Commission of the European Communities

energy

Options to improve gas production and consumption from manure fermentation

Demonstration project

Report

EUR 11976 EN

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Contract No EE-285-79

Final report

Directorate-General
Energy

1989

EUR 11976 EN

Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES
Directorate-General
Telecommunications, Information Industries and Innovation
L-2920 Luxembourg

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Cataloguing data can be found at the end of this publication

Luxembourg: Office for Official Publications of the European Communities, 1989

ISBN 92-825-9438-6

Catalogue number: CD-NA-11976-EN-C

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Printed in Belgium

SUMMARY

The research project carried out into the options to improve production and consumption of biogas from manure fermentation was split up into three parallel sub-projects.

The first sub-project aimed at improving the fermentation efficiency by means of a better process control and a more efficient conversion of biogas into electricity and heat. The main items were the monitoring of the slurry supply, the stirring of the fermenter contents and the heating and pre-heating of the (fresh) slurry. These aspects were examined to get an insight into the question of whether a biogas plant can be operated reliably in which the slurry is supplied through an intermediate tank and stirred by means of slurry recirculation.

When an intermediate tank is inserted before the slurry supply the amount of influent can be monitored more accurately, but this may impair the reliability of the plant. The effectiveness of the recirculation system was measured by means of tracer studies. After the system had been modified, the stirring improved considerably resulting in a smaller reactor dead space, but an increase in gas production could not (yet) be established. Because the gas production was low during the experimental period, it was difficult to collect sufficient information to establish the effects of slurry pre-heating on the energy balance.

The second sub-project dealt with biogas purification. Data were collected on gas drying and three purification techniques which can be applied on the farm. Effectiveness, safety and costs were examined of the following methods:

- dry biogas purification with iron oxide;
- gas scrubbing with iron-containing groundwater;
- adding iron chloride to fresh slurry.

The costs of gas purification are closely related to the amount of biogas produced. With a view to its effectiveness and costs, dry gas purification is preferred to scrubbing with groundwater and the adding of iron chloride to the manure. The effect of purification is improved if the gas is also dried.

The third sub-project dealt with measuring the energy flows on a number of farms of the main livestock sectors. This was done to record and analyse the energy consumption patterns. For two dairy farms, two pig farms (combined rearing and feeding) and two poultry farms (layers) the electric load patterns were measured. The thermal consumption was estimated on the basis of previous measurements performed on similar farms. Of the farms involved in the measurements the pig farms offer the best prospects for applying waste fermentation from the economic point of view as these have a relatively high and constant demand for electricity and moreover (for six months of the year) a high demand for heat.

CONTENTS

1 INTRODUCTION

As part of the research into the use of alternative energy sources which got off the ground in the Netherlands after 1973, much attention has been paid to waste fermentation in livestock farming.

The Wageningen Agricultural University made a start by performing a small-scale experiment into the fermentation of pig slurry to materialize biogas production and odour control. This was followed by a project dealing with methane production and utilization on livestock farms by IMAG, Wageningen Agricultural University (departments of Microbiology and Water Purification) and IW-TNO. This research aimed at the microbiological and technological optimation of the production of biogas and at indicating applications for (dairy) livestock farms.

The first practical waste fermentation plants were commissioned on Dutch livestock farms on the basis of the first research results released in 1979. In those years a number of publications were written dealing with the prospects of manure fermentation as a source of energy. This was done on the basis of the above university research and of research abroad. Farmers and manufacturers became interested. Stimulated by the soaring energy prices and a stagnating economy 25 biogas plants were installed on livestock farms in a few years' time. The Government granted large subsidies to encourage the realization of these plants.

All the biogas plants built so far have been given more or less intensive guidance by several agencies during their initial years. In this way experience was collected with waste fermentation for various livestock farming and biogas plant types.

By means of research and experience a better insight was obtained into the nature of the fermentation process and how it can be affected (Zeeman et al., 1984; Houwaard, 1984). Besides, the knowledge of the technology of biogas production and consumption became more profound (Hoeksma & Arkenbout, 1984; Ter Rele, 1984), whereas research was also performed into the question of how to reduce the costs in order to optimize the range of application (De Boks & Van Nes, 1983).

Research and experience have produced a set of conditions for the application of manure fermentation. But the information collected was not enough to serve as a basis for a workable concept for the construction of a reliable and affordable biogas plant.

A few aspects which can strongly affect the process reliability and efficiency were still paid insufficient attention to, such as the monitoring of the slurry input, the mixing and stirring of the reactor contents, the heating of the slurry, the purification of the gas product and the demand for energy on farms. These aspects were the items of the research project "Improvement of biogas production and consumption from manure fermentation".

The aim of the project was to obtain supplementary knowledge and information on the practice of biogas production for designing biogas plants and the integration of waste fermentation on farms.

The demonstration project can be distinguished into three sub-projects with the following objectives:

- **Improvement of the fermentation efficiency by means of a better process control (slurry input, heating, stirring) and a more efficient conversion of biogas into thermal and electric energy.**
- **Cleaning of biogas by means of (1) dry gas purification combined with drying, (2) adding of iron chloride and flocculation sludge to the slurry, and (3) gas scrubbing with iron-containing groundwater.**
- **Performing measurements to get an insight into the electric consumption pattern on various livestock farm types.**

The research into the improvement of the fermentation efficiency was carried out with the existing pilot plant on the experimental dairy farm "De Vijf Roeden" at Duiven, which therefore underwent a few adaptations. Also the gas purification and drying experiments were performed here. The experiments with adding iron chloride to slurry were carried out on a poultry farm in Nistelrode. The information on scrubbing with iron-containing groundwater was obtained at a dairy farm in Dwingelo. The electric consumption pattern was established for two dairy farms, two pig farms and two poultry farms.

The demonstration project was carried out on behalf of the Netherlands Agency for Energy and the Environment (NOVEM) and the Commission of the European Communities.

The results in this report can be used to develop new fermentation projects, e.g. in combination with a central waste processing scheme.

The knowledge of biogas purification need not only be applied to waste fermentation, but can also be applied to the anaerobic processing of sewage sludge and other organic wastes.

A proper insight into the energy flows of livestock farms is conducive to a more efficient use of energy available.

2 EFFICIENCY OF FERMENTATION

2.1 Introduction

The energy yields from waste fermentation tend to be low. The low efficiency of the present biogas plants is partly due to the need for energy to sustain the process and partly to technical deficiencies, especially the absence of control and monitoring facilities.

Most plants are directly supplied from the slurry pit. The supply pumps are controlled from a time clock, and the pump capacity appears to vary under the influence of a changing consistency of the slurry. In this arrangement the amount of influent slurry cannot be measured accurately. By means of an intermediate tank with level indicator the supply can be more accurate. Besides, in an intermediate tank the influent slurry can be pre-heated by hot water from a total energy unit. Then, in the fermenter only the transmission losses have to be compensated for; moreover the heat recovered from the total energy unit is used more efficiently.

Trouble-free operation of a slurry fermenter requires that its contents is stirred properly. Agitation brings about a homogeneous distribution of temperature and substrate for micro-organisms and prevents the formation of crust and sediment. Insufficient mixing of the fermenter contents can entail an inadequate flow and dead space, which results in shorter residence times of the slurry in the reactor and consequently in a lower gas production.

The last few years the stirring systems of several waste fermenters have appeared to be inadequate (Hoeksma, 1984), and of others the stirring performance is doubtful. Satisfactory experiences were gathered with the agitation by means of gas recirculation (Hoeksma & Arkenbout, 1984). However, such an agitation system not only requires a blower, but also a separate biogas circuit with additional safety valves and fittings, which make it rather complicated and vulnerable.

Slurry recirculation, as applied in slurry stores, is financially an attractive stirring concept, especially if the same pump can be used for supplying the slurry to the fermenter.

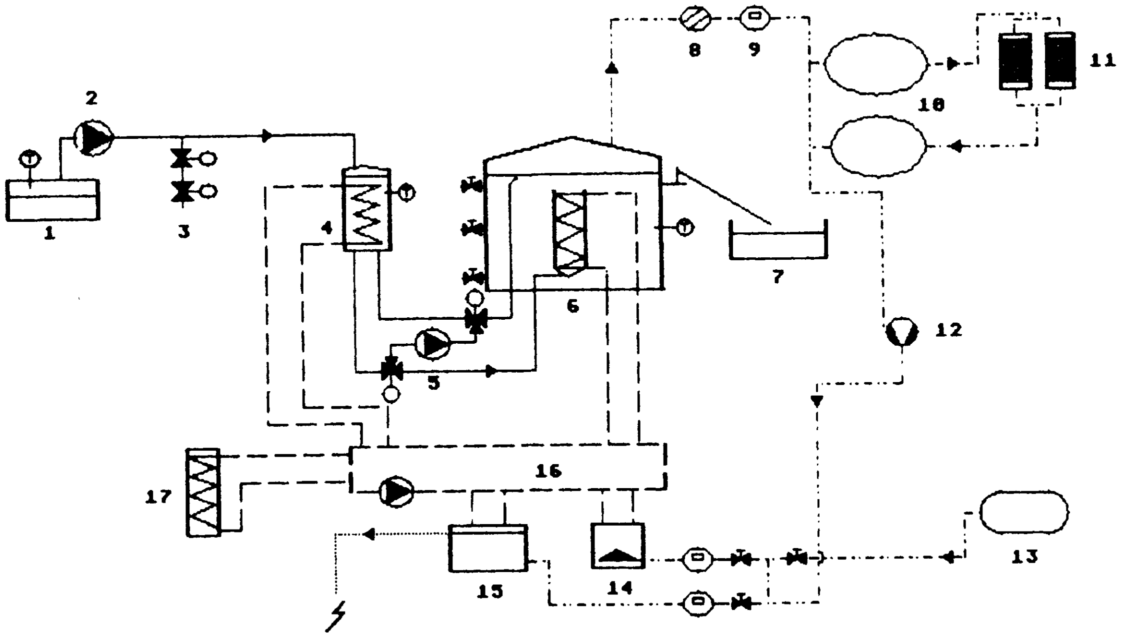
The research was to provide answers to the following questions:

- Can loading the fermenter through an intermediate tank be accurate?
- Is slurry recirculation adequate and efficient for stirring?
- Can a plant incorporating the above facilities be operated automatically and reliably?
- How does pre-heating of influent slurry affect the energy balance?

2.2 Materials and Methods

Pilot plant

For the research project several parts of the existing biogas plant of the Duiven experimental farm had been modified (slurry supply, stirring, heating, gas storage, control). This was done to achieve lower process and maintenance costs, a better reliability, and the option of a fully automatic operation. A diagram of the pilot plant is given in Figure 1. Appendix 2 contains a number of photos of the pilot plant.



1 slurry pit
2 supply pump
3 sampling unit
4 intermediate tank
5 loading/stirring pump
6 fermenter
7 storage of digested slurry
8 foam separator
9 gas meter
10 gas holder
11 gas purification
12 gas blower
13 propane tank
14 heating boiler
15 total energy unit
16 primary heating circuit
17 control room

Figure 1: Diagram of the Duiven Pilot Plant

Fresh slurry is pumped from the slurry pit below the cowhouse to an intermediate tank, where it can be pre-heated with residual heat from the total energy unit. The intermediate tank can at most contain half a day's production of slurry (3 m^3). The fermenter has a net reactor volume of 110 m^3. It is loaded from the intermediate tank by means of a pump which is also used for recirculating the slurry in the intermediate tank and in the fermenter. The transfer from intermediate tank to fermenter is performed automatically as soon as the slurry has adopted the correct temperature. If necessary, the fermenter contents can be heated additionally. In the centre of the fermentation room is a heat exchanger shaped as a double-walled cylinder through which the material is pumped.

The biogas is collected in a balloon (75 m^3) from where a blower sends it to the test setup for cleaning and drying. The purified gas is stored in a second balloon (50 m^3). The total energy unit and boiler can draw their biogas from either balloon.

Loading

The intermediate tank is loaded from the slurry pit twice daily. The supply pump (10 m^3/h) is switched on from a time clock and switched off from a level switch in the intermediate tank. In addition there is an extra indication which comes into action when the maximum slurry level in the vessel is reached, ensuring that the loading pump is switched off if the level switch should fail. The time needed to fill the intermediate tank may slightly vary depending on the slurry viscosity.

If the maximum level in the intermediate tank is not reached because of clogging or other causes, a time clock switches off the supply pump and the process is continued. To verify the amount of influent slurry the pumping time is (always) recorded.

