THE CRITICAL FIRST 180 DAYS IN THE LIFE OF AN AD PLANT

www.stephens-scown.co.uk

1 Why have we commissioned this White Paper

Industry feedback suggests that at any one time between 13% and 18% of the AD plants in the UK are experiencing problems.

A high proportion of these problems are caused by the volume of gas being produced which in turn links to the biological aspect of what is going on within the digester.

How many people actually understand the complex biological interactions within a digester and the biological conditions required to maximise gas production?

A single tank digester is always going to be a compromise from a biological aspect and therefore its successful operation requires detailed control and monitoring. Is this control and monitoring happening in practice?

To optimise gas production and have a healthy digester the first 180 days in its life are crucial to build up healthy colonies of bugs and also establish the control + monitoring procedures for long term high performance.

The AD industry employs a number of highly talented people but when it comes to the biology side of the process there are not enough ‘world class’ people for every firm to employ one. The guide is therefore designed to help offset this shortage and provide a process which if followed can contribute to any AD plant maximising its gas production.

Added to the biological issue are design factors, which if the expertise within the insurance sector had been utilised at the planning stage then modifications would have been recommended to the design. Within the guide we have therefore incorporated guidance from a leading insurance broker on the risk factors they regularly see.

2 Efficiency levels of Existing AD Plants in UK and Europe

A study of working AD plants across Europe found that it was possible to increase their operating efficiency by between 10% and 40% through changes that were not complex or difficult to implement.

Improving performance of the digester can be seen in terms of increasing the biogas or heat output, reducing the feedstock quantity for the same amount of output and more effective use of the outputs such as biogas, heat, electricity and digestate.

Improvement of biogas output generally requires additional digester capacity or modifications to a grid supply contract. A higher yield of biogas per ton of digestate can significantly reduce the amount of feedstock required and hence reduce production costs. Additional efficiency can be found by plant automation which can reduce labour and improve performance of the digester.

Listed overleaf are some of the proven means of performance enhancement confirmed at commercial biogas plants in Europe.

IMPROVEMENT EVALUATED	IMPROVEMENT IN PERFORMANCE	PLANT DESCRIPTION AND ELECTRICAL OUTPUT
Addition of glycerol	30% increase in biogas productivity	Feedstock - pig slurry and maize silage and grain 1MW plant
Change from manure to food and veg waste	50% reduction in feedstock	Feedstock - cattle and pig slurry and chicken manure 2MW plant
Use of heat from CHP	Increase 70% heat use Increase 80% heat use	2 plants taking cattle slurry and energy crops 2MW
Automatic process control	Increase of 30% biogas	Pilot scale plant
Automatic feed technology	50% labour reduction	Feedstock - livestock slurry and maize silage 1.4MW
Addition of enzymes to prevent swimming layer	Total reduction of swimming layer	Feedstock - livestock slurry and maize silage 1.4MW
Cover over digestate storage tank	3% more biogas productivity	Feedstock - livestock slurry and maize silage 1.4MW
Recirculation of the solid fraction of digestate	13% biogas yield increase	Feedstock - cattle slurry and silage 2.5MW
Serial coupling of digesters	10 to 30% increase of biogas yield/ton	Feedstock - cattle slurry and silage 2.5MW
Cooking with lime	20% increase in biogas yield/ton	Feedstock - cattle and pig slurry and manure and fat 2.4MW
Adjusting the C:N ratio	18% increase of biogas yield	Feedstock - pig slurry and chicken manure and fat 330kW
Improved mixing for feeding digester	Increased specific gas yield by 15% and reduced hydraulic retention time by 33%	Feedstock - pig slurry, fat and glycerol 1.2MW
Improved feeding device	Energy consumption reduced by 90% for feeding and labour by 50%	Feedstock - pig slurry and food waste 2.5MW

3 Digesters tend to be sold by engineers and project managers - not biologists.

With contract values often stretching into the millions it is perfectly understandable that the supplier/ customer relationship concentrates on the EPC terms, the cost, the payment terms and the project management.

Commissioning of the plant is usually based on the volume of feedstock that is going to be fed to the plant and when or a target of how many cubic metres of biogas will be produced by a given date, all of which affects the internal rate of return.

What we rarely see mentioned in the sales process is the biological side of things – given that biogas is actually produced by a biological process this could be seen as an industry failing.

A simplistic analogy would be when you buy a car the manufacturer tells you what fuel to use and what to do when things go wrong – how many 'owner's manuals' have you seen produced in the AD world? In the UK how much time has been invested in studying and getting to understand the biology of what actually happens inside a digester? Or perhaps more pertinently where could you go to learn such knowledge? The AD process is a natural one but we are attempting to industrialise the process and force the pace of nature.

This paper was commissioned to help address this industry failing but in a technology agnostic manner by calling upon the expertise and knowledge that the authors have acquired in a collective total of 20 years researching how digesters react to different feedstocks, temperature, management routines and designs. A time period spent not just in the UK but across Europe.

