The Future of Biogas Production

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Keywords Anaerobic digestion; Biogas; Biorefinery; Integrated concept; Renewable energy; Solid-liquid-separation; UASB reactor

Abstract

Biogas production has usually been applied for waste treatment, mainly sewage sludge, agricultural waste (manure) and industrial organic waste streams. Throughout the recent years the performance of biogas reactors has been increased through a better control of the process and improved reactor design based on a better understanding of the process mechanisms and inhibiting factors. In order to improve the economical feasibility of biogas production, a new concept will take over: biorefinery. The goal of the biorefinery concept is to convert close to 100% of the incoming biomass into energy or valuable by-products. One of the currently investigated biorefinery concepts for biogas production from manure implies the separation of manure into a solid and a liquid fraction and their specific treatment in a UASB (upflow anaerobic sludge blanket) reactor and a CSTR (continuous stirred tank reactor), respectively. The solid fraction can be pre-treated more adequately and each effluent of the two fractions has specific nutrient contents, which will improve its value as a fertilizer product.

1 Introduction

1.1 Renewable energy production on its way

In the end of the last century the production of energy from renewable resources has evolved from a playground of a few companies and research centers to a proven technology. After the oil crisis in the 70's, several countries initiated programs for the development of renewable energy technology in order to reduce the dependency on oil imports.

In the recent years, further reasons for the needs to find alternatives for the energy supply by fossil fuels have become obvious:

- The necessity of worldwide reduction of CO_2 emissions in agreement with the Kyoto protocol.
- The more and more accepted fact that oil production will reach its peak in a not so distant future while at the same time developing countries like China and India are on their way to multiply their energy demand.
- The start of an era of political and military conflicts based on claims on oil reserves.

Whether the worldwide oil production will have its peak by 2010 or 2030 (Duncan and Youngquist, 1999, Cavallo, 2002), the fact that oil reserves are limited is nowadays getting widely accepted, seen by the fact that even large oil companies start investing in renewable energy production.

Both political frames and the development of more efficient energy production processes will decide how fast the ratio of renewable energy production will increase in the future.

Due to promotion of renewable energy through political actions, Denmark was at the forefront of development, marketing and export of renewable energy from wind and biomass in the 80's and 90's. At the moment, other European countries are currently taking over the leading role. Germany is probably today's most growing market for renewable energy production in Europe as a result of the introduction of the Renewable Energy Source Act (Erneuerbare-Energien-Gesetz, EEG). The EEG, which is in force in its amended form since August 1, 2004, guarantees a fixed price per kWh for electricity produced from wind, biomass, hydropower, and solar and geothermic sources for the next 20 years.

In Germany, the production of biogas will probably be one of the most accelerating sectors of renewable energy production and it is expected to induce the construction of several hundred biogas plants. The amount of renewable energy from biogas will thus undoubtedly raise the incentive to develop more competitive and economically yielding processes for the production of biogas. This is, nevertheless, necessary in order to establish biogas production as a profitable process in large scale, when the subsidies are missing.

Compared to other processes for energy production from biomass, biogas production has the advantage of a reliable technology, which can be relatively easily installed in a decentralized structure. Furthermore, biogas is an efficient energy carrier when combined with CHP (Combined Heat and Power) plants and has its advantages to hydrogen since its energy content per m^3 is higher and the direct use of biogas in fuel cells for electricity production looks very promising (Baaske and Trogisch 2004).

1.2 Optimization of the biogas process

On a worldwide basis, the biogas process will still have its significance as a robust and easily to establish low-cost technology for the treatment of organic waste. Especially in developing countries like China, India and Africa thousands of simple small-scale reactors are under operation and will still in the future have their benefit of waste management combined with decentralized energy production (Wang and Li, 2005, Yadvika et al., 2004, Omer and Fadalla, 2003). However, these reactors are often running under sub-optimal conditions due to the variation of the following parameters that often make steady-state operation impossible:

- Changes in process temperature due to missing temperature control of the reactor and external heat supply
- Changes in the organic loading of the reactor due to
  - Seasonal/monthly/weekly/daily changes in composition of the organic waste
  - Seasonal/monthly/weekly/daily changes in the produced waste amounts

