ENERGY FROM BIOMASS

Summaries of the Biomass Projects carried out
as part of the Department of Trade and Industry's
New and Renewable Energy Programme

VOLUME 4: ANAEROBIC DIGESTION FOR BIOGAS

INTRODUCTION

These volumes of Summaries provide easy access to the many projects carried out in the Energy from Biomass programme area as part of the Department of Trade and Industry's New and Renewable Energy Programme.

The Summaries in this volume cover contractor reports on the subject published up to December 1997.

REPORTS SUMMARISED IN VOLUME 4[1]

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ETSU R-41	Potential for biogas on farms in the UK	R E H Sims, Massey University, New Zealand K M Richards, ETSU	1987	37
ETSU B 1295	Potential for biogas on farms in the UK 1990 update	F E Mosey VFA Services Ltd	1991	40
ETSU B 1294	Anaerobic digestion of industrial wastewater: a survey of potential applications in the United Kingdom industry	Environmental Technology Consultants Ltd (ETC)	1993	43
ETSU B/MS/00192/20/REP	The treatment, reprocessing and incineration of animal waste slurries and sewage sludges An evaluation of the state-of-the-art in the Netherlands and Japan	International Flame Research Foundation, IJmuiden, Netherlands	1993	47
ETSU B/FW/00239/REP	Anaerobic digestion in the UK: a review of current practice	ADAS, Silsoe	1993	50
2.3 Products and Their Treatment				
ETSU B 7006	*A survey of existing methods of biogas scrubbing and utilisation*	*BABA Ltd*	*1987*	*54*
ETSU B 1124	*A detailed investigation into possible ways of achieving heat recovery from anaerobic digestion of effluent*	*Anaerobic Digester Research and Development Unit, The Polytechnic of Wales*	*1987*	*58*
ETSU B/M4/00532/16/REP	Suitability of the liquid produced from anaerobic digestion as a fertiliser	Livestock Systems UK Ltd	1997	61
2.4 Centralised Anaerobic Digestion				
ETSU B/00/00173/REP	Equity and debt financing for centralised anaerobic digestion of farm wastes: a feasibility analysis	Sceptre Management Ltd	1994	65
ETSU B/M4/00487/09/REP	Review of planning and environmental issues relating to centralised anaerobic digestion facilities	The Barton Willmore Partnership	1995	68
ETSU B/W2/00399/REP/1	Transport and supply logistics of biomass fuels. Volume 1 - Supply chain options for biomass fuels	Transport Studies Group, University of Westminster Scottish Agricultural College	1996	72
ETSU B/W2/00399/REP/2	Transport and supply logistics of biomass fuels. Volume 2 - Biomass and strategic modelling	Transport Studies Group, University of Westminster Scottish Agricultural College	1996	75

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2.5 Relevant Case Studies				
ETSU B 1127	*A large, farm-scale digester at Pittrichie pig unit Aberdeenshire*	*Microbial Biochemistry Department, Rowett Research Institute Engineering Division, North of Scotland College of Agriculture*	*1986*	*78*
ETSU B/M3/00388/17/REP	Anaerobic digester performance at Hanford Farms, Dorchester	ADAS	1994	81
ETSU B/M3/00388/27/REP	Technical monitoring of a mesophilic anaerobic digester fed with poultry manure - Bitterley Court Farm, Shropshire	Enertech (1983) Ltd	1994	84
ETSU B/M4/00487/04/REP	Monitoring of the anaerobic digestion and CHP installation at Newlands Mill, Newmarket Hesketh, Cumbria, with various types of animal excreta as feedstocks	Enertech (1983) Ltd	1995	87
ETSU B/M4/00532/10/REP	Renewable energy pilot projects	West Wales Task Force	1996	90

1. FARM WASTE MANAGEMENT ISSUES

Report No: ETSU B/FW/00224 Publication date: 1993

APPRAISAL OF FARM WASTE MANAGEMENT OPTIONS

ADAS, Silsoe

Background

Four main factors are currently affecting agriculture in Europe:

- Common Agricultural Policy reform
- world trade agreements under the General Agreement for Tariffs and Trade
- environmental considerations
- the contribution of the recently democratised Eastern European countries.

As a result, food and farming industries will need to adjust to lower internal market support, less protection from external trade and increased pressure for environmental protection.

From an environmental point of view, UK agriculture will need to respond to the Water Act 1989, the Water Resources Act 1991, the Environmental Protection Act 1990 and the EC Drinking Water directives. Considerable changes to current practice will be required in areas affected by the Nitrate Directive.

Project Objectives

- To review and appraise UK farm waste management options for all types of livestock.

- To provide a computer economic model that will enable an economic comparison and a sensitivity analysis of the options to be undertaken.

Findings

Sources of waste

Livestock in the UK produce some 170 million tonnes of excreta each year. Of this, some 60 million tonnes is voided in buildings: the remainder is returned directly to the land by grazing animals. In 1990 cattle were responsible for two-thirds of total excreta output and for more than 80% of that generated in buildings. The remainder was generated by sheep and by pigs and poultry. Intensification is characteristic of the pig and poultry sector, with small numbers of units containing a high proportion of the total stock. For example, some 1200 finishing-pig units (7% of the total number) house 59% of finishing pigs, while less than 1% of laying-hen holdings have more than 72% of the total number of laying birds.

Counties with large numbers of livestock (high livestock unit values) and large areas of agricultural land include Cumbria, North Yorkshire, Devon, Dyfed and Powys, and occur mainly in the west. Several eastern counties have large land areas with small livestock unit values, although localised areas of intensive livestock production do occur - mainly pig and poultry units associated with the production of cereals for feed. Pig slurries and manures, for instance, are significant in Humberside, North Yorkshire, Norfolk and Suffolk. Areas with high concentrations of poultry waste include Norfolk, Lincolnshire, Hereford and Worcester, and Suffolk. Humberside, North Yorkshire and Hampshire also have significant quantities. Poultry waste contains a much higher concentration of dry matter, nutrients and polluting potential to both air and water than other livestock wastes.

Waste occurs in three main forms:

- As slurry and farmyard manure from cattle and pigs, and as slurry and litter from poultry units.

- As dirty water (dilute slurry) from rainwater run-off from fouled open concrete yards, and from the cleaning of dairy facilities and pig and poultry houses. Many of these dirty water sources contain residues of manure, animal feed, milk and a whole cocktail of detergents and disinfectants with, at times, silage effluent.

- As silage effluent, which consists of a mixture of rainwater and plant juices. These drain from the store during and after silage making.

Waste management systems

All animal manures are valuable sources of crop nutrients, but there is concern about the large number of livestock farmers who do not fully utilise the nutrient values of their manures.

Each farm's waste management system has to be tailored to meet the constraints imposed on it by local conditions. The more important factors that need to be taken into consideration are the location and sensitivity of the farm site in relation to neighbours, water courses, water catchment areas and aquifers.

Most livestock farmers will continue to use standard, straightforward approaches to the handling, storage and field spreading of slurries, but will increase their management input during the land application stage. However, some sectors of agriculture will need to change their systems to reduce the risks of direct water pollution and smell nuisance, and to comply with forthcoming nitrate-related regulations. This will probably involve storing wastes for longer periods and either treating them or providing specialist land-application equipment to improve access and reduce risk.

Where some form of treatment is required, there are various options (see Table 1 below). Slurries can be enhanced by removing the gross solids. This, in turn, facilitates pumping, improves liquid absorption into the soil and reduces emissions. Options for reducing odour include aerobic treatment (easier and less costly if slurries are dilute and have a low dry matter content), and anaerobic digestion (particularly useful for slurries with a dry matter content of 8-15%). Compared with aeration, anaerobic digestion normally results in a more intensive degradation of the organic content, with lower associated losses of gaseous nitrogen.

Of the feedstocks available, slurries will usually be more appropriate for anaerobic digestion than farmyard manure and poultry litter, both of which have a much higher dry matter content. The power and gross thermal energy potential of slurries is estimated at 980MW continuous, or 30,912 TJ/year.

The most environmentally friendly and effective method of using poultry manure is probably to burn it as a fuel. The result is a dry, sterile ash, which has a concentration of nutrients that can be re-used. However, strict guidelines to combustion apply, and these are outlined in the Secretary of State's Guidance Notes. Authorisation will be required.

Satisfactory solutions are still required in the sphere of land application. The removal of slurry from store and its subsequent application to the land can be achieved in several ways, the choice of system depending on factors such as slurry quality or consistency, quantities involved, travel distances and cropping patterns. Tanker systems are heavy and cause damage to land and crops. One useful alternative is a lightweight umbilical system with a special applicator, operating from static tanks. On sandy or loamy soils, modern slurry injectors can perform without technical problems and with little damage to the turf. However, on clay soils with backfill over drains, there is the danger that slurry will be released directly into the drains and water courses.

Table 1 Summary of waste management system options

Technique	Advantages	Disadvantages
Waste spread directly to land - still an option in some cases	Carried out as part of routine work Saves on storage/treatment costs Avoids peak activity	Damage to land Poor use of nutrient potential Danger of pollution
Slurry storage - most appropriate in majority of cases	Better timing of land applications Convenient at cleaning-out times Better use of nutrient potential	High capital cost Siltation and capping of store Requires powerful mixer Potential odour problems
Manure storage - appropriate and recommended in all cases	Better timing of land applications Convenient at cleaning-out times Better use of nutrient potential	High capital cost Rainfall causes effluent run-off Potential odour problems
Weeping wall store on dairy farm - excellent practical option for cow slurry	Convenient at cleaning-out times Passive separation of effluent Effluent use on land	Cost of compound and effluent store Two types of spreader needed Potential odour problems
Mechanical slurry separation - increasingly popular for new stores	Reduces store size required Reduces siltation/capping of store Easier pumping, less odour, saleable fibre Enhanced use of liquid on crops	Requires pit, chopper pump and mixer Requires management High power input High capital and operational costs
Aeration for odour control - best option for thin slurry	Mixing and aeration carried out simultaneously Various stabilisation strategies available Reduces biological oxygen demand and odour	Management is critical High capital and operational costs Not applicable to slurries with a high dry matter content
Anaerobic digestion - comprehensive option	Good odour control Several valuable by-products Continuous flow process Alleviates problems in store Eases pumping	High capital cost for full system Specialist management required More complex business decisions needed
Composting of fibrous solids - separate enterprise selling raw fibre	Can alleviate nuisance odours Markets likely to grow Option for diversification Many organic wastes can be composted	Can cause emissions if badly managed Very high marketing costs High capital, management and operational costs
Sale of dry poultry manure as fuel - appropriate where farm has no land	Reduces storage requirement Maintains a cash flow Little management required	Applies only to dry poultry litter Low prices paid to farmer Nutrients removed from the farm
Removal of manure from farm by contractor - appropriate where farm has no land	Limited farm facilities required Little management required	Very high continuous charges Nutrients removed from the farm

Report No: ETSU B/FW/00140/REP Publication date: 1994

REGULATIONS RELATING TO MANAGEMENT AND DISPOSAL OF AGRICULTURAL WASTE - EFFECT ON ENERGY RECOVERY

P J Scott, Consulting Engineers

Background

Recent years have seen considerable changes in farming techniques, combined with greater specialisation and intensity of production. Intensified crop production requires more fertiliser than is available from traditional sources of farm manure, and few large arable farms now carry livestock. More intensive rearing and farming systems have also been introduced for certain classes of livestock, eg poultry, and, because such units rarely have large areas of land, disposal of the associated wastes has become increasingly difficult.

Because farming is a low-cost industry, farmers have tended to dispose of these wastes in ways that may now be perceived as environmentally and ecologically undesirable. Many previously acceptable practices have now been questioned, and appropriate controls have been introduced.

Controlled disposal methods are more costly than the previous ad hoc methods, and consideration has therefore been given to how some benefit might be obtained from use of the waste materials. While small-scale energy recovery projects do exist, the money necessary for investment in such projects is limited by falling agricultural incomes. A more attractive alternative could be the development of independent facilities to which large quantities of waste might be delivered by a number of producers.

Project Objectives

- To summarise the legislation and controls that currently relate to the handling and disposal of agricultural wastes.

- To outline the effects of the regulatory system on farming.

Current Legislation and Controls

Town and Country Planning Acts

The *General Development Order 1988* increased the requirement for farmers to obtain planning permission before constructing buildings, stock yards, slurry stores etc. This allows planners to examine the siting, design, access and appearance of the proposed structures. Where livestock facilities are concerned, the planning authority requires details of the arrangements to be made for the control of noise and smell and for the disposal of waste. Local environmental health officers and the National Rivers Authority (NRA) are likely to be involved, and planning is unlikely to be granted for proposals that do not meet the expressed requirements of these agencies. A 1992 amendment requires outline notice to be given to the local planning authority for all proposals related to farming.

The *Town and Country Planning (Assessment of Environmental Effects) Regulations* of 1988 also applies to “major” agricultural developments - 5000 fattening pigs, 100,000 broilers or 50,000 laying hens. The purpose of the order is to ensure that developers are adopting best environmental practice so that pollution/nuisance is avoided at source. Applications must be accompanied by an “environmental assessment”, which examines how the proposal might affect local flora and fauna, the soil, water resources, climate and landscape, together with any possible interaction with the local cultural heritage.

Water pollution control

The legislative framework that exists to prevent the pollution of water courses and underground aquifers, and which applies as much to agriculture as to other areas of activity, consists of:

- the Water Act 1989
- the Environmental Protection Act 1990.

Under the terms of the Water Act, which set up the National Rivers Authority (NRA), the disposal of liquid wastes from farms may take place:

- after treatment to reach a quality standard set by the NRA, by discharge to a suitable water course

- by spreading untreated or partially treated liquid on to the land in a way that prevents the discharge of polluted material to a water course.

The NRA also requires, under the terms of The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations 1991, facilities for the storage of liquid wastes and slurries to be of specific minimum capacities, properly constructed and fully water retaining.

The Environmental Protection Act introduces the principle of creating a “Duty of Care”, whereby those producing wastes have a duty to ensure their safe - and legal - disposal. The legislative requirements are contained in a document prepared by the Ministry of Agriculture, Fisheries and Food (MAFF) entitled *Code of Good Agricultural Practice for the Protection of Water*. This comprehensive document provides practical guidance on the handling of most types of farm waste. Failure to follow the Code may be taken into account in any prosecution arising from the pollution of water courses.

Air pollution control

The provisions of the *Public Health Act 1936* in relation to nuisance (offensive smells, particularly in built-up areas) have now been superseded by those of the Environmental Protection Act 1990. These provisions represent a significant problem for farmers in the operation of their activities, especially as there are no accepted methods for evaluating the extent and intensity of smells.

The control of odour is, to some extent, a matter of following the MAFF *Code of Good Agricultural Practice for the Protection of Air*.

If a farmer wishes to install a process for the treatment or disposal of waste that gives rise to smoke (eg incineration), the gaseous emissions will be subject to control, the process will require planning permission and the process may also require the preparation of an Environmental Statement and other documentation. Such procedures are complex and can only be justified for reasonably substantial projects.

Ground contamination

Spreading farm and other wastes in liquid and sludge form provides plant nutrients but may also contaminate the land with undesirable materials. In 1993, MAFF issued a *Code of Practice for the Protection of Soil* which summarises the relevant legal framework and provides useful practical guidance. However, the contamination of agricultural land is not believed to be widespread, except where the application of nitrate-based fertilisers results in high nitrate levels.

Effect of the Regulatory System

The disposal and handling of farm waste has, because of recent legislation, become a more exacting administrative task. As a result, there is little likelihood of an individual farmer wishing to be involved in the complexities of setting up and operating any system for on-site energy recovery from the waste produced.

A more rational and attractive option would be the transfer of waste to some central disposal unit on a “no fee” or limited fee basis. Existing examples are the disposal of poultry litter to the Eye and Glanford power stations. Centralised facilities for the anaerobic digestion of farm slurries could be an option for the future, with the scale of operation providing both economies of scale and the chance of more successful economic operation than a farm-scale facility.

2. THE ANAEROBIC DIGESTION OPTION

2.1 The Biomass Resource

Report No: ETSU-B-1055 Publication date: 1981

RESOURCE MAPPING OF AGRICULTURAL WASTES AND RESIDUES

National College of Agricultural Engineering
The Open University

Background

Agriculture produces many by-products that are currently under-used but have to be disposed of. Disposal may incur some expenditure: it may also create problems associated with pollution.

Although most residues are returned to the soil to provide nutrients for future crops, they could be used either as fuels or, in some cases, for energy production, with the final residue being returned to the soil. However, the distribution of agricultural wastes and residues throughout the UK is uneven and reflects the variations in climate, soils, terrain and agriculture. There is also some seasonal variation in waste and residue arisings. A detailed knowledge of these variations is essential to determine the most appropriate location for plants converting wastes and residues to energy.

Project Objective

- To summarise and map the agricultural wastes and residues generated in each region of the UK, thereby providing the information necessary for the efficient and economic use of these wastes and residues as an energy source.

The report is in five volumes. Volume 1 examines the generation of wastes and residues in England and Wales as a whole, while Volumes 2 and 3 contain the relevant regional tables and distribution maps. Volume 4 summarises the information for Scotland and Northern Ireland. Volume 5 consists of Appendices.

Methodology

The production of residues and/or wastes was estimated for each major crop and each class of animal. The estimates for England and Wales were based on information drawn from the Ministry of Agriculture, Fisheries and Food (MAFF) Agricultural Census for June 1976. The parish data obtained were converted to data for 5km x 5km grid squares based on the Ordnance Survey National Grid. Some reallocation of information was necessary to minimise inaccuracies. Tables were generated for each waste or residue in each region, and the data files were also used to produce computerised regional maps.

A similar approach to the measurement of wastes and residues was adopted for Scotland and Northern Ireland. Estimates were based on the 1976 Agricultural Censuses carried out by the

Department of Agriculture and Fisheries for Scotland (DAFS) and the Department of Agriculture for Northern Ireland (DANI). However, both censuses are less comprehensive than the annual MAFF censuses.

Findings

England and Wales

Table 1 below summarises the production and availability of agricultural wastes and residues in England and Wales in 1976. Some of these wastes and residues are already being used for various purposes. For instance, about 95% of the waste from housed farm animals is ultimately spread on the land after various periods of storage. However, this material could generate energy using the anaerobic digestion process, with the residue being returned to the land. Straw, on the other hand, is either left in the field and burnt, or returned to the soil during cultivation, or baled and removed for feeding stock (particularly barley straw) or for animal bedding (mainly wheat straw). The straw that is currently burnt or ploughed in represents a significant potential energy source either on or off the farm, and the manure/straw mixture produced by housing livestock could be used to generate energy by anaerobic digestion.

Although nearly all animal wastes are potentially available for energy, crop waste/residue availability ranges from only about 10% for dried pea straw to 100% for items such as brassica residues, hop prunings and rye straw. Overall, 85% of the 17 million tonnes dry weight of wastes and residues produced in England and Wales is potentially available for energy production. The gross energy content is nearly 264PJ.

Estimates suggest that there will be significant increases in the production of certain crops and therefore in the wastes generated. Residues and wastes from wheat, barley, potatoes and sugar beet are expected to increase by 18-30% between 1976 and 2000, while the residues from oil-seed rape are likely to increase by 740% over the same period. Dairying, on the other hand is expected to decline, with a 25% reduction in total waste produced in the period 1976-2000. Waste generated by poultry, however, is expected to increase by 3-6%.