The progression from building to operating an anaerobic digester has been generally considered a routine procedure. However, inoculating the digester and ensuring the correct feeding regime to progress to full biogas production can be problematic and costly. At this point in the life of the plant, maximum capital has been expended and there is an understandable impatience to begin making a return on that investment. Starting too slowly will limit the overall income of the plant, but acting too aggressively can easily lead to a sour digester that must be emptied and re-commissioned.

Should the start-up process be more regulated or be part of the process of commissioning? The answer is that, in most cases, there is already some sort of start-up procedure recognised as part of the installation, but with regulation and more knowledge, better regimes could be implemented. The essential elements of ensuring a successful fermentation require clear organisation both before and after start-up, this discipline will minimise both the duration of the process and the likelihood of catastrophic failure, while providing a realistic timetable for the commencement of profitable operation.

A key part of the contract needs to be a defined commissioning phase. It needs to define the responsibilities of all parties and include a detail project plan, testing plan and project management structure. It is critical that the project manager follows the plan to deliver an operational plant. A key factor is to not allow certain parties to overfeed the plant such that a certain gas yield is achieved. This approach will yield a short term high gas output but may seriously limit the plant performance in the longer term.

The cost of this start up phase need to be defined in detail and included in the budget. This needs to include innoculant, feedstock, micro nutrients, water, plant heat up, testing and labour costs. The budget also needs to show the biogas output and hence income generation over this period.

4 Legal Contracts and AD Plants

With the solar and wind industry the ‘fuel’ is free but you have no control over its delivery

AD in contrast requires the right blend, quality and quantity of feedstocks to produce biogas. Add in the need to dispose of the digestate that gets produced and you have many more areas that need to be covered by legal contracts than a wind turbine or a solar farm.

Lawyers are often instructed late in the day when it comes to AD projects. There are generally numerous documents to review and draft:

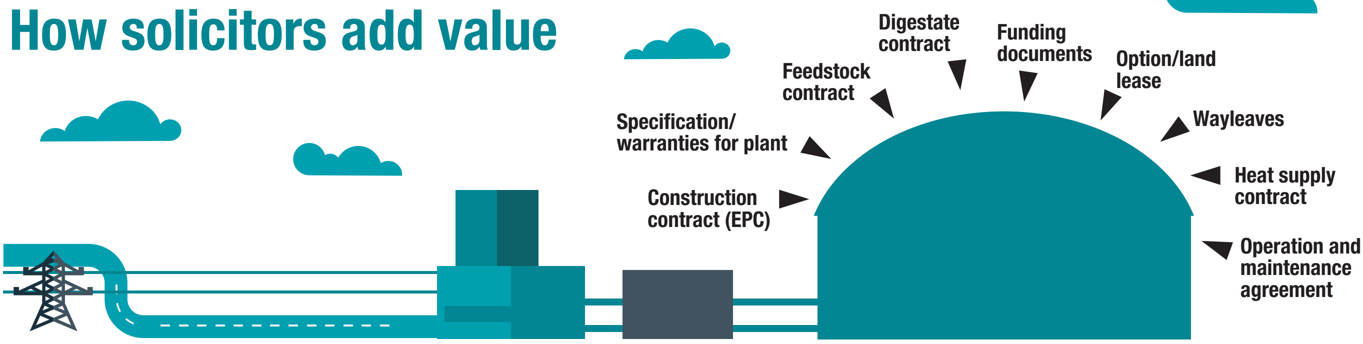
- Construction Contract (EPC)
- Specification/Warranties for plant
- Feedstock Contract
- Digestate Contract
- Funding documents
- Option/Land Lease
- Wayleaves
- Heat supply contract
- Operation and Maintenance Agreement

All of these documents are dependant upon the commissioning of the plant and a number of them will include specific reference to the timeframe for delivery and levels of productivity. Commissioning is vital for the performance guarantees in the EPC and will trigger the warranties for the plant. Start up feedstock needs to be considered in the feedstock contract and final draw down of funding is often based upon successful commissioning. The rent under the land lease usually kick in on commissioning and the other contracts will follow suit. If the first stages of the project come together this will underpin the success of production and financial stability going forward.

Working with firms that are experienced within the sector and understand the technology is essential.

Managing the Risks

How solicitors add value



5 Weighing, Testing and Storage of Feedstocks

Feedstock quality is critical for the plant and can dramatically affect the output. This is especially important during startup when the microbial community is developing. Poor silage can reduce the biogas output per ton by over 50% and changes in the C:N ratio can seriously affect the performance of the microbes.

It is important to have good quality feedstocks for the plant; the following criteria should be considered;

- Crop or silage precision cut to approximately 10mm length to maximize biogas output and minimize digestion time;

- Feedstock not contaminated with stones and foreign matter. This is to protect the plant from damage;

- Crops, silage or slurries stored correctly to protect its nutritional value;

- Feedstock's measured to determine dry matter, volatile solids and C:N ratio. The data is required for accurate planning of the feeding regime;

- Know the weight or volume of feedstock going into your digester to enable the process to be fine tuned and stabilised.

