CH2M HILL

Dairy Waste to Energy

EUROPEAN MANURE DIGESTION TECHNOLOGY

Complete Stirred Tank Reactor process (CSTR)

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1. ABSTRACT

This report is made under PIER-program project 3.1 Dairy waste to energy. It outline the European experience with biogas production based on manure with emphasis on the Danish experience because Denmark has been on of the leading countries in Europe to develop the technology through the last 30 years.

The European plants are today based on Completely Stirred Tank Reactor (CSTR) or complete mix reactors. In 1980 one Plug flow digestor was tested but it was closed due to operational problems.

The biogas plants are today depended on waste that is co-digested with manure. The waste has a higher gas yield and often generate an income through reception. However biogas plans are multi functional technology that is viable under various circumstances.

Biogas technology is still being developed to increase the economic performance and will also have a role as fuel for fuel cells in future.

2. BACKGROUND

In 2000 there were approximately 50 joint (centralized) biogas plants and 1500 farm (decentralized) scale biogas plants operating on manure in Europe [1]. Most operating as Completely Stirred Tank Reactor (CSTR) plants. All joint biogas plants are co-digesting manure with organic industrial waste and the farm scale are often co-digesting manure with pure fat from vegetable or fish production due to hygienic concern.

The biogas produced is CO_2 neutral and primarily utilized in Combined Heat and Power Engines producing up to 39% electricity and up to 50% heat. The electricity is feed into the national grid and the heat is used for the process and sold to the district heating networks. At the farm plants the heat is used for the process and in the stables at the farm. (If heat cannot be sold other utilization can be considered see section 8 – trends.)

The manure and organic waste treated in the biogas plants is returned to farm-land as an improved fertilizer for crops because nitrogen will be more accessible after the anaerobic process. When the nitrogen is taken up by the corps this will reduce the need for chemical fertilizer at the field and leaching to the ground water will be prevented. If nutrients are in surplus in an area the digested manure can more easily be separated in a solid and a nutrient fraction and water which will allow redistribution of the nutrients in a lager area.

Instead of evaporating from storage tanks to the atmosphere the methane will be used for electricity production and this will reduce the green house gas emission two fold. The produced energy is CO_2 neutral and replaces fossil fuel for electricity production. Methane is a Greenhouse Gas 21 times worse than CO_2 and the collection of the methane in the biogas plant reduces the amount of the methane that would have developed in the storage.

The biogas plant is and integrated energy production, waste treatment and nutrient redistribution facility for the benefit of renewable energy production, agriculture and the environment.

[1] Renewable Energy, EurObserv'ER, May 2002 No. 12, (available on : www.europa.eu.int/comm/energy/en/pds_alterner_en.html)

In Europe there are solid experiences in operating feasible biogas plants based on manure under different economical circumstances. These experiences can be valuable for the PIER program analyzing “Dairy waste to Energy”.

3. HISTORY AND AMOUNTS HANDLED

3.1 History

In the beginning of the 1970'ties Europe was like the rest of the world experienced an oil crisis leading to an increased interest for development of renewable energies. The first farm scale biogas plant was built in 1975 and the experience from different digester types made the basis for the first joint biogas plant in 1984. The energy production for the manure alone was however not sufficient for feasible operation which created the interest for co-digestion of manure with waste with higher energy potential and gate fee.

In the 1980'ties environmental restriction on storage, spreading of manure and nutrients in general was tighten. The restriction made biogas plants interesting from an agricultural point of view and the joint biogas plants became through this period more standardized.

Simultaneously a natural gas network was build up for de-central Combined Heat and Power production and industrial purposes.

With the increasing number of plants erected during the 1990'ties the plants where standardized and built with less and less investment subsidies. With the growing concern for Green House Gasses (GHG) these has been evaluated in connection with biogas plants