The fermenter is loaded as soon as the fresh slurry has reached the temperature set. The loading pump operates on the basis of temperature and maximum level in the intermediate tank. Should the slurry in the tank not have reached the input temperature within a time span set, a time clock takes care that the loading pump is switched on.

Heating

The residual heat from the total energy unit is distributed in a sequence to a certain preference as follows:

- intermediate tank
- fermenter
- control room
- farm
- emergency cooling.

The theoretical heat-exchanging capacity of the double-walled intermediate tank averages 22.6 kW over a temperature range of 5-35°C and at a water temperature of 80°C. This more or less agrees with the thermal capacity of the total energy unit. The time needed for heating up the tank contents is 3-4.5 h. During the heating process the slurry is frequently (every 10 min) recirculated to achieve an equal heat transmission. The boiler (on biogas or propane) is in principle intended for supplementary heating of the fermenter contents only. A thermostat controls the temperature inside the fermenter. If the process temperature falls below a set value the boiler is switched on.

Stirring

Intermediate tank and fermenter are stirred by the loading pump recirculating their contents. This pump can alternately be used for loading the fermenter from the intermediate tank, stirring the intermediate tank and stirring the fermenter. This is controlled by means of two three-way valves between intermediate tank and fermenter; these are operated from time clocks.

Inside the fermenter the slurry is alternately pumped through the central heat exchanger (Ø 40 cm) and a vertical pipe (Ø 15 cm) situated at 0.50 m from the wall and the end of which is in tangential direction on the level of the slurry. The alternating action is effectuated by having the pump work in clockwise and anti-clockwise direction, respectively.

The recirculation system was changed after residence time distribution measurements had shown that the stirring performance was not optimum. With the second version the pump flow can also be directed over the fermenter floor.

The process is controlled by a programmable logical controller (PLC).

Measurements

- Quantity of slurry input
  In automatic operation the quantity was measured on the basis of the intermediate tank contents; in manual operation this was done on the basis of the time that the supply pump was running.

- Composition of fresh and digested slurries
  Dry matter, chemical oxygen demand (COD), ammonia and volatile fatty acids were measured. The analyses were performed weekly at the IMAG laboratories for Environmental Technology to the NEN standards in force.

- Dry matter of fermenter contents
  These values were established monthly from samples taken from sampling valves at three levels in the fermenter.

- Gas production and consumption
  Daily readings from gas meters (dry gasometer)

- Gas composition
  Methane and hydrogen sulphide were measured monthly through a sampling valve near the gas production meter.

- Electricity production
  Daily readings from kWh-meter

- Slurry temperature
  Continuous measuring and recording by means of thermocouples (Pt-100) and datalogger of temperatures of pit, tank and fermenter contents, the latter at five locations.

Sampling of slurry

Fresh slurry was sampled by an automatic sampler which collected three sub-samples of 500 ml each from each batch. These were stored in closed containers. Of the sub-samples a laboratory sample was collected every week to be analysed.

Digested slurry was sampled every week at the fermenter overflow pipe. This was done in manual operation by collecting a sample of about 10 l of overflowing slurry in a bucket, from which the samples for laboratory analysis were taken.

Residence time distribution

The mixing of the fermenter contents and - related to that - the effectiveness of the agitator system were verified by measuring the residence time distribution. For this a tracer had been put into the fermenter, and its concentration in the effluent was monitored during the research period. The actual hydraulic residence time was calculated, and an insight was gained into the mixing status inside the reactor. The basis used for this was the concentration curve.

Use was made of experiences with this method by Petersen (1984) and Racs (1988). The model on the basis of which the calculations were made was described by Levenspiel (1972).

For measuring the residence time distribution the following materials and methods were used:

Tracer: Lithium chloride, solution of 200 g/l.
Supply: Once-only application to influent slurry, 27 g LiCl per m^3 of fermenter contents; this is 4.4 ppm, or rather about ten times the expected background concentration.
Sampling: Before LiCl was applied a reference effluent sample was collected from the fermenter; at the first loading of the fermenter after LiCl had been applied, an effluent sample was collected (= C_0). Next, daily effluent samples were taken at the same point of time for about 30 days. Samples were kept cool.
Sample treatment:
1. acidification with 10 ml HNO_3 (40%) per 100-ml sample
2. filtering
3. diluting (maximum four times)
4. analysis.

Analysing method: Atomic Emission Spectroscopy (AES)

2.3 Results

Experiences during operation

Technically, the plant met all the expectations based on experiences with other working plants.

The gas storage under pressure was replaced by storage under atmospheric pressure, which improved the reliability. The same applies to the replacement of the gas agitation/injection system by slurry recirculation.

No noticeable problems were experienced with the equipment operating on biogas, which was different from earlier experiences. For the heating boiler (Buderus, with Robertshaw control unit) and the gas engine (Fiat 124) the maintenance schedules were adhered to which were recommended on the basis of previous research: monthly cleaning of the boiler burner and oil changes of the engine every 250 operating hours. The oil used was the standard Fiat Totem oil.

The above-ground intermediate tank for accurate supply and pre-heating of the fresh slurry caused serious technical problems. Initially, no satisfactory solution could be found for a reliable level control.

Efforts were made to find a sensor to be incorporated in the tank to exclude weather influences. Other aims were that it would not be affected by soiling and corrosion, not be distracted by foam, be free from moving parts, require little maintenance, and be accurate. The first experiments were performed with a stainless steel oscillating element which received piezoelectric impulses to activate its resonant frequency. When the element dips in a liquid or slurry, its frequency will change, and a contactless switch responds. The element failed to meet the requirements. Crusting of slurry on its surface caused vibration to be absorbed, and consequently the element was no longer useful to control the supply pump.

A second attempt was made with micro-switches on the outside of the tank without direct contact to the slurry. The micro-switches are controlled from a float inside, via a counter-weight to the outside. The counter-weight level always indicates the slurry level. The system of float and counter-weight is reliable provided its moving parts are protected against dirt and frost. During the experiments no soiling occurred. Protection against frost can be achieved by amply using oil and grease. Frequent inspection remains necessary.

It took much time to find the correct and reliable level indication. As a result the planned automatic operation of the plant could not be realized for most of the experimental period. The fermenter loading was manually controlled. This resulted in an irregular progress of the technical process, and the measurements which were to provide an insight into the effects of slurry pre-heating on the process efficiency yielded results which were hardly useful.

Gas production

Figure 2 shows the curves for the biogas production, the process temperature and the loading of the fermenter between September 1985 and December 1986. The results of the fermentation process are summarized in Table 1.

Table 1: Process conditions and results for the period between September 1985 and December 1986

Duration of experiments	week	65
Reactor volume	m^3	110
Process temperature	°C	29
Slurry supply	m^3	1650
	m^3/day	3.6
Hydraulic residence time	days	31
Gas production	m^3	16120
	m^3/day	37
	m^3/m^3·day	0.32
	m^3/m^3·slurry	9.8

Figure 3 shows the concentrations for dry matter, COD, ammonia and volatile fatty acids in fresh slurry (influent) and in digested slurry (effluent) for the period between September 1985 and December 1986. In this period a total of 21,343 kg COD was converted (reduction = 14%). The theoretical methane production amounted to 0.35 x 21,343 = 7970 m^3, which corresponds with approx. 11,490 m^3 of biogas.

Stirring

Figure 4 shows the results of the residence time distribution measurements. The results of the tracer analysis are given as E functions (Exit age distribution). These indicate the residence time distribution at the exit (overflow) of the fermenter. The figure also states the E curve as applicable for a continuously stirred tank reactor (CSTR). Measurements 1 and 2 were performed before and after the stirring system modifications. The stirring intensity was adjusted such that one equivalent of the fermenter contents could be recirculated daily. The characteristic values for the recirculation system during the measurements are given in Table 2. The mean hydraulic residence time (HRTm) and the inactive capacity (reactor dead space; DS) calculated from the measuring data are given in Table 3.

Table 2: Characteristic values for the recirculation system during the residence time distribution measurements

Installed electric stirring capacity	kW/m³ of fermenter	0.05
Pumping capacity	m³/h	120
Stirring intensity	min/2 h	5
Stirring energy	kWh/m³ of fermenter·day	0.05

Table 3: Mean hydraulic residence time and percentage of dead reactor space for measurements 1 (before) and 2 (after stirring system modifications)

		Measurement 1	Measurement 2
HRTm	days	15.1	17.1
DS	%	18	7

Table 4: Results for total energy unit for 1986

Operating hours	h	659
Gas consumption	m³	5530
	m³/h	8.4
Electricity generation	kWh	8559
	kWh/m³	1.55
Electric power	kW	13.0
Electric efficiency	%	25.5

Electricity generation

The performance of the total energy unit for 1986 is given in Figure 5. The average results for this period are stated in Table 4.

Oil changes were made at 250 and 500 operating hours; the plant was overhauled at 500 h. From the point when 500 h were completed, the engine was run on purified biogas. Samples were taken of the engine oil, which were analysed by Shell; the analyses are shown in Table 5.

Table 5: Engine oil analyses of the total energy unit running on raw and purified biogas

Engine operating hours	3760	4029	4270
Purified biogas	-	-	+
Visc. at 40.C, mm2/s	95.2	91.0	92.8
Visc. at 100.C, mm2/s	10.7	10.9	10.9
Flash cc, .C	> 190	> 190	> 190
Watercontent, % v/v	< 0.05	< 0.05	< 0.05
TBN, mg KOH/g	5.0	5.5	7.2
Combustion soot	< 0.20	< 0.20	< 0.20
Dispersancy	93.1	95.4	94.8
METAL-ANALYSIS:			
Silicon, mg/kg	4	4	1
Iron, mg/kg	59	52	29
Aluminium, mg/kg	5	4	6
Chromium, mg/kg	2	1	1
Molybdenum, mg/kg	0	0	0
Copper, mg/kg	18	9	11
Tin, mg/kg	3	0	0
Lead, mg/kg	7	4	3
Nickel, mg/kg	0	0	0
Manganese, mg/kg	0	0	0
Silver, mg/kg	0	0	0

Comments**:

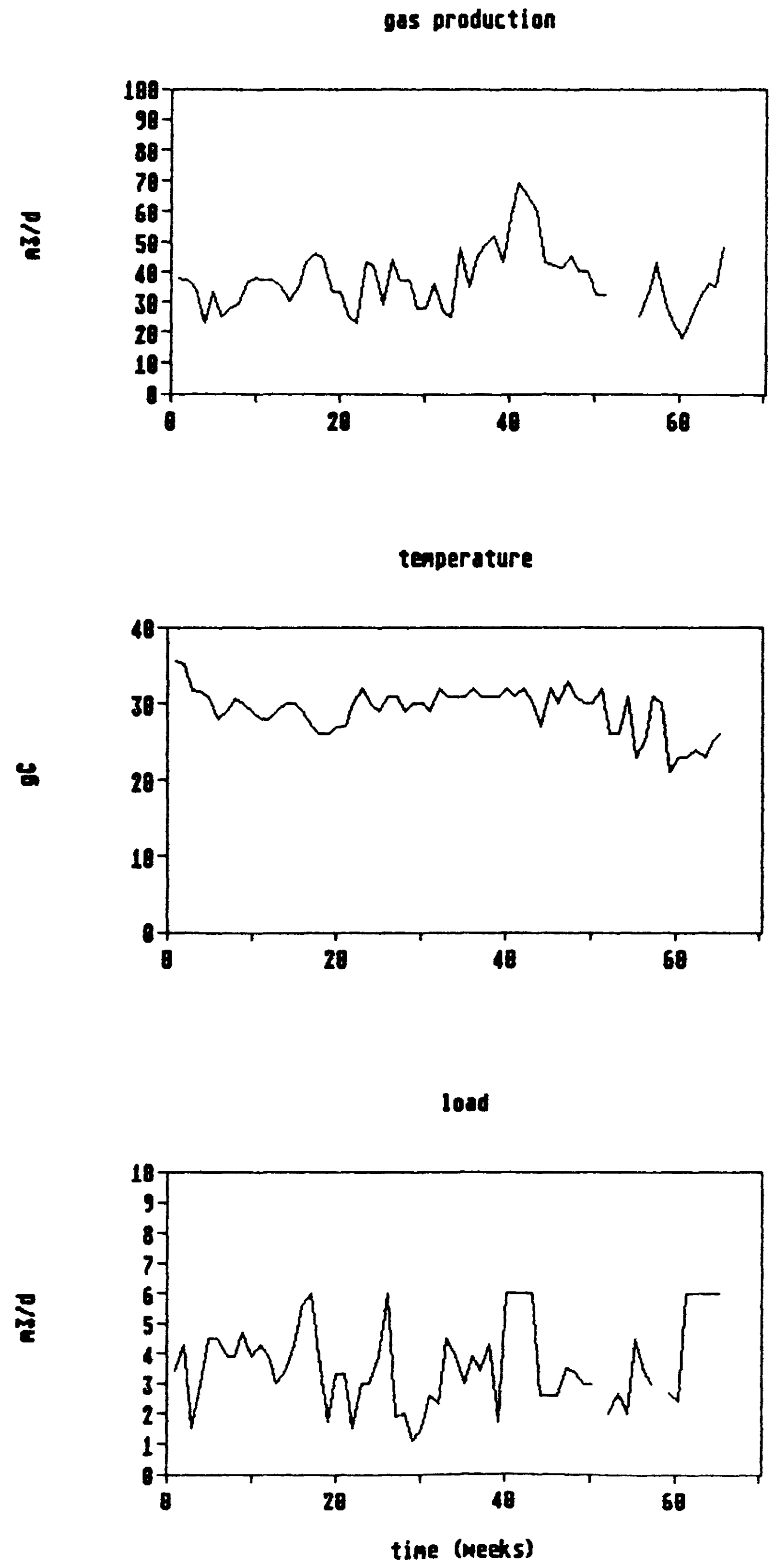


Figure 2: Biogas production, process temperature and loading of the fermenter between September 1985 and December 1986

