**INTERIM TECHNICAL REPORT**

# PERFORMANCE SUMMARY FOR ANAEROBIC DIGESTION OF DAIRY COW SLURRY AND GRASS SILAGE AT AFBI, HILLSBOUGH PHASE 3

**August 2012 – January 2013**

Figure 1: Photograph of AD plant at AFBI (digester tank centre)

Stephen Gilkinson and Peter Frost

November 2013

**AFBI**
**Hillsborough**

# INTERIM TECHNICAL REPORT

# PERFORMANCE SUMMARY
# FOR ANAEROBIC DIGESTION OF DAIRY COW SLURRY CO-DIGESTED WITH GRASS SILAGE
# AT AFBI HILLSBOUGH
# PHASE 3
**August 2012 – January 2013**


Stephen Gilkinson

and

Peter Frost


November 2013

## SUMMARY OF RESULTS

This report summarises the results of work at AFBI, Hillsborough on phase 3 in the research programme that is investigating co-digestion of grass silage with cattle slurry. As this current report is part of a series of reports it is important that it is read in that context. Reports for each of the previous phases can be accessed through the AFBI internet[1].

Phase 3 which is summarised in this report ran from August 2012 to January 2013 and involved feeding grass silage at treble the amount of organic matter of that fed in phase 1. The results are summarised below.

1. One tonne of fresh grass silage containing on average 249 g/kg dry matter produced 82 $m^3$ of methane, equivalent to 820 kWh of gross energy.
2. One tonne of grass silage organic matter produced 365 $m^3$ of methane.[2]
3. Compared to the slurry only feeding phase, the amount of organic matter fed during this phase 3 of grass silage co-digestion was 38% greater and produced 93% more biogas, equivalent to 82% more energy production as methane.
4. One tonne of fresh grass silage produced on average 9.4 times the amount of energy from that obtained from 1 tonne of dairy cow slurry.
5. 29.3 kWh energy per tonne of feedstock (as heat) was required to maintain mean digester temperature at $37^0$C (19 % of gross energy produced).
6. The available nitrogen concentration in digestate was 24 % greater than that in the feedstock mix.
7. Average hydrogen sulphide concentration of the biogas was 1,035 ppm.
8. The dry matter concentration of digestate was 28 % lower than that of the feedstock mix (data from 1st 15 weeks only).

## PHASE 3 PERFORMANCE OF THE AFBI ON-FARM DIGESTER

Over the 6 month period from August 2012 to January 2013, the digester was fed five days per week with on average of 2.4 tonnes of grass silage on each of these days (25% dry matter), plus 19.8 tonnes of dairy cow slurry fed every day (7.2% dry matter). The total amount of organic matter fed per week was on average 38% more than that fed during slurry only feeding, but energy produced was 82% greater. This increased energy production reflected the higher digestibility and higher methane yield from grass silage organic matter, compared to that from slurry only.

Table 1 presents a summary of the AFBI digester performance for the 3 co-digestion phases, alongside that from the previous 30 months, when dairy cow slurry was the sole feedstock. Table 2 which summarises the silage composition indicates that the silage used in phase 3 was well preserved and of medium digestibility (D value of 66). The main points to note are that during phase 3 co-digestion:

[1] http://www.afbini.gov.uk/index/services/services-specialist-advice/renewable-energy-2012/re-anaerobic-digestion.htm

[2] Organic matter equals dry matter content minus ash content. Ash content of grass silage is approximately 6-8% of the dry matter content and is not digestible, hence it is subtracted from the dry matter content.

- Biogas production increased by 93% relative to the slurry only period.
- Methane production (energy) increased by 82% relative to slurry only period.
- Methane content of biogas decreased by 5% (from 55.7% during slurry only feeding to 52.7% during phase 3).
- The concentration of available N in digestate after co-digestion with grass silage was 1.81 g $NH_3$-N/kg, *cf.* 1.46 g $NH_3$-N/kg in the feedstock mix of slurry and grass silage (24 % increase).
- Grass silage produced 2.3 times more methane per tonne organic matter fed, compared to the organic matter fed in dairy cow slurry (365 $m^3$ *cf.* 158 $m^3$), equivalent to 1,277 kWh electricity, (assuming a CHP electrical efficiency of 35 %).

**Practical issues**

During silage feeding into the digester the macerator occasionally blocked with silage. Clearing these blockages created mess and took time to clear. In order to solve these problems the macerator plate was removed, on advice, at the start of this phase. Three months into phase 3 the current clamp of silage was finished and a new silo clamp opened in early October (average quality 2nd cut). In early November a crust on the surface of the digester contents was observed. This was evidenced by a drop in the dry matter content of the digestate removed from the digester and also by the lack of fibre contained in it. On inspection through an inspection port hole on the top of the digester, it was evident that there was a problem with a floating layer. Despite this layer, biogas production was maintained. On inspection during mixing by biogas recirculation, gas break through the surface crust was not apparent.