There are some fundamental rules that need to be adhered to if there are many different feedstock types entering the digester. This primarily involves not shock loading with an entirely new feedstock even though the loading rate is below that of the previous feedstock. This is because the microbial community in the digester need to adapt to changes in feedstock which takes time.

6 The stages in the AD process and the conditions required for the Bug Population to thrive

Before we define the best way to initiate a digester into action, it is important to consider the biological complexities of biogas production

Anaerobic digestion (AD) is the process that enables biogas to be produced from larger chains of carbon containing molecules of carbohydrates, lipids and proteins.

This process is very similar to that of mammalian digestion. However, while a digestive tract comprises several stages each with its own distinct environment, a commercial anaerobic digester may only have one vessel to achieve the necessary breakdown of feedstock for conversion to biogas.

There are 4 phases to biogas production;

1 Hydrolysis
2 Acidogenic
3 Acetogenic
4 Methanogenic

For simplicity this is normally considered as 2 main phase, Hydrolysis and Methanogenesis.

The critical part to understand is that the bacteria in hydrolysis are fast growing and replicate in a matter of hours compared to methanogenesis where the microbes (called Archaea) are slow growing and take days to replicate. It is important to understand this at start up to ensure each population of microbes has time to develop.

Imagining the new AD plant as a baby animal can be helpful, where providing a balanced diet with adequate micro-nutrients and not overfeeding too early will lead to a long and healthy life.

7 Common AD plant designs and the compromises that single tanks systems introduce

Hydrolysis and methane production are two different processes. They require different conditions and the most important difference is pH.

Hydrolysis occurs between pH 5 to 6.5
Methane production is optimal from pH 6.8 to about 8

Generally in a single digester the pH is around 7 so hydrolysis is reduced and less biogas produced. However a problem that occurs is overloading which occurs when methane production cannot keep up with hydrolysis. This eventually shows itself as a reduced pH (acidification) and a major drop in biogas production but in a single tank system with a long retention time this can occur a long time after the overloading event occurred.

In a multi-vessel system the operator can reduce the loading rate to prevent acidification of the methane stage which stops below pH 6.5. A single vessel will also have a considerable time lag before responding to overloading and once started acidification or souring is difficult to prevent.

8 Control and monitoring systems for AD plants

An important aspect to effective start-up of any fermentation is monitoring, whether for pharmaceutical drugs, beer or biogas and it should not be forgotten that we are introducing a 24/7 industrial process to a workplace environment that is unlikely to have industrial experience! The tendency not to monitor is common and understandable due to the effort involved, but we should recognise that we have an industrial process and the start-up conditions largely dictate the digester performance for the rest of it's working life. This is because the microbial population will be so large that changes will require considerable displacement of microbes within the inoculated digester once started. We can significantly influence the digester for effective biogas production at start-up so monitoring at an appropriate daily frequency will bring great benefits. The long-term difference between good and poor start-up is significant and could represent as much as a 20% efficiency loss meaning of course that 20% more feedstock may be required to achieve the target output! By effective monitoring we can identify any poor start-up issues and make an informed decision as to how to recover the correct environment for the optimum methane producing microbial community.

In order to achieve a meaningful analysis of the start-up activity we should aim for the following regime:

1. Work with representative daily samples, from each vessel if the process has multiple reactors

2. Perform analysis rapidly, as results from a laboratory miles away may become irrelevant due to time lags. Modern, compact analytical equipment such as a spectrophotometer has proven effective for total volatile fatty acids, alkalinity and ammonia. Titration kit can also be used onsite for VFA/Alkalinity ratio determination for more details.

3. Maintain thorough, organised records. The use of process charting techniques can significantly improve the rapid identification of process trends.

Running a digester effectively is an industrial process rather than a simple daily chore and requires a statistical or numerical approach that can be provided automatically by computers. Increasingly more manufacturers are using automatic monitoring, but not at a high enough level to assess or predict overloading. So what means of assessing the loading rate does the operator have? There are several and we can concentrate on one to understand the principals. However changing the feedstock loading rate comes with a warning as the response of the digester to loading is lagged or delayed and this will be proportional to the hydraulic retention time of the digester. Therefore rapid changes are not recommended.

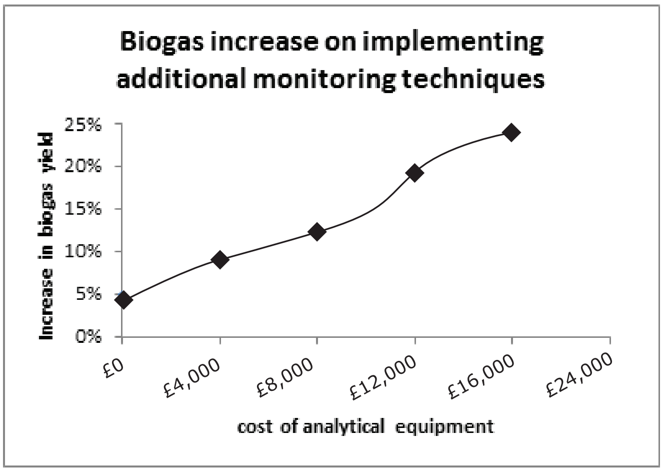
One of the best means of assessing digester feeding rate is by an on-site analytical measurement of volatile fatty acid content ratio compared to the alkalinity. A commonly used version of this is FOS/TAC ratio, this can be measured using a TIM 840 automatic titration system from Hach Lang. The table overleaf shows the rules of thumb from the assessment:

FOS/TAC RATIOS	COMMENT	ACTION
>0.6	Highly excessive feedstock input	Stop adding feedstock
0.5 – 0.6	Excessive feedstock input	Add less feedstock
0.4 - 0.5	Plant is heavily loaded	Monitor plant closely, adjust feed
0.3 – 0.4	Optimal biogas production	Monitor, maintain feed rate
0.2 – 0.3	Feed rate too low	Slowly increase feed rate
>0.2	Feed rate far to low	Increase feed rate

The other core tests required to monitor the plant are pH, conductivity, temperature and gas output and composition. These require the following pieces of test equipment;

- Calibrated pH sensor
- pH calibration and storage solutions
- Conductivity sensor
- Temperature sensor in tank (fitted by supplier)
- Gas volume meter
- Gas quality meter, covering as a minimum methane and hydrogen sulphide

The table to the right gives a measure of the effect of monitoring the AD plant.



9 The role of the plant manager, training and Health & Safety

One of the most overlooked aspects of AD plants is just how important the role of the plant manager is. The impact on gas production of good plant management routines can be as high as 40%

The plant manager has a number of roles the first of which is to manage the plant. It is critical to have a 3 month rolling plan for the plant operation covering feeding and testing. The other core activity is logging the testing data to develop an accurate picture of the plant performance. These activities are critical because the process time for the plant can be between 30 and 120 days. This means that actions taken today may not have an effect for 30 days. Hence it is critical to have a plan and test data to adjust the plan as required.

Health and safety on-site is of paramount importance and we should mention additional factors for mechanical feedstock and digestate handling equipment. The production, storage and use of biogas or biomethane safely is important especially near electrical equipment. Further some feedstock and chemicals will require special handling and safety. Details can be found from the plant manufacturer and the Government health and safety executive. A health and safety advisor is recommended for the different stages of installation and regular usage at the very early stages. Some of the major responsibilities are;

- Ensure all employees are properly inducted;
- Ensure all plant is operating safety;
- Ensure procedures are in place, including risk assessments and emergency plans;
- Ensure all investigation and reporting procedures are performed and remedial action performed promptly;
- Ensure safety and protective equipment is readily available;
- Visitors accompanied by a responsible employee;
- Attention to documentation collated for the site.

10 How often should you be testing the plant?

The frequency of assessing the fermentation performance should be about daily on start-up, for a change in feedstock and on poor performanceas it is better to have regular incremental assesments at these times to be sure of what is happening. This will assist in providing means of predicting future changes of performance. Generally any change of performance needs to be monitored with respect to measurement of the volatile fatty acid content and the alkalinity content of the digestate. The ratio of the values will determine overloading or under-loading, which is the greatest issue facing the operator. Section 15 contains the recommended daily and weekly checks

11 Where do you get your start up bugs from?

When the plant construction is complete and approved it is then time to load the systems with microbes and start generating gas. The starter culture of microbes is called the innoculum. The key part of this activity is sourcing suitable microbes.

The simplist and quickest approach is to source fresh hot liquid digestate from an operation AD plant running similar feedstocks at a similar temperature. This will ensure the population of microbes includes the different type of bacteria requied for hydrolysis and Archaea for methanogenesis. The microbes will have already adapted to breaking down the planned feedstock types so start up will be relatively quickly.

A good idea is to build the supply of the innoculum into the equipment supply contract. This ensures the supplier will provide the innoculum from one of their operational plants.

If this approach is not possible then the plant needs to be loaded with dairy slurry, rumen stomach content and/or sewage sludge. These all provide sources of microbes. This approach will take longer to establish the microbial community in the plant.

A good idea is normally to fill the plant partially with water which is heated to the correct operational temperature before adding the innoculum. To support the growth of the microbes will require a small amount of food and micro nutrients.

12 The Start Up Process and Timeline of the Commissioning Process

A working guide to the first 180 days

At start-up we must assume that some basic requirements are met. These include a gastight digester that does not introduce air because the process is essentially anaerobic (e.g. without oxygen). There should also be the capacity to mix at the correct intensity although initially normal mixing slows the process of start-up. Gentle mixing is best. These capabilities should be covered by an installation set of tests to complete before the plant proceeds to start up.

There are several types of anaerobic digester systems in use, including double vessel systems operating in sequence. However, the most common style of wet digester mostly operates as a single vessel for liquid AD, with dry matter content between about 7 to 20% w/w. Dry digesters are less common and information on start-up will not be presented in this paper.