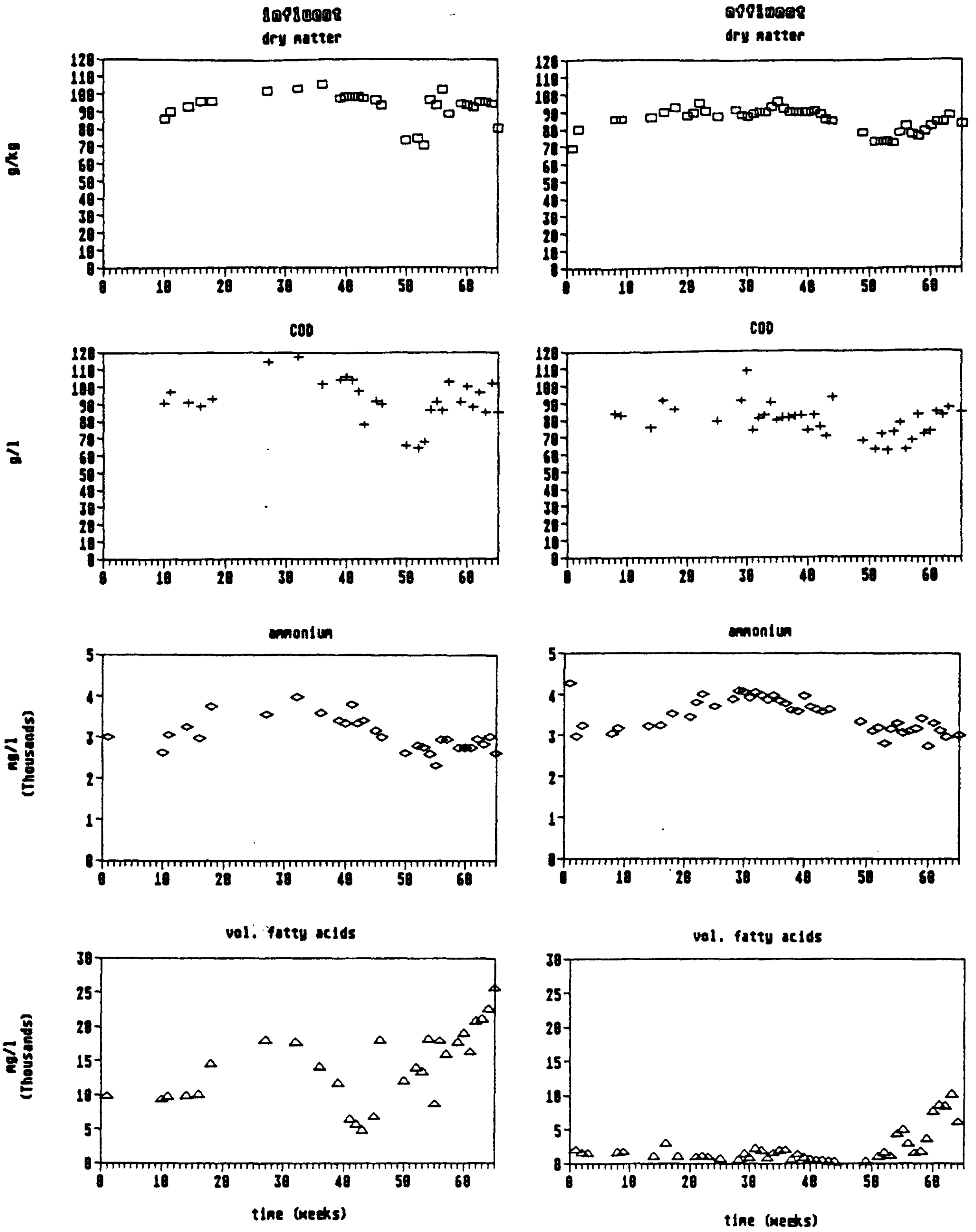
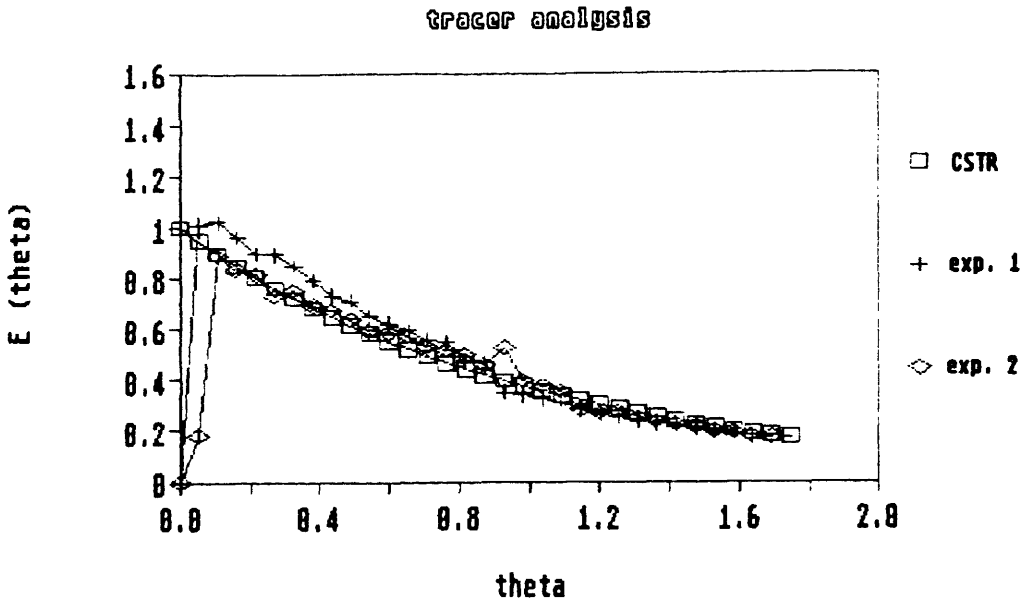


Figure 3: Concentrations of dry matter, COD, ammonia (NH_4-N) and volatile fatty acids (total C2-C5) in fermenter influent and effluent between September 1985 and December 1986



x axis: θ theta = t/τ
y axis: E (theta) = C_t/C_0

Reactor volume	m^3	110
Slurry supply	m^3/day	6
Theoretical residence time (τ)	days	18.3
Process temperature		
- measurement 1	°C	30
- measurement 2	°C	25
Tracer:	Lithium (given as Lithium chloride)	
Li^+ dosage	g	491
Concentration calculated at t=0 (C_0)	mg/l	4.46

Figure 4: Results of the residence time distribution measurements. Measurements 1 and 2 were performed before and after the stirring system modifications

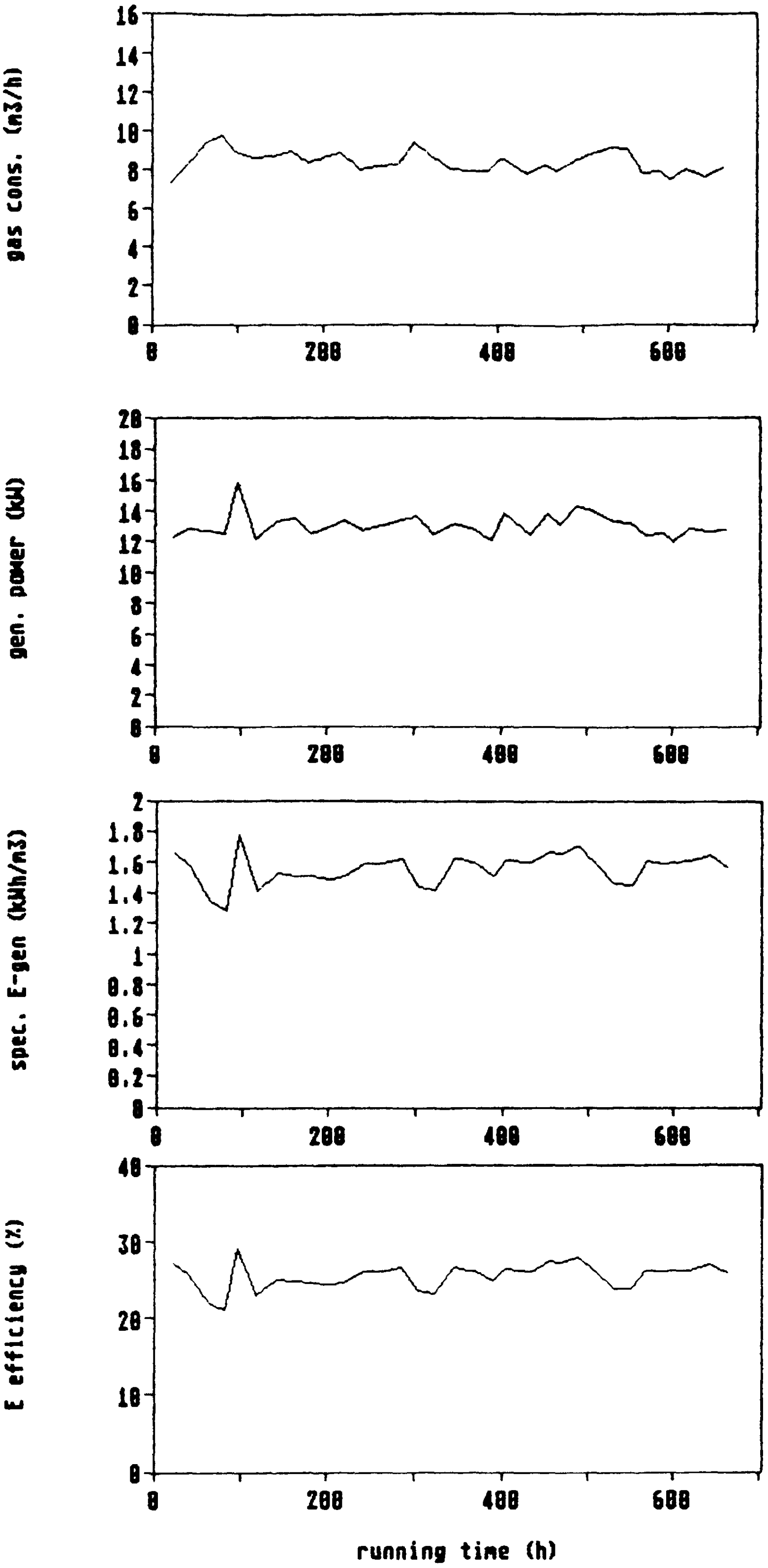


Figure 5: Gas consumption, energy supply, specific electricity generation and electric efficiency of the total energy unit (Fiat Totem) for 1986.
Overhaul at 500 operating hours.
Oil changes at 250 and 500 operating hours.