In order to help break up the crust the gas mixing was set to continuous operation on 16th November. (It had originally been set to run 10 minutes in every 15 minutes). After 3 weeks of continuous mixing there was no visible change in the crust formation. In order to help prevent further crust formation the macerator plate was refitted on 20th December 2012 and silage feeding continued until mid January, when phase 3 was completed.

Table 1: Provisional; performance summary of the AFBI anaerobic digester during co-digestion of dairy cow slurry and grass silage at two different amounts, compared to slurry only digestion over 30 months

| | | Slurry only[3] | Slurry + grass silage Phase 1[4] | Slurry + grass silage Phase 2[5] | Slurry + grass silage Phase 3[6] |
|---|---|---|---|---|---|
| **Inputs** | Slurry (tonnes/day) | 19.9 | 19.8 | 19.8 | 19.8 |
| | Grass silage (tonnes/day) | - | 0.75 | 1.28 | 1.70 |
| | Dry matter (total solids) (tonnes/day) | 1.41 | 1.45 | 1.83 | 1.85 |
| | Organic matter (tonnes/day) | 1.10 | 1.22 | 1.47 | 1.52 |
| | Organic matter (kg/$m^3$ digester per day) | 2.06 | 2.08 | 2.58 | 2.66 |
| | Retention time (days) | 26.8 | 27.1 | 27.2 | 26.7 |
| | Temperature ($^0$C) | 37.1 | 37.0 | 37.1 | 36.9 |
| **Outputs** | Digestate (tonnes/day) | 19.7 | 20.1 | 20.1 | 21.2 |
| | Biogas ($m^3$/day) | 312 | 414 | 589 | 603 |
| | Methane ($m^3$/day) | 174 | 208 | 307 | 317 |
| | Methane content of biogas (%) | 55.7 | 50.5 | 52.2 | 52.7 |
| | Hydrogen sulphide content of biogas (ppm) | 1670 | 1733 | 1470 | 1035 |
| **Efficiency** | $m^3$ biogas/tonne fresh input | 15.7 | 20.2 | 28.0 | 28.1 |
| | $m^3$ biogas/$m^3$ digester/day | 0.59 | 0.75 | 1.03 | 1.05 |
| | $m^3$ biogas/tonne dry matter (total solids) | 223 | 285 | 324 | 329 |
| | $m^3$ biogas/tonne organic matter | 285 | 358 | 401 | 406 |
| | $m^3$ methane/tonne organic matter | 158 | 181 | 209 | 214 |
| | Digester heating (kWh/tonne input) | 32 | 33 | 32 | 29.3 |
| | Energy required for digester heating (% gross energy produced) | 37 | 33 | 21.9 | 19.4 |
| **Slurry** | Dry matter (kg/tonne fresh) | 71.1 | 65.4 | 76.3 | 71.9 |
| | Organic matter (kg/tonne fresh) | 55.5 | 51.0 | 59.5 | 55.3 |
| | Nitrogen (kg/tonne fresh) | 3.33 | 3.03 | 3.68 | 3.22 |
| | Ammonia nitrogen (kg/tonne fresh) | 1.78 | 1.50 | 1.83 | 1.54 |
| | pH | 7.23 | 7.34 | 7.30 | 7.12 |
| **Digestate** | Dry matter (kg/tonne fresh) | 55.3 | 53.4 | 64.7 | [7]61.5 |
| | Organic matter (kg/tonne fresh) | 41.3 | 39.1 | 47.5 | 45.0 |
| | Nitrogen (kg/tonne fresh) | 3.36 | 3.09 | 3.89 | 3.41 |
| | Ammonia nitrogen (kg/tonne fresh) | 2.10 | 1.78 | 2.23 | 1.81 |
| | Ammonia nitrogen /Total nitrogen | 0.63 | 0.58 | 0.57 | 0.53 |
| | pH | 7.92 | 7.95 | 8.02 | 7.78 |
| | Dry matter digested (%) | 24 | 28 | 34.3 | 35.9 |
| | Organic matter digested (%) | 31 | 36 | 42.5 | 61.5 |

[3] January 2009 to July 2011
[4] August 2011 to January 2012
[5] February 2012 to July 2012
[6] August 2012 to January 2013
[7] Figures in red are for the first 15 weeks of Phase 3, up to the point when a crust was identified on the surface of the digester contents

Table 2: Grass silage parameters during phase 3

| Dry matter (kg/t fresh) | Nitrogen (kg/t fresh) | Ammonia nitrogen (kg/t fresh) | D value | Proportion of silage organic matter to slurry organic matter | Methane yield/tonne organic matter ($m^3$) | Methane yield/tonne fresh silage ($m^3$) |
|---|---|---|---|---|---|---|
| 249 | 4.96 | 0.56 | 66 | 0.43 | 365[1] | 82[1] |