Scotland

Table 2 below summarises the production and availability of agricultural wastes and residues in Scotland in 1976. Because little information exists on availability, the values have been determined using the same approach as in Table 1.

Table 1 Production and availability of agricultural wastes and residues in England and Wales, 1976

	Total production		Available production	
	Dry weight	**Gross energy content**	**Dry weight**	**Gross energy content**
	000 tonnes	**TJ**	**000 tonnes**	**TJ**
Livestock				
Dairy cattle wastes	2,176	38,087	2,176	38,087
Beef cattle wastes	1,242	21,743	1,242	21,743
Pig wastes	832	15,810	825	15,652
Poultry wastes	1,265	18,756	1,246	18,509
Crops				
Straw	9,276	177,511	7,224	140,078
Sugar beet tops	1,084	16,690	810	12,471
Potato haulm/waste	290	5,042	285	4,932
Oil-seed rape straw	109	1,967	109	1,967
Pea and bean wastes	460	8,251	367	6,599
Brassica wastes	123	2,076	116	1,964
Root vegetables	63	1,028	55	895
Hop residues	10	181	10	181
Orchard prunings	14	276	14	276
Orchard grubbings	23	465	21	418
Total	**16,967**	**307,883**	**14,500**	**263,772**

Northern Ireland

Table 3 below summarises the production and availability of agricultural wastes and residues in Northern Ireland in 1977. Because little information exists on availability, the values have been determined using the same approach as in Table 1.

Table 2 Production and availability of agricultural wastes and residues in Scotland, 1976

	Total production		Available production	
	Dry weight	Gross energy content	Dry weight	Gross energy content
	000 tonnes	TJ	000 tonnes	TJ
Livestock				
Dairy cattle wastes	308	5,382	308	5,382
Beef cattle wastes	513	8,983	513	8,983
Pig wastes	72	1,364	72	1,364
Poultry wastes	156	2,326	154	2,300
Crops				
Straw	1,318	23,568	840	15,023
Potato haulm/waste	52	895	51	885
Pea and bean wastes	17	297	16	282
Brassica wastes	3	40	3	39
Root vegetables	4	62	4	49
Raspberry residues	9	152	9	152
Total	**2,449**	**43,069**	**1,967**	**34,459**

Table 3 Production and availability of agricultural wastes and residues in Northern Ireland, 1977

	Total production		Available production	
	Dry weight	Gross energy content	Dry weight	Gross energy content
	000 tonnes	TJ	000 tonnes	TJ
Livestock				
Dairy cattle wastes	169	2,955	169	2,955
Beef cattle wastes	229	4,009	229	4,009
Pig wastes	80	1,530	80	1,530
Poultry wastes	122	1,778	122	1,778
Crops				
Straw	145	2,597	91	1,637
Potato haulm/waste	26	445	26	445
Brassica wastes	<2	13	<1	10
Root vegetables	<2	33	<1	24
Total	**774**	**13,360**	**719**	**12,388**

RUMINANT LIVESTOCK MANURE QUANTITIES BY ELECTRICITY COMPANY REGION WITH CONSIDERATION FOR ITS USE FOR FUEL OR FERTILISER

Agricultural Development and Advisory Service (ADAS)

Background

Environmental pollution as a result of livestock farming has increased over the past 20 years and is a matter of growing public concern. Legislation, notably the Water Act 1989 and the Environmental Protection Act 1990, has already been enacted, and more is likely to follow.

Ruminant livestock - dairy and beef cattle, sheep and goats - are relatively large animals with a high water intake and output. The problem is exacerbated by rainwater falling on soiled yard areas, while the use of these wastes entails costly storage, treatment and land application facilities and equipment, and a high level of management.

Alternative waste management options are being developed in addition to the adaptation of conventional techniques. These include conditioning the manure for use as a fertiliser for agriculture and horticulture, and using the manure as a fuel - either burning it or subjecting it to anaerobic digestion to produce biogas.

Project Objective

- To establish the quantities and location of ruminant livestock manure with respect to the Regional Electricity Companies (RECs), with consideration of its use for fuel or fertiliser.

Methodology

This study has assessed the quantities of manure collected during the winter housing period - normally October to March, although the dates of autumn housing and spring turn-out will vary between regions and between farms in any one area. The livestock information used has been obtained from the Census data, and county livestock information has been apportioned to the relevant REC on the assumption that there is a uniform distribution of livestock within each county. Estimates were then made for each REC of the proportion of stock housed in different housing systems - or not housed at all.

Findings

Manure production

Dairy cows produce between 32 and 54 litres/day of excreta, depending on animal body weight and feeding regime, with a dry matter content of around 12%. The quantities of bedding used are equally variable, depending on the type and form of bedding and on the housing system. In loose yards, long straw use at the rate of 8 kg/cow/day (1.5 tonnes/cow/180-day housing period) is recommended. Recommended bedding rates for

cubicles/kennels are, for long straw, 2 kg/cubicle/day and, for chopped straw, 1 kg/cubicle/day. The overall trend is towards using greater quantities of bedding, except for dry cows, young stock and beef animals.

The output of excreta from housed beef cattle is estimated at 10 litres/head/day up to six months and from 19 to 28 litres/head/day for animals between six months and sale at, possibly, 14 months old. Straw use varies with the system used, and figures quoted range from 0.7 tonnes/head for a cereal beef unit to 1.25 tonnes/head when cattle are finished at 14 months in a fully bedded house.

Overall, cows and heifers produce around 27 million tonnes of collectable manure per year, while other cattle produce a further 16 million tonnes per year.

Sheep and goats are estimated to contribute less than 3% (one million tonnes/year) of the total quantity of collectable manure. This is based on a limited degree of housing.

Overall, ruminant livestock in England and Wales produce an estimated 44 million tonnes of collectable manure per year. Of this, 66% is in the form of farmyard manure with a dry matter content of around 30%. The remaining 34% is slurry with a dry matter content of 12-20%, depending on the degree of drainage and drying during storage.

Five electricity company areas account for about 62% of all collectable manure in England and Wales (see Table 1 below) - nearly 59% of all the farmyard manure and 69% of the total slurry production.

Table 1 The main electricity regions producing collectable manure

Area	Total raw waste		Proportion of total
	Type	Tonnes	%
South west	Slurry	2,925,219	6.6
	Farmyard manure	4,866,582	11.0
North western	Slurry	1,981,569	4.5
	Farmyard manure	2,830,119	6.4
Midlands	Slurry	1,902,986	4.3
	Farmyard manure	2,991,347	6.7
Southern	Slurry	1,597,948	3.6
	Farmyard manure	3,733,474	8.5
ManWeb	Slurry	1,945,036	4.4
	Farmyard	2,601,996	5.9

Using livestock wastes

Use as fertiliser

Ruminant slurry and farmyard manure are usually spread on the land and provide around 5 kg/tonne of nitrogen (low), only 30% of which is readily available to plants, 2-3 kg/tonne of phosphate and 5-7 kg/tonne of potash. The value of these nutrients is assessed at £320/tonne, £500/tonne and £180/tonne, respectively. However, the spreading procedure causes odour nuisance problems at the time of application and generates concerns about water pollution. There is therefore a growing interest in processing the raw material, with or without other agricultural residues, into organically based crop growth products.

Poultry manure and litter is also available as fertiliser. Assuming a considerable degree of drying (to 85% dry matter for manure and to 70% dry matter for litter), the total quantity of poultry manure available can be summarised as follows:

- Litter from duck, goose and turkey production: 417,538 tonnes, of which 42% is generated in the Eastern electricity region, nearly 20% in the Yorkshire region and more than 17% in the East Midlands region.

- Manure from laying hens, pullets, breeders and broilers: 375,653 tonnes, of which 44% is generated in the Southern, East Midlands and Eastern electricity regions.

- Litter from laying hens, pullets, breeders and broilers: 822,452 tonnes, of which almost 48% is generated in the Eastern, East Midlands and Southern electricity regions.

Poultry manure and slurry has a high fertiliser value, meeting most crop needs at applications of 10 tonnes/ha or less.

Use as fuel

Pressing and drying the 44 million tonnes of ruminant manure could give around 14 million tonnes of fuel with a gross calorific value of 12 GJ/tonne - a total energy content of 168 million GJ/year if the logistical problems of collecting this fuel source could be overcome.

Poultry litter with an 84% dry matter content has a gross calorific value of almost 13.5 GJ/tonne. Its combustion is controlled under the Environmental Protection Act, and strict guidelines apply. The ash is potentially useful as a fertiliser.

Recommendations

Investigations are recommended in four main areas:

- drying of wastes using waste heat from combustion and other drying processes
- the composition of ash from the combustion of poultry litter and raw manure
- the nutritional or toxic effects of using the ash as a fertiliser for growing plants
- economic appraisal of the value of litter and manure as fuel.

2.2 The Technology and its Potential

Report No: ETSU B3118a Publication date: 1981

CONVERSION OF BIOMASS TO FUELS BY ANAEROBIC DIGESTION PHASE 1: REVIEW AND PRELIMINARY ASSESSMENT

Ader Associates

Background

Biological systems that owe their existence to photosynthetic growth can be seen as a storehouse of solar energy. All forms of biomass can therefore be considered as potentially convertible into an appropriate form of energy. Various methods have been used in the past to convert biomass into energy or fuel. This project has focused on anaerobic digestion, in which the microbial decomposition of organic matter in the absence of air produces methane, carbon dioxide (CO_2) and water.

Project Objectives

- To review the technology of anaerobic digestion.
- To examine past and present experimental studies and development projects.
- To undertake an economic evaluation of the technology.
- To make recommendations for further work.

Findings

The technology

The mechanism of bacterial growth and substrate decomposition is believed to be a three-stage process:

- the organic matter is hydrolysed to soluble compounds
- the soluble compounds are converted into fatty acids
- the fatty acids are degraded in the “methanogenic” stage into CO_2 and methane.

The maximum theoretical yield of biogas has been estimated at 700 litres/kg of proteinaceous compound and up to 1200 litres/kg of fatty compounds. Yields in practice are 250-500 litres/kg.

The anaerobic digestion process is technologically simple. The main item of equipment is the digester, the type of digester used varying with the consistency and solids content of the feedstock, with investment factors and with the purpose of digestion - pollution reduction or biogas production. There are four main types of digester (see Table 1 below). Of these, the most common are conventional stirred (“high rate”) digesters that use gas recirculation to improve the energy balance and enhance gas production.

Table 1 Types of digestion system

Reactor type	Preferred feedstock	Biogas production per unit volume of digester	Capital cost of digester	Rate of solids conversio n to biogas	Other comments
Plug flow or displacement	High solids content	Low	Low	Low	Long retention times and high labour input.
High rate					
No solids retention	<15% solids content	Medium	Medium	Medium	
Solids retention	<15% solids content	High	Medium	High	Useful for maximising gas production
Contact	<1% solids content	Medium	High	High	Suitable for industrial effluents
Packed bed	<0.1% solids	High	High	High	Solids retained in packed bed

Effective digester operation requires the careful control of various parameters, particularly start-up conditions, loading rates, temperature, mixing, retention time and residue discharge. For instance, constant loading of a pre-heated feed is preferable, with subsequent operation at 30-40°C and with intermittent gas recycling to encourage mixing. Solids retention will vary with feedstock from as low as ten days to, typically, 20-30 days. Liquid retention should be minimised to, typically, ten days, although it may be as low as a few hours where solids retention is high. Supernatant liquors should be discharged slowly to minimise "wash out".

Biogas can be used straight from the digester or with minimal purification. Other options involve storage, which adds appreciably to the capital costs, or stripping CO_2 to convert the biogas to SNG. This study only considers immediate use.

The residual sludge consists of the microbial population and undigested feed. It has potential as an animal feedstuff additive and as a fertiliser/soil conditioner and may be subjected to some degree of solid/liquid separation prior to use.

Applications

Anaerobic digestion is only used on a large scale for sewage treatment. Most high-rate digesters are large and costly and are used to stabilise sewage sludge and convert it to a more readily disposable material. The biogas produced is used on-site as a fuel.

Anaerobic digestion has also been applied to animal wastes, both for pollution control and for fuel purposes. Particular attention has been given to pig slurries. These pose serious pollution problems but could be digested with a liquid retention period of ten days or less to give a gas yield of 300-450 litres/kg. Cattle waste digestion projects are of more recent origin. Where straw contents are high, retention times of up to 20 days may be required, and there may be mechanical handling and mixing problems. However, cattle waste arises in large volumes, and project economics are enhanced by the potential for on-site sludge recycling into feedstuffs. Gas yields are relatively low at around 200 litres/kg.

There has been relatively little work on the digestion of crop residues and green plants, although aquatic plants (micro-algae and seaweed) have been the subject of intensive studies. Grasses and cellulosic plant matter with a low lignin content appear to be fairly readily digestible: aquatic plants are good digestible substrates for gas production, although the farming/harvesting of aquatic plants may incur very high costs.

The anaerobic digestion of municipal refuse has received considerable attention, especially in the USA. Attractive gas yields have been reported, but the relatively low volatile solids content - and the difficulty of handling refuse - results in poor net energy yields and relatively high biogas costs.

Industrial effluents have also been treated by anaerobic digestion as a means of reducing the biological oxygen demand (BOD), although the relatively low concentration of digestible substrates is unlikely to make effluent digestion a significant supplier of biogas. However, recent demonstrations using contact and packed-bed digesters have combined very low retention times with high gas yields, indicating that anaerobic effluent treatment is a potentially valuable industrial technique that can also provide gas to supplement on-site fuel requirements.

Economic evaluation

The “model” used for the economic evaluation involved a continuous high-rate digester with a mesophilic temperature range, a ten-day liquid retention period and agitation by gas recirculation. It was assumed that the system could handle a solids content of up to 10% and conversion ratios of up to 60% - equivalent to a gas yield of 450 litres/kg solids. The scale of operation ranged from farm-scale $30m^3$ and $100m^3$ packaged units to large-scale plants with $500m^3$, $2500m^3$ and $5000m^3$ digester units.

Compared with current costs of alternative fuel gases, biogas produced under the model conditions would be broadly competitive with natural gas (£1.40-£1.90/GJ) for a $5000m^3$ digester, and with liquid propane (£3.30-£3.80/GJ) for a $100m^3$ digester.

Cost sensitivity analyses have shown that changes in the feedstock solids content have the most pronounced effect on biogas costs, with costs rising steeply with falling solid content and/or a reduction in yield. The required retention time also has a significant effect.

An *ad hoc* assessment of three specific feedstocks gave the following results:

- *Cattle manure* A 10% solids content is likely to give a biogas yield of only 200 litres/kg and require a retention time of up to 20 days. However, if there is no credit from the sale of residues, either biogas yield would need to exceed 320 litres/kg and/or liquid retention time would need to be less than ten days to give biogas costs of less then £3/GJ. Sale of the residue at £25/dry tonne will make a $100m^3$ digester viable at 200 litres/kg gas output and a ten-day retention period, while a $2500m^3$ digester would be viable with a 20-day retention period.

- *Pig slurry* Assuming a 6-7% solids content, a biogas yield of about 320 litres/kg is likely with a ten-day liquid retention period. It may even be possible to obtain 450 litres/kg with a five-day retention period. A $100m^3$ digester produces biogas for around £3/GJ only at the highest yields and with the shortest liquid retention periods. Furthermore, although a $2500m^3$ digester can tolerate longer retention periods, yield must not fall much below 450 litres/kg. Residue sales have limited effect.

- *Grasses* At a raw material cost of £25/dry tonne, even the $2500m^3$ digester can only achieve biogas costs of £3/GJ under the most optimistic assumptions of biogas yield, liquid retention time and residue credit.

Recommendations

- Comprehensive evaluation of potential feedstocks.
- Detailed consideration of the value of digester residues.
- Assessment of potential modes of biogas use, and definition of markets.
- Pilot plant process development work, focusing on cattle manure and green plant matter.
- Laboratory-scale studies in support of the above.

Report No: ETSU L/2 Publication date: 1984

ANAEROBIC DIGESTION: A CREDIBLE SOURCE OF ENERGY

Dr K M Richards, ETSU

Background

Anaerobic digestion is the complex, naturally occurring bacterial process by which organic matter is decomposed in the absence of oxygen. The principles of anaerobic digestion were first applied on any practical scale to the treatment of domestic sewage and wastewater, and the process is now widely used for this purpose. The Department of Energy is now exploring the extent to which the anaerobic digestion of sludges and other wastes can be used to produce biofuels.

Biogas and its Utilisation

Biogas produced from the digestion of biomass varies in composition from waste to waste. It is also affected by the type of digester used and its temperature of operation. A typical biogas would comprise 60-70% methane, 30-40% carbon dioxide, 0-0.1% hydrogen sulphide and 0-10% hydrogen. It would have an average energy content of 27 MJ/m^3 and would contain traces of ammonia, nitrogen, carbon monoxide and various hydrocarbons.

The energy savings that might be achieved by using biogas depend on the methods of utilisation. Untreated gas may be burnt quite effectively in conventional boilers or in modified gas engine systems, with hot water or recovered heat being used to maintain the digester. However, the trace acidic gases in untreated biogas cause excessive component corrosion, particularly where the intermittent use of gas engines results in regular condensation. Partial treatment of the digester gas to remove these elements is likely to be cost effective in the larger digesters, and the simplest technique would involve a water tower with the gas and water passing in contra-flow.

Digester Markets

Four major market segments have been identified for anaerobic digestion technology:

- domestic sewage
- industrial effluents
- agricultural wastes and crops
- domestic landfill.

Domestic sewage treatment

Approximately 60% of all UK sewage sludge is now treated by anaerobic digestion. The process reduces sludge volume, controls odour, kills many pathogens and produces a fuel that can be used to generate electricity and heat for other sewage treatment processes. Improved digester systems are now being introduced which not only help to maximise throughput without sacrificing gas production, but also allow smaller sewage works to install a digester cost effectively.

Currently, most of the biogas produced is used untreated to generate heat for the digestion process and for office space heating. This accounts for only about 50% of the gas produced, the remainder being flared. One way of improving gas utilisation would be to generate electricity. At present, the capital costs involved make this an uneconomic option for all except the larger sewage works serving a population of 400,000 or more. Where the gas is used in dual-fuel diesel engines for electricity generation, heat recovered from the jacket cooling water and the exhaust is normally sufficient to heat the digesters and the offices. Water authorities are now considering the use of spark-ignition engines for electricity generation in smaller works.

There is also some investigation into the treatment of biogas prior to liquefying or compressing it into a fuel for fleet vehicles.

Industrial effluent

The use of anaerobic digestion for treating industrial effluents is technically easier than for other wastes as the effluent occurs as substantial, fairly constant streams which are generally hot, thereby obviating the need for digester heating. The overall effluent resource, however, is fairly limited, often being widely dispersed at small sites. The most promising sectors for the technology have been identified as the dairy industry and other food industries. To be economically viable at current energy prices, industrial digesters must have a capacity of $200m^3$ or more and must be correctly sited.

Agricultural wastes and crops

Animal wastes

The disposal of animal wastes and vegetation can be a major problem on many intensive farms. Waste collection and storage is difficult, and leachate may be a problem. The Department of Energy's R&D programme has assisted in the design, construction and evaluation of farm-based units. In addition to laboratory and pilot-scale digesters, two full-scale units have been constructed, both operating on piggery waste which is amenable to digestion, gives good gas yields and is a cause of significant environmental concern because of its odour. To date, however, there have been problems with ancillary equipment failure and poor feedstock availability, and it is clear that farm digesters will only operate satisfactorily where farmers have adequate slurry or waste collection systems - the exception rather than the norm. Problems are also associated with the compositional inconsistency of the feedstock and the fact that it is usually fibrous and cold. Nevertheless, on some farms, anaerobic digestion may make sense environmentally, with energy production being of only secondary importance. This would apply on numerous sites if tighter pollution legislation were to be enforced.