2.4 Discussion of Results

Loading through intermediate tank

Initially, there were quite some problems with the level control in the intermediate tank. It was found, however, that the reliability of the fermenter loading process can be adequate if control equipment is kept out of contact with the slurry. Related to the reliability of the system is the accuracy of slurry supply. Subsequent verification of the number of loadings is desirable and can be performed by means of a timer on the supply pump. During the research it was confirmed that control equipment in direct contact with the slurry cannot be applied in automatic systems.

Stirring by recirculation

The results of the residence time distribution measurements show that the modified recirculation system can effectively stir the fermenter contents. Initially the effectiveness of the recirculation system was insufficient in that only part of the contents was agitated, with the rest remaining inactive. This resulted in a shorter residence time than assumed on the basis of the slurry throughput set. A COD reduction of 14% was established, whereas under comparable conditions in a well-stirred reactor this is approx. 25%.

To verify the performance of the fermenter it is essential to measure the residence time distribution by means of tracers. In slurry analyses and temperature measurements it was found to be impossible to establish whether the entire reactor capacity participates in the process.

Gas production

Initially the causes of the low biogas production were thought to be biological, such as undernourishment (poor quality of the influent) and inhibition of the process due to a high ammonia concentration in the fermenter. It appeared that it could not have been undernourishment because of the organic load and the curve for the volatile fatty acids content in the effluent. Till the 60th week the fatty acid content roughly varied between 1 and 4 g/l. Between the 60th and 65th week the fatty acid content rose to 10 g/l, which indicates overnourishment. In this period the organic load was 3.8 kg/m^3·day at an average process temperature of 25°C.

Ammonia may have inhibited the methane formation, however, not to such an extent that this would fully explain the loss in production. The effect of ammonia inhibition in a full-scale plant is difficult to establish. The concentration level of ammonia in the period between the 24th and 40th week was found to be approx. 4 g/l. This is higher than usual in slurry digesters. In the same period the slurry input had a high ammonia concentration (because of high-protein diet?).

After the low organic conversion had been detected, the residence time distribution was measured, and it was found that the actual residence time of slurry in the fermenter was a few days shorter than thought to be. The actual value was approx. 15 days, instead of the theoretical value of 18 days. This explains the low conversion and the low gas production.

Total energy unit

The average performance of the Fiat Totem plant corresponds with that achieved by the same plant a few years ago. After 4000 operating hours no decrease in electric capacity and efficiency could be observed.

In the experimental period the plant was used very irregularly because of the mediocre gas production. Consequently, the week averages (Figure 5) vary strongly; the electric efficiency varies between 22 and 29%.

The overhaul at 500 h and the oil changes at 250 and 500 h did not noticeably influence the performance. The oil analyses show that the combustion of raw biogas entails a stronger decrease in total base number (TBN of new oil: 8) than that of purified gas. This implies that with raw biogas the neutralizing activity decreases faster than with purified gas and that oil changes have to be more frequent. Ter Rele (1984) recommended oil changes every 250 h when raw biogas is used. If the biogas is purified, the frequency can be lower.

The oil samples of raw gas contain more iron than the sample of purified gas. This indicates that gas cleaning results in a lower wear of the engine.

3 GAS PURIFICATION

3.1 Introduction

Because of the presence of H_2S and CO_2, combined with vapour, biogas has corrosive properties. Class (1969) provides a survey of experiments performed dealing with corrosion. Whether corrosion of the plant occurs in the presence of H_2S, CO_2 and water (vapour), depends on the quality of the materials and the circumstances (pressure, temperature and concentration) under which the corrosive gas and the materials get in contact.

"Sweet corrosion" is caused by CO_2 and water out of which H_2CO_3 is formed, and its attack manifests itself by "pitting". "Sour corrosion" is caused by H_2S and water. Hydrogen sulphide reacts with iron to FeS. In the presence of O_2 and/or CO_2 the release of hydrogen atoms causes stress corrosion as the atoms diffuse through the metal and can cause cracking (Groenewoud, 1987).

The flue gases from sulphur-containing gas contain the sulphur as SO_2 and minor quantities of SO_3, from which H_2SO_4 is formed.

To prevent corrosion special materials could be used, but this is an expensive measure and - with a view to SO_2 emission - not very useful either. Corrosion and emission problems can only be prevented by controlling the gas humidity and reducing the H_2S content.

The present research collected data on a few biogas drying and cleaning techniques which would seem to be promising to be applied on the farm. The following methods were covered:

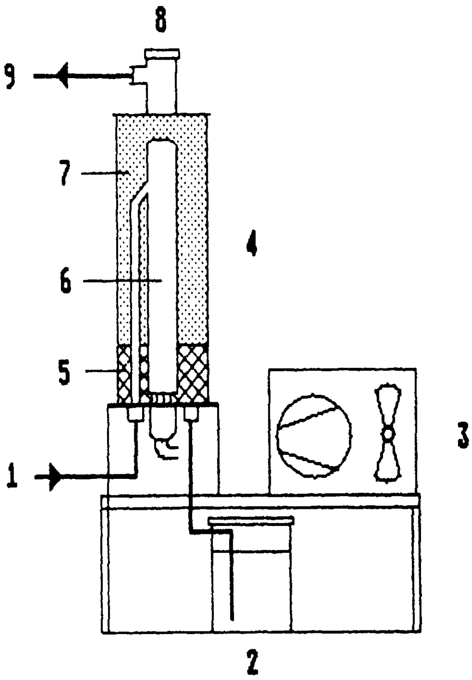
- dry purification of biogas
- adding $FeCl_3$ to fresh manure
- scrubbing of gas by means of groundwater.

3.2 Materials and Methods

Drying of biogas

The drying experiments were carried out at the pilot plant at Duiven, with a cooling/absorption drier, mounted between gas holder and purification equipment. The cooling/absorption drier is represented in Figure 6. It has a capacity of 10 m³/h.

A blower sends the biogas to the cooling/absorption drier, where it is cooled down to a dew precipitation point of 5-2°C. At this temperature there is also absorption. Because of the absorption of water (vapour) the dew point can be reduced further to approx -5°C. A large proportion of water vapour present in the biogas (approx. 15 g/m³) is separated by cooling and absorption. After the absorption step the ambient temperature warms up the gas to 10-25°C. The relative humidity of the gas will now be between 12 and 47%. The absorption material is potassium chloride (KCl) tablets. The drier can contain 25 kg of absorption material.



1 gas supply
2 water seal/condensation trap
3 cooler
4 cooling/absorption column
5 support packing
6 heat exchanger
7 absorption tablets
8 filling hole for absorption material
9 gas outlet

Figure 6: Diagram of the cooling/absorption drier

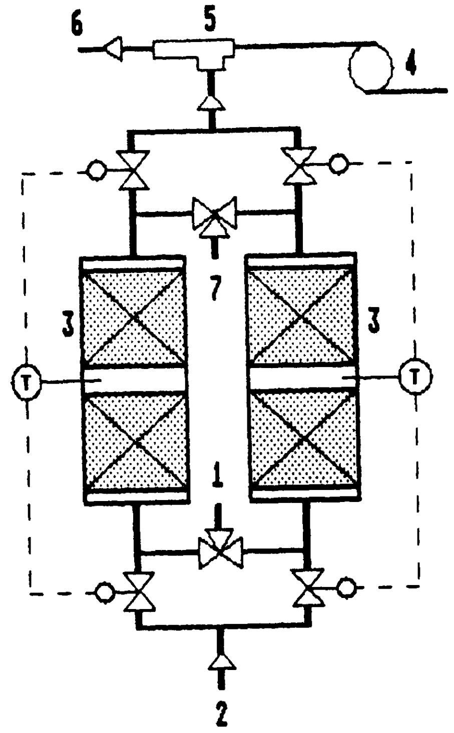
Measurements and calculations

- relative humidity of gas input and output
- consumption of absorption tablets
- energy consumption
- costs.

Dry gas purification

For dry cleaning research a purification plant was designed paying extra attention to the safety aspect when regenerating the absorption material as well as to the ease of operation when loading and emptying the columns.

The purification plant (Figure 7) consists of two parallel stainless steel columns containing 255 l each. There are two grids in the centre of the columns. The columns are filled with iron oxide grains on either end. The air supply during the regeneration of the iron oxide is controlled thermally by means of a thermo-couple between the grids. The grids shall also improve the gas distribution through the columns.



1	gas supply	5	ejector
2	air inlet	6	air outlet
3	purification columns	7	gas outlet
4	fan		

Figure 7: Diagram of the purification plant

A blower sends the raw gas through the plant, which may or may not include the gas drying unit. Before the biogas is treated, the purification column is scavenged with biogas to prevent that air would have made the gas lean when it is to be burnt. The scavenging is performed with a fan and an ejector. These create a vacuum in the system so that the regeneration process is accelerated. The regeneration frequency depends on gas flow, H_2S content and temperature rise. In the two columns there is purification and regeneration alternately. The purification plant is operated fully automatically. The experiments were carried out with two types of iron oxide, as shown in Table 6. The raw biogas was pre-dried to a relative humidity of 25-30%. In this range the effectiveness of Fe_2O_3 is the best. For the experiments a regeneration frequency of once every 24 h was maintained.

Table 6: Iron oxide types used for dry gas purification

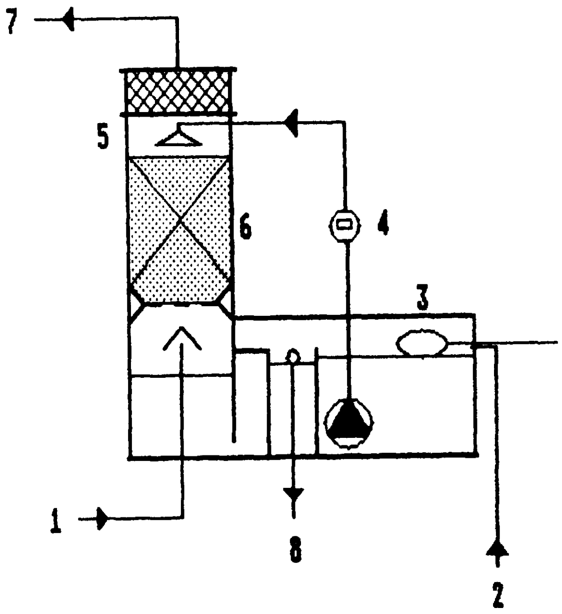
Make	Fe_2O_3 content % m/m	Price Hfl/kg
Giuline Chemie	38	1.10
Landustrie	25	2.00

Measurements and calculations

- H_2S contents of gas input and output
- consumption of absorption tablets
- costs.

Scrubbing with iron-containing groundwater

The research was carried out on a dairy farm with a fermenter capacity of approx. 5000 m³/year. The gas scrubber was arranged between gas holder and the gas users. A diagram of the scrubber is given in Figure 8.



1 biogas supply
2 groundwater inlet
3 float
4 water meter
5 sprinkler
6 scrubbing column
7 gas outlet
8 water outlet

Figure 8: Diagram of the gas scrubber

The scrubber consists of a 135-l column with "polynettes" tower packing to increase the contact surface. The iron-containing water is pumped from a depth of 27 m and sprinkled on top of it. The raw biogas is led through the column in counter-flow. There is a constant groundwater flow of 880 l/h. The gas flow can be adjusted. The iron content of the groundwater was established once and found to be 6.72 mg/l.

Measurements and calculations

- effectiveness of H_2S removal
- amount of groundwater needed at iron contents of 6.72 and 20 mg/l
- costs.

Adding iron chloride to manure

The research was carried out on a farm where a mixture of poultry and pig manure is digested.

The H_2S formation in biogas can be prevented by binding sulphides in the fermenter by adding $FeCl_3$ to the slurry. In the research a 35-% $FeCl_3$ solution was added daily to the fresh slurry in the intermediate tank. In measurements it was established how much iron chloride was needed.

3.3 Results

Drying of biogas

Figure 9 shows the relative humidity in biogas before and after the drying process. Drying appears to reduce the relative gas humidity to below the critical value of 60%. The measurements were performed on separate days. The duration of the measuring periods was between 2 and 5 h. The values given in Figure 9 are averages per measuring period. Measurements were performed at ambient temperatures between 16 and 25°C.