[1] Calculated by subtracting the assumed methane production from slurry component – based on previous slurry only results

After completion of Phase 3 a decision was taken to physically examine the crust through the inspection hatch on the top of the digester. Before opening the inspection hatch to carry out this examination it was necessary to purge the digester headspace of flammable and toxic gases. In order to achieve this, digester feeding ceased temporarily and the digester contents were aerated for 2 days using the gas mixing system, with air being drawn in from ambient. After this period the hatch (30 cm diameter) was opened by a trained operator from the AD service company who followed the correct safety protocol. On examination it was determined that there was a crust of at least 2 m depth in the location directly below the hatch. It was speculated that this depth of crust was over most of the surface of the digestate.

After further advice and consideration, it was decided to install a system to circulate digestate from the bottom of the digester into the surface crust, in the anticipation that this would break up the crust and prevent the problem re-occurring. The system installed initially used a tractor driven pump. After many hours of digestate circulation (albeit intermittent, as and when staff were available) the crust had not dispersed. Subsequently during routine maintenance by the AD service engineer it was discovered that during gas mixing the biogas was leaking into several gas ports, rather than going through just one at any one time. This resulted in many of the ports blocking up, with mixing largely ineffective, as per observations through the inspection port. Following repair to the mixing system, the dry matter content of the digestate increased significantly and the crust showed evidence of breaking up. However there was still some crust present and a fixed electrically driven pump is currently (November 2013) being installed to replace the tractor pump. This will allow recirculation to be controlled by the AD computer system, without the need to manually monitor tractor operation. Resumption of silage feeding will not recommence until the recirculation pump is fitted / commissioned and the crust has fully dispersed.

In conclusion, it seems that the crust developed due to several factors occurring simultaneously; inadequate mixing, lack of maceration and feeding of fibrous silage. Once formed, the crust was very resistant to breakup. Evidence from other on-farm digesters using grass silage as a major feedstock suggests that crusting can be/is a problem. It would appear that mechanical mixing can alleviate crusting problems more easily than gas mixing.

Grass silage as a major feedstock for digestion is not common in Europe. Hence the Northern Ireland AD industry has to deal with issues first hand, without the benefit of established practice of what works best and what does not.

**Further Comments**

AFBI is researching co-digestion of grass silage with cattle slurry, both at lab-scale and farm-scale. Results to date indicate that the yield of biogas/methane is in direct proportion to the quantities of each feedstock used. There does not seem to be any synergy between the ratio of slurry and silage fed. AFBI has found that the amount of methane produced per tonne of grass silage fed is unaffected by the feedstock ratio (slurry : grass silage). Figure 2 indicates that there is a straight line relationship between amount of silage fed (organic matter basis) and the methane produced from that silage (after subtracting the assumed contribution from the slurry fed).

In order to maximise efficiency of the AD system it is important that the quantity of biogas produced should equal demand. Assuming demand for biogas is fixed by engine capacity and that it is not feasible to alter the volume of slurry produced by livestock and fed to the digester on a daily basis, then the daily amount of grass silage fed could be adjusted easily to help match supply of biogas to demand. It should be remembered that while slurry only produces about 10% of the volume of biogas produced by grass silage per tonne fresh, slurry contains the bacteria that produce methane, the nutrients needed by those bacteria and aids a stable fermentation process.

Grass silage presents challenges for AD, both in getting the material into the digester and in keeping the digester contents mixed. Despite these challenges, the AFBI results indicate that the methane energy produced from grass silage is similar to that produced from maize silage. The income from digesting grass silage *via* the sale of ROCs (Renewable Obligation Certificates) and electricity is approximately twice the cost of procuring the grass silage[8].

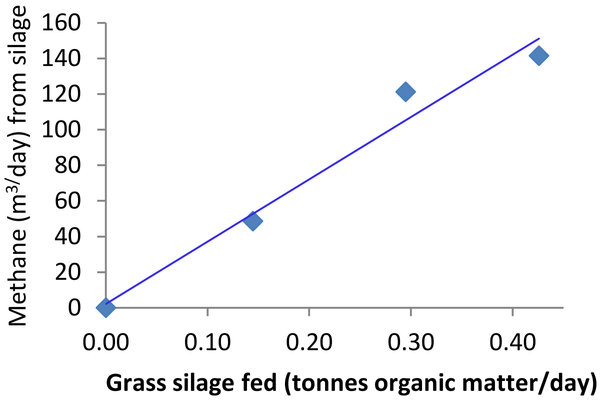


**Figure 2.** Effect of increasing the amount of grass silage fed on daily methane production

[8] Assuming income from electricity generation of £65/tonne of fresh silage @ 25% DM (0.82 MWh x 4 ROCs @ £45/ROC + £45/MWh sold to grid), silage cost £30 per tonne fresh