STAGES OF START-UP

Acquire inoculum

Optimise biochemical parameters

Optimise physical parameters

Identification of biogas production

Programme to adapt loading rate to digester performance

PRIMARY STAGE

The first stage involves introducing the microbial community (inoculation) from an existing effective digester or rumen livestock manure. Inoculation of the digester is probably the most important event because this determines the capacity of the digester to produce high yields of biogas per ton of feedstock. There are several means to start-up or introducing methanogens to the digester. One that is commonly used on livestock farms involves the use of cattle slurry. Rumen manure has the appropriate hydrolysis micro-organisms that can digest cellulose material effectively, as well as methane producers. The criteria for start-up with cattle manure are:

1. Cattle slurry of about 6 to 12% dry matter;
2. Heat to a set digester temperature +1ºC normally between 36-40ºC;
3. Low mixing rate to increase methanogen growth;
4. Fresh manure is normally best as this contains both feed and reasonable levels of methanogens;
5. The addition of water will help methanogen formation and prevent blockages if the dry matter is greater than about 10% w/w;
6. Generally no trace element additions are necessary but adding them has shown that methanogens and biogas production occurs more quickly.

Livestock manure is not necessarily the best means of start-up. If rumen livestock manure is not available, more stages are necessary. There are several sets of criteria that at present are recognised as necessary. These are:

1. The acquisition and loading of digestate from a high performance digester using similar feedstock. If digestate from different digesters can be acquired then this will help the biogas yield/ton of feedstock as well as provide robust digester performance. This is because a more diverse microbial community is less likely to suffer from changes such as a toxic event;
2. Mixing should be slow, as rigorous mixing reduces biogas productivity. Higher dry matter inocula need more mixing because they are more viscous;
3. The feedstock to inoculum ratio in the first instance should be about 1:1 on the basis of volatile solids content. (Volatile solids are normally about 70 to 90% of the dry matter weight);
4. The addition of water may be necessary to fill the digester as many do not function on low volumes and transport of inoculum can be time consuming and expensive especially for large digesters. A full digester will also minimise the headspace for the explosive methane air mixture;
5. Trace elements are necessary so that significant biogas production occurs more quickly.

Once the inoculum has been added there is a high possibility that the biochemical environment is not optimal for biogas production so we may need to alter important parameters.

SECOND STAGE

Biochemical environment

To achieve optimum performance there are parameters that should be within specific ranges. These include pH. Additionally there should be trace elements present to enhance the growth and performance of methanogens. Also the correct ratio of carbon (C), nitrogen (N) and phosphorus and trace elements should be present in the digester. Some other trace elements are not typically present, and may be required for certain feedstocks like energy crop feedstock; these are principally the heavy metals cobalt and nickel; others include selenium, copper and iron. Such recipes are feedstock dependent.

Range for biochemical parameters:

1. For the single vessel digester the pH should be between 6.7 and 7.5.
2. The ratio of C to N by weight should be in the range of about 15 to 30 although in some instances these limits can be exceeded. This translates into about 3-4% N present as a percentage of the chemical oxygen demand (COD) of the feedstock. Phosphorus is also required between 0.5 and 1% of the COD. The COD is the quantity of oxygen necessary to convert organic material into CO_2 and can be related to methane yield of the feedstock;
3. Fermentation stability is measured as the ratio of total volatile fatty acids to alkalinity. The ratio should be about 0.1 to 0.3;
4. Generally the alkalinity range is from about 2500 to over 10000 mg/litre and expressed as bicarbonate buffering capacity;
5. The volatile fatty acid concentration should not exceed about 1500 mg/litre, especially at the beginning;
6. There are minimum concentrations for each of the trace elements (in mg/litre) which are Iron 1-10, Sulphur 1-10, Nickel 0.005 to 0.05, Cobalt 0.06, Molybdenum 0.05, Selenium 0.008 and Manganese 0.005-0.050. Often these are present in the feedstock, except for energy crops (selenium, cobalt and nickel) and food waste (requires selenium and cobalt).

Physical environment

The temperature is important to digestion and should be a constant value that is not affected by loading rate. Generally the top digester and bottom digester temperature should be within about 1ºC which indicates the effectiveness of mixing, which is required for nutrient and heat distribution in normal operating conditions. Interestingly, mixing is also important to temperature equality throughout the digester, but the recommendation at start-up is a low mixing rate. If the mixing is too gentle then the temperature distribution maybe poor and this will lead to slower development of the digester. So a mixer speed that is a compromise is important, for example if the feedstock sinks or (as is more likely) floats then a more effective mixing regime will be necessary. Mixing requirement will be lower at start-up and may not meet the mixing criteria. Additional problems can involve the production of foam, although this is often a product of overloading which can be avoided by maintaining the VFA concentration below about 3 to 4g per litre.