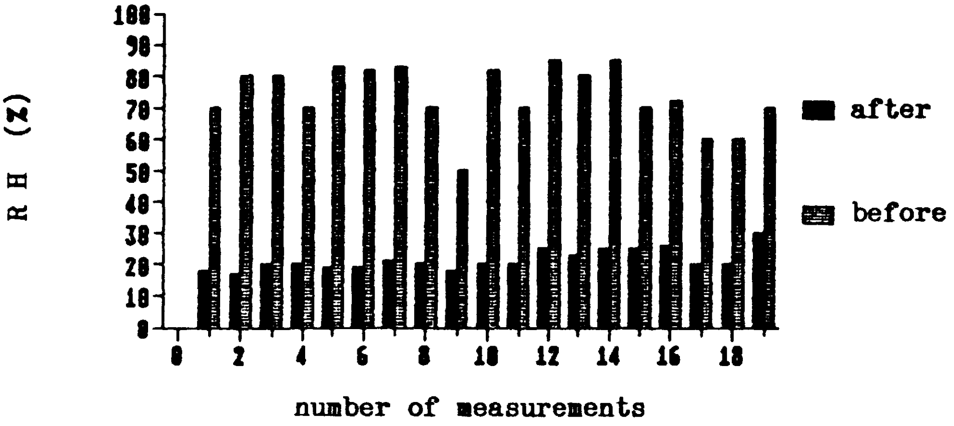


Figure 9: Relative humidity in biogas before and after drying

The water-absorbing capacity of the absorption tablets is 3 kg/kg. From 1 m^3 of biogas an average of 3 g of water is removed by absorption. The absorption tablet consumption is 1 g/m^3 of biogas. Every 2000 m^3 of biogas the absorption column has to be replenished.

Table 7 states the fixed and variable costs of gas drying by means of a cooling/absorption drier.

Table 7: Fixed and variable costs of gas drying by means of a cooling/absorption drier, in Hfl

Investment costs		6,500
Interest and depreciation	16.5%	
Labour and maintenance	2.0%	
Fixed costs, per year		1,202.50
Absorption material, per kg	8.00	
Energy, per kWh/m^3	0.08	
Variable costs, per m^3		0.022

Dry gas purification

The measurements of the purification plant were carried out together with those of the drier. The H_2S content was reduced to zero. The H_2S content in raw biogas varied between 1500 and 2500 ppm. 1 m^3 of biogas contained an average of 3.4 g H_2S. In total 13,300 m^3 gas was purified, with each column absorbing 22.6 kg H_2S. The sulphur load of the absorption materials used is then: Landustrie 22.1% and Giuline Chemie 17.5% m/m.

This is not the maximum absorption capacity of the materials. The quantity of biogas available for these measurements did not suffice to force a "breakthrough" at the regeneration frequency used of once every 24 h. Measurements on other farms which generate biogas have shown that the maximum load of the absorption materials is approx. 25%.

Table 8 states the fixed and variable costs of dry gas purification by means of iron oxide.

Table 8: Fixed and variable costs of dry gas purification by means of iron oxide, in Hfl

Investment costs		6,500
Interest and depreciation	16.5%	
Labour and maintenance	2.0%	
Fixed costs, per year		1,202.50
Absorption material, per kg	2.00	
Variable costs, per m^3		0.034

Gas scrubbing with iron-containing groundwater

Theoretically, 1 m^3 water of 14°C can dissolve 4.522 g H_2S at atmospherical pressure (an H_2S concentration of 3500 ppm corresponds with 4.9 g H_2S per m^3 of biogas). If the water contains iron, an additional quantity of 0.91 g H_2S is bound. A concentration of 6.72 mg Fe per l in water results in an increase in H_2S absorption capacity by 34-58% depending on the H_2S concentration. With 20 mg/l the increase in absorption capacity amounts to 50-80%.

Iron is not selective for sulphur and can also bind other substances. Therefore, the practical demand for iron (water) will be greater than the theoretical value.

Table 9 states the measurement results found with the gas scrubber. The effectivity of the scrubbing process is low, but can be raised by choosing a longer residence time. The optimum residence time of gas in the scrubber is 6 min during which an effectiveness of 50% is feasible.

Table 9: Results of scrubbing with iron-containing groundwater

Gas flow	Water flow	Fe content in water	H_2S content in gas	
			in	out
m^3/h	l/h	mg/l	ppm	ppm
2.3	880	6.72	3500	1500
4.0	880	6.72	3500	2500

Scrubber dimensioning

On the farm where the scrubbing experiments were performed the gas flow is 20 m^3/h for a considerable time (demand by total energy unit). The 6-min residence time and the corresponding volume load on 10 $m^3/m^3 \cdot h$ is achieved with a scrubber capacity of 2 m^3. With a groundwater flow of 6 m^3/h, the H_2S content in the gas appears to be reduced to 200-300 ppm.

Table 10 indicates the costs of gas scrubbing by means of iron-containing groundwater for the conditions as described above.

Table 10: Cost indication of gas scrubbing by means of iron-containing groundwater for a gas production of 75,000 m^3/year, in Hfl

Investment costs (incl. pump)		5000
Interest and depreciation	16.5%	825
Labour and maintenance	1.0%	50
Energy		500.00
Fixed costs, per year		1,375.00
Costs, per m^3 of biogas		0.018

Adding iron chloride to slurry

Figure 10 shows the decrease in H_2S content in the produced gas at increasing $FeCl_3$ doses (35-% solution). The H_2S reduction appears not to be linear. Relatively much iron chloride is needed for the reduction in the concentration range below 1000 ppm. Only with very high iron chloride dosages an H_2S-free gas could be obtained.

The amount of $FeCl_3$ needed depends on the amount of H_2S to be bound, and this again depends on quantity and composition of the fresh slurry. Stoichiometrically, per mol Fe_3^{+} about 0.3 mol H_2S can be bound. Theoretically, for an H_2S concentration of 3500 ppm (4.9 g H_2S/m^3) 1 kg of $FeCl_3$ (35%) will suffice for approx. 22 m^3 of purified biogas. Because there can be secondary reactions and the iron chloride may be unevenly distributed over the slurry, the practical need for $FeCl_3$ is larger than the theoretical value. Besides, the H_2S content of the gas is not reduced to zero, unless a large excess of $FeCl_3$ is used.

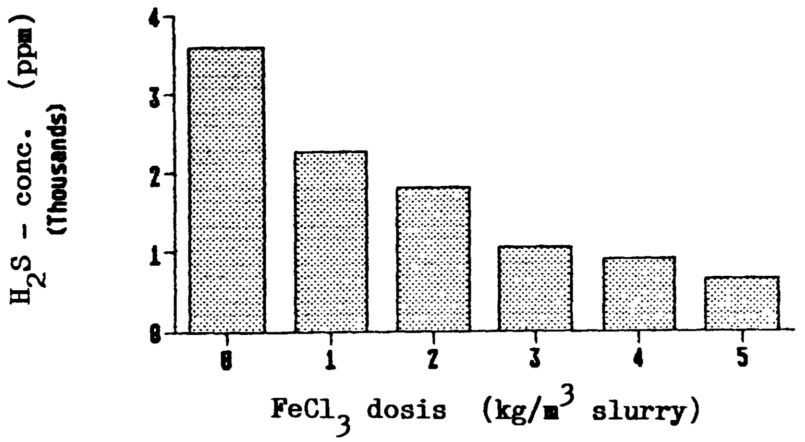


Figure 10: H_2S contents in biogas with various $FeCl_3$ dosages

The costs of gas conditioning by adding iron chloride to fresh slurry mainly consist in the purchase of the chemical. Table 11 states the fixed and variable costs involved. The calculation is based on an $FeCl_3$ demand of 4 kg/m^3 at a gas production rate of 20 m^3 per m^3 of slurry.

Table 11: Fixed and variable costs of gas purification by means of adding $FeCl_3$ to the slurry, in Hfl

Investment costs		2000
Interest and depreciation	16.5%	
Labour and maintenance	1.0%	
Fixed costs, per year		350
Iron chloride, per kg	0.25	
Variable costs, per m^3		0.05

Costs of gas purification

Figure 11 shows the costs of gas drying and the various purification processes related to the annual biogas production.

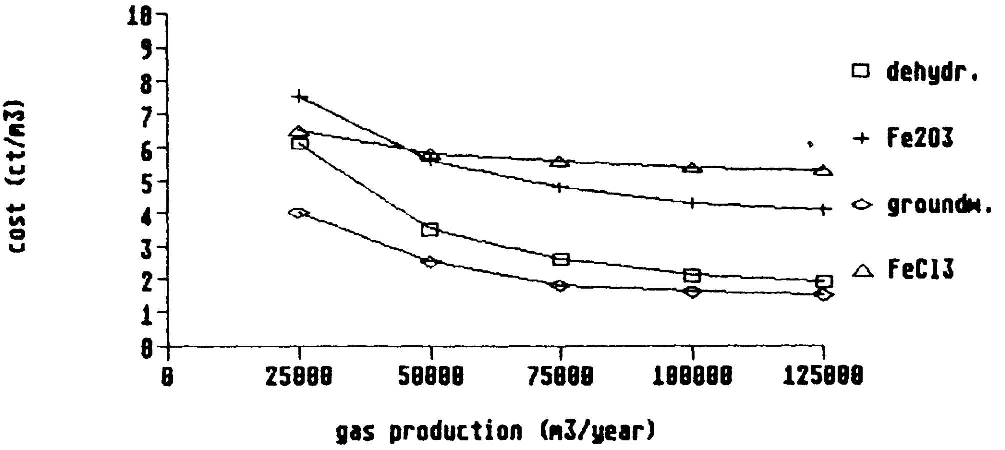


Figure 11: Costs of gas drying and purification related to the annual gas production

3.4 Discussion of Results

Gas drying

The usual method of gas drying by means of cooling and absorption has proved to be more expensive than estimated. Especially the capital investment required for the drier (prototype) turned out to be (too) high. This should be much less, otherwise this process will not be interesting for farms with gas productions up to 50,000 m^3/year.

An alternative for forced drying can be condensation traps in the gas duct system which has to be so laid to cool the gas, e.g. by laying part of the ducts underground (low soil temperature) and part above soil (low night temperature). If additionally the units operating on the gas are installed in a heated room (at least 15°C) the condition is met to reduce corrosive attack of equipment considerably.

Gas purification

For two reasons H_2S has to be removed from dry biogas. First, it is a further step to reduce corrosion. Secondly, the SO_2 emission standard has to be met when the gas is burned. Various research projects have shown that it is desirable to reduce the H_2S content to 100 ppm to comply with the SO_2 emission standard. When biogas is burned with 2500 ppm H_2S, 310 g SO_2 is formed per GJ of biogas (1 GJ $\approx$ 43 m^3 of biogas). With 100 ppm H_2S the SO_2 emission is 12.4 g/GJ, whereas for the combustion of natural gas 1.5 g SO_2/GJ is allowed.

Purification technique

Reliability, ease of operation, frequency of maintenance and safety are major technical criteria for gas purification systems.

Simple equipment does suffice for gas scrubbing with groundwater and adding iron chloride to fresh slurry.

Dry gas purification with iron oxide requires a plant with a rather complicated monitoring and control system, which implies that the reliability has to be assessed lower than for the two other methods, though this was not substantiated in the (too) short duration of the experiments.

The equipment tested was designed to be operated with a minimum of labour and maintenance. Scrubbing almost only requires regular visual inspection, no labour and hardly any maintenance. With the two other methods the absorption medium has to be replaced at regular intervals.

Scrubbing with groundwater is carried out in a closed system without oxygen being added (that is, in addition to what is present in the water), and therefore does not require extra safety precautions.

Dry gas purification with iron oxide develops an explosive gas mixture during the regeneration with atmospherical oxygen. It may become ignited spontaneously in high temperatures. Therefore, this method requires a 100-% safe temperature protection.

Effectiveness of the purification

A complete H_2S removal can practically only be achieved with dry gas purification, provided the correct regeneration frequency is observed. If the hydrogen sulphide content of the purified gas is measured regularly, it can be determined when the absorption material has to be replaced.

When iron chloride is added to fresh slurry, an H_2S reduction to the desired level of 100 ppm can only be achieved if large amounts of $FeCl_3$ are used, which is not interesting economically. An alternative is the use of $FeCl_3$-containing flocculation sludge, a waste product from slaughterhouses. An additional advantage of this sludge is its richness in fat and proteins which are easily converted anaerobically into biogas. A disadvantage can be the formation of crust and sediment in the fermenter. It has to be mentioned, however, that there is only limited supply of flocculation sludge.

Scrubbing with iron-containing groundwater can only be practised effectively in areas where the groundwater has a high iron concentration. An important additional effect of scrubbing is a reduction in CO_2 content of the gas so that a natural gas quality is obtained. This makes it suitable to be burned in natural gas boilers and engines, without modifications being needed. During the scrubbing also a small amount of methane will dissolve in the groundwater.

