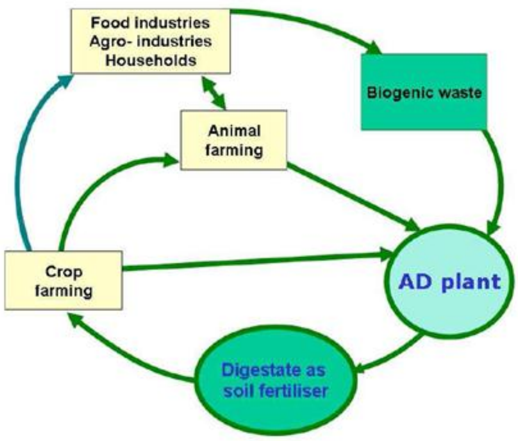

Fig -9: Schematic representation of the closed cycle of centralized AD

This way, centralized co-digestion represents an integrated system of renewable energy production, organic waste treatment and nutrient recycling. Experience shows that the system (Fig. 10) 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 emissions, improved veterinary safety through sanitation of digestive, improved fertilization efficiency, less nuisance from odors and flies, and economic benefits for the farmers.

Centralized co-digestion plants can be organized as co-operative companies, with farmers supplying manure an energy consumers as shareholders and owners. The management of the biogas plant is undertaken by a board of directors, which also employs the necessary personnel and is responsible for economic and legal binding agreements concerning the construction of the plant, the feedstock supply, the distribution and sale of digestive, the sale of biogas or/and energy and the financing activities. The co-operative company proved to be a functional organizational structure, economically feasible in countries like Denmark, but other organization forms like Ltd. companies or municipally owned companies are also frequent.

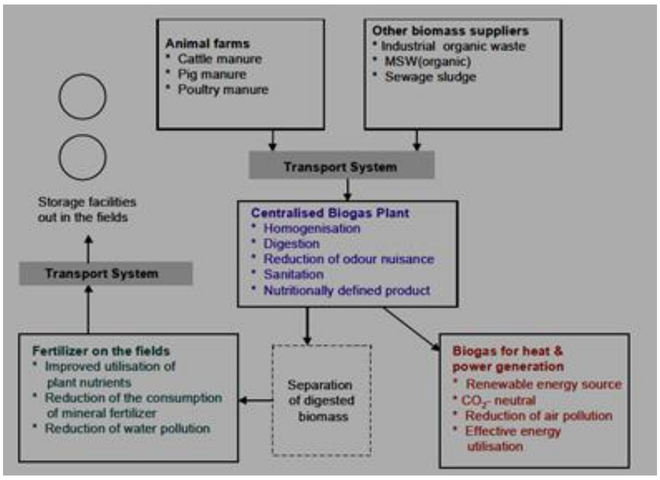

Fig -10: The integrated concept of centralized co-digestion plant

3. WASTE WATER TREATMENT PLANTS

AD is largely used for treatment of primary and secondary sludge, resulted from aerobic treatment of municipal waste water (Fig. 11). The system is applied in many countries in combination with advanced treatment systems where the AD process is used to stabilize and reduce the final amount of sludge. Most engineering companies providing sewage treatment systems have also the capability to provide AD systems. In European countries, between 30 and 70% of sewage sludge is treated by AD, depending on national legislation and priorities.

The AD treated sludge effluent can be further used as fertilizer on agricultural land or for energy production by incineration. There are still countries where the effluent is disposed on landfill sites. As this practice can have negative consequences for the environment due leakage of nutrients to ground water and emissions of GHG to the atmosphere, it is therefore banned in most European countries.

Fig -11: Waste water treatment plant in Psyttalia, Greece (FARNSWORTH 2004)

4. MUNICIPAL SOLID WASTE (MSW) TREATMENT PLANTS

In many countries, municipal solid waste is collected as mixed stream and incinerated in large power plants or disposed on landfill sites. This practice is actually a waste of energy and nutrients, as most of the organic fraction could be source separated and used as AD feedstock. Even bulk collected wastes can be further processed and used for biogas production.

In recent years, source separation and recycling of wastes received increasing attention. As a result, separate fractions of MSW are now becoming available for more advanced recycling treatment, prior to disposal. The origin of the organic waste is important in determining which treatment method is most appropriate. Kitchen waste is generally too wet and lacks in structure for aerobic composting, but provides an excellent feedstock for AD. On the other hand, woody wastes contain high proportions of lignocellulose material are better suited for composting, as pre-treatment is necessary in order to be used for AD.

Utilization of source separated organic fraction of household waste for biogas production has a large potential and several hundred AD plants, processing organic fraction of MSW, are in operation around the world. The aim is to reduce the stream of organic wastes to landfills or even to incineration and to redirect them towards recycling.