Range for physical parameters

1 The temperature should be within 1°C of a set temperature in either the range of 37 to 45°C (mesophilic) or 50 to 60°C (thermophilic) depending on the digester design;

2 Mixing is simply measured by the difference of temperature between two points or more in the digester generally between the top and bottom of the digester. Temperature variation should be less than 5°C in the start-up phase.

digester temperatures

- start with a low mixing rate to encourage methanogens
- increase the mixing rate until temperature remains constant

digester not meeting the set point value

- increase the mixing rate until the temperature meets the set point within 2°C

digestate forms floating or sinking layers

- increase the mixing rate until the layers disappear

THIRD STAGE

Evolving feeding rate

Assuming all the criteria above are mostly achieved then we need to proceed to the next stage. Generally biogas production starts within days, and after about three days, irrespective of whether methane is produced or not we should add about 0.5kg VS /m^3 (of digester volume) of feedstock per day for about 4 days. Biogas should be produced at this point and the digester stability should remain a stable point i.e. a VFA/Alkalinity ratio of about 0.1 to 0.3. If the ratio is less than 0.1 then we should increase the feedstock loading rate further by about 0.25 VS m^3 per day.

These are generic points and the maximum loading rate will depend upon the digester design and the feedstock degradability rate. However, as we approach the maximum rate of digestion we will obtain the maximum biogas productivity i.e. maximum biogas $m^3.m^{-3}.day^{-1}$. This is beneficial if a high biogas volume is required as in the case of high capital costs or a rapid payback regime. However, this will be at the expense of utilising the feedstock quickly and a digestate that may have high residual methane capacity. The other maximum output of specific methane yield which is the amount of biogas per ton of feedstock. In this case the capital or payback costs are small and the feedstock production or acquisition costs are higher. In this case the operator is likely to meet the PAS110 requirements for residual biogas capacity and VFA content. The feeding strategy is simplified in a progression below.

Acquire representative digestate sample to perform analysis in a relevant time to digester hydraulic retention time

▼

Determine dry matter (%) and volatile solids content as a percent of dry matter

▼

Determine biogas production and methane percent in biogas

▼

Determine VFA to alkalinity ratio - check ratio

▼

Increase feedstock by 0.25 kg/m3 in VFA / ALkalinity ratio is less that 0.15 and methane percentage in biogas is increasing see note**

** If the response time of the digester is significant i.e. when the HRT is large (for cellulolytic materials such as energy crops) then hydrolysis will be slow. This means that while loading may seem necessary because of low total VFAs (less than 1g/litre) this may not be necessary because there is already a substantial amount of degradable material that will produce VFAs in the coming week(s).

Once the digester is mechanically functioning the inoculum can be acquired and placed in the digester. Feedstock can now be added and should not exceed the organic content of the inoculum. Do remember to add small increases of feedstock because a build-up of unconverted feedstock in a one vessel digester will go sour and cannot be prevented. As a consequence the digester will require emptying to start again. Methane maybe produced after large content of carbon dioxide so monitoring the headspace content is important. Once methane content become over 50% you may be able to progress to full plant productivity. Certain feedstock types such as food waste and energy crops need additions on trace metals and they can be purchased as a mixture. They contain trace elements nickel, cobalt, molybdenum, iron and selenium. Once the biogas yield increases more feedstock can be added.

13 Profile of a successful and a failed start-up

In the following figures we show a failed start-up (Fig.1) and a successful start-up (Fig.2). Figure 1 shows the effects of loading too quickly and expecting the microbial communities to grow rapidly. Unfortunately, the methanogens are slow growing compared to the bacteria that perform the hydrolysis of the feedstock. As a consequence, an excess of volatile fatty acids occurs to reduce the pH and once below (approx.) 6.6 pH methane production stops and the VFAs accumulate to produce an acid environment. To rectify this situation the digester needs to be emptied to start again. There are other options involving the addition of alkali to counter the acidity but this may meet with limited success.

In figure 2 a slower rate of feedstock increase enables the methanogens to grow consuming the VFAs. In this case there is a balance between VFA production and consumption by the methanogens to produce methane. By simply measuring the alkalinity and total VFA concentrations we can determine the digester stability and enable successful start-up.

Often by using a low carbon to nitrogen feedstock such as manure, the alkalinity is more likely to remain high, but a high carbon to nitrogen source such as sugar beet will have more associated risks at start-up. However, monitoring will give a clear guide to feedstock loading rate changes (increase or decrease). The important rule is that the biogas output will not respond quickly to changes in feedstock loading rate, but the fermentation parameters may do so.