Green crop materials

Studies have also been devoted to certain green crops - catch crops such as rape and fodder radish, perennial crops such as bracken and reed grass, and dedicated energy crops such as the *gunnera* species. There are still many technical and economic issues to be resolved before commercialisation of this technology can be considered seriously.

Landfill

Around 90% of the 28 million tonnes of domestic, commercial and industrial organic refuse generated in the UK is disposed of by landfill, and many landfill operations are on a large scale.

The landfill site may be considered as a large batch digester, with gas production varying with the availability of oxygen in the refuse, the water content of the refuse and the density of the refuse. The gas produced comprises about 55% methane, 40% carbon dioxide and 5% other gases, mainly nitrogen. Theoretically, each tonne of refuse will produce $400m^3$ of landfill gas under optimum conditions.

1981 saw the identification of 20-25 landfill sites where viable landfill gas extraction schemes could be installed. There have also been extensive field trials into the feasibility of landfill gas abstraction, and the results show that, although there are still technical problems to be overcome, the gas can be effectively harvested and used. In the longer term, it may be possible to increase gas yields by a factor of ten by adopting methods to optimise and conserve landfill gas production.

Conclusion

Anaerobic digestion, when applied with care in appropriate situations, can be a winner, particularly when associated with waste treatment initiatives designed to provide environmental as well as energy benefits.

Report No: ETSU B 1118 Publication date: 1986

RESEARCH INTO THE DEVELOPMENT OF PROTOTYPE UNITS FOR THE PRODUCTION OF BIOGAS METHANE FROM FARM WASTES AND ENERGY CROPS

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Project Objectives

- To establish a research station with four different types of anaerobic digester.
- To determine the technical feasibility of digesting crop materials and pig waste for energy production and undertake a preliminary economic study using the data generated.

Methodology and Findings

Digester assessment

The *hydraulic digester* is a multi-tank design with a "contents" tank volume of $2m^3$. It was operated at 35°C and heated/mixed by liquor recirculation through an electrically heated external water bath. The unit was used, with and without insulation, at retention times that varied from 50 days to 3.3 days. The feed substrate was pig waste.

The digester provided high yields at very low retention times and demonstrated a high level of digestion efficiency, with chemical oxygen demand (COD) reductions of 60-70% at retention times as low as 3.3 days. The evolution of the biogas under pressure increased its methane content to 80-85% at retention times of less than 15 days. Continuous, as opposed to daily, feeding should enhance the benefits further.

The $1.5m^3$ *anaerobic filter* consisted of a converted bulk liquid container filled with a plastic filter media at the rate of 120 m^2/m^3. The unit operated at 35°C, with and without insulation, and the heating/mixing mechanism was as for the hydraulic digester. The feed substrate consisted entirely of pig waste, with retention times varying from 30 days to seven days. The filter achieved reductions in COD of 70% at a retention time of 15 days and of 50-60% at a retention time of seven days.

The $30m^3$ *plugflow digester* was installed below ground, was operated at controlled temperatures of 15-35°C and was also allowed to equilibriate with ambient temperatures down to 0°C. A propane-fired water boiler provided hot water to an internal heat exchanger for heating purposes. No mixing was applied, and the experiments used retention times of 60-15 days, with substrates (mainly pig waste but some crop material) being fed semi-continuously (daily).

Digestion in the plugflow digester varied with temperature, although it was not halted even at low temperatures, and overall performance compared well with the more costly contact digester. The simplicity of the design minimised downtime, and its low aspect ratio allowed it to be installed without unsightly consequences. The crop material used was not macerated and floated on the inlet surface. Very little is believed to have entered the digester, and the floating mat had to be removed to avoid blocking the system.

A conventional high-rate *contact digester* was also installed. It was used to digest pig waste at temperatures of 35-37°C, and a biogas-fired/electrically heated water boiler provided hot water to an internal heat exchanger for heating purposes. Gas recirculation was used for mixing, except during the winter when freezing was a problem. Studies were carried out at hydraulic retention times of 40, 30, 20 and 15 days. Limited trials were also carried out using macerated crop material and a 30-day retention period. The unit was fed hourly using a bucket and chain feeding mechanism controlled by a pre-set timer. Results from the contact digester were very comparable with those from the plugflow digester.

Anaerobic digestion of crop materials

The digesters used for laboratory trials comprised one-litre glass containers with airtight lids. In each case a feed tube extended from the lid to 6-7cm below the effluent level, allowing small pieces of plant material to be passed into the core of the digester. The gas liberated by the digester passed to a gas holder, where it was collected over water.

Four energy crops, kale, rape, radish and *Bromus* were tested. The whole plants were diced, and a 50:50 mix of leaf and stem was stored at 4°C until required. Each crop was fed to a separate digester at the rate of 1g per day, the effluent was then stirred, and a constant temperature of 37°C was maintained throughout the monitoring period. Tests were also carried out with tomato crop waste, grass and ensiled forage pea.

Good yields of gas were obtained, although at relatively long hydraulic retention times. The rate of biogas production increased dramatically when the crop, whether fresh or ensiled, was macerated prior to use. Maceration was also found to increase the percentage of methane in the gas, despite the shorter retention times required for the macerated crop compared with the whole crop material.

Fertiliser value of digester effluent

Trials were also carried out to assess the fertiliser value of digester effluent on grassland. The effluent came from a 300m^3 digester that is operating using mainly pig waste with an occasional cattle waste input. The hydraulic retention time is 15-25 days, and the unit regularly produces up to 200 m^3/day of biogas. The effluent passes to a vibrating screen for separation: the solids are bagged and sold as fertiliser, while the liquid is pumped to an artificial lagoon and applied to the land as required.

High growth yields were obtained compared with those achieved with the application of a commercial fertiliser, and it was also established that the fertiliser value of digester effluent was slightly better than that of untreated slurry - a valuable finding as the effluent has a much reduced pollution load, causes less soil damage than slurry and can be transported more easily.

Report No: ETSU B 1129 Publication date: 1986

A MICROBIOLOGICAL STUDY INTO PROCESSES CONTROLLING ANAEROBIC DIGESTION

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Background

Anaerobic digestion is usually considered to be composed of three stages: Polymers are hydrolysed and fermented in the first stage, producing some acetate and hydrogen (H_2). In the second stage the various fermentation products are converted by acetogens to acetate, H_2 and carbon dioxide (CO_2). The final stage is methanogenesis.

The production and utilisation of acetate is an important event during anaerobic digestion since about 70% of the available organic carbon to methane (CH_4) is channelled through this compound. It is therefore important to have information on the interactions between the acetogenic and the hydrolytic organisms. At present, less is known about these stages and the organisms involved than about the final methanogenic stage.

Project Objective

- To establish a better understanding of the microbiology of anaerobic digestion so that the process can be optimised.

Methodology and Findings

Literature summary

Hydrolytic bacteria are a complex of fermentative bacteria that hydrolyse lipids, proteins and major polymers such as cellulose, and degrade the products to organic acids, alcohol, H_2 and CO_2. Apart from the cellulolytic bacteria in this group, which have been studied in relation to rumen microbiology and its ecology, hydrolytic bacteria have not been well documented, although studies have established that most fermentative bacteria are strict anaerobes.

Acetogenic bacteria produce acetate, H_2 and sometimes CO_2 from the organic acids and alcohols of the first stage. These are the least understood of the three groups of organisms, and the only well-authenticated case of their operation is in the degradation of alcohols such as ethanol. *Clostridium thermoaceticum* is one of the few other acetogens that have been characterised biochemically.

Methanogenic bacteria convert the products of the first two stages to CH_4 and CO_2 and have already been the subject of extensive study.

Hungate has undertaken considerable work on anaerobic methods and techniques. This has included extensive research into anaerobic mesophilic cellulolytic bacteria. Lundie and Drake sought to establish the basic nutritional requirements of *Clostridium thermoaceticum*, while

Braun and others developed an isolation procedure for acetogenic bacteria in which the methanogenic bacteria neither interfere with nor dominate the process.

Mesophilic digesters

Two digesters, A and B, were used initially to examine mesophilic digestion. They were operated at 35°C and fed with a feed substrate of fresh pig manure at a rate of 3.3%, giving a hydraulic retention time (HRT) of 30 days. A third digester (H) was introduced when Digester B broke. Initially, this was operated identically to Digester A. After four months the pig manure feed was changed to a synthetic feed, all other parameters remaining the same.

Data collected daily included gas production, pH and temperature. Data collected weekly included ammonia concentration, chemical oxygen demand (COD), biogas analysis, protein concentration, total and volatile solids and volatile fatty acids. After analysis, the data were compiled on computer for subsequent summarisation purposes.

Biogas production and methane content were found to follow one another closely within each digestion system. The digesters showed high levels of stress during the early stages of operation and when new batches of pig manure were introduced. This was reflected in a reduction in COD removal efficiency and in biogas and methane production, and an increase in C_2 concentrations. However, as the microbial consortium overcame the stress, there was an increase in biogas and methane output. As systems became more established and stabilised, the degree of reaction to stress declined. Digester H, which was supplied initially with effluent from Digester A, reached stability very quickly, despite the fact that C_2 concentrations at start-up were at and above the toxic level. No conclusions were drawn about the synthetic feed.

Thermophilic digesters

Four digesters were used to investigate thermophilic digestion. Digesters C and D were operated at 570°C and were fed with a feed substrate of fresh pig manure at a rate of 3.3%. After seven 30-day HRT periods, during which it was shown that Digesters C and D were performing poorly with a low biogas production, two new digesters, E and F, were started up and seeded with fresh cattle manure. The operating parameters were the same as for Digesters C and D. Digesters D and F were switched to a synthetic feed substrate after 14 and seven HRT periods respectively. Data collection was as for mesophilic digesters.

Digesters C and D produced negligible quantities of biogas and methane. As COD removal efficiency increased, propionic acid (C_3) concentrations also increased, eventually reaching critical values that caused removal efficiency to fall sharply to about 5%. The C_2 concentrations during HRT periods 1-7 followed the C_2 concentrations for pig manure, indicating that acetate added in the form of the manure was not used by the methanogens.

Comparison of organic loading rates and removal efficiencies indicated that both digesters were inefficient at low organic loading rates but used the substrate more efficiently at higher loading rates. At the start of HRT period 9, both digesters were reseeded with cattle manure, and showed an increase in biogas and methane production that lasted during HRT periods 10 and 11. The loading rate and removal efficiency also increased during the same period, indicating that the microbial population of the digesters were more efficient in removing substrate added. Biogas and methane production subsequently decreased.

Neither digester reached complete stability, although a degree of stability was achieved during HRT periods 7-12. A thermophilic digester can take 18 months or more to achieve stability.

Digesters E and F quickly showed an increasing removal efficiency, with low C_2 concentrations, and this lasted during HRT periods 9-12, despite high C_3 concentrations. Subsequently, however, the high C_3 concentrations reduced the removal efficiency and showed that the initial stabilising effect of the cattle manure has been lost. At the same time, C_2 concentrations increased and there was a reduction in biogas and methane production. Once C_3 concentrations levelled off, a slow improvement took place.

A comparison of Digesters C and D with Digesters E and F showed that:

- none of the four digesters achieved a steady stable state, although all seemed to approach it

- high C_3 concentrations have an adverse effect on removal efficiency and biogas/methane production

- there seems to be a critical level at which the organic loading rate becomes too great and the microbial populations are unable to maintain a high removal efficiency

- Digesters E and F were less sensitive to stress than Digesters C and D. They reached stability earlier and achieved efficient substrate removal more rapidly. This clearly shows the value of including cattle waste with the regular feed material.

Microbiology of the digester systems

The isolation of pure non-methanogenic bacteria cultures was not achieved, and further work is required in this field.

Conclusions

- Changes in feedstock invariably produced temporary loss of performance.

- The use of fully defined feed allowed more/less rapid attainment of steady states, with more/less biogas production.

- Thermophilic digesters were always less satisfactory than mesophilic digesters. All benefited from the use of cattle manure as a seed.

Report No: ETSU B 1077 Publication date: 1987

LIMITS TO PROCESS INTENSITY IN METHANE (BIOGAS) GENERATOR SYSTEMS

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Background

The successive stages in the bioconversion of organic matter to methane and carbon dioxide are functions of a diverse but potentially stable microbial population. However, knowledge of these populations is limited and existing findings are not always based on relevant ecosystems. Virtually nothing is known about how the bacterial population varies in digesters that are receiving different substrates, although certain essential general system properties are becoming clear.

Project Objective

- To establish the effect of external parameters such as design and operating mode on the overall performance of a biogas reactor.

Methodology and Findings

Relatively simple laboratory-scale reactors were set up to test, separately, the advantages and disadvantages of three key design and operating principles:

- thermophilic versus mesophilic operation
- mixed versus unmixed (stratified) reactor contents
- homogeneous versus heterogeneous (solids recycle) operation.

Simple reactors

The simple reactors used to assess thermophilic versus mesophilic and mixed versus unmixed reactor contents were operated:

- at 35°C or 55°C
- in batch, fed-batch or continuous mode
- using cattle waste, milled straw or crystalline cellulose, all substrates for which solubilisation is a limiting characteristic
- with manual or automatic pH control.

During operation the reactors were used to develop and assess analytical methods for key internal parameters. As a result, it was possible to characterise reactor performance by applying a selection of the following measurements:

- temperature, pH, substrate loading (controlled)
- solids removal rate
- cell (protein) level and formation rate
- total gas production rate
- gas composition (methane, carbon dioxide, hydrogen)
- methanogen population (F_{420})
- volatile fatty acids content and composition (acetate, propionate and higher)
- carbon balance
- acid generation rate
- acid removal potential (added acetate).

The findings were as follows:

- Thermophilic (55-60°C) reactors solubilised cellulosic substrates 33-46% more rapidly and up to 31% more efficiently than mesophilic reactors operating at around 35°C. They generated similar amounts of biogas and methane per gram of total solids removed, but batch times were typically only 64% of those for a mesophilic reactor. The overall result of these differences was that the thermophilic process was 1.5-2.5 times more efficient than the mesophilic process. Thermophilic reactors were also quite resistant to pH and loading shocks but were subject to delayed recovery after cooling shock.

- Although stirred reactors solubilised cellulosic substrates more rapidly and more completely than unstirred (stratified) reactors, they were much less effective than stratified reactors in converting the secondary products to methane. Methanogenesis appeared to be inhibited by the stirring (which was relatively mild): with cellulose as the substrate, methane generation per gram of solids (including volatile solids) was only 25% of that produced in the comparable unstirred reactor, while with milled straw as the substrate, the methane yield was 42% lower than with the unstirred reactor.

- In both stirred and unstirred reactors where the substrates were cellulosic, the active bacterial population, especially the methanogenic bacteria, were particularly associated with substrate particles and with flocs. Values were highest in the bottom fractions of the reactor and towards the surface layer, but lowest in the middle zones where suspended solids were virtually absent.

- Retention or recycling of the microbial biomass and particulate solids reduced substrate conversion times, intensified biogas production and accelerated recovery from pH and temperature shock.

- Where reactors were at or near steady-state operation, the actual rate of volatile fatty acid (VFA) production was stoichiometrically close to the actual rate of VFA removal calculated from the methane production rate. The potential rate of VFA removal, determined from methane production with an added excess of acetate, was closely related to the methanogen content measured by the F_{420} assay.

- The excess of potential VFA removal over actual VFA removal increased in parallel with the steady-state VFA pool size. This was consistent with the idea that methanogen growth is limited by VFA levels over a wide range of acetate concentrations.

Experimental heterogeneous reactor

A basic laboratory-scale two-stage digester was constructed to test some of the design principles developed using the simple reactors. It consisted of a lower first stage where mixing was combined with settled solids retention, and an upper second stage with liquid upflow over a stratified methanogenic biomass.

Compared with the simple reactors discussed above, the heterogeneous design gave significantly higher rates of solids removal under both thermophilic and mesophilic operation, down to a hydraulic residence time of five days. Below that level, solids removal was confined to the lower first stage.

Methane generation from the solubilised substrate was fully efficient. However, the conversion capacity of the second stage proved to be much greater than the solubilisation capacity of the first. This was confirmed when the reactor feed was supplemented with acetate.

Energy generation

The energy that can be obtained from a digester is the difference between the energy in the gas produced and the energy used to maintain the process. Net energy generation calculations were carried out under thermophilic conditions for different loading rates, feed dilutions and feed versus operating temperatures. As expected, any extra fermentation efficiency under thermophilic conditions was likely to be more than offset by the energy required to raise the temperature of an initially cold feed. However, where the feed was initially hot, eg fresh stillage and some food processing wastewaters, the extra effectiveness of thermophilic operation offered definite advantages.

Report No: ETSU B 1052 Publication date: 1987

REPORT ON ANAEROBIC DIGESTION OF DAIRY CATTLE WASTES TO OCTOBER 1981

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Engineering Division, North of Scotland College of Agriculture

Project Objective

- To assess the effectiveness of anaerobic digestion for the treatment of dairy cattle wastes.

Methodology

Whole dairy cattle wastes

The pilot plant consisted of a 150-litre, continuously stirred, single-stage digester, which was heated (and, if necessary, cooled) by a water jacket controlled by thermostats that operated a circulation pump. Feed from a continuously stirred feed tank was added at intervals ranging from ten minutes to 30 minutes. The digester was started using seed from a pig waste digester and has been in continuous operation for five years.

The large-scale plant consisted of two digesters, with capacities of $13.5m^3$ and $12m^3$ respectively. Both were single-stage, stirred-tank digesters which were loaded at one-hour or half-hour intervals. Number 1 digester was heated by an external, sludge-recirculation heat exchanger containing hot water from a digester-gas-fired boiler. It was mixed using an intermittent mechanical stirrer. Number 2 digester was heated using an experimental draught-tube heat exchanger which also mixed the digester contents. Number 1 digester had been operating on piggery waste prior to these experiments, but was converted to make it suitable for whole cattle wastes and started up using its original digested pig waste content.

The slurry used in both plant was a whole dairy cattle waste that was collected in bulk every 10-14 days, diluted, and stored at ambient temperature outside the digester building. The cattle producing the slurry were fed on silage, oats and some distillers draff. The slurry consisted of faeces, urine, washing water and some sawdust from bedding: it therefore varied in consistency.

Both total solids and retention times were varied during the experiments, and all units were monitored for gas production and for the solids content, biological oxygen demand (BOD), chemical oxygen demand (COD), volatile fatty acids (VFA) content and ammonia content of both the feedstock and the digested sludge.

Separated dairy slurry

These trials used a 25-litre glass and stainless steel digester, which was operated at 35-36°C and subjected to continuous stirring using a paddle stirrer at 50 rpm. The digester was started using digested whole dairy cattle slurry. Separated waste was then added at a low rate for several weeks to replace the whole waste with digested separated waste. During the subsequent experimental period, separated waste, with a total solids content of 3-4%, was fed to the digester from a continuously stirred feed vessel using a roller-type peristaltic pump.

Some microbiological experiments were also carried out.