The residual product from gas scrubbing is a large amount of sulphur-containing water which is discharged into the surface water and pollutes the environment.

Costs of purification

The three purification techniques differ greatly in their financial consequences. The cost level of dry purification is about twice as high as that of scrubbing with groundwater. In both cases the costs per unit of gas are strongly related to the biogas production. Dry purification and scrubbing entail mainly fixed costs (investments). The costs of $FeCl_3$ application to fresh slurry are mainly related to the amount of gas produced. Even with higher gas yields, the costs of 1 m^3 of gas will not be less than 5 cents.

On the basis of effectiveness and costs per unit of biogas, dry purification is recommended for high biogas productions (from 50,000 m^3/year up).

The applicability of scrubbing with groundwater strongly depends on the iron content of the water. There are considerable regional differences. The residual water is a problem.

The adding of iron chloride to fresh slurry is not attractive from the economic point of view. In a few cases the use of flocculation sludge is an alternative.

4 ENERGY DEMAND OF LIVESTOCK FARMING

4.1 Introduction

The usability of the gas produced is one of the factors which determines the economic efficiency of a biogas plant. A proper insight into energy flows (as to both quality and quantity) in livestock farming is a must to come to a profitable utilization of the gas. At present only approximations can be given for the energy consumption patterns in livestock farming. So far, feasibility studies on biogas production could be based on theoretical patterns only (Offermans et al., 1982; IMAG, 1982; Van Heugten, 1984; De Boks & Van Nes, 1983).

It is known that great differences in energy consumption occur among comparable livestock farms (Oosterlaak, 1984 & 1985). Within the three livestock sectors there are specific operations with specific needs for heat and electricity. Table 12 gives a survey of the operations found in each sector.

Table 12: Major electricity and heat-consuming operations in the three livestock sectors

Sector	Electricity	Heat
Dairy farming	feed transport milking milk cooling cleaning waste handling	water heating
Pig farming	feed transport ventilation heating (pigs) cleaning waste handling	water heating space heating
Poultry farming	feed transport ventilation lighting egg transport waste handling	space heating

The use of biogas for just heating can only in special circumstances result in efficient management of a biogas plant (Hoeksma, 1984; Van Heugten, 1984). The use of the gas in a total energy unit offers better prospects. Dimensioning and control of the total energy unit have to be performed on the basis of the specific need for energy (heat and electricity) for the farm in question.

If the dimensioning of the total energy unit is based on the amount of biogas available and not on the need for energy, this could lead either to prolonged operation under partial load in isolated operation, which impairs the electric efficiency, or to selling the surplus electricity to the public grid in parallel operation, which has consequences for the financial yield.

Arkenbout (1984) provided useful generating diagrams on the basis of which the electric power can be selected and the total energy unit be controlled:

1 Electric base load with a high number of operating hours and disposal of heat surplus.
2 Electric partial load with optimum utilization of heat and highest possible amount of operating hours.
3 Electric peak load with low number of operating hours and disposal of heat surplus.
4 Thermal partial load and selling of electricity surplus to public network combined with highest possible amount of operating hours.

The electricity consumption patterns of a few farms of each livestock sector had been established and analysed. The heat consumption of these farms was estimated on the basis of earlier measurements on similar farms.

4.2 Materials and Methods

Electricity

On the farms the power consumption was measured on the main battery or a distributing battery for a period of five or six days. By means of clip-on instruments the current and voltage were measured for each phase. The advantage of these direct measurements - compared with the usual current measurement - is the fact that mains fluctuations are reflected in the results.

The clip-on instruments used have a range of 1-600 A. This implies a relatively large inaccuracy for the smaller section of the range. For these measurements an error of 7-11% has been allowed. Figure 12 shows a diagram of the measuring setup.

The channels (phases) connected were scanned every 15 s for five or six days. The results are processed into blocks of 15 min. For every 15-min span the highest, lowest and average values are given per phase and for the entire connection. These 15-min data were processed to load patterns. From the data for the total period of five or six days the average day load pattern was calculated.

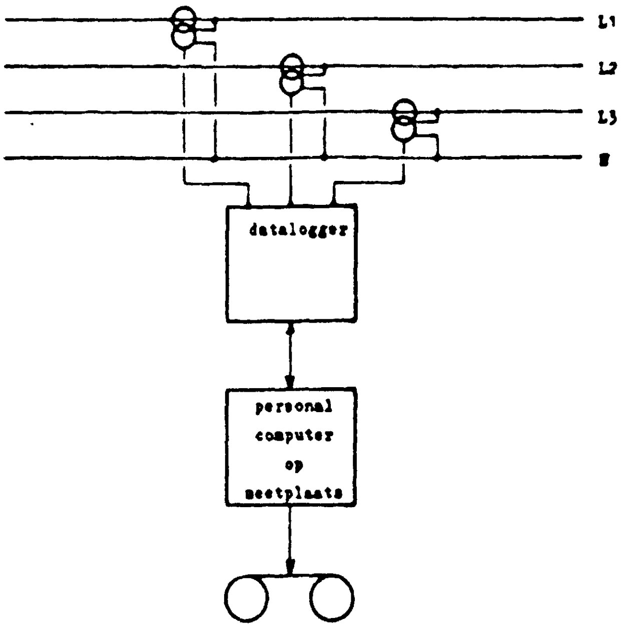


Figure 12: Setup for the power measurements

Selection of farms

The measurements were carried out on two dairy farms, two pig farms (combined rearing and feeding) and two poultry farms (layers) selected on the basis of the following criteria:

- presence of a biogas plant
- representativeness for the sector
- possibility of risk-free arrangement of measuring equipment
- presence of an installation diagram.

Heat

The demand for heat on the farms selected was estimated on the basis of previous research or calculations. The following sources were consulted:

- Heat demand on dairy farms per cow per day (IMAG, 1980)
- Heat demand on pig farms per pig place (Oosterlaak, 1985)
- Heat demand on poultry farms per hen place (Oosterlaak, 1984)
- Heat demand distribution over the year on various farms (IMAG, 1982; Van Heugten, 1984).

4.3 Results

Dairy farms

Farm M1

Dairy farm with 80 dairy cows accommodated in cubicle house with natural ventilation, milk cooling, electric hot water preparation and a biogas plant with total energy unit (15 kW).

Figure 13 shows the average daily electric load pattern of the farm including the farm house. The specific electricity consumption amounts to 1.27 kWh/cow·day. The heat demand of the farm is estimated at 50 kWh/day, with half of it being needed for water heating and half for heating the fermenter.

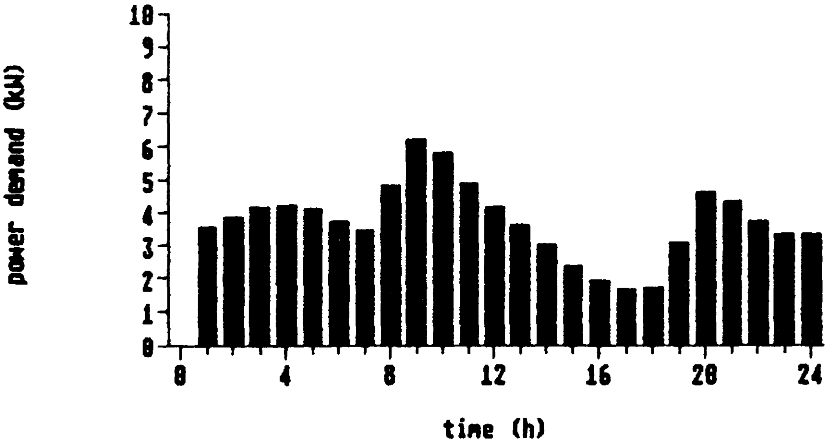


Figure 13: Average electric load pattern for a dairy farm with 80 dairy cows, incl. farm house (period covered: 30th October till 4th November 1986)

Farm M2

Dairy farm with 55 dairy cows accommodated in cubicle house with natural ventilation, milk cooling and electric hot water preparation.

Figure 14 shows the average daily electric load pattern (no farm house). This farm has a very low base load and two characteristic peak loads for milking and milk cooling. The specific electricity consumption amounts to 0.44 kWh/cow·day. The heat demand for water heating to clean the milking parlour is estimated at 19 kWh/day.

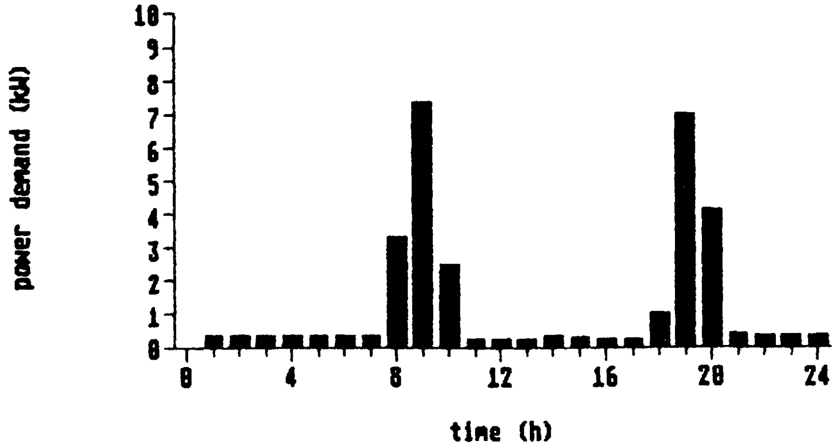


Figure 14: Average electric load pattern for a dairy farm with 55 dairy cows, no farm house (period covered: 9th - 15th November 1986)

Pig farms

Farm V1

Pig farm with 400 sows and 1400 fatteners provided with feeding, lighting, ventilation and heating facilities with automatic control. The farm has a biogas plant. Recently a total energy unit (15 kW) was installed.

Figure 15 shows the average daily electric load pattern for farm and farm house. The specific electricity consumption amounts to 0.19 kWh/place·day. The heat demand of the farm is estimated at 258 MWh/year, of which 98% applies to the period from November till May (IMAG, 1982). This means that the heat produced by the total energy unit can only be made use of in the winter months.

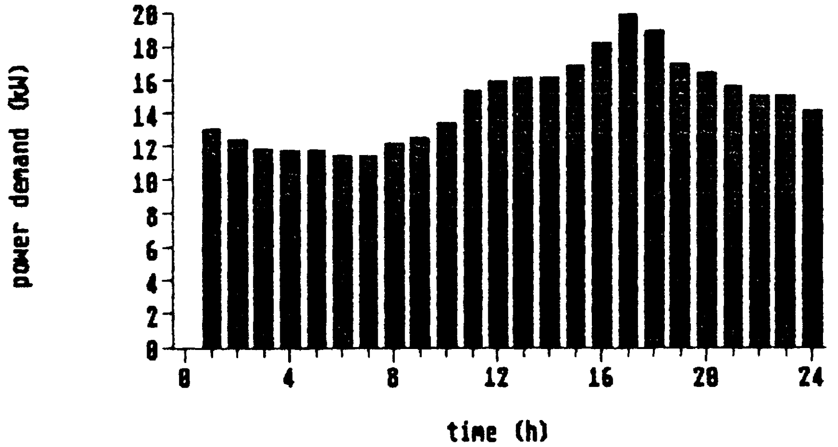


Figure 15: Average daily electric load pattern of a pig farm with 400 sows and 1400 fatteners, incl. farm house (period covered: 31st May till 5th June 1986)

Farm V2

Pig farm with 250 sows and 1200 fatteners provided with feeding, lighting, ventilation, heating facilities and a biogas plant.

Figure 16 shows the average daily electric load pattern of farm and farm house. The pattern roughly agrees with that of farm V1. It is characterized by a high base load (approx. 12 kW) and few fluctuations. The specific electricity consumption amounts to 0.22 kWh/place•day. The heat demand of the farm was found to be 207 MWh/year, which will practically only be required in the winter months.