Fig.1
Typical catastrophic failure caused by progressively overloading from start-up

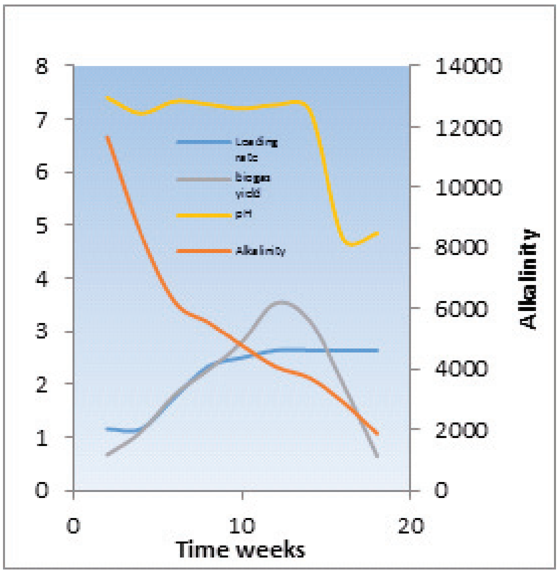
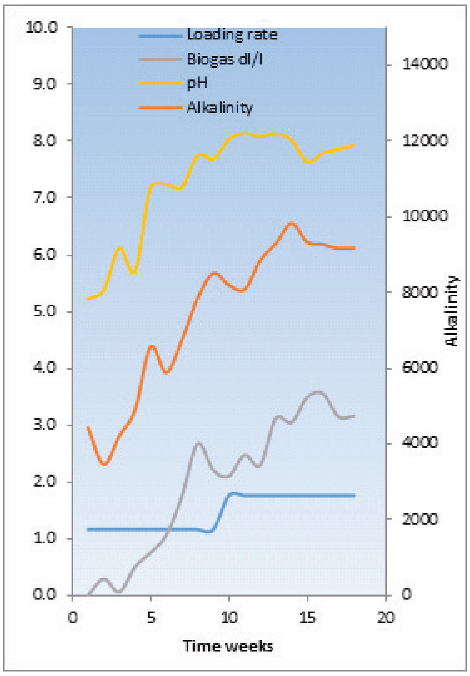


Fig.2
Effective start-up as measured by alkalinity, biogas output and pH



14 11 common issues with AD plants and how to address them

There are a range of technical issues that arise, but the overarching factor that has the biggest influence according to surveys in Europe is the one of maintenance. Poor maintenance will lead to more downtime and a considerable drop in profits. The major issues are in terms of occurrence are:

1. CHP breakdown which requires an effective maintenance regime. However the causes of maintenance can be high sulphide content in the biogas;
2. Mixing is also important and should be at the appropriate level for the digester design and the viscosity of the feedstock. A high viscosity requires more mixing energy either as mixing time or mixing motor energy. The solution is a larger motor or more efficient stirrer;
3. Overloading the digester will be recognised as a drop in pH to less that about 6.7 and a drop of biogas output. Closer attention to the digester parameters is required so as not to overload in the future. If the biogas yield is not being achieved to run the CHP then a change to a quality or more appropriate feedstock is required. Assessment of feedstock to biogas conversion is necessary, if the quality is poor enzymes can be added or a liquid feedstock may be an option;
4. Foaming does occur with overloading digesters and can be prevented by first reducing the loading rate and secondly by added products to minimise the foam. Often some mechanical dispersion is possible with a rotating blade or sprinkler system;
5. Under-loading the digester can be recognised by poor biogas output, often high methane content in the biogas and low volatile fatty acids in the digester. The solution is to slowly add more feedstock (and monitor volatile fatty acid content closely) as often the digester is not performing near the optimum loading rate;
6. Sometimes the digester can have the optimum VFA content but have a low biogas yield. This may be because of low trace element content. Analysis can be performed to determine the content of these elements such as iron, nickel, cobalt molybdenum and selenium and a proprietary product added to adjust the content;
7. While problems may be attributed to complex fermentation issue one should always inspect for mechanical problems such as gas leaks especially. These are not only dangerous but also costly. Repairing the gas leak should be performed professionally. Digestate leakages can be repaired by skilled personnel as well;
8. Less easily spotted blockages are a problem and are often caused by bulk biomass materials. Dismantling may be required or pump reversal if possible;
9. Floating layer can also be caused by biomass addition to the digester and further suspension by gas uplift. This is often the result of low mixing rates, suspension of loading is also necessary
10. When feedstock is added there can be a temperature shock of a few degrees. Methanogens are sensitive to temperature change and the effect can be significant. If this affects plant performance then preheating the feedstock can be effective;.
11. Rapid change of feedstock because a lorry load has turned up on-site is an issue. The fermentation microbes will be in shock and need time to adjust. Gradual introduction into the digester is the necessary solution.

15 Long term health checks and supplements – e.g. introduction of trace elements/metals to help keep a healthy bug population

The plant manger is responsible for creating and maintaining detail plans covering feeding, testing and maintenance, these are all critical for long term reliable performance. Below are a list of the daily checks that should be performed:

- Log volume of biogas produced in last 24hrs;
- Log % of methane in biogas;
- Log % of Hydrogen sulphide in biogas;
- Log plant temperature;
- Log feed type and volume;
- Sample test pH and conductivity and log results;
- Log any plant issues and changes to conditions;
- Generate run charts for logged criteria;
- Check plants systems in line with maintenance plan;
- Load plant in accordance with plan ensure correct dry matter content in plant is maintained.