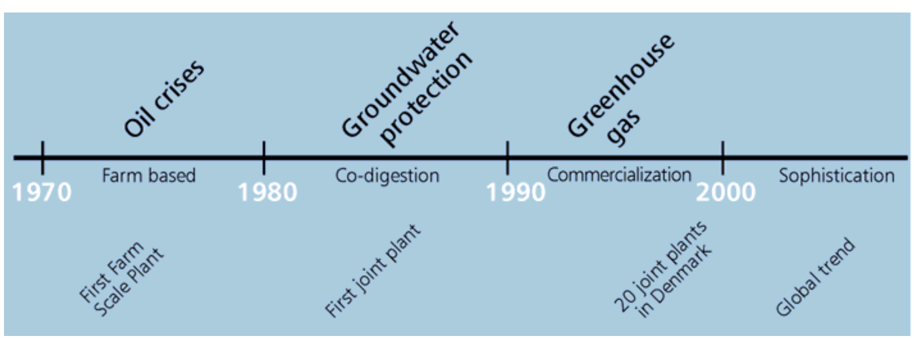

Figure 3.1 Development of manure based biogas plants in Denmark

In future the biogas plants are likely to be a step before the nutrients in the manure is separated in a solid and liquid fraction and perhaps separation of the liquid fraction in concentrated nutrients and water. Concentration of the nutrients in the manure will make the redistribution between animal and crop farming less transport demanding. Future trends are further elaborated in section 8.

3.2 Status for manure and waste handled in Europe

In 2000 there was approximately 1500 decentralized agricultural biogas plants and 50 joint co-digestion units operating. The decentralized units produced approximately 50,000 ton of oil equivalent and the joint plants 40,000 ton of oil equivalent [2].

3.3 Status for manure and waste handled in Denmark

In 2001 the following amounts of manure and waste was handled at the biogas plants in Denmark (the number of farm scale biogas plants was in 2001 approx. 35).

Biomass	**20 Joint biogas plants** m^3	**35 Farm scale plants** m^3	**Total** m^3
Manure	1.149.542	220.000	1.369.542
Organic industrial waste	232.270	28.000	260.270
Waste water sludge/fat trap	21.361	-	21.361
House hold waste	8.496	-	8.496
Biomass total	**1.411.669**	**248.000**	**1.659.669**
Share of total	85%	15%	

Table 3.1 Amount of manure and different waste types handled the Danish biogas plants in 2001. (Danish Energy Authority)

[2] Renewable Energy, EurObserv'ER, May 2002 No. 12, (available on : www.europa.eu.int/comm/energy/en/pds_alterner_en.html)

4. EUROPEAN TECHNOLOGY FOR DAIRY WASTE

In 1974 the first farm based biogas plant was build and was put in to operation in 1975.

In 1978 a Co-operation group for technological development of Biogas (STUB) was formed that led to the building and testing of two different reactor types Continues Stirred Tank Rector (CSTR) and a Plug flow digester.

The plants were build in 1980 and test but the plug flow digester was given up in 1986 due to low gas production and extensive maintenance. The big problem of the plug flow digester was the settlement of slurry and creation of canals were most manure passed through with very little retention time. The Plug Flow digester was tried restarted in 1994 but was again given up due to operational problems.

All biogas plants in Northern Europe digesting manure are today operating with the CSTR concept.

With the first joint biogas plant co-digestion was introduced. The advantages of co-digestion is explained in section 5.

In the following the concept of the biogas plant will be explained:

4.1 Technology

4.1.1 *Collection of manure.*

Slurry is collected at the farm with a tanker in most cases from a pre-storage tank at the farm. In Denmark pigs are in stables all year (manure DM 4-6%) and cows are out side 5-7 moths a year during day time (manure DM 8-10%). A very small percentage of the manure received at the biogas plants is solid manure (25% DM) the solid manure is collected with a tractor with a loader in the front.

4.1.2 *Reception of manure and waste at the biogas plant*

The manure and waste is received in a closed reception hall to eliminate odour impact on the surroundings. Liquid manure and waste is pumped to the pre-storage tank and solid manure and waste is tipped from a skip to the pre-storage tank. Air from the reception hall is led to a bio-filter to remove odour.

4.1.3 *Pre-storage tank*

In the pre-storage tank the manure and waste is stored for 5-7 days. Transport therefore only happen during day time form between 6 a.m. and 6 p.m. The pre-storage is also important to allow very even pumping intervals to the digester for the benefit of the biogas production. Air from the pre-storage tanks is also led to the bio-filter for odour removal.

4.1.4 *Digester*

All farm scale plants and 7 of the joint plants are operated in at mesophilic temperature. 13 of the joint plants are operated in the termophilic temperature range. The tanks are due to the Danish climate insulated and the manure is either heated in a heat exchanger or heated directly by heating coils in the digester. The material for the tank is either concrete or steel. The tank is stirred continuously to ensure a good contact between in coming material and the material in the digester. A stable process is depended on stable conditions in the digester and the mixing ensure this.