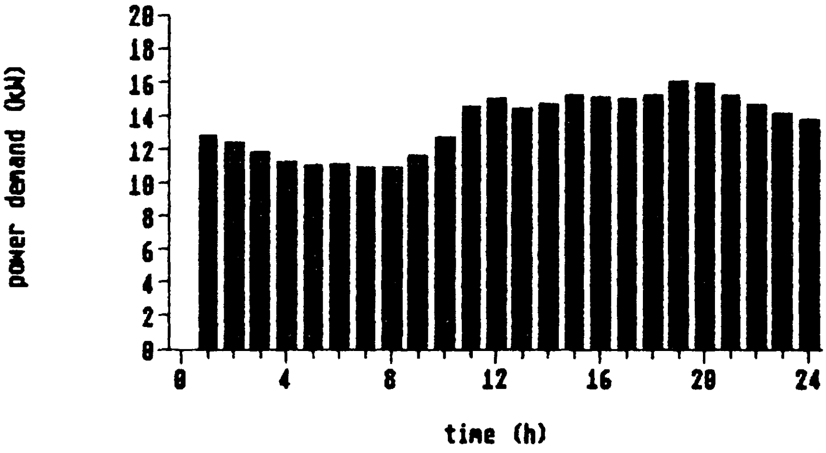


Figure 16: Average daily electric load pattern of a pig farm with 250 sows and 1200 fatteners, incl. farm house (period covered: 7th till 12th June 1986)

Poultry farms

Farm P1

Poultry farm with three houses for a total of 90,000 layers in multi-tier cages provided with automatic feeding, lighting, ventilation and egg collecting facilities.

Figure 17 shows the average daily electric load pattern (no farm house). The specific electricity consumption amounts to 5.6 Wh/animal•day. During the measurements much ventilation was practised. The heat demand of the farm is nill. For a large part of the year there is a heat surplus.

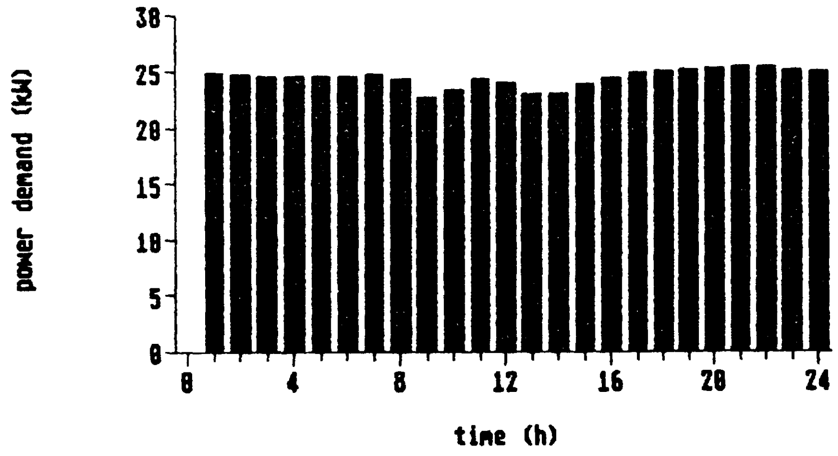


Figure 17: Average daily electric load pattern of a poultry farm with 90,000 layers, no farm house (period covered: 15th till 21st May 1987)

Farm P2

Poultry farm with 30,000 layers in cages, provided with facilities for automatic feeding, lighting, ventilation and egg collecting as well as a manure drying plant.

Figure 18 shows the average daily electric load pattern (no farm house). The higher average load at night and early morning attracts one's attention. This was found on the first day of measurements and cannot be explained. Like with farm P2 this is a summery situation with a rather high ventilating level. The specific electricity consumption amounts to 7.9 Wh/animal·day.

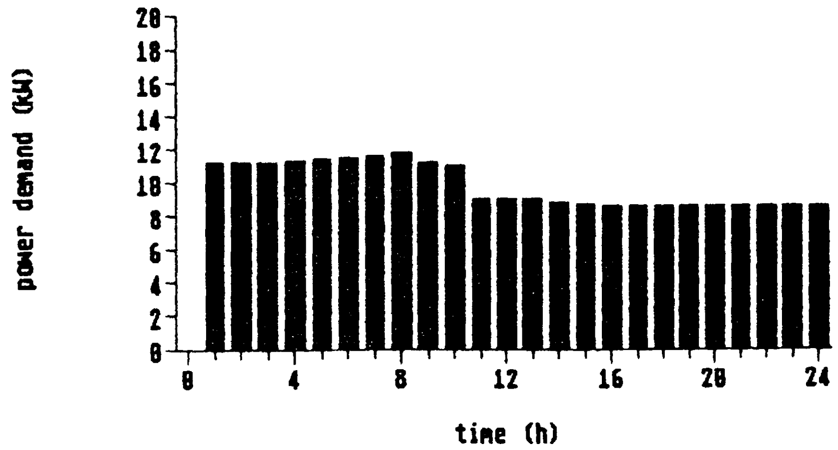


Figure 18: Average daily electric load pattern of a poultry farm with 30,000 layers, no farm house (period covered: 22th till 28th May 1987)

4.4 Discussion of Results

Dairy farms

The electricity demand of dairy farms is mainly due to the milking and milk cooling processes. The corresponding load occurs twice daily concentrated in time spans of 3-4 h. For the rest of the day the electricity demand is low. This characteristic consumption is expressed very clearly on farm M2. The load on farm M1 outside peak hours is unexpectedly high. Especially the high load over the night, which was found throughout the measuring period, was remarkable (It is not clear what caused this).

The heat demand of dairy farms is low. Practically only some hot water for cleaning is needed (3-4 l of 80°C per cow per day). The rest of the hot water is consumed for domestic purposes.

It is obvious that the energy demand of farm M2 is too low to enable the economic operation of a biogas plant. Farm M1 has a biogas plant with total energy unit. The generator of a nominal power of 15 kW runs in parallel operation. For other farms, e.g. the experimental farm at Duiven, it has appeared that the power supplied is approx. 13 kW. When the plant is operated, in all cases more than 50% of electricity generated will be sold to the public grid. In this situation a positive performance would only be feasible if the heat produced were fully utilized. Under the normal management conditions this cannot be realized on this farm. The total energy unit present is over-dimensioned.

From the purely energetic point of view it would be preferable for this farm to have a total energy unit in isolated operation of a maximum capacity of 6 kW. The economic feasibility of this small type of unit is doubtful.

Pig farms

The load patterns found of pig farms (combined rearing and feeding) offer prospects for auto-generation. A total energy unit of an electric capacity of 13 kW could be fully productive for 24 h during the summer months. The heat produced then cannot be fully utilized.

A continuous operation of such a total energy unit requires approx. 200 m^3 of biogas daily. The amount of slurry produced on farm V1 is not sufficient for this. A small amount of poultry manure is added to be able to meet the demand for gas.

If operated continuously, the total energy unit (7800 h/year) produces heat to a quantity of 234 MWh, of which about half (in the winter) can be utilized on the farm. A small portion will be needed to heat the fermenter.

For farm V2 it is not attractive to have more slurry come from other farms because the farm is situated in a surplus area from where it is an expensive affair to get rid of animal waste.

For farm V1 it has been decided already to install a total energy unit of the required capacity (Fiat Totem). For farm V2, where there is no total energy unit yet, this is recommended.

Poultry farms

Auto-generation in a combined heat and power plant is not considered efficient for poultry farms because of their very low heat demand. Auto-generation of electricity is very attractive because of the nearly constant demand for electricity. The units that would match the power demands of the farms involved, achieve an electric efficiency of at most 30%. The yields from electricity alone do not suffice for an efficient exploitation. If the heat produced cannot be made use of, the production of biogas on poultry farms should be dissuaded.

Measuring system

With the measuring system used in the research it is easy to obtain an insight into the actual load pattern of plants that consume electricity without the need to switch off the current. On farms with automated management this is a useful method by which measurements can be carried out without interfering with the management system.

5 CONCLUSIONS

Loading the fermenter via an intermediate tank reduces the reliability of the biogas plant. If an automatic plant is preferred, this type of slurry supply is dissuaded.

Temperature measurements and dry-matter analyses at a few levels in the fermenter cannot properly assess the stirring performance. A tracer analysis can provide a good indication of the actual residence time.

Gas purification will reduce the wear of biogas engines. With purified gas, oil changes will have to be performed about four times less than when raw gas is used. The purification effect is better if the gas had been dried before.

Forced gas drying by means of a cooling/absorption drier is expensive. A useful alternative is dewatering via condensation traps at locations where the gas cools down. The gas-fired pieces of apparatus should be installed in heated rooms.

With a view to effectiveness and costs dry gas purification by means of Fe_2O_3 is preferred to scrubbing with iron-containing groundwater and adding of $FeCl_3$ to fresh slurry for gas yields of more than 50,000 m^3/year. A disadvantage of scrubbing with groundwater is the environmental threat posed by the large water consumption which - when disposed of - contains sulphur.

An alternative for the adding of iron chloride to fresh manure is the use of flocculation sludge. This is relevant for farms which can easily obtain this sludge and can easily get rid of it when digested.

The load pattern should be known to be able to take a well-founded decision as to waste fermentation and to dimensioning and control of equipment to be operated on the biogas produced. In the past at some farms wrong decisions were made concerning this aspect.

The energy consumption of the dairy farms involved is too low for an efficient exploitation of the biogas produced, also because there are no total energy units of an electric capacity of less than 5 kW on the market.

For the pig farms involved there are favourable conditions for the application of biogas fermentation and the combustion of the gas in a combined heat and power plant.

The poultry farms involved have a nearly constant daily demand for electricity. The heat demand of these farms is practically zero. Auto-generation in a total energy unit is not feasible from the economic point of view because the thermal energy cannot be utilized at all.

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SYMBOLS AND UNITS

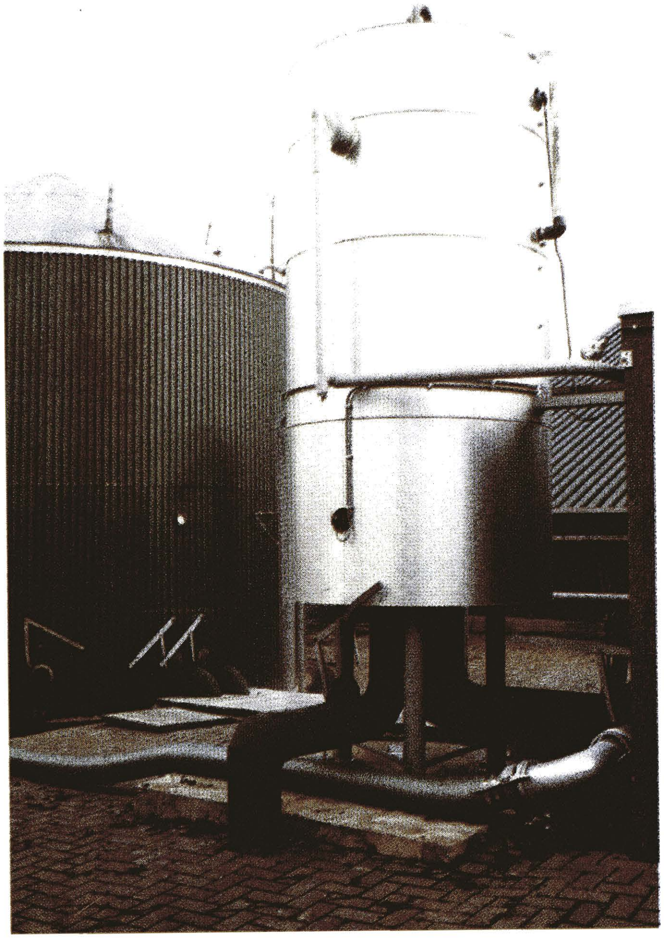
Appendix 1

AES - atomic emission spectroscopy
C2-C5 - volatile fatty acids: acetic acid, propionic acid, butyric acid and valeric acid
C_0 - concentration at time zero
C_t - concentration at time t
cc - closed cup (method of measurement)
COD - chemical oxygen demand
CO_2 - carbon dioxide
CSTR - continuous stirred tank reactor
d - day
DS - dead space
E function - exit age distribute function
Fe - iron
$FeCl_3$ - iron (III) cloride
Fe_2O_3 - iron (III) oxide
FeS - iron (II) sulphide
g - gram
°C - degree Celsius
GJ - gigajoule
h - hour
HNO_3 - nitric acid
H_2CO_3 - carbonic acid
H_2S - hydrogen sulphide
H_2SO_4 - sulphuric acid
HRT - hydraulic residence time
HRT_m - mean hydraulic residence time
KCl - potassium chloride
kg - kilogram
KOH - potassium hydroxide
kW - kilowatt
kWh - kilowatthour
l - litre
m - metre
m^3 - cubic metre
min - minute
mg - milligram
mm^2/s - square millimetre per second
% m/m - percentage by mass
Li - lithium
$LiCl_3$ - lithium chloride
NEN - Dutch standard
NH_4^+-N - ammonium nitrogen
O_2 - oxygen
PLC - programmable logical controller
ppm - parts per million
RH - relative humidity
s - second
SO_2 - sulphur dioxide
SO_3 - sulphur trioxide
TBN - total base number
t - time
τ - mean residence time
θ - dimensionless time unit t/τ
% v/v - percentage by volume