Optimization of the biogas process has in recent years focused on process control to maintain a well-balanced process of the microorganisms involved, on the acceleration of the process by improvement of reactor design and higher operational temperature and on increasing the biogas yield from lignocellulosic biomass through pre-treatment (Ahring, 1995, Hartmann, 2000). As some achievements can be mentioned the development of reactors with immobilized active biomass like the UASB (upflow anaerobic sludge blanket) reactor, which has made anaerobic treatment of high strength wastewater possible and the UASB reactor to one of the most applied anaerobic reactors worldwide, used for the treatment of industrial wastewaters (Seghezzo et al., 1998). Profound research on the mechanisms of the biogas process has made it possible to run co-digestion of different types of organic waste in centralized biogas plants and to achieve profitable economical operation (Ahring et al., 1992, Hartmann et al. 2002). In Denmark, for instance, centralized biogas plants are based on manure and up to 25% of organic waste with a high biogas potential is added to. The volume of this organic waste is, however, limited Danish Energy Agency (1995) and future biogas plants have to increase their energy yield by running the biogas process more efficient on lignocellulosic biomass and by expanding the variety of biomass used.

2 The biogas concept of the future: Biorefinery

Although huge amounts of manure are available, the operation of Danish centralized biogas plants exclusively on manure is currently not economically feasible due to high transportation costs per m^3 compared with the benefit from the biogas yield per m^3. A low biogas yield per ton manure is due to two factors:

- The content of organic matter is typically about 5% for swine manure and 8% for cow manure, meaning that 92-95% of each ton is water.
- A large part of the organic content in manure is consisting of lignocellulosic fibers that are recalcitrant to anaerobic degradation.

The benefit of the anaerobic treatment will, therefore, very much depend on the improvement of the process regarding a higher biogas yield per m^3 of biomass and an increase in the degree of degradation. Furthermore, the benefit of the process can be multiplied by the conversion of the effluent from the process into a valuable product. Compared to combustion, this concept has the advantage of preserving the nutrients, which can be recycled to agricultural land. In order to show the real benefit of biogas technology, biogas production should therefore always be combined with full recycling of the nutrients.

In order to improve the economical benefit of biogas production, the future trend will go to integrated concepts of different conversion processes, where biogas production will still be a significant part. In a so-called biorefinery concept, close to 100% of the biomass is converted into energy or valuable by-products, making the whole concept more economically profitable and increasing the value in terms of sustainability.

2.1 Biogas production in combination with bioethanol production

One example of such biorefinery concept is the Danish Bioethanol Concept (DBC, International patent WO 01/60752 A1) that combines the production of bioethanol from lignocellulosic biomass with biogas production of the residue stream (figure 1). In this concept the production of bioethanol as liquid fuel for transportation is the central aim in order to increase the part of renewable energy used in the transportation sector, which is in countries like Denmark, for example, the most increasing energy-consuming sector. In order to reduce the costs for the production of ethanol, the novelty of the process is not only a higher sugar release through an improved pre-treatment method and a fermentation of xylose, but also the integration of the treatment of the effluent stream from the fermentation in a biogas reactor (Torry-Smith et al., 2003). The biogas treatment has two benefits: An extra energy yield in the form of biogas and the purification of the effluent stream in the biogas process so it can be used as process water.

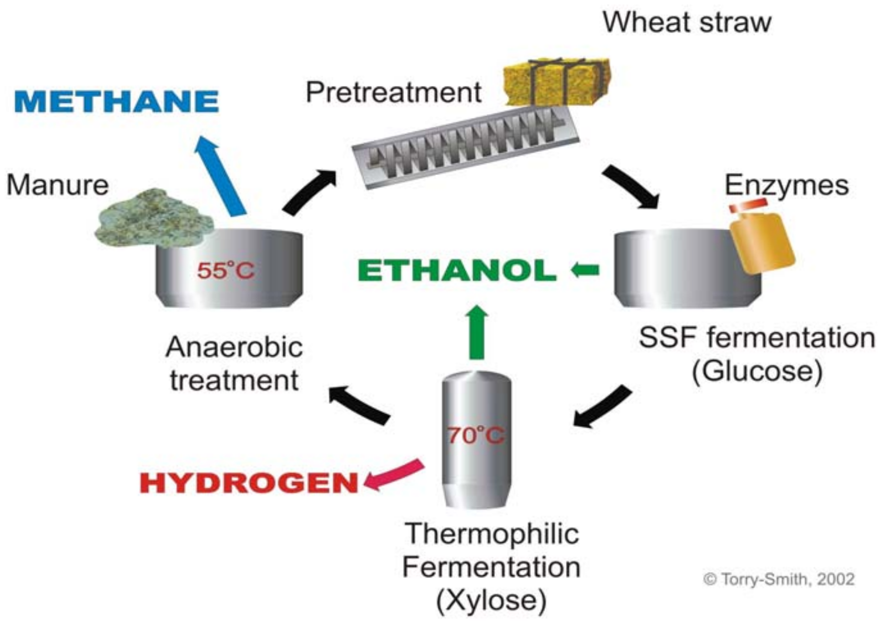

Figure 1 *The Danish Bioethanol Concept*

2.2 Biogas production in combination with separation and use of by-products

Another example is the combination of biogas production from manure with manure separation into a liquid and a solid fraction for separation of nutrients. The separation opens the way for the following benefits:

- The separation of the two fractions lowers the transportation costs when applying on-site treatment of the liquid fraction at the farm site and treatment of the fiber fraction at the centralized biogas plant
- A more adequate treatment of each fraction, i.e. the liquid fraction in a UASB reactor, and the solid fraction in a CSTR reactor with recirculation of process water, with specific adjustment of the organic loading rate (OLR) and hydraulic retention time (HRT) and specific pre-treatment for each fraction
- The separation provides specific N- and P- fertilizer fractions that can be further processed to high quality fertilizing products.

It has been recently shown that solid-liquid separation of manure can be successfully applied using either decanter centrifugation or chemical precipitation (Møller et al., 2004). The separation of manure into a solid and a liquid fraction does, furthermore, comply with legislation on nutrient control, which is on its way in Denmark.

In a project financed by the Danish Energy Agency cost-benefit calculations are currently performed on 9 different concepts including solid-liquid separation as pre-treatment on the local farms, solid liquid post-treatment and recirculation of the fiber fraction, wet oxidation of the fiber fraction and treatment of the liquid fraction in UASB reactors. One of the most promising concepts is the treatment of the liquid fraction on the farm-site in a UASB reactor while the solid fraction is transported to the centralized biogas plant where wet-oxidation can be implemented to increase the biogas yield of the fiber fraction (figure 2).

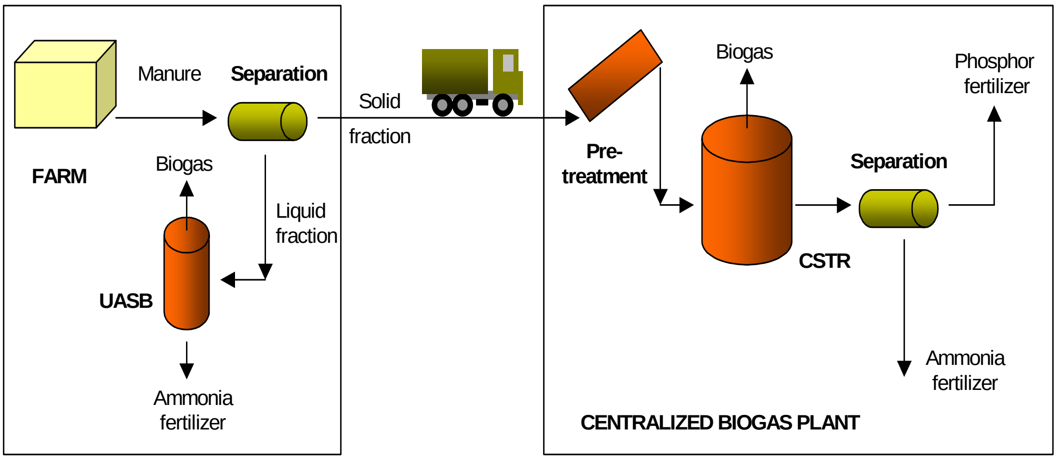

Figure 2 *Solid liquid separation of manure with treatment of the liquid fraction in a UASB reactor at the farm and of the solid fraction in the centralized biogas plant after pre-treatment*

The efficiency of this new concept will rely on both the biogas yield of the solid fraction at the centralized plant and of the liquid fraction at the farm site.

3 Treatment of the liquid fraction in UASB reactors

Small units of UASB (upflow anaerobic sludge bed) reactors are the most promising method of choice for anaerobic treatment of the liquid fraction on the farm. The immobilization of the active biomass inside the UASB reactor enables a high flow and a low retention time so that the reactor size can be kept small. Currently only a few investigations have been undertaken on the treatment of the liquid fraction of manure in UASB reactors (Castrillon et al. 2002, Kalyuzhnyi et al., 1998). Recent investigations at DTU show that methane yields of 240 l/kg-VS can be reached for an OLR of 6 kg-VS/m^3/d, but the reactor can be operated stable at OLR of 36 kg-VS/m^3/d with a methane yield of 130 l/kg-VS, corresponding to a methane production rate of almost 5 m^3/m$^3_{reactor}$/d. (figure 3).