4.1.5 *After storage- return of digestate*

After the main digestion process the digestate is stored in an after-storage tank before it is brought back to the storage tanks at the farms or in the fields (or before a post treatment). Most Danish joint plants will have a gas collection at this stage contributing with 10-25% of the total gas production. The tank is not insulated or heated but will have stirring. Tanks are made in either steel or concrete.

4.1.6 *Gas storage*

Gas from the digester and after-storage is stored in low-pressure gas storage with capacity up to 24 which is the maximum for feasible gas storage. The gas storage is made with a PVC membrane.

4.1.7 *Gas cleaning*

Biogas will in most cases contain H2S higher than 500 ppm (which is the limit for use in engines). The gas can be cleaned biologically just by adding atmospheric air (about 4%) and letting it have contact with bacteria (are present in the manure) removing the sulphur in either the after-storage or in a separate tank where the bacteria are growing on the surface of plastic or ceramic material. Except from the gas the bacteria must have access to nutrients as NP and K.

4.1.8 *Gas utilisation*

The biogas can be utilised in many ways such as

- Boiler
- Engines
- Micro turbines
- Vehicle
- On the basis of the

Most of the biogas in Denmark is today used in CHP engines with a electricity efficiency of approx. 37% and heat efficiency of approx. 50%. The new biogas engines will have an electricity efficiency of 39%. The electricity is sold to the national grid and the heat is sold to the district heating network.

5. CO-DIGESTION AND BIOGAS PRODUCTION

The first farm based biogas plants were only digesting manure from the farm. With the first joint biogas plant was put in operation in 1985 co-digestion was introduced. The big advantage of co-digestion is the combination of stable process conditions created by the manure and the high gas potential in the organic waste. The organic waste may origin form industry, households or sewage treatment plants. In case of recycling of nutrients back to farmland the treatment of the waste must comply with the veterinary regulation in the country.

Anaerobic digestion is a sensitive process vulnerable to rapid changes in: Temperature, amount and composition of input material, pH and concentration of inhibiting components (ammonia, Cl, antibiotics etc.). To create an effective process with a high destruction of volatile solids stable process conditions must be ensured and monitored in order to sustain a high gas output.

Co-digestion allow use of organic waste fractions that otherwise will be problematic to handle. Many types of organic waste (with poor fluid dynamics, aggregating waste particulate materials, floating waste, materials with high inhibiting components) can much easier be used as co-substrates to the more homogeneous main substrate manure.

In the table below is the total biogas production form the manure based Danish biogas plants. The gas production has been increasing over the years at especially the joint operated plants due to better process understanding/operation and improvement of the equipment so long down periods for maintenance is avoided. However a gas production of minimum 30 m^3 per m^3 input is in the Danish situation necessary for being economical viable.

	Joint biogas plants	Farm scale plants	Total
Gas			
Biogas production, 1000m3	57,796	7,700	65,496
Gas prod. (v. 65% CH4), TJ	1, 345	179	1,524
Share of total	88%	12%	

Table 5.1 Biogas production in 2001. (Danish Energy Authority)

6. COST/BENEFIT

6.1 Investment costs

The investment costs for a biogas plant has an economy of scale because e.g. equipment is not twice as expensive with the double capacity. In 2002 there was made a Socio economic analysis of Joint Biogas Plats with the aim of clarifying the costs of reducing CO_2 [3]

In connection with the analysis an estimation of investment costs for 3 different plant sizes were made: (300 m^3/d (109,500 m^3/year), 500 m^3/day (200,750 m^3/year) and 800 m^3/day (292.000 m^3/year). In table 6.1 it can be seen that the investment costs per handled m^3 per year is reduced from approximately 64 to 41$.

In the table investment cost is estimated on the background of the experience from the existing joint biogas plants. However the most cost effective plant in the future will vary from case to case due to local circumstances of raw material and suppliers available.

The first 5 joint biogas plants build have all been modified after erection due to malfunctioning design or equipment. However the experience achieved have been incorporated in the following plants through the Danish Biogas Follow up program run by the Danish Energy Authority. Today the biogas technology is economic viable technology. However still depended on the availability of waste with a high gas potential.