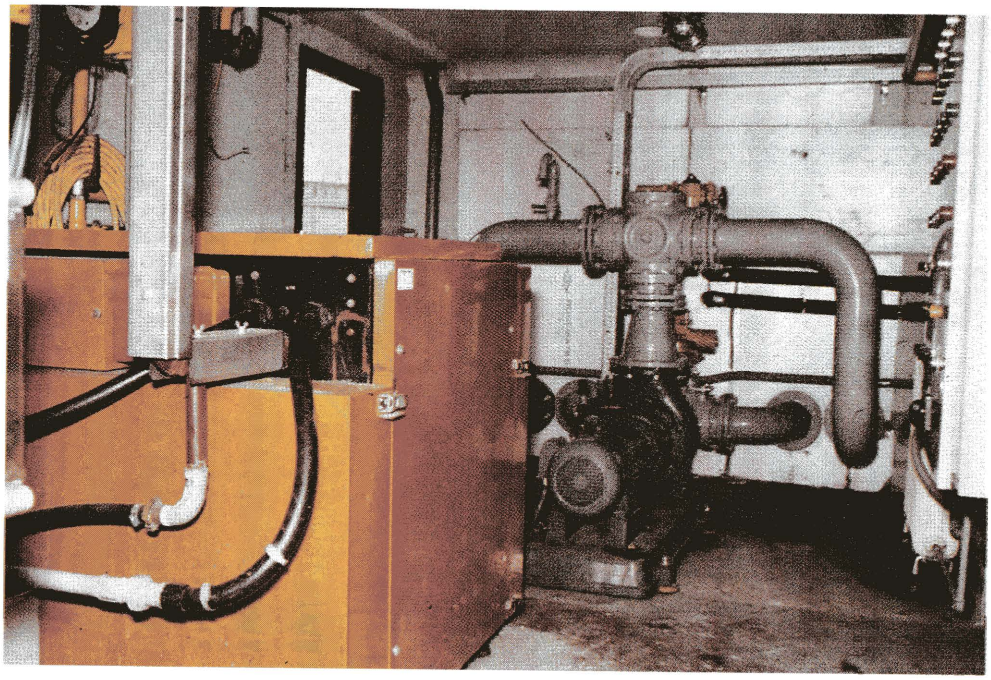
Appendix 2

PICTURES OF THE PILOT PLANT

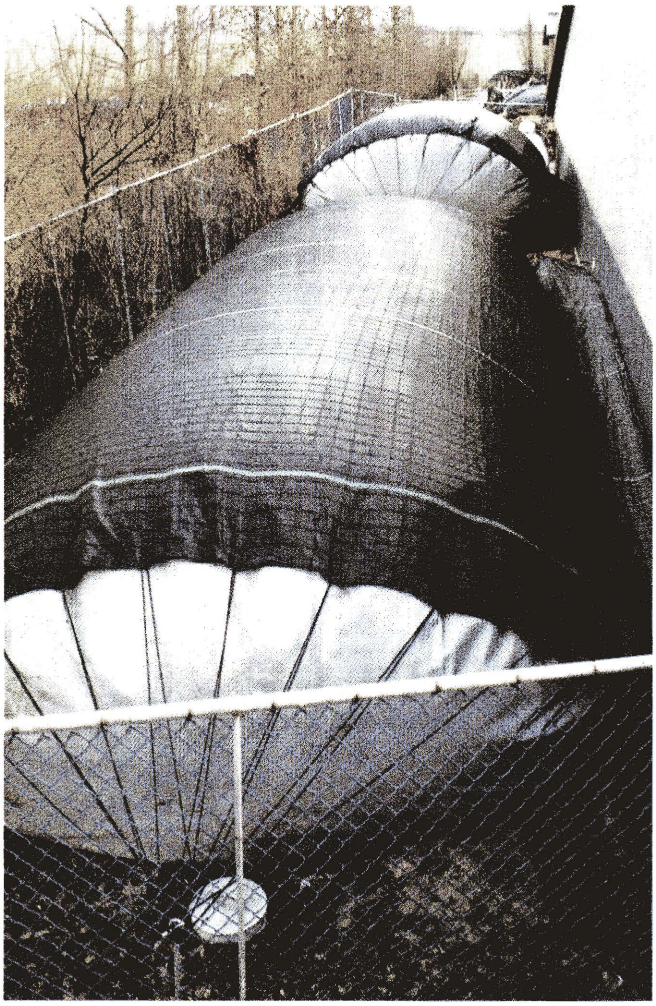
Picture 1: View of the original Pilot Plant in Duiven



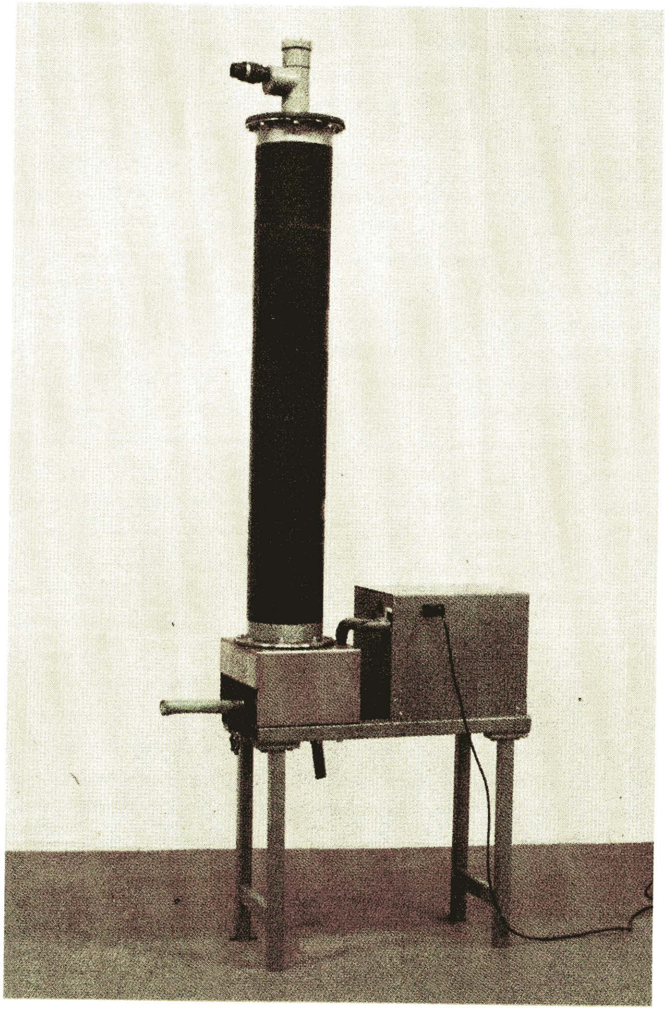
Picture 2: Intermediate tank for the pre-heating of fresh manure and controlled slurry supply to the fermentor



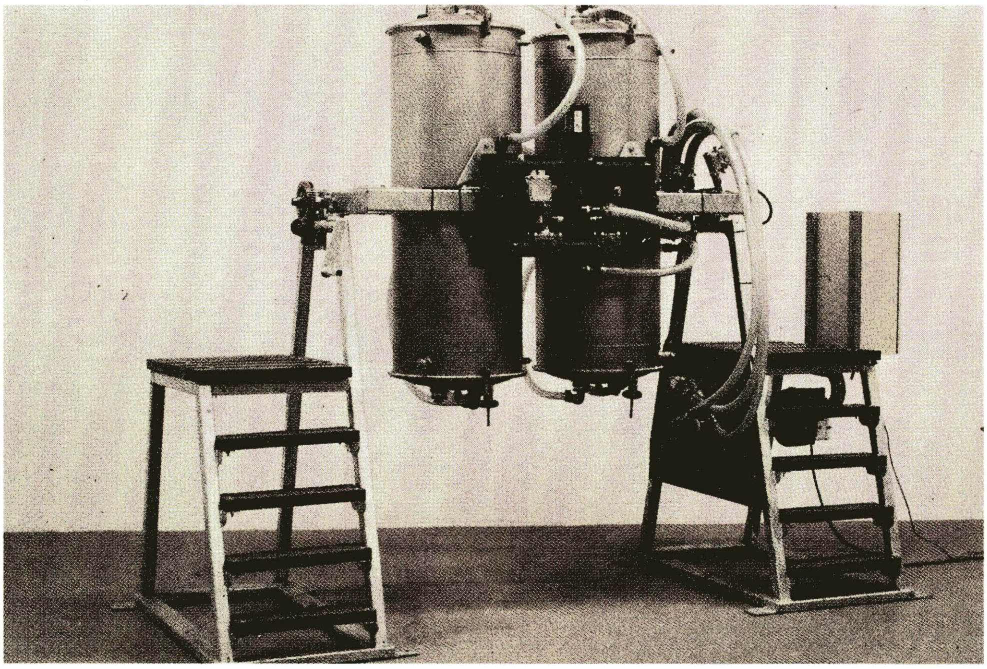
Picture 3: Engine room with total energy and supply pump



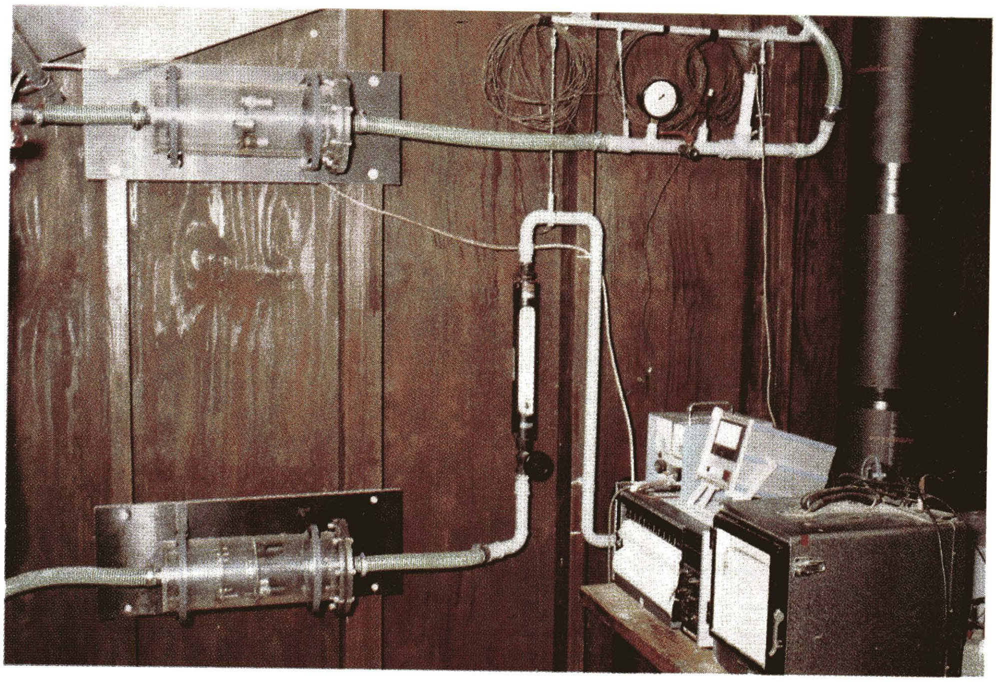
Picture 4: Gas holders for gas storage under atmospheric pressure



Picture 5: Cooling/absorption drier



Picture 6: Unit for dry gas purification



Picture 7: Measuring setup for research into gas purification

European Communities — Commission

EUR 11976 — Options to improve gas production and consumption from manure fermentation
Demonstration project

P. Hoeksma

Luxembourg, Office for Official Publications of the European Communities

1989 — VI, 50 pp. — 21.0 × 29.7 cm

Energy series

EN

ISBN 92-825-9438-6

Catalogue number: CD-NA-11976-EN-C

Price (excluding VAT) in Luxembourg: ECU 6.25

The aim of the project, which comprises three parts, was to improve the production and utilization of farm biogas. Systems for improving biogas fermentation and purification were developed. On the farm, energy flows and consumption patterns were examined. Pig farms offer the best application for this technology.