Findings

Whole dairy cattle wastes

A linear relationship was established between gas production and total solids destruction for slurries with a total solids content of more than 4-5%. There was also a relationship between gas production and the loading rate expressed as kg of total solid added per m^3 of digester volume per day. Gas production was fairly constant over the range of loading rates likely to be used in practice, with a proportion of the gas (15-25%) coming from acids in the slurry. The methane content was about 55%. Comparison with the literature showed that dairy cattle waste digestion produced less gas than the digestion of fattening cattle waste. This reflects the more exact feeding schedule for dairy cattle and the lower quantity of digestible feed residue in their excreta.

All the results showed that 20 days is about the best retention time for dairy wastes digested at 35°C. For a waste with a total solids content of 12%, this is equivalent to a loading rate of about 6 kg/m^3/day.

The digested sludge was stabilised and less odorous than the feed, and a typical pollution reduction analysis is shown in Table 1 below for a 21-day retention at 35°C. Gas production was 0.206 m^3/kg total solids added.

Table 1 Typical reduction of pollutants by digestion: whole dairy cattle waste

Component	In	Out	% reduction
BOD (mg/litre)	18,470	3,840	79
COD (mg/litre)	80,280	66,490	17
Total solids (%)	7.3	5.9	17
VFA (mg/litre)	4,780	1,220	74.5
Ammonia (mg/litre)	1,040	1,146	Nil

Separated dairy slurry

Problems with blockages to the pump limited any variation in loading rate. However, the reliable results obtained appear to be representative and are shown in Table 2 below. The retention time was 13 days. Gas output was 0.278 m^3/kg of total solids added, with a methane content of 71.2%, a carbon dioxide content of 18.2% and a nitrogen content of 10.4%. The nitrogen content was higher than might have been expected, and this suggests that air was leaking into the system.

Table 2 Typical reduction of pollutants by digestion: separated dairy slurry

Component	In	Out	% reduction
Total solids (%)	3.6	2.5	30.5
VFA (mg/litre)	6,930	1,510	78.2
Ammonia (mg/litre)	1,970	1,860	Nil

The increased digestion of solids compared with whole dairy wastes is explained by the removal of poorly degradable fibre during the separation process. This increased the proportion of fine material and resulted in gas with a higher methane content. If the higher methane content is confirmed in future experiments, slurry separation would seem to offer some advantages, although the economics and energy costs of buying and operating a separator, and the equipment's reliability, must also be taken into account.

Report No: ETSU R-41 Publication date 1987

POTENTIAL FOR BIOGAS ON FARMS IN THE UK

R E H Sims, Massey University, New Zealand
K M Richards, ETSU

Background

Anaerobic digestion is an energy-producing and depolluting process in which the organic matter content of the plant or animal feedstock is converted in a digester to biogas and a residual, stabilised effluent. The raw biogas consists mainly of methane but also includes a considerable proportion of carbon dioxide plus traces of hydrogen sulphide, ammonia and water vapour. The gas can be used as a fuel for heating or, preferably after cleaning, for an internal combustion engine. Digested livestock manures can be used as a fertiliser or plant growth medium.

Report Objective

- To review the Department of Energy's research programme into the production and use of biogas in the agricultural industry.

The Research Programme

After initial desk studies had confirmed anaerobic digestion as the most promising method by which wet biomass might be used to produce a fuel, various laboratory-scale experimental projects were established to research issues such as the conditions for maximum methane production, the limits of intensification, the digestibility of green plant materials, and the relative merits of thermophilic, mesophilic, mixed, unmixed, heterogeneous and homogeneous system operation. Parallel studies examined the potential volume of on-farm feedstocks.

After a series of pilot plant confirmatory and development studies, two full-scale prototype plants, both digesting pig slurry in a typical working environment, were constructed and evaluated. This resulted in the identification of some additional research projects. By 1983 it was clear that the economic prospects for on-farm biogas production were uncertain, even for the more advanced digester designs. The programme responded with a period of consolidation, and no further development work was undertaken.

The programme has been complemented by a similar programme undertaken by the Ministry of Agriculture, Fisheries and Food (MAFF) and the Department of Agriculture and Fisheries in Scotland (DAFS).

Findings

Feedstocks

Approximately 2.5 million tonnes coal equivalent per annum (mtcepa) of animal wastes, up to 4.5 mtcepa of green plant material from catch crops and 27 mtcepa from native crops such as bracken have been identified as "technically feasible" digestion feedstocks. Only a fraction of this can be considered a useful resource since an economic demand for the biogas is also necessary for development.

With animal wastes it is necessary to increase the total solids concentration to provide consistent feedstock quality at the digester. The ideal way of achieving this is to integrate the slurry handling and storage system with the digester at the construction stage. Most existing livestock enterprises would need expensive modifications to achieve the same effect. The use of crops as digester feedstock is technically feasible but still at the development stage in relation to maceration and handling. Any scheme requires a high level of expertise at the farm level if it is to be successful.

Biogas production

Currently, less than one third of the carbon present in the feedstock is converted to methane by digestion. Gas yields could be greatly increased if the ligno-cellulosic material could also be converted, and research is ongoing under the landfill gas programme. Monitored digesters using a livestock feedstock have achieved only 60-65% of their design projections, and these levels have not been sustained over long periods because of variability in the feedstock quality. Acceptable yields of 1 m^3/m^3 are difficult to obtain in practice in commercial livestock units.

Although digester designs are adequate, the ancillary equipment has proved to be insufficiently robust for the rigorous, low maintenance environment found on typical UK farms.

Biogas utilisation

High gas yields have rarely been sustained, so there has been little incentive to maximise utilisation. The problem is compounded by the varying energy demand on farms, both seasonally and daily. Even at low gas yields, full utilisation is unlikely unless the farm can supply an adjacent continuous processing facility with a high energy consumption.

Environmental controls

Environmental benefits of the anaerobic digestion of farm wastes are considerable. The residue can be spread on the land without polluting groundwater or causing nuisance by odours, and with no loss of nutrient content over the raw slurry. Although it seems unlikely that more rigid environmental controls will be applied to the disposal of animal wastes in the UK, anaerobic digestion is one of several techniques that could be used to control water pollution and odours should such legislation be introduced.

Economics

Very few anaerobic digestion plants in Europe and the UK have achieved economic success, and there is little likelihood of commercial farm digestion becoming more economically viable in the short term. There has been little progress, despite research, in improving full-scale digestion efficiencies; capital investment costs need to be significantly reduced; growing and harvesting crops for feedstock is likely to be uneconomic, even if high gas yields were to prove possible; and there are cheaper ways of dealing with farm wastes given current legislation.

At current energy prices, an acceptable rate of return is only likely to be achieved if:

- the feedstock is of good, consistent quality
- a credit can be given for environmental benefits
- the gas supply can be fully and profitably used on the farm.

Future potential

Research and development into anaerobic digestion technology is proving of benefit to municipal sewage treatment plants, to industries that need to treat their effluent and, potentially, for the treatment of landfill leachate. However, on-farm biogas production and utilisation, although technically feasible, will remain unattractive as a process for widespread use on farms until environmental considerations assume greater importance. The individual farmer with a specific environmental problem may find it a worthwhile investment, with the biogas being used to offset the costs of controlling the problem.

Report No: ETSU B 1295 Publication date: 1991

POTENTIAL FOR BIOGAS ON FARMS IN THE UK 1990 UPDATE

F E Mosey
VFA Services Ltd

Background

Anaerobic digestion has always been an attractive concept for generating renewable energy from farm slurries while preparing them for return to agriculture. The technology is already widely used in the UK water industry for deodorising and disinfecting sewage sludges for subsequent farm use, but has long been assumed to be too capital-intensive for on-farm application.

The Department of Energy's R&D programme of the late 1970s and early 1980s concluded that:

"On-farm biogas production ... is technically feasible but the economic potential remains doubtful. Unless environmental pressures are increased concerning disposal of farm wastes, further research and development into agricultural digestion systems cannot be justified."

Since the 1987 report (Report No. ETSU R-41), there have been new economic developments together with new environmental constraints on conventional methods of slurry disposal.

Project Objective

- To determine whether new anaerobic digester design concepts, increasing environmental constraints on farm waste disposal and the electricity industry's Non-Fossil Fuel Obligation have modified the conclusions of the 1987 report.

Findings

Digester developments

The cost of a conventional "package plant" digester is around £100-£350/m^3 of installed digestion tank capacity. The digester tank itself has already been optimised in terms of materials, rating and cost, and prime targets for the next stage of cost optimisation are the mixing systems and gasholders. Another development option is the plug-flow digester. Investigated initially in the US during the late 1970s, the concept was taken up by Farm Gas Ltd in the UK and produced in more rugged form, but the high-intensity mixing systems involved mean that these digesters behave like conventional completely mixed digesters. A genuine plug-flow digester for farm wastes has not yet been investigated.

Anaerobic composting has also been the subject of investigation. It could be used as a batch fermentation process, with crop residues being loaded in the autumn to produce gas throughout the winter, and unloaded in spring/summer to provide soil conditioner and plant nutrients. The relatively low fermentation rates of straw and similar residues in a high solids batch digester could be particularly advantageous.

Environmental constraints

The UK Government has announced its intention to take steps to resolve two farming-generated problems:

- the gradual increase in nitrate concentrations in water resources
- pollution of the aquatic environment by farm slurries.

The growth in nitrate concentrations since 1945 is a result of the increasing use of chemical fertilisers and intensive animal husbandry. In some areas of the country, concentrations either exceed or are at risk of exceeding the World Health Organisation limit of 50 mg/litre that is specified in the EC Drinking Water Directive 80/788.

Farm slurries are massively polluting to the aquatic environment, and even a modest spillage can devastate the fish life of a river. More than 4000 water pollution incidents from UK farms occurred in 1988.

To minimise the impact of modern farming methods on water quality and the aquatic environment, farmers will need to store large quantities of slurry on the farm (to ensure that it is applied to land in the correct season) and then spread that stored slurry more thinly over a wider area (to ensure that it is applied in the correct dose). This approach will enhance the likelihood of odour nuisance and increase the need for effective odour-abatement technologies.

Legislative constraints

The proposed Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations 1990:

- require farmers to have sufficient storage capacity to hold the maximum quantity of slurry that is likely to be produced in any continuous four-month period

- require and specify minimum standards of construction for slurry storage tanks

- require and specify minimum standards of construction and effluent collection facility for silage silos, bunkers and clamps.

Agricultural measures for reducing nitrate concentrations in drinking waters are likely to include:

- ensuring that sufficient land is available for slurry spreading
- restrictions on manure application rates to ensure plant take-up of all added nitrogen
- avoidance of autumn slurry applications.

Economic incentives

The Ministry of Agriculture has made available grants of up to 50% of the capital cost of new or uprated waste-handling facilities (up to a maximum grant of £37,500) under the MAFF Farm and Conservation Grant Scheme.

Another attractive option could be the Non-Fossil Fuel Obligation. This was set up as part of the Electricity Act 1989 and requires electricity supply companies to obtain a proportion of their electricity from renewable energy sources. Suppliers generating electricity from renewable sources will be invited to bid competitively for contracts to supply “renewable electricity”. Large farm waste units or district schemes serving around 10,000 pigs or 2000 cows that are capable of generating at least 100 continuous kilowatts of electricity could find this an attractive option.

Marketing opportunities

With the growing level of interest in organic farming and gardening, there appear to be good prospects for processing and marketing slurry fibre and digestate solids, particularly as renewable substitutes for imported fossil peat in garden composts.

Potential for biogas on UK farms

Under the terms of the Non-Fossil Fuel Obligation, CHP schemes fuelled by “free” biogas from landfill sites or sewage treatment plants are likely to prove very attractive. The economic viability of farm waste digestion, on the other hand, is wholly dependent on the perceived environmental benefits of the anaerobic digestion process to the farmer and the marketing opportunities for farm waste/animal slurry digestate products. Only if the digester can become financially self-sufficient as an environmental plant will its CHP scheme become profitable as a source of renewable energy.

Recommendations

Research needs to be funded in two major areas:

- cost-engineering of the digester’s ancillary equipment to minimise the capital cost of the plant

- the development of simple, low-cost, high solids digestion systems that maximise the saleable outputs - biogas and fibre for compost.

There is also a need for marketing/field trials of processed slurry products as peat substitutes.

Report No: ETSU B 1294 Publication date: 1993

ANAEROBIC DIGESTION OF INDUSTRIAL WASTEWATER: A SURVEY OF POTENTIAL APPLICATIONS IN THE UNITED KINGDOM INDUSTRY

Environmental Technology Consultants Ltd (ETC)

Background

Considerable efforts have been made in the last decade to develop the anaerobic digestion process specifically for treating industrial wastewaters, and the technology is now an attractive alternative to aerobic treatment methods. The methane produced by this process may be used directly by the industry to reduce its consumption of natural gas or fuel oil. Alternatively, it may be used to produce electricity. However, in the UK, potential users are often reluctant to install the process because of the lack of detailed information concerning process selection and performance.

Project Objectives

- To review current and anticipated future legislation and the relevant standards pertaining to the discharge of industrial wastewaters.

- To carry out an exploratory study on the nature and scale of potential UK users of anaerobic digestion for the treatment of industrial wastewater.

Findings

Current and anticipated future legislation

Industries generally produce a wastewater that is a pollutant and that may require treatment before discharge to the environment. Disposal options that minimise environmental damage and/or abatement costs to the industry concerned include:

- discharge of untreated wastewater to sewer, incurring costs for its reception and subsequent treatment

- discharge of partially treated wastewater to sewer, incurring reduced costs for reception and subsequent treatment but increased on-site costs for the installation, operation and maintenance of an appropriate treatment plant

- discharge of wastewater to a watercourse after full treatment to meet the regulatory agency standards for discharge.

The newly privatised Water Companies set the effluent quality requirements and charges for discharge to sewer. Standards will also be regulated by Her Majesty’s Inspectorate of Pollution (HMIP).

The National Rivers Authority, under the terms of the Water Act of 1989, controls discharges directly to a watercourse.

If wastewater treatment generates a sludge, then its discharge to land is regulated by the Sludge Regulations (1989). If a gas is produced, any flarestack emissions are controlled by HMIP for a Scheduled process and by the local environmental health officer for other processes.

Changes to current permitted discharge levels in terms of biological oxygen demand and suspended solids may be necessary as the UK implements the Draft EEC Directive: Municipal Wastewaters, Sensitive and Non-Sensitive Areas, which makes specific reference to industrial wastewaters.

Sources and characteristics of industrial wastewaters

Table 1 below summarises the main sources and characteristics of industrial wastewaters that are suitable for anaerobic digestion.

Potential for anaerobic digestion for industrial wastewater treatment

Industries that could benefit most from the application of anaerobic systems are those producing a wastewater containing a high level of organic matter, eg food and beverage, pharmaceutical and organic chemical industries. Furthermore, regulatory agencies such as the NRA and the Water Companies are putting pressure on these industries to reduce the levels of pollution in their discharges. Environmental groups are pressurising for the conversion of organic wastes into re-usable energy.

Anaerobic processes could replace existing, energy-inefficient systems that not only have high operating costs but also generate large quantities of excess sludge that is difficult to dispose of. The total energy potential of treating all the UK's industrial wastewaters in this way would be equivalent to 500-700MW of electricity. In practice, the resource level would be considerably lower than this.

Reactor configurations

The critical solids retention time (SRT) for a reactor to operate effectively has been estimated at about ten days in a system operating at 35°C. Various reactors have been or are being developed to meet the requirements.

The first high-rate process to be developed was the anaerobic contact process. This uses a settlement tank to concentrate biomass that has left the digester in the effluent flow and return it to the digester. The anaerobic contact process is now used to treat a broad range of industrial wastewaters and it may in future be used for treating effluents that contain large quantities of suspended solids.

Table 1 Main sources and characteristics of industrial wastewaters suitable for anaerobic digestion

Waste-producing industry	Characteristics of wastewater
Food and beverages	
Dairy	High in organic matter. BOD_5 [(1)] = 300-2375 mg/litre, mainly protein, fat and lactose.
Brewing and distilling	High in dissolved organic solids. COD[(2)] = 1500-10,000 mg/litre. Contains nitrogen and fermented starch.
Edible oil	High in organic matter. $BOD_5 \rightarrow$ 20,000 mg/litre. Contains fatty matter.
Starch processing	Dilute suspension of solids in water. Higher level of dissolved substances - nitrogenous compounds, carbohydrates, organic acids, minerals. Average COD = 19,980 mg/litre.
Sugar	High in dissolved organic matter. $BOD_5 \rightarrow$ 10,000 mg/litre.
Meat and poultry	High in organic matter - mainly protein, fats, oils, greases.
Pharmaceutical	Very high in dissolved and suspended organic matter. COD $\rightarrow$ 300,000 mg/litre, including vitamins. High in carbohydrates and dissolved salts.
Pulp and paper	High or low pH, colour, high level of suspended, colloidal and dissolved solids, inorganic fillers. Average BOD_5 = 980 mg/litre.
Chemicals and petrochemicals	High $BOD_5 \rightarrow$ 2500 mg/litre. Contains metals. COD/BOD ratio and compounds inhibit biological action.
Textile industries	Highly alkaline, coloured. $BOD_5 \rightarrow$ 3000 mg/litre. High temperature. High level of suspended solids.

(1) Five-day biological oxygen demand
(2) Chemical oxygen demand

The anaerobic packed-bed reactor consists of a flooded bed of inert filter material, up through which the wastewater is passed. There is low turbulence and efficient sedimentation and it is possible to maintain at long SRT at high hydraulic loadings. This design has proved very satisfactory in most cases.

The upflow sludge blanket is the most widely used process and seems to represent the most advanced form of anaerobic treatment. Wastewater flows through an expanded bed (blanket) of active biomass, which is kept in suspension by controlling the upflow velocity. The upper part of the reactor contains a purpose-designed baffle arrangement for gas-solids separation, thereby allowing gas collection and internal sludge recycling. This process offers several advantages over the contact process and the packed-bed reactor. These include significantly higher loading rates and no requirement for either mixing or packing media.

Both the upflow sludge blanked reactor and the expanded/fluidised bed reactor appear to provide the most desirable configurations for the anaerobic treatment of low-strength wastes such as domestic wastewaters.

No system is applicable to every wastewater and every situation. Each design configuration has its own merits, limitations and potentials, and the selection of a specific process will depend mainly on the particular situation and the type of wastewater to be treated.

Barriers facing the anaerobic digestion of industrial wastewaters

Most of the early *technical* barriers to anaerobic digestion have now been solved. However, some barriers remain in the application of this technology to industrial wastewaters. These include the development of better ancillary equipment, improved hydrolysis rates, upstream processing, problems with odour generation, the development of new sensors and control models, and research into the application of anaerobic digestion to the chemical, textile and pharmaceutical industries where the breakdown of recalcitrants in waste streams is required.

Certain *organisational* barriers also exist. The UK has a mature market for pollution control equipment. This has resulted in the widespread provision of sewers and treatment works throughout the UK and has allowed industry the option of discharging effluents directly to the public sewer. A second, but less significant factor, has been the relatively low costs incurred by UK industry for wastewater treatment, particularly when compared with those levied in some other European countries. This has made on-site treatment less financially attractive. Other organisational barriers include the lack of any Government intervention in terms of aid programmes or research co-ordination, and the fact that, until privatisation of the UK water industry in 1988, capital expenditure for wastewater treatment was financed from the public sector, allowing repayment over long periods of time. This encouraged the continued use of traditional process designs and allowed research and development within the industry to stagnate.