[3] Socio economic analysis of joint biogas plants, Danish Research Institute of Food Economics, Report no. 136, 2002 (only with English summary)

Investment specification for biogas plants at different sizes in USD

Exchange rate (1 $ = 6,32 DKK)

	300 m3/ day	**550 tons / day**	**800 tons / day**
	109.500 m3/year	200,750 m3/year	292.000 m3/year
Site	158.	190.	222.
Ground works	158.	190.	222.
Associated facilities: road, fence	285.	364.	427.
Buildings	475.	554.	633.
Tanks: prestorage tank, mixing tank, hygienisation tank, storage tank	587.	935.	1125.
Biogas reactors	633.	1187.	1899.
Heatsystem: heatexchanger, heat storage, start-up boiler	578.	759.	854.
Gassystem: filters, transmission, blowers, torch, gas storage	1218.	1646.	1820.
Odour control filter	158.	206.	206.
Equipment: mixing equipment, pumps	570.	820.	973.
SCADA and el installation	316.	396.	396.
Consulting, engineering and mounting	1211.	1680.	2067.
Equipment and building adaptions on the farms	173.	318.	462.
Total price	**6520.**	**9244.**	**11305.**
Investment per m3 handled per year	*64*	*51*	*43*

Table 6.1 Estimated investment costs at plants with different plants size.

6.2 Operation costs

The operation costs for the 3 different plants in table 6.2 sizes are also showing an economy of scale except for transport costs that will be slightly increasing.

Treatment capacity m^3 per day	**300**	**550**	**800**
USD per m^3 handled per year			
Transport	2.5.	2.5	2.8
Gas production etc.	8.4	6.5	5.5
Total	**10.9**	**9.0**	**8.4**

Table 6.2 Estimated investment costs at plants with different plants size

At table 6.3 the sales revenue and operation costs income at 11 different joint biogas plants is shown (in DKK). The older plants and plants owned by municipalities are not included because the differences in economical and organisation differ so much that it does not make a meaningful comparison to the other plants.

Sales revenue represents income from sale of energy, revenue from reception of waste and/or other income at the plant.

Operation costs include all expenses for the production of the biogas such as transport, repair and maintenance, staff salary and administration.

The income is compared with a lowest income the plant must achieve for payment of interest, loan and reinvestment.

Biogas plants tend to go through development in the economic balance where the first years might be below the demand for lowest income but after experience is build up on the plant the economy start to improve. Furthermore the existing plants show the same tendency as described above with an economy of scale.

1000 DKK	Development in joint biogas plants income									Demand for Income 2002 level
	1994 or 1993/94	1995 or 1994/95	1996 or 1995/96	1997 or 1996/97	1998 or 1997/98	1999 or 1998/99	2000 Or 1999/00	2001 or 2000/01	2002 or 2001/02	
Ribe										
-Sales revenue	7.189	7.910	8.085	8.833	9.534	10.276	11.098	11.684		
-Operation costs	4.295	4.680	4.924	5.534	5.680	6.468	5.612	7.230		
Income	2.895	3.230	3.161	3.298	3.855	3.809	5.486	4.453		2.700
Lintrup										
-Sales revenue	8.162	8.113	7.450	8.803	8.824	6.939	11.770	13.360		
-Operation costs	4.541	4.508	4.811	4.938	5.367	6.632	7.997	8.467		
Income	3.622	3.605	2.639	3.865	3.457	307	3.772	4.893		3.500
Lemvig										
-Sales revenue	10.318	10.358	10.175	10.939	10.892	12.030	13.204	12.960		
-Operation costs	6.391	5.716	6.327	6.495	6.539	7.272	7.945	8.825		
Income	3.927	4.642	3.848	4.444	4.353	4.758	5.259	4.135		4.350
Hashøj										
-Sales revenue	1.144	2.944	2.978	3.686	4.269	4.371	4.898	5.677		
-Operation costs	654	1.442	1.637	1.803	2.287	2.483	2.640	2.146		
Income	490	1.502	1.341	1.882	1.982	1.888	2.258	2.831		1.700
Thorsø										
-Sales revenue	2.050	4.661	5.224	5.722	6.706	5.851	7.791	8.768		
-Operation costs	1.747	3.179	3.468	3.699	4.212	4.471	4.447	4.571		
Income	303	1.482	1.756	2.023	2.495	1.381	3.344	4.197		2.700
Filskov										
-Sales revenue	-	1.634	3.015	3.234	3.553	4.289	4.293	4.729	5290	
-Operation costs	-	892	1.621	1.708	1.879	1.940	2.569	2.495	2972	
Income	-	742	1.394	1.526	1.674	2.349	1.724	2.234	2318	2.300
Blåbjerg										
-Sales revenue	-	-	3.355	6.657	7.901	7.449	8.360	10.190		
-Operation costs	-	-	1.679	3.566	4.092	4.375	4.352	5.719		
Income	-	-	1.676	3.090	3.809	3.074	4.008	4.471		3.000
Snertinge										
-Sales revenue	-	-	-	4.646	5.377	6.327	6.027	7.406	7960	
-Operation costs	-	-	-	2.991	3.198	3.556	3.695	4.197	4851	
Income	-	-	-	1.655	2.180	2.771	2.332	3.213	3109	3.600
Blåhøj										
-Sales revenue	-	-	-	1.685	3.660	4.433	4.256	4.399	5132	
-Operation costs	-	-	-	1.111	1.628	1.926	2.077	2.482	2751	
Income	-	-	-	574	2.032	2.507	2.179	1.917	2381	2.000
Nysted										
-Sales revenue	-	-	-	-	2.922	5.787	5.674	6.333		
-Operation costs	-	-	-	-	3.145	4.604	4.093	4.224		
Income	-	-	-	-	-223	1.183	1.581	2.109		3.600
Vaarst/Fjellerad										
-Sales revenue	-	-	-	-	4.436	4.711	5.790	6.315		
-Operation costs	-	-	-	-	2.983	3.390	4.194	3.544		
Income	-	-	-	-	1.453	1.321	1.596	2.771		2.100