5. INDUSTRIAL BIOGAS PLANTS

Anaerobic processes are largely used for the treatment of industrial wastes and waste waters for more than a century and AD is today a standard technology for the treatment of various industrial waste waters from food-processing, agro-industries, and pharmaceutical industries. AD is also applied to pre-treat organic loaded industrial waste waters, before final disposal. Due to recent improvements of treatment technologies, diluted industrial waste waters can also be digested. Europe has a leading position in the world regarding this application of AD. In recent years energy considerations and environmental concerns have further increased the interest in direct anaerobic treatment of organic industrial wastes and the management of organic solid wastes from industry is increasingly controlled by environmental legislations. Industries using AD for wastewater treatment range from: food processes, beverage industry, and industrial products.

Industrial biogas plants bring about a number of benefits for the society and the industries involved:

added value through nutrient recycling and cost reductions for disposal, utilization of biogas to generate process energy, and improved environmental image of the industries concerned, through environmental friendly treatment of the produced wastes.

It is expected that the environmental and socio-economic benefits of AD, complemented by higher costs/taxation of other disposal methods, will increase the number of applications of industrial biogas in the future [8].

6. LANDFILL GAS RECOVERY PLANTS

Landfills can be considered as large anaerobic plants with the difference that the decomposition process is discontinuous and depends on the age of the landfill site. Landfill gas has a composition which is similar to biogas, but it can contain toxic gases, originating from decomposition of waste materials on the site.

Recovery of landfill gas is not only essential for environmental protection and reduction of emissions of methane and other landfill gases (Fig. 12), but it is also a cheap source of energy, generating benefits through faster stabilization of the landfill site and revenues from the gas utilization. Due to the remoteness of landfill sites, landfill gas is normally used for electricity generation, but the full range of gas utilization, from space heating to upgrading to vehicle fuel and pipeline quality is possible as well (Figs. 13 and 14).

Landfill gas recovery can be optimized through the management of the site such as shredding the waste, re-circulating the organic fraction and treating the landfill as a bioreactor. A landfill bioreactor is a controlled landfill, designed to accelerate the conversion of solid waste into methane and is typically divided into cells, provided with a system to collect leachate from the base of the cell. The collected leachate is pumped up to the surface and redistributed across the waste cells, transforming the landfill into a large high-solids digester.

Fig -12: Gaseous emissions and leaching to ground water from landfill sites are serious threats for the environment

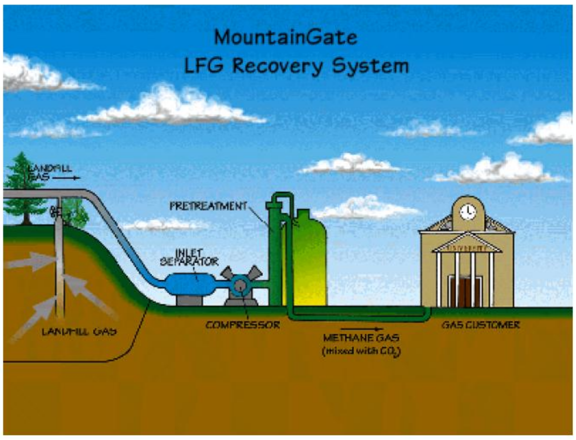

Fig -13: Landfill gas recovery system

(NST ENGINEERS 2007**)**

Fig -14: Ano Liosia Landfill gas exploitation project, Athens, Greece

7. CONCLUSIONS

There is a considerable potential of biogas production from anaerobic digestion of animal manure and slurries in Europe, as well as in many other parts of the world. Anaerobic digestion of animal manure offers several environmental, agricultural and socio-economic benefits through improved fertilizer quality of manure, considerable reduction of odors and inactivation of pathogens and last but not least production of biogas, as clean, renewable fuel, for multiple utilizations.

The last decade brought about huge steps forward, in terms of maturation of biogas technologies and economic sustainability for both small and large scale biogas plants.

One of the driving forces for integrating biogas production into the national energy systems will continue to be the opportunities offered by biogas from anaerobic co-digestion of animal manure and suitable organic wastes, which solves some major environmental and veterinary problems of the animal production and organic waste management sectors.

Rewarding manure processing for biogas production and for the environmental benefits provided by this would ensure the future development of the manure based biogas systems.

Biogas systems turn the cost of waste management into a revenue opportunity for farms, dairies, and industries. Converting waste into electricity, heat, or vehicle fuel provides a renewable source of energy that can reduce dependence on foreign oil imports, reduce greenhouse gas emissions, improve environmental quality, and increase local jobs. Biogas systems also provide an opportunity to recycle nutrients in the food supply, reducing the need for both petrochemical and mined fertilizers.

Biogas systems are a waste management solution that solve multiple problems and create multiple benefits, including revenue streams. However, to reach its full potential, the industry needs consistent policy support. Reliable funding of Farm Bill energy title programs and a strong Renewable Fuel Standard encourage investment and innovation in the biogas industry. If the governments intend to diversify their fuel supply and take action against climate change, it should strongly consider the many benefits of biogas [9] – [42].

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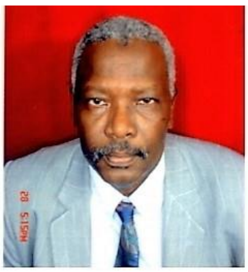

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