Recommendations

Further investigations are required on an industry-by-industry basis to establish precise details about wastewater volumes and organic loadings. This would allow reliable estimates to be made of the anaerobic digestion potential, the quantity of gas that would be produced, and the energy savings potential.

Report No: ETSU B/MS/00192/20/REP Publication date: 1993

THE TREATMENT, REPROCESSING AND INCINERATION OF ANIMAL WASTE SLURRIES AND SEWAGE SLUDGES

An Evaluation of the State-of-the-Art in the Netherlands and Japan

International Flame Research Foundation, IJmuiden, Netherlands

Background

Many countries produce substantial amounts of animal and human waste as slurries and sludges. Current disposal methods cause environmental problems, particularly the pollution of groundwater by nitrogen- and phosphorus-based compounds, and atmospheric emissions of methane and ammonia. Although a proportion of the wastes produced are processed and used as manure-based fertiliser, production is far in excess of what can be used in this way, and new, effective disposal methods are needed.

Incineration with energy recovery is one possible solution. However, many combustion-related issues need to be addressed, particularly oxide of nitrogen (NO_x) emissions, ignition and combustion stability, ash slagging and fouling, and emissions of heavy metals. In addition, animal slurries must generally be dewatered before incineration.

Project Objectives

- To determine the state of the art with respect to the conversion, treatment and reprocessing of animal waste slurries in Europe (especially the Netherlands) and Japan.

- To generate preliminary information on the processes used to treat human wastes (municipal sewage sludge) in the same countries.

Findings

Animal slurry handling and processing

The Netherlands produces 15 million tonnes/year of animal waste slurry. Of this, approximately 65% is spread directly as fertiliser, less than 3% is incinerated, and the remaining 32% is dumped on the land as excess fertiliser.

Two pig slurry processing and treatment technologies are currently used in the Netherlands. Both separate the slurry into a liquid stream and a solid phase. The liquid phase undergoes treatment to bind the ammonia present, and the liquid is then vaporised. The concentrate and the solid phase are then dried, and the waste drying gases are incinerated. Consideration will shortly need to be given to pollutant emissions.

The overall efficiency of these slurry treatment processes could be improved by process optimisation and by incinerating the residue in a purpose-built slurry incinerator as part of a combined heat and power generation scheme. The process steam would then be used both to generate electricity and for the drying and vaporising process. An alternative option would be to locate the slurry treatment plants near an existing power station or waste incinerator. Waste heat from these plants could then be used for the slurry evaporation and drying processes.

The Dutch Government is to levy a new tax to reduce phosphate levels in the Dutch water system and stimulate further the development and implementation of animal waste slurry treatment processes.

The Vefinex process is a more recent process for treating chicken litter. It uses a direct drying system in which hot flue gases come directly into contact with the manure and create a waste gas stream containing ammonia, NO_x, N_2O, carbon monoxide and carbon dioxide. One of the most suitable techniques for treating this waste gas appears to be thermal after-burning at around 800°C.

However, although the technologies for processing and treating animal wastes exist in the Netherlands, the costs render them uneconomic. One tonne of treated manure has a market value of approximately NLG 20. Treatment costs, however, range from NLG 30 to NLG 45 per tonne of slurry, and less expensive processing methods will need to be developed.

There is no direct incineration of the initial slurry in the Netherlands.

Biogas production from animal waste slurries is a topic of investigation in many European countries. The main advantage of this approach is the increased utilisation of nitrogen, phosphorus and potassium, leaving a more homogeneous degassed high quality mixture for spreading on the land.

In the UK, satisfactory results from studies on the incineration of partially dried chicken litter in cyclone combustors has resulted in the construction and operation of a commercial plant in Suffolk. This has a generating capacity of 12.5MW and burns approximately 125,000 tonnes of chicken litter each year.

Japan has few problems with livestock waste surpluses and most livestock waste is dried, fermented and used as fertiliser.

Sewage sludge handling and processing

The Netherlands produces about seven million tonnes of sewage sludge each year. This is collected, digested and dried in purification installations. About 4.5 million tonnes are then recycled as fertiliser, although heavy metal concentrations can limit its use for this purpose. Two and a half million tonnes are dumped and less than 3% is incinerated.

Incineration on any scale is only carried out at one location, in a 6000 tonne/year multiple hearth furnace. Three 20,000 tonne/year fluidised bed incinerators for sludge incineration are now being built on the same site. In the south of the country, a sludge treatment system based on wet oxidation (the Vertech principle) is to be developed. Co-firing with coal in a pulverised fuel power station has been considered and rejected because of concerns over emissions and emissions legislation.

Several European countries use either anaerobic processes or composting techniques to treat sewage sludges. Composting offers advantages from the point of view of storage, recycling and final product specification. However, anaerobic processes are usually preferred and the production of biogas makes them more energy efficient.

Sewage sludges can also be burnt on a limited scale with municipal waste in an incinerator. Co-firing may, however, require additional flue gas cleaning systems, particularly co-firing with coal in existing power stations, and additional research and development is needed.

In Germany, about 10% of the sewage sludge produced is incinerated for energy recovery: 60% is landfilled and the remainder used as fertiliser. In some locations the dried sludge is incinerated in fluidised bed combustors co-fired with fine coal residues from coal washeries.

In Japan, where sewage sludge incineration and treatment are of extreme importance, the technological problems associated with sludge drying and pollutant emissions have been solved. However, questions still remain in relation to the efficiency of sludge drying. The country has also developed cyclone slagging combustors for a dewatered sewage sludge feed with a moisture content of around 65%. Although reasonable slag capture is obtained, NO_x emissions are a potential problem. The fluidised bed incineration of dewatered sewage cake is also regularly used. The main research emphasis is currently on drying and slagging processes and subsequent integration with a power station and/or cement production plant.

Report No: ETSU B/FW/00239/REP Publication date: 1993

ANAEROBIC DIGESTION IN THE UK: A REVIEW OF CURRENT PRACTICE

ADAS, Silsoe

Background

Legislation relating to waste treatment and land application is growing and covers the pollution of water, air and soil, the planning and siting of waste treatment facilities, the construction of new structures for storing wastes, and the health and safety aspects of waste treatment and handling systems. Of particular significance is the EC Nitrate Directive, which, as it comes into force, will require a change in waste disposal practice in some parts of the UK. Another issue of importance is the current interest in power generation from non-fossil fuels.

There is a great deal of ignorance and confusion about current legislation and its implications, and some farmers, to protect their business, are open to persuasion about the merits of various solutions. This can lead, and has led, to false expectations.

Anaerobic digestion can play a positive role in overcoming problems associated with storing and using effluent. It can also resolve certain problems currently encountered in dealing with animal wastes. Anaerobic digestion involves feeding raw slurry into a closed tank and maintaining it at a given temperature (typically 35°C) in the absence of oxygen. The products comprise biogas and fibrous compostable solids, and there is some improvement in the form of the slurry liquid, which can be applied to the land with fewer application problems.

Project Objective

- To review the success of farm digesters, identify the criteria for purchase, and provide information on current digester demand, taking into account opportunities for environmental protection and power generation.

Findings

Environmental benefits

The anaerobic digestion of slurries with a high dry matter content (8-15%) is particularly useful for odour reduction. However, anaerobic digestion on its own, while it does achieve some reduction in biological oxygen demand (BOD), is not a complete treatment for reducing the polluting strength of the slurry. The polluting potential of the BOD is still 20 times greater than that of raw domestic sewage, and the ammoniacal content would be capable of causing fish death. Post-digestion storage to the required standards remains essential, while good management and an awareness of the pollution risks during land application are clearly as important for digested slurry as for raw slurry.

The economic importance of the by-products

Anaerobic digestion produces a gas and a digestate. The economic viability of a digester cannot rest with gas production alone, so greater attention has recently been paid to obtaining a financial return from the digestate. Options including composting the digestate for subsequent use as a peat replacement material, an organic manure or a soil conditioner. Some marketing initiatives may be required to offset production, packaging and marketing costs.

Anaerobic digestion is a useful means of improving the fertiliser value of the slurry effluent. It transforms a higher proportion of the organic-bound nutrients into a form that makes them more available to plants.

UK digesters

Anaerobic digestion plants have been installed on UK farms since the late 1970s for research, commercial, practical or management reasons. Despite the development of packaged plant design and installation, and despite promotional work by the leading companies, take-up has been limited. Most of the 43 farm digesters identified in the UK are on pig or dairy farms, although some handle poultry litter or a combination of feedstocks. Twenty-five of these digesters, most of them simple in design, are known still to be operational. Seven are known to have been decommissioned, often after only three to five years of operation during which they experienced a sharp increase in maintenance costs.

The early digesters were installed for odour control or for energy production. Today, the factors encouraging installation are pollution issues or fibre sales, combined with growing concern about increased fertiliser use.

Problems are frequently experienced with waste-handling systems, sedimentation and poor quality feedstocks. The gas produced is rarely fully and effectively used and, despite the sale of by-products, projects are often difficult to justify economically unless the need for odour control is paramount.

Trials carried out during the 1980s have shown that using biogas for heat rather than for power is the better option for most typical dairy farms with more than 200 cows. A modest profit may be possible at this level as long as there is 50% grant aid and, more particularly, a reliable and valuable market for the separated fibre. Electricity generation is unlikely to be viable, even under the Non-Fossil Fuel Obligation, unless significant fibre sales can be achieved. Furthermore, the costs of entry to such a scheme are likely to be substantial.

Anaerobic digesters in Denmark

Between 1986 and 1991, the Danes carried out a programme that involved designing, constructing, monitoring and trialling nine large-scale centralised digesters. In each case the economic, technical and environmental aspects were examined. The digesters, which were not solely for agricultural use, were located near towns with centralised heating schemes, thereby providing a ready market for the heat and electricity generated. Government grants of around 35% were provided, together with reduced-rate financing.

The Danish mesophilic digesters produced 1.2-2.1m^3 of gas per m^3 of digester vessel per day. This compares with an average of 0.66 m^3/m^3 of digester per day from full-scale UK digesters. There are hidden credits to the tune of about £910/year per participating farmer. These include cost savings because less on-farm storage is required, a reduction in the labour needed for slurry spreading, the application of digestate to previously unmanured fields, the improved fertiliser value of the digestate, and the improved timing of applications.

Environmental benefits include a reduction in CO_2 emissions because of fossil-fuel savings in the adjacent towns, the digestion of some industrial waste, reduced odour problems, and the dispersion of manures from intensive units to fertilise a wider area.

The UK potential for centralised digesters

Based on Danish digester costs, the UK cost of a digester that would generate 1MW of electrical power was assumed to be £6.6 million before any grant. Assuming grant aid at 50% on all capital, and amortisation over ten years at a 15% interest rate, total annual costs would be £1.313 million, of which £0.57 million would be for labour and transport.

Estimates that a project of this nature could make a profit of £1394/year are based on the following assumptions:

- a feedstock that is 88% agricultural and 12% industrial
- electricity output of 1MW (8760 MWh/year)
- heat output of 60 TJ/year (17 million kWh/year)
- electrical energy sales at 7p/kWh
- sales of hot water and fibre.

If markets for the hot water and fibre were not forthcoming, the project would make a loss. A market for the fibre alone would make the venture possible, even with grant aid limited to 30%. If the high specific gas output were not achieved, then the energy benefits would be reduced, and the venture would depend on environmental benefits and on co-operation between livestock farmers, water companies, electricity producers and managers of the land on which the digested effluent may be effectively used.

The future for anaerobic digesters in the UK

UK interest is likely to focus on three types of digester:

- farm-scale - for odour control and other benefits
- large farm scale - financed by fibre sales
- co-operative scale - providing energy to the grid and selling fibre.

For these to be economically successful, depending on scale, it will be necessary:

- to take advantage of Ministry of Agriculture, Fisheries and Food (MAFF) or EC grants
- to use the biogas fully for energy production
- to minimise labour inputs
- to obtain a guaranteed high-value contract for the digested fibrous solids

- to use the liquid effectively as fertiliser
- for the NFFO value of electricity production to be increased significantly.

2.3 Products and Their Treatment

Report No: ETSU B 7006 Publication date: 1987

A SURVEY OF EXISTING METHODS OF BIOGAS SCRUBBING AND UTILISATION

BABA Ltd

Background

Biogas is generated in the UK mainly from animal and other agricultural wastes, domestic sewage, industrial effluents and landfilled wastes. The volume generated varies widely. Farm digesters will produce 200-5000 m^3/day, sewage digesters and industrial effluent plant 1000-6000 m^3/day, and large landfill sites 10,000-100,000 m^3/day. The gas will either be flared off on site, or directed to on-site or off-site applications. On-site applications involve burning to produce heat or steam, use in a stationary internal combustion engine for electricity or power generation, or use as a fuel for on-site vehicles. Off-site uses generally involve distribution by pipeline. Alternatively the gas may be used as a compressed or liquefied fuel for transport purposes.

Biogas is a complex mixture of gases and entrained fluids, the major constituents being methane (around 60%) and carbon dioxide (around 40%). Minor constituents include hydrogen sulphide (H_2S), hydrogen (H_2), carbon monoxide (CO), nitrogen (N_2) and oxygen (O_2), as well as a wide range of minor organic components, the exact nature and concentration of which depends on the raw material being digested. In addition, all biogas contains water as vapour or droplets.

Methane is the only component of biogas with a significant fuel value. However, while the carbon dioxide (CO_2) and nitrogen are inert diluents that reduce the calorific value of the gas, the water, O_2, H_2S, CO_2 and trace organics are corrosive to metals and can cause damage to equipment and pipes. Some degree of cleaning may therefore be required prior to use.

Project Objective

- To consider the technical and economic aspects of removing impurities from gas generated during the anaerobic digestion of wastes and other organic materials.

Findings

Reasons for cleaning biogas

Biogas may be cleaned:

- to improve its calorific content
- to reduce the corrosion of equipment associated with gas distribution and use
- to reduce potential health hazards
- to reduce environmental pollution.

Although there is no general need to clean biogas, except to remove water vapour, three specific reasons for cleaning have been identified:

- to reduce the level of H_2S to less than 0.05% before using the gas in small internal combustion engines

- to remove H_2S, CO_2 and other trace contaminants, thereby providing a product with more than 98% methane that can be compressed or liquefied for use as a vehicle fuel

- to remove CO_2 H_2S and organic contaminants so that the gas meets the stringent quality standards necessary for introduction into national grid pipelines.

Cleaning techniques

Various techniques exist for the removal of contaminants from gas. They include:

- physical absorption by a liquid or a solid
- chemical reaction with a liquid or a solid
- membrane separation
- compression or cryogenic separation.

Water

Virtually all uses for biogas require the removal of at least some of the water present. This can be achieved by chilling, compression or by using absorbents such as silica gel, alumina or molecular sieves.

Acid gases (CO_2 and H_2S)

The traditional way of removing H_2S from gas is to pass it through a bed of iron oxide. The technique can be adapted to any size of gas generation plant and is the only satisfactory approach for small and medium gas production facilities. It is also the only satisfactory approach for large gas producers where the H_2S concentration is less than 1%. Large plant with a high H_2S content can benefit from the Stretford process, which allows the recovery of elemental sulphur as a by-product.

The most effective way of removing CO_2 (and low levels of H_2S) on a small scale is to use a pressure water scrubber - either a flow-through system or a closed system with clear water regeneration. There are numerous larger-scale CO_2 removal technologies involving the use of chemicals, solvents, molecular sieves or selectively permeable membranes.

High H_2S concentrations can occur on farms and in industrial effluent digesters. The corrosion caused in small-scale power generation sets has been one of the main reasons for lack of confidence in digestion on farms. Furthermore, because there are relatively few farm-scale digesters in the UK, insufficient attention has been paid to the production of a cheap, appropriate method of H_2S removal. Experience is restricted to iron oxide boxes and water pressure scrubbing systems of the flow-through type. However, most of the biogas produced in the UK is not cleaned (except to remove water).

Equipment available

It is possible to obtain standard equipment - gas pumps, compressors, engines, boilers etc - from existing manufacturers. However, problems have arisen in the use of this equipment for raw biogas because of the latter's corrosive nature. At present, the size of the UK market is such that manufacturers are not encouraged to develop material specifically for biogas use. Gas compression and liquefaction systems and ancillary items are also available - again developed for use with natural gas rather than biogas.

The economics of biogas cleaning

Very few biogas cleaning systems have been installed and accurately costed in the UK. The findings below are based on the costs of systems used for cleaning other gases, on manufacturers' publicity material, on information from the few manufacturers and operators of existing biogas cleaning systems, and on details of overseas installations.

The costs of gas cleaning per m^3 of biogas processed are lower if only H_2S is removed than in the case of cleaning to produce a high-purity methane.

The cost of H_2S removal on a small scale is estimated at £0.003-£0.006/m^3 for capital costs, plus £0.004/m^3 for operating costs - a total of around £0.50/kg of H_2S removed. This cost is estimated to be less than the additional cost of engine maintenance if the H_2S is not removed. However, although removal appears to be cost effective using existing technology, disposable cartridge modifications to the iron oxide box are needed.

Large-scale removal with sulphur recovery reduces costs to about £0.10/kg of H_2S removed.

Capital costs for the production of pure methane tend to increase with throughput - there are no real economies of scale.

Pressurised water scrubbing to remove CO_2 and small amounts of H_2S is the most suitable and cost-effective way of producing methane with a 95-98% purity from gas flows of 500-14,000 m^3/day. Such systems have been used to produce compressed gas for subsequent use as vehicle fuel. Provided the plant operates to capacity and as long as the gas is "free", ie it comes from a sewage works or landfill site, fuel can be produced for around £1.00/gallon equivalent. Capital costs are around £0.03/m^3, and operating costs are similar. The economics for systems that match operation to a limited gas demand are much less attractive.

Other methods of gas cleaning to 95%+ methane (solvent scrubbing, membrane systems, molecular sieves etc) have capital costs for large plant of £0.013-£0.016/m^3. Operating costs increase as plant size falls, but may be around £0.03/m^3.

Recommendations

Further research and development is needed in three areas:

- gas composition
- small-scale use of membrane cleaning systems
- improved instrumentation for monitoring gas production rates and composition.

Development and demonstration should be encouraged in four areas:

- iron oxide cartridge systems for H_2S removal in small-scale units, particularly on farms
- improved low, intermediate and high pressure gas storage systems
- large-scale liquefaction of cleaned biogas for use as vehicle fuel
- improvements in the use of compressed biogas in dual/diesel-fuelled engines.

Demonstration projects should be encouraged in two areas:

- a reliable small-scale engine/generator package incorporating H_2S removal

- a closed-loop pressure water scrubbing system associated with gas compression for vehicle use on farms.

Report No: ETSU B 1124 Publication date: 1987

A DETAILED INVESTIGATION INTO POSSIBLE WAYS OF ACHIEVING HEAT RECOVERY FROM ANAEROBIC DIGESTION OF EFFLUENT

Anaerobic Digester Research and Development Unit, The Polytechnic of Wales

Background

Technologically, anaerobic digestion is one of the most appropriate processes available for extracting energy from biomass, with most digesters operating at around 30°C. To maintain this temperature, energy must be provided:

- to offset any thermal losses from the operating vessel
- to heat the fresh slurry feed from ambient to process temperature.

The energy requirement, particularly for heating the fresh feed, could be equivalent to 70-90% of the energy contained in the gas produced by the process.

Normally, the loading of fresh slurry is accompanied by the rejection of an equivalent amount of digested slurry. The digested slurry is at process temperature, and it would therefore be advantageous, economically, to recover some of the energy contained and use it to raise the temperature of the fresh slurry feed.