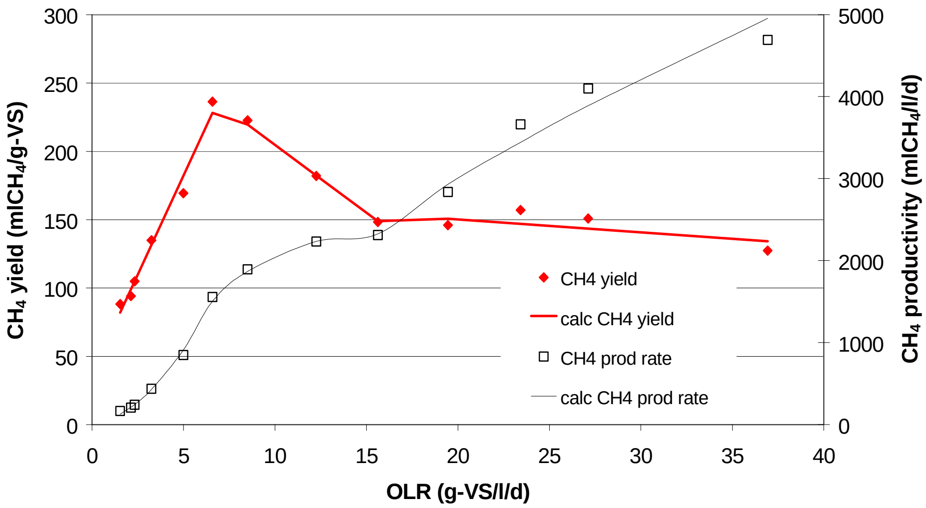

Figure 3 *Methane yield and productivity versus organic loading rate in UASB reactor*

Figure 4 shows on the basis of mass flow of the separation unit and with methane yields usually achieved from swine manure how the increasing separation and the separate treatment increases the methane productivity of the whole system. The methane yield per t of influent delivered to the plant increases from 16 m^3 to 25 m^3, when 75% of all manure supplied to the centralized biogas plant is separated. The methane yield from the liquid fraction is only 10 m^3/t, the productivity per reactor volume, however, is about 10 times higher in the UASB than of the CSTR since the HRT in the UASB system is only 1.5 days compared to usually 15 days in the CSTR.

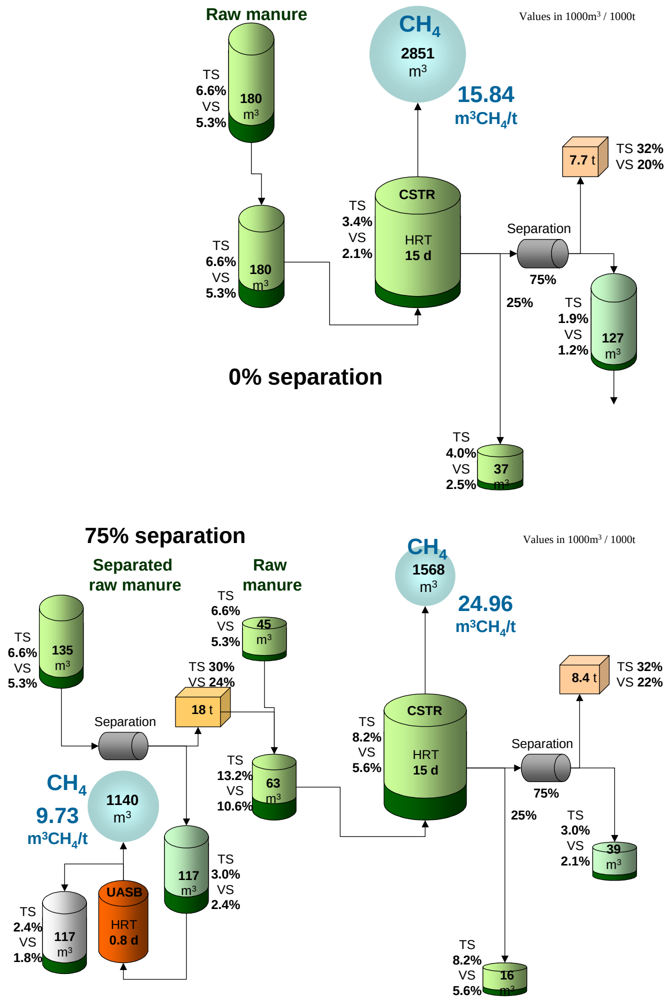

Figure 4 *Mass flow, methane yield and methane productivity for the system of manure separation (below) compared to the conventional system without separation(above)*

4 Pre-treatment of the solid fraction

Due to the separation of the fibers, any pre-treatment method to increase the degradation of lignocellulose can be applied more specifically since the treatment has its highest benefit on the fiber fraction. In figure 5 the effect of wet oxidation pre-treatment, which is performed at 170°C, 15 bar pressure, and under addition of oxygen, is shown for raw manure and on manure fibers only. Measurements of the biogas potential before and after wet oxidation treatment show that the wet oxidation treatment had an increasing effect on the methane potential mainly of the manure fibers while the effect was lower on the whole manure. After 14 days of incubation the increase was 98% for manure fibers, and only 23% for whole manure.