Table 6.3 Economics data for 11 Danish Biogas Plants in the period 1994-2001 [4]

[4] Gregersen, Kurt Hjort, Økonomien i Biogasfællesanlæg, Udvikling og status, 2002 (Economics of Joint Biogas Plants. Development and status) only with English summary.

7. OTHER BENEFITS/APPLICATIONS

7.1 Energy

In the Danish situation it has been possible to utilize the heat for a co-generation unit in a district heating network but it is important to note that there is also other way of using the energy. Heat can be transformed to cold for cooling of buildings or stocks (combined cold and power plant) or can be used for reducing the volume of the digestate if nutrients are in surplus in an area.

Biogas can after cleaning and compression be sent in to a natural gas grid. It will have an influence on the wob index so a decision of this kind must be made on State level before it is implemented.

Biogas is also an excellent fuel for vehicles such as city buses garbage trucks or other transportation driving on routes this application is widely used in Sweden.

The utilization of the biogas in fuel cell is investigated and will have interesting perspective for a new application

7.2 Improved nutrient balance (Mix of manure and waste)

Mixing of different manure and waste often has a positive effect on the nutrient balance in the digestate improving it as a fertilizer. The digestate also have a positive effect on the formation of vegetable mould

7.3 Less odour

An important side effect of the digestion process is a substantial odour reduction in the manure and waste. Studies show that beside less odour when spread on farmland the odour will also reduce more rapidly.

8. NEXT STEPS – TRENDS

The tends in the Research and Development of the biogas plants are mainly happening in three areas: Less investment cost, improved gas production and gas utilization.

Today process monitoring is mainly happening though monitoring the gas production. The gas production is an excellent parameter for getting an overall picture of the well being of the process. However when the gas production drop it is to late to make interventions that will have an immediate effect. It will take some time before the gas production is stable again or in the worst case the process have to be restarted.

Technical University of Denmark has developed a online Volatile Fatty Acid devise (that at the moment is tested in full scale) which allow the plant manager to intervene at an earlier stage if the process is undergoing to rapid changes in input, pH, etc. A better process understanding will in the future allow the plants to be run more intensively and with a higher gas production. A higher gas production will also mean a reduction in solids in the digestate.

Reduced investment cost can among others be obtained by reducing the retention time. A significantly lower retention time will demand new digester technology/designs. Researchers goal is to get down to 4-6 days retention in a termophilic process and 7-10 days mesophilic process. Another way to improve the economics of the biogas plant is to reduce equipment (pumps and moving parts) and thereby maintenance costs.

A new EU-regulation is setting standards for the pre-treatment of waste before it enters the process. The pre-treatment is expected to give higher gas production and higher elimination of xenobiotics because these are reduced more significantly with higher temperature (a termophilic process is in this case also better than a mesophilic process)

In Europe animal farms are steadily growing in size and the need for a post treatment where nutrients and water is separated is therefore growing. Several methods have been developed but more concepts must be expected to develop.