Project Objective

- To investigate technologically feasible and economically viable methods for recovering low-grade waste heat from anaerobic digestion effluents.

Methodology

The study involved:

- a computer search into the rheological and thermophysical properties of slurries
- visits to three experimental or commercial digester facilities
- economic assessments of working digesters
- contacting heat recovery equipment companies for advice on the opportunities available.

Findings

Types of heat exchanger

The main types of heat exchanger that might be applied to anaerobic digestion include:

- closed-cycle heat pump systems that raise the temperature of low-grade heat by a process of evaporation, compression and condensation

- plate heat exchangers - available in a range of sizes and able to achieve a high degree of heat exchange, but limited to an upper operating temperature of about 250°C and a maximum pressure of 20 bar

- spiral heat exchangers with a maximum surface area per unit of about 200m^2 - particularly useful for handling slurries and sludges

- double pipe exchangers whereby heat is exchanged between fluids flowing counter to one another

- shell-and-tube exchangers - the most commonly used type of heat transfer equipment.

Choice of heat exchanger

Different types of heat exchanger suit different process conditions. For example, the smallest plate heat exchanger requires a minimum flow rate of 1 m^3/hour for continuous operation and can only handle effluents containing particles with a maximum size of 6mm. The spiral heat exchanger, on the other hand, requires a minimum flow rate of 6 m^3/hour but can accommodate a particle size of 25mm.

Choice of heat exchanger will therefore depend on:

- the nature and content of the solids component
- particle size and distribution
- particle settling characteristics
- flow rates in and out of the digester, and the type of feed and extraction mechanism
- fouling effects and corrosion.

Because most anaerobic digestion is mesophilic, the emphasis will be on a high degree of heat recovery using, for instance a plate or a spiral heat exchanger. However, the narrow gaps between plates make it unlikely that a plate heat exchanger would be effective, even after effluent separation. The spiral unit would be more effective, because of its larger gap, but the cost would be four times greater.

Another option is to use a double-tube heat exchanger such as the Spiraflow Monotube exchanger. This simple, corrugated, twin-tube device was specially designed for heavily contaminated media such as digester effluents. It has a unit area of 1.91m^2, costs £1050.00 (December 1983) and would incur mounting frame costs of £68.00 and interconnecting pipework costs of £150.00 (all excluding VAT).

Calculating the area required for a particular application

Where no details are available on the overall heat transfer coefficient of a heat exchanger, it is important to obtain values for the main physical properties - density, viscosity, specific heat and thermal conductivity - of the slurries being treated. However, data on the physical properties of slurries are virtually non-existent in the literature, and progress is only possible where physical property data for the solids and liquids that make up a slurry are either known or can be estimated, and appropriate equations can be derived.

Some experimental values for heat transfer coefficients have been identified in the literature. The most relevant is for a counter-current double pipe heat exchanger system using an internal pipe with a diameter of 80mm and an external pipe with a diameter of 120mm, and passing cattle slurry through the internal pipe and water through the annulus. The heat transfer coefficient was found to vary from 500 to 2000 watts per m^2 per °C, depending on substrate velocity and total solids content. Computations based on these values have shown increases in heat transfer area are proportionately smaller than increases in digester size. For example, a four-fold increase in digester size requires only a 25% increase in heat transfer area.

Economic feasibility

A $1000m^3$ digester operating on a 20-day retention period adds $50m^3$ of fresh slurry each day. If the temperature of this slurry has to be raised from 10°C to 35°C, the daily energy requirement is 60.8kW. Installing a Spiraflow Monotube heat exchanger with an efficiency of 68% and a heat transfer surface of approximately $40m^2$ would extract 41.3kW from the slurry discarded each day.

The system would cost £30,500 to install (1984 prices), with an additional £1500 for the pumps. The energy required to operate the pumps would be negligible - about 30 W/day for pumping $50m^3$ - although the value would vary from one installation to another, depending on pipe length and configuration, rates of flow, the physical properties of the fluid and the height through which that fluid needed to be raised.

Assuming a 10% total solids content of the slurry feed, the digester would produce $1000m^3$ of gas per day, with an energy content of around 281kW. Assuming a typical boiler efficiency of 80%, the 41.3kW of recovered heat is equivalent to about 51.6kW, or 18.4% of the energy available in the gas. The recovered energy therefore represents a gas saving of about £12.27/day.

Assuming 350 days operation per year, the total saving would be £4295/year, giving a payback on investment of 7.4 years. This would fall to about three years for a $3000m^3$ industrial digester.

Recommendations

- More experimental/theoretical analysis of slurry heat transfer coefficients.
- Experimental programme on the physical properties of slurries.
- Experimental programme using the Spiraflow Monotube heat exchanger.
- A detailed investigation into slurry separators and separation techniques.
- More investigation into heat exchanger clogging and the possibility of back-flushing.

Report No: ETSU B/M4/00532/16/REP Publication date: 1997

SUITABILITY OF THE LIQUID PRODUCED FROM ANAEROBIC DIGESTION AS A FERTILISER

Livestock Systems UK Ltd

Background

Anecdotal reports from the owners of anaerobic digesters on livestock farms suggest that grass growth is exceptionally good where the digested effluent is spread on the crop. Various other reports have confirmed these findings, indicating that the use of anaerobically digested slurry liquid (ADSL) in place of a standard after-cut fertiliser did not compromise subsequent grass cuts for ensiling, and sometimes provided an increased yield.

Research published in 1991 by the AFRC Institute of Grassland and Environmental Research has shown that the nitrogen in the separated liquid is used more efficiently than nitrogen in whole slurry, giving grass dry matter yields 20-35% higher, depending on the level of application.

These findings suggest that ADSL might be superior to raw slurry as a fertilising material, with increased availability of nitrogen and enhanced performance as a result of mechanical separation.

Project Objectives

- To determine the value of ADSL as a fertiliser on grass used for ensiling.
- To consider the economic use of slurries as sources of all nutrients.

Methodology

Trials were carried out at two locations: Cheshire College of Agriculture at Reaseheath, and a private farm at nearly Austerson. The locations had contrasting soil types - Reaseheath a sandy loam and Austerson a clay loam. Slurry supplies were obtained from a farm digester (ADSL) and from a dairy herd (undigested slurry liquid (USL)).

Table 1 below summarises the treatments given at both trial locations. Amounts are shown as $N:P_2O_5:K_2O$ in kg/ha. AN = ammonium nitrate; TSP = triple superphosphate; MoP = muriate of potash.

The first treatments were applied on 27 March 1996 at both sites. Subsequent applications were made immediately after cutting.

Table 1 Treatments applied at both trial locations

Treatment	Cut 1	Cut 2	Cut 3
A	No fertiliser or slurry	No fertiliser or slurry	No fertiliser or slurry
B	120:30:60 as AN, TSP and MoP	100:30:80 as AN, TSP and MoP	80:0:40 as 250 kg/ha of 25:0:16 + 17.5 kgN/ha as AN
C	33.7 m^3/ha USL + 120 kgN/ha as AN	33.7 m^3/ha USL + 93:0:60 as 25:0:16	No slurry: 75 kgN/ha as AN
D	33.7 m^3/ha USL + top-up to 120 kgN/ha as AN	33.6 m^3/ha USL + top-up to 100 kgN/ha as AN	No slurry: 80 kgN/ha as AN
E	Slurry (USL) to 60 kgK_2O/ha + top-up to 120 kgN/ha as AN	Slurry (USL) to 80 kgK_2O/ha + top-up to 100 kgN/ha as AN	Slurry (USL) to 40 kgK_2O/ha + top-up to 80 kgN/ha as AN
F	33.7 m^3/ha ADSL + 120 kgN/ha as AN	33.7 m^3/ha ADSL + 93:0:60 as 25:0:16	No slurry: 75 kgN/ha as AN
G	33.7 m^3/ha ADSL + top-up to 120 kgN/ha as AN	33.6 m^3/ha ADSL + top-up to 100 kgN/ha as AN	No slurry: 80 kgN/ha as AN
H	Slurry (ADSL) to 60 kgK_2O/ha + top-up to 120 kgN/ha as AN	Slurry (ADSL) to 80 kgK_2O/ha + top-up to 100 kgN/ha as AN	Slurry (ADSL) to 40 kgK_2O/ha + top-up to 80 kgN/ha as AN

Findings

Table 2 below summarises the dry matter yield obtained at each location, both for each cut and in total.

Table 2 Yields for each treatment at both sites

Treatment	Reaseheath				Austerson			
	Cut 1	Cut 2	Cut 3	Total	Cut 1	Cut 2	Cut 3	Total
A	4.72	0.77	0.88	**6.38**	5.63	3.83	1.00	**10.46**
B	8.40	1.51	2.98	**12.89**	5.89	4.82	2.41	**13.12**
C	7.74	1.26	4.13	**13.13**	6.03	3.97	2.66	**12.66**
D	7.50	1.55	3.46	**12.51**	6.01	4.74	2.20	**12.95**
E	7.29	1.55	3.46	**12.31**	6.03	3.70	2.52	**12.25**
F	7.21	1.39	4.14	**12.73**	6.15	4.56	2.61	**13.32**
G	7.37	1.77	4.16	**13.30**	5.70	4.23	2.53	**12.46**
H	6.91	1.30	3.19	**11.40**	5.89	4.68	2.37	**12.94**

Apart from Treatment A (nil application), there was no statistically significant difference in total yield between treatments.

At Reaseheath, all treatments except C yielded significantly less at Cut 1 than the standard treatment (B). At Cut 2, Treatment G (nitrogen-balanced ADSL) was significantly higher yielding than the standard. At Cut 3, Treatments C (USL disposal), F (ADSL disposal) and G (nitrogen-balanced ADSL) yielded significantly more than the standard.

At Austerson, there were no significant differences between treatments at Cut 1. At Cut 2, Treatments A (nil application), C (USL disposal), E (calculated USL) and G (nitrogen-balanced ADSL) had yields significantly below the standard. At Cut 3, Treatment A was significantly lower yielding than all other treatments.

Over the seaon, all treatments reduced dry matter content by a similar amount compared with nil treatment.

All treatments reduced water soluble carbohydrate in both fresh and dry matter compared with the nil treatment. Most treated samples fell below the target level for ensiling.

A few treatments at Reaseheath fell below the target of 64% digestible matter in the organic matter at Cut 3. No treatments fell below 63%.

All treatments produced grass with a crude protein content in excess of the target for ensiling (15-20% CP in the dry matter).

The sites differed markedly in the leaf nitrate-N content. At Austerson, levels frequently exceeded the target set: at Reaseheath, some samples exceeded the target. Excessive values can cause high ammonia levels in the silage, rendering it very unpalatable to stock.

Leaf potassium contents were markedly higher at Reaseheath than at Austerson and more frequently exceeded the target level. Although an excessive potassium content in silage is a potential cause of animal nutrition problems, the levels achieved would be unlikely to cause problems if there is adequate sodium in the diet.

None of the samples exceeded the target level for buffering capacity.

Metabolisable energy was highest in the nil treatment. Apart from this there was little variation between treatments. Levels were good to excellent for silage production, with those at Austerson being consistently higher than at Reaseheath.

Soil fertility increased relative to the standard fertiliser treatment (B), indicating that regular slurry treatments would increase and maintain fertility over the long term.

Conclusions

The trials showed that both types of slurry would produce dry matter yields of good quality grass comparable with those produced under a standard mineral fertiliser programme. Both materials were very effective in programmes balanced for the supply of nitrogen (D and G) and potash (E and H). The efficiency of the available nutrients was slightly less in ADSL than in USL, but dilution of the ADSL before use could mitigate this problem.

The use of ADSL in disposal and nitrogen-balanced programmes cannot be recommended on environmental grounds and is likely to affect silage quality. ADSL should therefore be used as part of a complete mineral/organic programme.

It should be possible to produce liquid fertilisers using ADSL as the source of all P and K, and balancing the available nitrogen with ammonium nitrate. This would allow a single liquid application for each cut.

2.4 Centralised Anaerobic Digestion

Report No: ETSU B/00/00173/REP Publication date: 1994

EQUITY AND DEBT FINANCING FOR CENTRALISED ANAEROBIC DIGESTION OF FARM WASTES: A FEASIBILITY ANALYSIS

Sceptre Management Ltd

Background

Anaerobic digestion involves feeding raw animal slurries into a closed tank where they are maintained at a given temperature in the absence of oxygen. The biogas produced has a significant methane content and can be burned to generate heat or electricity or, via a combined heat and power unit, both. The liquid digestate that leaves the digestion tank can be spread on fields as a fertiliser. Alternatively, it can be screened to separate the solid and liquid components, with the liquid effluent being spread as a fertiliser, and the solid component having a potential value as a soil conditioner or, after composting or heat treatment, as an alternative to peat in potting composts.

The performance of farm-scale anaerobic digestion plants in the UK and elsewhere in Europe has been relatively poor. Reasons include a limited demand for the energy produced, poor gas yields and ineffective feedstock control. Many of these problems could be overcome through centralised anaerobic digestion.

The centralised anaerobic digestion of farm wastes has been developed extensively in Denmark, and ten such plants were in operation by late 1993. The feedstocks used include slurry from farms and organic wastes from abattoirs, food manufacturers and sewage treatment plants. The digested slurry is returned to farms. Heat from biogas combustion is sold mainly to district heating systems. Power is sold into the electricity grid and benefits from advantageous tariffs.

Centralised anaerobic digestion is perceived to have significant benefits. It reduces the polluting power of wastes, controls odour, generates heat and power from a renewable source, improves the fertiliser value of the digested materials and reduces the spread of disease and weed seeds.

Project Objectives

- To establish how a centralised anaerobic digestion facility might be developed in a way that proved to be bankable and attractive to potential investors.

- To establish how the first - and most risky - scheme would need to be funded.

Methodology

The programme of work included:

- a review of existing literature
- a visit to an operating plant in Denmark
- development of a spreadsheet model of a possible first UK plant
- a detailed banking analysis in relation to the model
- a detailed equity analysis in relation to the model
- an assessment of how financing might develop after construction of an initial UK plant.

Findings

Banking analysis

The banking analysis concluded that, for a first centralised anaerobic digestion plant in the UK, bankers invited to lend on a project-financing basis would be likely to stipulate certain requirements:

- the dominant project sponsor to be a corporate entity with real financial substance

- project contractors to provide specific technical performance undertakings

- the project to be built under a fixed-price turnkey construction contract

- independent corroboration of projected biogas production

- long-term contractual arrangements for the supply of farm and other organic wastes

- detailed analysis of arrangements for overcoming seasonal fluctuations in feedstock composition

- long-term contractual arrangements for the sale of any product other than electrical power - if such revenues are used to support lending

- contractual operating and maintenance relationship with an experienced centralised anaerobic digestion operator.

The quantitative banking analysis determined that the economics of a plant of the type assumed would appear to be satisfactory, with electrical power sales alone being used to repay financing based on 65% debt and 35% equity, and with the debt being repaid over a six-year period. This would require the electrical power to be sold at a minimum price of 10.75p/kWh (to be escalated in line with inflation).

Equity analysis

Taking the base case used for the banking analysis as its point of departure, the equity analysis established that financing based on 65% debt and 35% equity, and a power sales contract at a contractual price of 10.75p/kWh (unescalated) would be likely to generate a nominal internal rate of return (IRR) of the order of 28.4% (21.6% real IRR). Similar rates of return were recorded for cases where it was assumed that revenues for the sale of heat could also be obtained.

The equity analysis concluded that an investment opportunity of this type would be likely to be of interest both to existing investors in the renewable energy sector and also, potentially, to new entrants to the field.

Future developments and financing

The study concluded that the successful financing and construction of an initial centralised anaerobic digestion project - and its satisfactory initial operation - would be likely to encourage potential sponsors to consider further plants. It also foresaw scope for some relaxation by bank lenders of their terms in respect of interest margins (slightly smaller), percentage of debt to equity in the overall funding package (an increase), and the period for the repayment of borrowed funds (extended).

However, the most important likely medium-term development was felt to be the establishment of mature markets for separated fibre. The effect of such schemes becoming bankable was analysed in terms of their likely impact on the power price required to make project economic - both as banking and investment projects. It was found that, at fibre prices of £30/m^3, a power price of 8.4p/kWh was required to generate a nominal IRR of 28.4% for investors (21.6% real IRR). To generate a real IRR of 15% (21.3% nominal IRR on the inflation/interest rate assumptions used in the study’s centralised anaerobic digestion model) a power price of only 6.34p/kWh was required, again assuming that the fibre could be sold for £30/m^3.

Report No: ETSU B/M4/00487/09/REP Publication date: 1995

REVIEW OF PLANNING AND ENVIRONMENTAL ISSUES RELATING TO CENTRALISED ANAEROBIC DIGESTION FACILITIES

The Barton Willmore Partnership

Background

Anaerobic digestion - the bacterial fermentation of organic waste material in oxygen-free conditions - produces a biogas that can be burnt to generate heat and/or electricity. The sludge residue can be used as a fertiliser or, after treatment, as a compost/soil conditioner.

As well as generating useful by-products, the anaerobic digestion of organic wastes - livestock slurries and manure, sewage sludge, food industry waste etc - reduces the potential for water pollution, odour emissions and the spread of infection. The technology has long been used for the treatment of sewage sludge and, although there were only 22 operational farm-based digesters in the UK in April 1995, legislative pressure and the Government's encouragement of renewable energy is stimulating further development in this sphere.

Recent studies suggest that there is significant potential for energy production from the anaerobic digestion of farm wastes, particularly from centralised facilities such as those that are now well established operations in Denmark.

Project Objectives

- To discuss planning and environmental issues with planning authorities and environmental health officers to establish their concerns.

- To prepare an information memorandum for both the authorities and project developers, outlining how the perceived problems might be resolved by a centralised anaerobic digestion scheme.

Methodology

The main components of the work comprised:

- a literature review of anaerobic digestion processes and of UK and European experience with centralised facilities

- a review of relevant town and country planning legislation and Government guidance

- a review of current Government policy and existing and emerging development plans within the UK, the aim being to establish policy towards this technology and the issues identified by local planning authorities (LPAs)

- a review of two on-farm centralised UK facilities, Newlands Mill Farm in Cumbria (operational) and Attwell Farms at Redditch in Worcestershire (at the planning stage), plus discussions with the relevant LPAs

- a visit to an off-farm centralised biogas plant in Denmark to identify the planning and environmental issues that have arisen there.

Findings

A centralised anaerobic digestion facility handling waste from several farms and from industry is likely to include:

- a waste reception facility with collection tanks
- an appropriately sized digester
- gas storage and handling equipment
- electricity generating equipment
- storage facilities for wastes and liquors
- control and monitoring equipment

In most cases, development will require planning permission. Depending on the type, size and location of the scheme and on its likely environmental impact, it may also require an environmental assessment. When considering a planning application, the LPA will take into account Central Government advice, the provisions of the development plan and other factors. If it grants planning permission, it may impose planning conditions or seek to secure a legal agreement in order to regulate the development or use of the land that is the subject of the proposals.

Development plan policies for renewable energy in general, and anaerobic digestion in particular, are still evolving. Limited UK experience means that there are few examples of policies relating specifically to anaerobic digestion. A more informed policy approach is likely to result from a combination of the annex to PPG22 “Renewable Energy”, which deals with anaerobic digestion, and recent planning studies carried out by LPAs in consultation with ETSU and other consultants. This review has shown that the primary concerns of LPAs relate to the siting and location of the development, its visual impact, traffic generation and impact, odour emissions and noise.