The weekly checks that should be performed are as follows:

- Take sample and measure pH, Conductivity, FOS/TAC ratio, volatile fatty acids, log data;
- Sample any new feedstocks and check dry matter and volatile solids, log data;
- Weekly plant checks in line with maintenance plan;
- Add micro nutrients, defined quantity;
- Review meeting to cover results and refine feed plan for the next week.

As required testing may expand to include C:N ratio and key micro nutrients, and monitoring feedstock in respect to contamination is important so the plant is not damaged by stones and other foreign items.

16 Risk issues from an insurance perspective

The first 180 days of the plant is critical to maximising performance and ultimately output but the issues surrounding risk need to be assessed as early as the design stage. You need to consider the plant layout, key components being used, primary and secondary digestate containment. Who are your contractors; do they have a proven record and do they work in partnership with an experienced insurer and broker who will provide impartial due diligence and loss mitigation advice? It is at this stage insurers may have requirements around fire suppression and fire / gas detection equipment which can be factored in. Your CAPEX cost at this stage will be far lower than trying to retrofit when you are about to go live.

Once your design is approved you need to work through this during the construction phase to ensure it is adhered to and to make sure the contractors manage the site safely in accordance with best practise. Insurers will also wish to survey the site during the construction phase and you should welcome this as this will give them a greater understanding of the risks they are to insure and will assist in negotiating the best possible terms.

Once operational you will then need to pay particular attention to who is operating your plant, do they understand what they are doing? How have they been trained? Do they understand what they have been taught? Look at your feedstock contracts; do you fully understand what you are responsible for? It is then paramount to ensure your plant is fully maintained. Consider who is maintaining your plant, and how is it being monitored so in the event of a breakdown it can be picked up quickly. What are the service level agreements and do you have any spare parts on site, if not how quickly can you get them?

The above is by no means an exhaustive list so the best advise is involve an insurer and broker at the earliest opportunity, work in partnership with them and by doing so they will fully understand what they are insuring which in turn will reduce premiums, mitigate against loss and, coupled with the above advise on the first 180 days, will ultimately improve your return on investment.

17 Summary

The challenge levied at the Renewables Sector is that it does not provide base load capacity.

AD defeats this argument and with the capability to create energy from waste it is a technology with a long term future.

But it has been a technology where in the UK successful deployment has been challenged by the lack of specialist knowledge of the most crucial part of the process – the biological interaction within the digester.

Now with this paper we have a template that the vast majority of new plants can employ to maximise their chances of successful commissioning and optimising gas production.

The message that does come through is the need for attention to detail and a rigorous routine of testing to optimise biological conditions.

The benefits of achieving of full scale biogas production rapidly and with the minimum use of feedstock are critical to the success of a newly installed biogas plant. Success depends upon:

- Detailed planning of the start up phase, covering inocula loading, feeding and testing;
- The acquisition and use of an efficient inocula from rumen sources or a fully operating digester;
- Providing the correct physical and biochemical environment to initiate biogas production;
- Recognition of when to add feedstock by timely and appropriate monitoring of the anaerobic fermentation;
- Application of the fermentation parameters to gradually increase the feeding rate.

Ultimately the long term success of an anaerobic digester is all about the biology. None of us can control changes in government policy or what energy prices are at any given time. What you can control is the health of your bug population within your digester and this paper outlines the procedures to followed. Healthy bugs will enhance your financial health.

If you require further information regarding anaerobic digestion please contact the report authors.

18 About the authors

Stephens Scown

Stephens Scown's renewable energy is the largest dedicated renewables team in the South West and is recognised by independent legal guide, Legal 500, which highlights the expertise of the team's head Sonya Bedford. The firm have provided the legal services for anaerobic digesters ranging from 500kw to 6mw and are currently involved in a number of community energy digester projects. Through their close interaction on these projects the importance of the biological side became clear and led to this report being commissioned.

New Generation Biogas Ltd

New Generation Biogas Ltd were formed in 2009 and have created the ground breaking 'Archemax' AD system.Called Archemax®, this new, advanced AD unit is ideally suited to small and medium-sized farms and is the result of five years' R&D that has successfully reduced the amount of time required to break down typical input feedstocks from around 30-60 days to just six days. This ground-breaking speeding up of the digestion process has been achieved because at the heart of the Archemax® process is a thermophilic bio-digester that is optimised to operate at around 55°C, rather than a conventional mesophilic AD system that operates at around 35°C.

Dr Phil Hobbs, one of NGB's founders and directors has written over 70 peer reviewed papers on the field of AD and ancillary disciplined of microbial ecology, waste treatment, odour control and waste processes. He is a leading international expert in biogas research and in regular demand from both the EU and the UK government.

Jelf Insurance Brokers Ltd

Jelf is a leading independent, full-service consultancy supporting businesses and individuals with expert advice on matters relating to insurance, employee benefits and financial planning.

At Jelf, we look to build long-term relationships with our clients, working together to understand the risks that they face before using our experience and expertise to develop tailored solutions.

By working closely with a number of trade associations we have valuable insight and knowledge into the renewable industry and its insurance requirements. We work with a broad spectrum of clients and our specialist renewable team is committed to professionalism and client care.