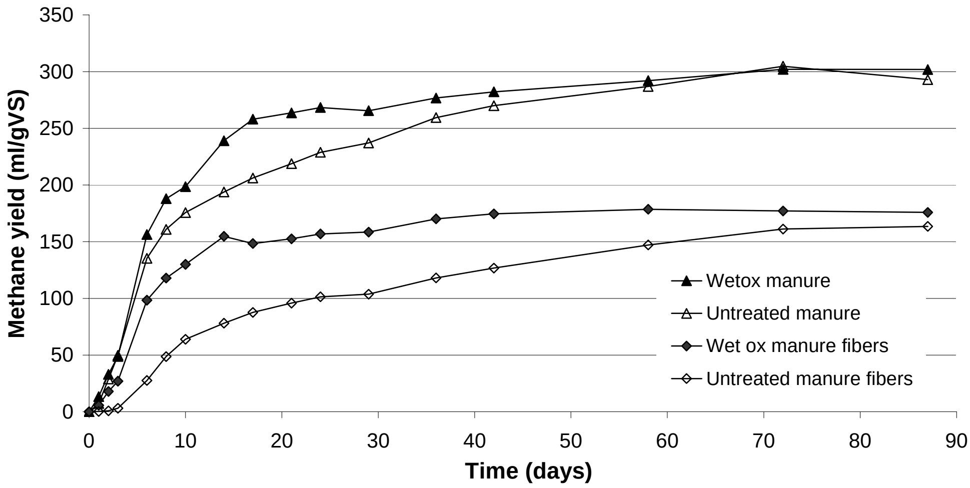

Figure 5 *Biogas potential before and after wet oxidation of unseparated cow manure and of manure fibers*

Applying the doubling of the methane yield when the separated solid fraction is pre-treated by wet oxidation, the methane yield will increase to 39 m^3 per t of treated material (figure 6).

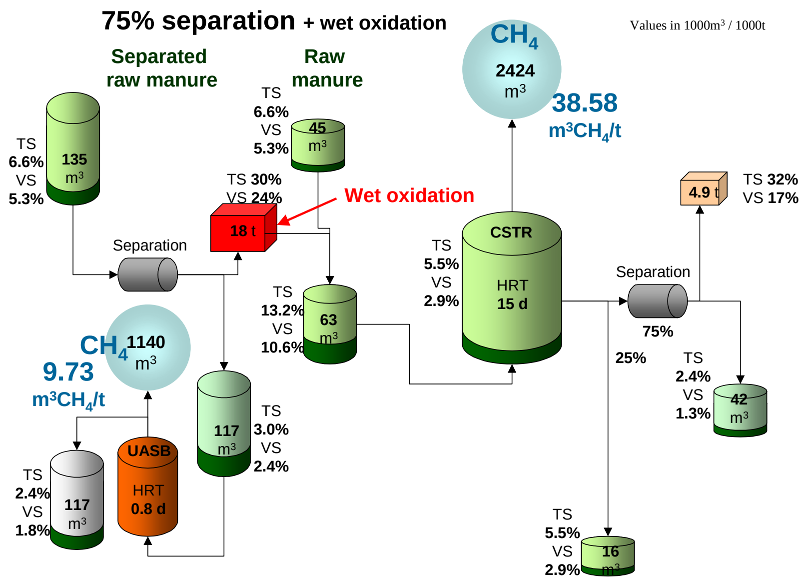

Figure 6 *Mass flow, methane yield and methane productivity for the system of manure separation combined with wet oxidation of the solid fraction*

5 Conclusion

In order to extend its market position in the future, biogas production has to become part of an integrated biorefinery concept, where up to 100% of the incoming biomass is converted into energy or valuable products. Applying this concept to manure, the separation of manure into a solid and liquid fraction with subsequent treatment in a UASB and CSTR reactor is a very promising way to achieve a significant increase in the economical benefit of biogas systems. Integration of the wet oxidation pre-treatment of the solid fraction leads to a high degradation efficiency of the lignocellulosic solid fraction. Based on these results, the operation of this system should make it economically feasible to produce biogas only from manure. Further refining of the effluents from the process into a high quality fertilizer product would further increase the economy of the concept.

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