The primary concern of the LPAs involved in the Cumbria and Redditch schemes related to the environmental implications of importing waste to the plant. Both LPAs have sought to control the source of feedstock. At Redditch, the LPA is seeking a legal agreement to restrict the feedstock to that generated by four named farms under the same ownership. In Cumbria, the LPA has attached conditions to the permission, limiting the importation of poultry litter to one load per week and restricting transportation to a specified route. Visual issues have been satisfied by careful siting of the plant alongside existing agricultural buildings.

The Danish plant visited, at Ribe, is an off-farm facility that receives, each day, about 300 tonnes of cattle and pig slurry and 100 tonnes of slaughterhouse and food industry waste. Tanker delivery generates about 56 traffic movements per day, with the wastes coming from around 120 participating farms within a 10-11km radius of the plant, and from other sources up to 50km from the plant. The biogas is transported by a 2.5km pipeline to a CHP plant on the edge of Ribe. The heat is used locally for district heating. The electricity produced (1MW) is exported to the grid. The digestate is returned directly to member farms or to other plant growers for use as fertiliser. Relevant planning issues identified were visual impact on the landscape, the control of air, noise and water emissions, and traffic generation.

Conclusions

Developers seeking planning permission for the centralised anaerobic digestion of farm wastes should:

- examine the policies and proposals of the LPA's development plan to establish a policy framework for the development and to identify any constraints that need to be taken into account

- meet with officers of the LPA to ascertain their views, to establish what supporting information is required, and to determine whether a formal environmental assessment is necessary.

The main planning and environmental issues that are likely to arise fall into four main categories:

1. ***Site location*** - The development and its associated power plant should be located close to the feedstock source to minimise transport costs. It will require good access to the road network for deliveries. Suitable locations might be:

    - on-farm, adjacent to existing buildings
    - adjoining existing industrial buildings
    - adjacent to an existing water treatment works (where sewage sludge is to be used).

The associated power plant can be located either adjacent to the digester or at a site that is more suitable in terms of using the heat and/or electricity generated.

1. ***Visual impact*** - The extent of the buildings and structures will depend on the scale of operation, the most significant being the digester tanks, gas holder, reception/storage tanks and power plant. All will need to be carefully sited to limit visual intrusion within the landscape, and mitigation measures may be necessary such as bunding and planting around the site and the partial burial of tanks. The latter is very costly and likely to affect project viability adversely. It should only be considered in the most sensitive locations.

2. ***Air/noise/water emissions*** - The anaerobic digestion of farm wastes considerably reduces their water polluting strength and can reduce odour potentials during subsequent storage and application by up to 80%. However, odour can be a problem during waste delivery and storage, during the cleaning of tanks and when gases are flared off. Odour emissions can be controlled using a comprehensive odour-control system, enclosed tanker reception facilities and sealed reception and storage tanks.

Noise emissions are associated with tanker deliveries, pumps, compressors and any power plant. They can be controlled by planning conditions, which involve restricted external noise readings and require the use of sound attenuation measures within buildings.

Supporting information supplied with the planning application will need to identify the principal sources and the nature of any odour and noise to be generated by the plant, and the methods by which any potential nuisance will be eliminated. It will also be necessary to provide information to the National Rivers Authority about the proposals for disposing of effluent and contaminated surface water from buildings or delivery tankers.

3. ***Traffic and highways* -** The developer will need to provide the local highways authority with information about likely traffic generation, types of vehicle, sources of feedstock and destinations of digestate. The information will be assessed in relation to both the standard of roads serving the plant and the environmental implications of the proposed traffic movements. Conditions may be imposed to restrict vehicular movements, to limit the sources of feedstock and to prevent the use of certain roads by unsuitable types of vehicle.

Report No: ETSU B/W2/00399/REP/1 Publication date: 1996

TRANSPORT AND SUPPLY LOGISTICS OF BIOMASS FUELS
VOLUME 1 - SUPPLY CHAIN OPTIONS FOR BIOMASS FUELS

Transport Studies Group, University of Westminster
Scottish Agricultural College

Background

Biomass offers certain advantages as a fuel: it is sustainable; its use will help to reduce pollutant gas emissions, ensure the security of UK fuel supplies and contribute to employment creation; and it can offer visual and wildlife benefits in the form of coppice crops and forestry.

The production and use of biomass also faces certain problems, notably the economic cost of supply and environmental issues relating to transportation and power stations. Some of these problems will need to be addressed by managing the operational logistics (transport, storage, handling) in an integrated way.

Transport is the key link in the biomass fuel supply chain, linking discrete activities such as harvesting, storage, handling and delivery to the power station. Transport arrangements will be determined by storage facilities at the power station, while factors such as vehicle size, transport distance and time spent loading and unloading vehicles will have a significant effect on transport cost. Road transport will nearly always predominate, accounting for up to 70% of total delivered fuel costs, depending on the biomass type under discussion.

Project Objective

- To present the options for supplying biomass-fuelled electricity generating stations with fuel of the right specification, in the right quantities at the right time from resources that are typically diverse and often seasonally dependent.

The report examines forest fuels, short rotation coppice (SRC) crops, straw, miscanthus and animal slurries. This summary focuses on the findings as they relate to animal slurries.

Methodology

To help investigate the supply chain as a whole, the project has developed a series of spreadsheet-based supply chain option models. These are designed to incorporate and cost in detail all the activities involved in the supply of fuel from harvesting to final delivery to a power station. The models have been developed for a range of different biomass fuels and provide details of:

- total delivered cost to power station

- the constituent components of total delivered costs and an assessment of how they accumulate along the supply system

- activity costs for each supply system - ie the contribution of each cost category to the total delivered cost.

Findings

Delivered costs

The lowest delivered costs for animal slurry were achieved by using the largest payload articulated road tanker (23 tonnes) that is currently permissible. However, the modelling also showed that a supply system using a high speed agricultural tractor with an agricultural slurry tank trailer is capable of producing a slightly lower delivered slurry cost than that achieved using a rigid road tanker of the same payload. This suggests that using powerful agricultural equipment rather than haulier-operated road tankers can result in lower supply costs in certain circumstances.

Comparison with other biomass fuels

Biomass fuel costs vary, with certain straw delivery systems providing the lowest delivered costs (around £28.00/tonne of dry matter for Hesston bales). Forest fuel systems provide the next lowest delivered costs (£32-£37/tonne of dry matter), followed by SRC (£47-£54/tonne of dry matter) and miscanthus.

It is not realistic to compare the delivered costs of animal slurry with those for other biomass fuels. The major cost in animal slurry supply systems is the transportation and handling cost. Minimising transport distance will therefore be critical. However, large vehicles may have difficulty operating on the small roads connecting cattle and pig farms to centralised digesters, and it may be necessary to use smaller tankers or trailed tanks drawn by high-speed agricultural vehicles.

In all cases, the use of intermediate storage facilities with double handling and transportation adds 10-20% to delivered costs. However, the use of such stores is likely to be essential to the provision of a year-round supply of fuel - a fuel supplier supplying straw, for instance, will probably have to make use of an intermediate store supply system as well as a farm store supply system.

The effect of road transport distance on delivered costs

Delivered costs for animal slurry are very sensitive to transport distance. Increasing this distance from 5km to 20km can, for instance, increase delivered costs by 30-65%. Straw, forest fuel, SRC and miscanthus, on the other hand, are relatively insensitive to transport distance, and modelling has shown that doubling this distance from an 80km round trip to one of 160km adds only 5-15% to delivered costs.

Overall, cost savings can be achieved by sourcing fuel from closer rather than more distant locations, and such savings may be crucial to the financial viability of the electricity generation scheme.

Transport systems

Factors influencing transport distance

The catchment area for the biomass, and hence the transport distance over which biomass will have to be moved, will depend on several key factors:

- the size of power station and the conversion technology used
- the quantity of biomass produced per ha
- the proportion of land adjacent to the power station that produces the biomass resource
- the degree of competition for the crop or by-product.

Modelling the transport systems to meet power station requirements

Transport system requirements for biomass power stations have been modelled in terms of the number of vehicle deliveries (per day and per year); the maximum number of round trips per vehicle per day; the number of vehicles and drivers required; and vehicle kilometres travelled (per day and per year).

A 1MW anaerobic digester would, for instance, require four vehicles and 18 vehicle deliveries/day, a total of 90,000 vehicle kilometres/year.

Environmental implications of biomass schemes

Although biomass offers several environmental benefits, there are negative environmental impacts that need to be considered. As well as the negative impacts of constructing and operating a biomass power station, these include the fuel consumed during harvesting, transportation, processing and handling; possible effluent run-off from stores; the fire risks associated with storage; the health risks associated with mould growth during storage; and the environmental impact of transportation - emissions, noise, traffic levels etc.

The significance of these environmental impacts will depend on the specific location and the physical and human geography of the surrounding area. Public perception is also an important factor in the development of energy from biomass.

Conclusions

All the supply systems modelled in the report are plausible and have the potential to be used to provide fuel for power stations. It is critical that a balanced fuel supply strategy is adopted that is capable of meeting power station requirements in terms of quantity, timing and quality. In practice, minimising costs is not the only issue, and several supply systems are likely to be operated to ensure security of supply.

Report No: ETSU B/W2/00399/REP/2 Publication date: 1996

TRANSPORT AND SUPPLY LOGISTICS OF BIOMASS FUELS
VOLUME 2 - BIOMASS AND STRATEGIC MODELLING

Transport Studies Group, University of Westminster
Scottish Agricultural College

Background

This report is the second of two reports examining the transport and supply logistics of biomass fuels. It contains the biomass resource analysis and the strategic modelling of power stations in relation to resources.

Project Objectives

- To examine existing and potential biomass resources in terms of the total quantities available and their geographical distribution throughout Britain, and to consider seasonality of supply.

- To use strategic modelling to describe the distribution of the biomass resource in terms of its supply potential for power stations.

The report examines forest fuels, short rotation coppice (SRC) crops, various types of straw, and animal slurry. This summary focuses on the findings as they relate to animal slurry.

Findings

Resource distribution and availability

The highest concentrations of animal slurry are found in western England, south Wales and south-western Scotland. They reflect to some extent the distribution of dairy and beef cattle in the UK. In the most concentrated areas, output may reach 18 tonnes of slurry/ha/year, and there are extensive areas where production exceeds three tonnes/ha/year.

While the maximum slurry output for Britain as a whole is estimated at 45.67 million wet tonnes/year, generators are more likely to be interested in summer levels of slurry production as these represent the minimum guaranteed levels available all year round. The total minimum output of slurry is estimated at 24.45 million wet tonnes/year, and the main areas of high production appear to be more widely distributed, with notable concentrations in areas of intensive pig production such as East Anglia and Humberside.

Strategic modelling

The project has involved the development of a strategic modelling program that allows various factors affecting the number and location of potential power stations to be examined. The program can:

- alter the biomass resource data set to reflect different scenarios for resource availability

- change the catchment area around the power station from which the biomass can be sourced

- alter the size (MW capacity) of power stations to explore the effect on power station numbers and location.

The model assumes that each power station lies in the middle of a catchment area from which the biomass is sourced. Implied in this is that, once a catchment size has been defined, the power station constructed would be sized to consume all the resource available in that catchment, thereby avoiding transportation between catchments.

Calculating a "total tonnes/km" value for each catchment provides an indication of the "goodness of supply" and allows decisions to be made as to the order in which catchments should be allocated power stations.

Results of strategic modelling

Slurry exists in sufficient concentrations in some 10km x 10km squares in Britain for it to be possible to fuel a 1MW anaerobic digester from entirely within one such square. This would limit the transport distance to a maximum of 14km (7km if the digester were to be located at the centre of the square). Data for the maximum annual output indicates the existence of 21 10km x 10km squares that produce sufficient animal slurry to power a 1MW digester. These squares would appear to be prime locations for the siting of anaerobic digesters.

Conclusions

Significant quantities of several biomass resources, including forest fuels, already exist in Britain. In addition, large quantities of SRC could be produced. There is a marked variation in the geographical distribution and degree of concentration of these resources, which means that different solutions in terms of power station location and size will be needed for each resource.

The work has also demonstrated that there is sufficient biomass resource to achieve relatively low transport distances in supplying the fuel to biomass power stations in the capacity range currently being considered by power station developers.

Finally, the transport distance over which biomass resources would have to be transported depends on resource availability. This, in turn, is determined by demand from non-biomass users and the price they are prepared to pay, by annual production, and by other factors such as the willingness of farmers and forest owners to produce and/or supply biomass. Further work is required in these areas.

Although the project has achieved its objectives and contributed to the understanding of power station size and location in relation to the resource base, the findings do have their limitations because of the simplifying assumptions that have been necessary for the strategic modelling.

2.5 Relevant Case Studies

Report No: ETSU B 1127 Publication date: 1986

A LARGE, FARM-SCALE DIGESTER AT PITTRICHIE PIG UNIT ABERDEENSHIRE

Microbial Biochemistry Department, Rowett Research Institute
Engineering Division, North of Scotland College of Agriculture

Background

Research into the anaerobic digestion of farm animal wastes since the 1960s has shown the process to be effective at both small and larger laboratory scales and also in a small farm-scale plant. The farm-scale unit, with a capacity of $13.5m^3$, was located at the North of Scotland College of Agriculture and was used as a demonstration plant for farmers from 1971 onwards. Not only was this plant felt to be too small for the requirements of even a relatively small farm, but visiting farmers assumed the existence of full back-up in terms of workshop facilities and skilled staff. There was clearly a need for a demonstration plant on a commercial farm, operated by farm staff.

Project Objectives

- To design and build a full-scale experimental, prototype pig slurry digester, with ancillary equipment for generating heat and electricity from the biogas produced.

- To install a commercial slurry separator for pre- or post-digestion separation purposes.

- To monitor the digester and biogas utilisation systems for long-term performance, reliability and operability, and to identify opportunities for overall system modification and improvement.

Methodology and Findings

The digester plant

An experimental single-stage, mesophilic, stirred-tank digester was constructed to treat the slurry output of a 1200-sow piggery at Pittrichie. The digester had a working volume of $680m^3$ and was designed to treat a total solids content of 6% in a retention time of 10-12 days. The digester operated continuously from start-up in December 1980 until September 1985. It was monitored from start-up until November 1984.

The biogas produced was burnt either in a 283kW boiler or in a spark ignition engine driving a 65kVA alternator. The electricity generated was used in the piggery and digester. The heat produced by the boiler, or recovered from the engine cooling systems, was directed to the piggery and digester heating systems via hot water pipes.

Biogas production

From a microbiological point of view the digester behaved in the way that had been predicted by the small-scale experiments. The digester flora proved stable and were unaffected by stoppages or changes in digester loading. No re-inoculation was required.

However, the daily production of biogas proved disappointingly low at only 9.17m^3 per m^3 of feed for the monitored period 9 March 1983 - 2 April 1983. This low biogas output was primarily a result of two factors:

- the very low solids content of the slurry (2% or less for most of the monitoring period)
- a low digester feed-rate (again about 33% of the design value).

These low values were caused almost entirely by the design and operation of the piggery and its slurry storage and removal system.

The composition of the gas was the same as the gas produced in small-scale pig-waste digesters, ie about 70% methane and 30% carbon dioxide, with various trace gases.

System reliability

Although the digester and its associated equipment operated more or less as expected and with reasonable efficiency, overall system reliability was unsatisfactory. A major obstacle to steady-state operation was the design of the piggery for slurry storage in channels under slatted floors within the building, with removal every few weeks. This contrasted with the daily slurry removal needed for effective digester operation. However, modification would have been too costly.

Another critical factor in system reliability and efficiency was the time period between fault occurrence and fault correction. Fault diagnosis and correction requires considerable knowledge and skill on the part of those on the spot and, unless controls can be made self-diagnostic, further automation is likely to exacerbate the problems.

Environmental issues

Anaerobic digestion proved effective as a means of pollution control. The digested slurry was much less odorous than the undigested slurry, and further improvements in this respect were achieved by subsequent storage. However, digestion did nothing to reduce the volume of slurry involved - disposal being this farmer’s main problem.

Economic issues

Unless or until pollution control has a value to farmers, digester economics will depend on energy generation and use. In this instance, gas production was very low compared with the value of 20m^3 or more per m^3 of feed that is required if a project is to be successful in energy or economic terms. This suggests that slurry digestion for energy production is unlikely to be viable for piggeries unless units are designed to produce slurry with a high solids content that is removed to store on a daily basis.

The high capital cost of digester installations combined with the prohibitive cost of storing biogas for more than half a day (at full production rate), means that the gas must be 100% utilised within a short period of its production. A modern, energy-efficient piggery is likely to be able to use half (or less) of the energy available from a digester if all the slurry is digested and gas output is about $20m^3$ per m^3 of slurry. The most economic way of using the remaining energy is, in most cases, to export it as electricity either to neighbouring enterprises or to the grid. However, this will require a buy-back price of at least 4p/kWh, compared with the 1.8-2.5p/kWh currently paid, if digestion for energy purposes is to be viable.

Furthermore, if electricity is to be exported to the mains, parallel operation with the mains will be essential to allow the engine to run near full load and so keep conversion efficiency high.

Report No: ETSU B/M3/00388/17/REP Publication date: 1994

ANAEROBIC DIGESTER PERFORMANCE AT HANFORD FARMS, DORCHESTER

ADAS

Background

Anaerobic digestion plants have been installed on UK farms for various reasons since the late 1970s. Much associated research work was undertaken during the 1980s and, in 1991, a study of the Bethlehem Abbey digester highlighted many interesting issues, including the potential value of the by-products, certain fundamental aspects of digester operation and, most notably, the relatively poor specific gas production. A recent Department of Trade and Industry report has concluded that there may be a future for correctly planned and managed digesters at three different levels: the domestic farm scale, the managed intensive farm scale and the centralised co-operative farm scale.

Project Objectives

- To evaluate typical operational performance at Hanford Farms near Dorchester.

- To identify why UK digesters have a specific gas production efficiency of 0.6m^3 per m^3 of digester when Danish centralised digesters can achieve 1.2-1.6m^3 per m^3 of digester.

The overall objective is to enable a better evaluation of centralised digester viability in the UK.

Methodology

The project involved:

- a review of historic energy production records

- the design of a mass and energy flow measurement and monitoring system and its application over a three-month period.

Findings

The Hanford Farms digester system

The digester has a capacity of 750m^3 and operates at 30-35°C with a 10-day retention period. The feedstock consists mainly of pig slurry and food industry waste, but is also subject to considerable dilution from washing-down water and rainwater. The slurry passes to a reception pit where a mixing pump prepares the material before it is pumped into the digester. The digestate leaving the digester is piped to a vibrating screen where a large proportion of the solids is separated out. The liquid is pumped to a large store prior to being spread on the fields. The separated solids are drained and composted.

The gas produced by the digestion process is temporarily stored in a 7.5m^3 bell over water storage vessel. Based on standard figures, the 70 m^3/day feed at a dry matter content of 5% could provide 26,250 MJ/day. The biogas is used by two spark ignition engines, each coupled to a 45kVA generator set working at around 80% of design output. Engine coolant water is used to heat the digester, with the surplus being used for space heating in an office block. The electricity generated is exported off site to the Regional Electricity Company under the Non-Fossil Fuel Obligation.

Historic electrical energy production

Total electrical energy production varied for each year studied, ranging from a little over 100,000kWh in the commissioning year to more than 500,000kWh in 1992/93.

The rated generation potential was 90kW (45 kW/engine) and, when an engine was running, power production was found to be marginally higher than design. However, in the context of the eight-year period examined in this study, overall engine utilisation and consequent power output was little higher than 50%. This can partly be explained by the variation in digester temperature (28-42°C), which appears to have had some effect on gas yield and, consequently, on energy output.

Specific gas production for the 1984-1986 period ranged from 0.31m^3 of gas per m^3 of digester to 1.35m^3 of gas per m^3 of digester, with an average of 0.7m^3 per m^3 of digester. For the 750m^3 digester, this gives a gas output of 525 m^3/day, equivalent to 3,622 kWh/day. Assuming a 30% conversion to electricity, this gas is estimated to produce 45kW of electrical energy and 105kW of heat energy, some of which is used for digester heating.

Although it may be concluded that this pattern is typical, gas production from the digester is erratic and well below its potential. Attention therefore needs to be given to feedstock quality, particularly to total solids content, volatile solids content and volatile solids loading rate.

Monitored results

Monitoring of the plant was carried out over a three month period (February - April 1994). The feedstock volume was 66 m^3/day with a low total solids content which averaged 2.06% and ranged from 0.7% to 4.6%.

Estimates of gross gas production potential were only 15% above actual measured values for the period, and some of this loss may have been caused by gas escaping at the bell over water gasometer. Metered gas flow averaged 472 m^3/day, ie 0.63 m^3/day per m^3 of digester. This equates to an average gas energy production of 3278 kWh/day.

Methane levels ranged from 51.7% to 70.56%, with an average of 66%. Applying these figures in bands to the measured gas flow showed that there was a reasonable correlation between the electrical energy potential based on 30% conversion rates and measured electrical energy exports. For the period up to 8 April, the average conversion to electrical energy was estimated at 31.5%. Average daily electricity production was 1026 kWh/day, giving an annual total of 375 MWh.

Environmental impact

The digestion process dramatically reduced both biological oxygen demand (BOD) and volatile fatty acids (VFA). The VFA reductions averaged 85%, and it was assumed that these reductions would have an equivalent effect on odour potential. The BOD reductions averaged around 76% and, while these would reduce the impact in terms of water pollution, the power to pollute would still be ten times greater than that of raw domestic sewage and 100 times greater than that needed for discharge.

The main source of gaseous emissions from site was the gasometer which, when fully raised, acts as a pressure vent. These methane losses indicate that the gasometer is fully raised and venting gas for perhaps 18% of the time.

Recommendations

- Increase feedstock strength by reducing yard water ingress, thereby minimising uncontrolled dilution.

- Increase the volatile solids in the feedstock by the controlled addition of higher grade feedstocks such as silage effluent and confectionery residues.

- Increase total solids in the feedstock by the controlled addition of poultry litter.

Report No: ETSU B/M3/00388/27/REP Publication date: 1994

TECHNICAL MONITORING OF A MESOPHILIC ANAEROBIC DIGESTER FED WITH POULTRY MANURE - BITTERLEY COURT FARM, SHROPSHIRE

Enertech (1983) Ltd

Project Objectives

- To establish the viability of using the anaerobic digestion of hen excreta to produce biogas for the generation of heat and, possibly, electricity.

- To assess the technical performance of the Bitterley Court Farm digester and confirm whether ammonia inhibition drastically reduces biogas yield under current operating conditions.

Methodology

The methane and hydrogen sulphide contents of the gas are continuously displayed on appropriate equipment. The methane values were confirmed by on-site readings using a Gascoseeker of checked calibration and by bag samples analysed at a British Gas laboratory. The hydrogen sulphide content was confirmed using Draeger tubes as indicators and also by the analysis of gas samples. Samples were taken to determine the presence of oxygen and nitrogen.

A datalogger was used to record the heating water flow and return temperatures for the digester and other temperatures. It also recorded electrical consumption. Appropriate instrumentation was installed to measure gas, sludge and water flows.

Findings

The system installed

Bitterley Court Farm has 22,000 laying birds arranged in nine lanes and housed in a single building. The manure is collected automatically from three lanes and manually from the other lanes. The total collected is fed, via a conveying system, to an anaerobic digester with a capacity of $150m^3$. A gas circulation system operates for 12 hours/day to mix and agitate the digester contents. Gas generated is retained in the domed portion of the digester, and this is connected to a small floating roof gas holder from which excess gas is vented to atmosphere.

The sludge extracted from the digester is drawn off using a variable speed pump. It then passes to a separator/belt press where the fibre and liquor components are separated. The fibre is stored in $1.4m^3$ containers and then removed from site for composting before being used as a peat substitute. The liquor is piped to an open-air lagoon from which it is periodically removed and spread on an adjacent field to encourage growth.

The gas produced by the digester is used first for digester heating, secondly for fuelling two greenhouse heaters and finally, if available, for a swimming pool heating system and the house central heating. A small gas-fired boiler produces hot water for heating the digester so that it maintains its operating temperature of 35°C. Two hydrogen sulphide gas scrubbers, connected in parallel, are installed in the gas pipework serving the greenhouse, house and swimming pool.

Feedstock quantities and characteristics

Digester feedstock quantities were estimated using published data from reputable sources. Estimates indicate that the quantity of excreta produced by 22,000 laying birds is likely to be between 2.332 and 3.143 tonnes (m^3) per day. The equivalent retention time in a digester with a capacity of 150m^3, assuming no water dilution, would be between 63.8 and 47.7 days.

Assuming a daily input to the digester of 3.143 m^3/day of excreta with a moisture content of 70%, plus 6.287m^3 of water to reduce the solids content to 10%, the total input is 9.430 m^3/day, giving a digester retention time of 15-16 days.

Gas production and quality

A laboratory analysis of the excreta gave the following values:

moisture content (by loss on drying):	65.2% w/w
dry matter (by difference):	34.8% w/w
residue on ignition at 700°C:	9.5% w/w
organic matter (by difference):	25.3% w/w

Assuming that, typically, 30-40% of the organic and volatile matter is destroyed in the formation of biogas, gas production is estimated to be of the order of 10-13 m^3/hour. This figure was partly confirmed by the gas flow measurements taken during gas use. These varied from 8.6 m^3/hour early in the programme, with the digester heating boiler and one greenhouse heater in operation, to 10 m^3/hour for one 24-hour period during which the digester heating boiler, both greenhouse heaters and the house central heating system were operating. These values do not include any gas vented to atmosphere.

Gas production is inhibited by the ammonia content in the digester. An increase in ammonia levels first destabilises the digestion process, then reduces gas generation and results, ultimately, in the cessation of the process. Ammonia concentrations can be reduced by introducing additional animal wastes or suitable industrial wastes into the system. The addition of extra water appears to have a similar effect.

The methane content of the biogas produced was found to vary, initially, between 30% and 40% by volume, and the presence of oxygen and nitrogen in two of the readings indicated some degree of air ingress. Better quality gas was produced during the later stages of monitoring, when more stable digester operation had been achieved. The methane content increased to around 50%, the latest analyses giving a value of 55.2% with no oxygen present.

The hydrogen sulphide content of the gas, which can inhibit gas production, was generally in the 3200-3800ppm range, although levels as high as 4400ppm were observed.

Sludge characteristics

The sludge removed from the digester had a typical solids content of 8-9%, a pH of 7.9 and an ammonium salts content (as NH_4) of 0.32% w/v.

The subsequent separation process generated approximately 20 tonnes/month of recovered fibre with a moisture content of 74%.

Analysis of the fluids entering the digester and the belt press showed that the efficiency of pathogen kill varied - around 90% for faecal *coliforms* and rather lower for faecal *streptococci*. Pasteurisation of the excreta before it is fed to the digester would probably be necessary to ensure a higher level of pathogen kill.

Efficiency of digester heating system

The heat required to raise the temperature of the sludge input to the digester from 20°C to 40°C and maintain the required temperature over a 24-hour period has been estimated at approximately 9.15kW. Digester heat losses were estimated at 3.408kW.

Conclusion

Although some problems were experienced with the plant, the indications are that consistent operation could be achieved, with an associated improvement in gas quality.

Report No: ETSU B/M4/00487/04/REP Publication date: 1995

MONITORING OF THE ANAEROBIC DIGESTION AND CHP INSTALLATION AT NEWLANDS MILL, NEWMARKET HESKETH, CUMBRIA, WITH VARIOUS TYPES OF ANIMAL EXCRETA AS FEEDSTOCKS

Enertech (1983) Ltd

Background

Poultry production units in the UK usually operate as part of a larger organisation which handles the production of four to five crops/year of new chicks and their rearing/sale right through to culling and mucking out.

The aim after each mucking out is to remove the litter from the farm as quickly as possible so that the poultry house can be thoroughly cleaned before the next intake of young stock. The litter is transported to a disposal site - often, by agreement, the nearest farm, where it is dumped or spread. However, odour problems limit suitable dumping sites.

Although poultry litter is a very rich source of nutrients, the uptake of nutrients from the as-spread manure is both inefficient and unpredictable, and this can have a deleterious effect on crops. There are also adverse implications for local water courses. One possible alternative is to digest the waste before using it as a fertiliser. This would not only enhance its value to growing crops but also generate energy from a renewable resource.

Project Objectives

- To monitor biogas production from a digester using different feedstocks.
- To ascertain the effect of different feedstocks on methane and hydrogen sulphide levels.
- To ascertain the potential for using the by-products of the digestion process as fertilisers and fibrous products that could be returned to the growing chain.

Methodology

Three digester feedstock mixtures were evaluated:

- sawdust-based chicken litter + cattle slurry
- straw-based chicken litter + cattle slurry
- straw-based chicken litter + cattle and pig slurries.

Monitoring involved installing a gas flow meter, a gas sampling module designed to display the methane and hydrogen sulphide contents of the gas, Envirolog monitors to record hydrogen sulphide levels, digester heating water flow and return temperatures, ambient temperatures and digester effluent temperatures. Gas samples were also taken and delivered to British Gas for analysis. Their findings agreed with manual readings taken with a Draeger tube and with the other installed equipment.

Findings

The plant

The anaerobic digestion plant at Newlands Mill was installed to produce liquor for use as fertiliser and compost for use as a peat substitute. A combined heat and power (CHP) unit was added later as a peak-lopping exercise to eliminate or minimise the Mill's excursions into peak electrical cost regions.

The digester has a capacity of $750m^3$, with twin feed augers in the feed hopper, a single extraction auger and a separate slurry feed. A pressurised gas circulation system provides mixing and agitation. Panel-type heat exchangers are installed inside the digester.

The digester has a floating roof water seal gas holder capable of holding $2.5m^3$ of gas. Although this roof incorporates a pressure-relief valve, gas venting has been all but eliminated by the installation of a flexible, low-pressure (0.5 inch water gauge) gas bag with a storage capacity of some $300m^3$.

The plant also includes two GASRAP hydrogen sulphide absorption modules.

A separator is fitted after the extraction auger and operates for up to 12 hours/day. The resulting solids (12-15% dry) are first deposited on a concrete slab and are then transferred to containers in the building. The liquor flows to two storage tanks beneath the cattle shed. These have a total capacity of around 50,000 gallons.

Feedstocks

The chicken litter is collected from local sources and stored in a partially enclosed area close to the digester. Dumper vehicles transfer the litter to the digester feed hopper for feeding into the digester.

About 100 beef cattle are kept in a cattle shed adjacent to the digester. Their litter is collected in channels in the shed and then flows into an external concrete trough from which it is pumped into the digester. The imported pig slurry is discharged into the same trough and pumped into the digester.

Loading takes place every weekday morning.

Gas production

Initial gas production was limited by the fact that about 40% of the chicken manure fed to the digester consisted of feathers, which have a very high protein content and caused an imbalance. Once this situation had been remedied, gas output increased, although overall output was limited by the fact that the digester was designed to produce sufficient gas for operating the digester rather than for running an engine as well.

Using a cocktail of manures enhanced gas production and improved the quality of the by-products. Although increases in ammonia and hydrogen sulphide in the gas were observed on occasions, both can be controlled using additives, and equipment is available to reduce the hydrogen sulphide content in the gas to a level that is acceptable to the manufacturers of spark ignition engines using biogas as fuel.

By the end of the monitoring period, gas production was more than 400 m^3/day and more than matched site requirements so that the generator was operating for around eight hours/day. However, there is believed to be the potential for doubling this output if certain improvements are made. One such improvement is the reduction of the solids content of the digester to around 8%. At present the extraction system precludes this because an auger is used rather than a variable speed slurry pump.

Gas composition averaged around 54% methane, 45% carbon dioxide, just over 0.5% nitrogen and practically no oxygen, ammonia or higher hydrocarbons. Hydrogen sulphide levels measured on three occasions were, respectively, 2500ppm, 3000ppm and 1900ppm. The GASRAP modules were shown to reduce this to 100ppm.

Recommendations for digester design

- Tank constructed of coated steel with a conical base and a high level of insulation.

- Tank roof constructed of GRP or steel, with good insulation. Should be capable of supporting the weight of the pressure/vacuum relief valve and any mechanical mixing requirements.

- Reinforced concrete base with provision for connections to an extraction chamber and pipework for easy removal of any sediment build-up in the base of the tank.

- Digester heating by a combination of mixing solids with liquid prior to feeding to the digester, pre-heating by the outgoing digestate, and internal heating within the tank.

- Combination of mechanical mixing with a pump forced feeding system.

- A nest of balls within the digester to provide added surfaces for bacterial growth. Recirculation of some of the liquid digestate so that new material is quickly incorporated within the biologically working mixture.

Conclusion

Centralised digesters could and should be run on a mixture of manures, but must be operated as process plant, with gas production taking priority. Digester design has an important role to play. A process approach would benefit the environment and the farming community, producing good quality natural fertilisers from existing wastes.

Report No: ETSU B/M4/00532/10/REP Publication date: 1996

RENEWABLE ENERGY PILOT PROJECTS

West Wales Task Force

Overall Background

The West Wales Task Force was set up by the Secretary of State for Wales in 1992. Its purpose was to combat the downturn in the economy resulting from the closure of local defence establishments. Its specific objectives were to strengthen and support existing businesses and business opportunities in the area; to develop skills for existing and emerging businesses; to encourage self-reliance; to secure effective land-use and infrastructure improvements; and to promote partnerships between Government departments, agencies and local businesses and organisations.

In spring 1995, a renewable energy audit was carried out in the West Wales Task Force area. This examined:

- the current extent of research into the conversion of biomass and natural elements into usable energy

- the working technology already in existence

- the financial, environmental and physical considerations essential to the establishment of actual projects

- the potential for new projects within the West Wales Task Force area.

The audit identified gaps in the knowledge and understanding of renewable energy and showed that this lack of understanding was affecting the possible take-up of renewable energy resources.

In 1996 a study of three separate pilot projects designed to bridge these gaps in the understanding of renewable energy systems was completed. This focused on three areas:

- wood fuel storage, handling and usage
- the composting of fibre from the anaerobic digestion of farm waste
- the establishment of an anaerobic digester kit.

This summary focuses on the second and third of these projects. The first is included in Volumes 2 and 3 in this series.

THE COMPOSTING OF FIBRE FROM ANAEROBIC DIGESTION OF FARM WASTE

Background

The anaerobic digestion of organic wastes produces methane gas and a partly digested slurry. The gas can be used for heat and/or power generation. The slurry can be separated to produce a liquor and a fibre. Partly digested slurry liquor is relatively odourless and contains nutrients of value to plants. The fibre contains little by way of nutrients but, if subject to bacterial composting, does have a role and a potential market as a peat substitute or soil enricher.

Although one Northern Ireland digester has achieved an income from its sale of composted fibre that is four times the value of the electricity generated from the gas produced, most anaerobic digestion units are not taking advantage of this potential market. There are two reasons for this:

- inadequate separation of the partly digested slurry, giving a dry matter of around 20% instead of the 35% required for successful composting

- the lack of any practical method of handling and storing the fibre during composting.

Project Objective

- To identify a realistic method of producing and marketing composted fibre.

Findings to Date

The project has identified a relatively new working farm anaerobic digester. This is located on a dairy farm running 150 dairy cows and followers together with a flock of 150 breeding ewes. The farm has 207 acres in two units and is located 15 miles north of Cardigan.

The digester was installed in 1993 to help resolve environmental problems. The methane produced is used to heat the farmhouse. Considerable efforts were made to compost the waste fibre during the first year of digester operation. Sometimes this was achieved successfully, and a useful outlet was established at a local garden centre. At other times the final product was unacceptable, largely because of the relatively high moisture content of the fibre leaving the digester. Some handling and storage problems were also experienced.

The existing belt and roller press separator will be replaced by one incorporating a rotating drum separator and screw compactor. This will be supplied by Optima House Group and will produce a fibre with a dry matter content of 35% or more. The separator is arranged above the collection area, into which farm trailers can be reversed. It normally takes two or three days to fill a four-ton trailer. The contents of the loaded trailers are tipped on to concrete standings under cover.

The project will explore two methods of treating the fibre, to determine whether one works better than the other. In one case the tipped fibre will immediately be shredded, left in bulk on the floor for two weeks and loaded into boxes that will hold about 0.5 tons. The boxes can be stacked three high using conventional pallet-handling machinery. In the second case, the tipped fibre will be stored on the floor for two weeks, and will then be shredded and loaded directly into the bulk boxes.

The material will be sold in bulk, either in the boxes or in half-tonne polypropylene bags, taking advantage of the existing garden centre outlet that has been established. Some may also be bagged and marketed for consumer use although, in general terms, the development of a retail market is more likely once a farmer has established a satisfactory reputation for the product.

Maintenance of the separator unit will be carried out by farm staff.

The project will be closely monitored and reported on until July 1998, and the results will be disseminated through a series of open days, press releases and publications. The unit will then be decommissioned.

Total costs are estimated to be nearly £34,000, of which about two-thirds is for capital, hire and installation costs. Operating the unit is expected to cost nearly £3000, maintenance £520, insurance £250 and monitoring and reporting a further £7000.

ESTABLISHMENT OF AN ANAEROBIC DIGESTION SUPPLY KIT

Background

Anaerobic digester units exist in their millions, particularly in China and the Far East. The UK has about 20 modern units which operate on the same principles as those world-wide but tend to involve more complicated structures and site works and require the services of specialist consultants and construction teams. Anaerobic digestion in the UK is therefore a costly method of handling farm wastes compared with some of the alternatives available.

Project Objective

- To record and monitor the installation of an anaerobic digester on a farm and to use the information to simplify future installations and reduce their cost.

Findings to Date

The project is to be located on a 300-cow farm. An anaerobic digester unit will be installed on the farm to handle the waste from the cows. A video recording will be made of the specification, planning and construction procedures involved, and a handbook will be produced.

The purpose of this project is to provide farmers with the necessary information to plan and build an anaerobic digester using local builders. Livestock Systems Ltd, the company likely to install the project digester, believes that this approach could reduce the capital and installation cost of a unit by 25%, bringing it closer to the capital cost of conventional slurry and waste handling facilities. This will encourage farmers to consider anaerobic digestion as a viable alternative. It will also allow greater use to be made of local labour by eliminating the need for expensive consultancy support and specialist building teams.

The project is not paying for the digester installation, which is expected to be an integral part of a new visitor centre at the farm. One of the key roles of this centre will be to explain and promote the benefits of renewable energy in various forms.

Project preparation, site planning and preparation of the manual will cost £3800. The filming will account for a further £6500 and monitoring and reporting £2600.