ENERGICA

ENERGY ACCESS AND GREEN TRANSITION COLLABORATIVELY DEMONSTRATED IN URBAN AND RURAL AREAS IN AFRICA

DELIVERABLE 5.2 : Easy access start-up manual and day-to-day operations instructions

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DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

Dissemination Level		
PU	Public, fully open, e.g. web	
CO	Confidential, restricted under conditions set out in Model Grant Agreement	x
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Quality procedure			
Date	Version	Reviewers	Comments
10/10/2023	V1	Fausto Marcigot (TWT)/ Gustav Rogstrand (RISE)	Various comments to strengthen different chapters
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Guideline Starting up a biogas process digesting food waste

1. Contents

The table below shows the revision history of this document.

Rev.	Date	Author	Status
0	09-03-2023	ADT	
1			
2			
3			

1. General information

When operating a Waste Transformer biogas installation, it is important to monitor certain parameters that will provide insight in the health of the biological system which will enable optimization or maximization of the biogas outputs.

The specific health process parameters that need to be measured may change based on the input substrate, dilution liquid that will be used, operational constrains and other requirements. The selected parameters need to be monitored with a frequency defined in this document.

The document is divided into three (3) main sections:

1. Inoculum selection, inoculation and activities before start-up
2. Start-up phase
3. Stabilization phase

2. Digester health process parameters

Measuring of gas composition

The carbon dioxide content is measured with fermentation Saccharometer according to EINHORN with EINHORN measuring tube. It is a simple method to measure the amount of carbon dioxide. The carbon dioxide created in the fermenting process would rise to the top of the closed tube and force the level of liquid down.

Measuring biogas content

It is possible to measure the biogas compositions methane (CH4), carbon dioxide (CO2), hydrogen sulfide (H2S), oxygen (O2) with a portable ATEX infrared digital analyser for biogas, for example BG-5000 or Cubic-Ruiyi Gasboard-3200Plus.

The gases that can also be measured with an in-line sensor are CO2 and H2S but depending on the Waste Transformer configuration, H2S is not a mandatory part of the Waste Transformer.

Measuring pH

The pH value of the digestate is measured manually using a handheld pH meter.

Measuring Dry matter content

The dry matter content of the digestate is measured manually using a moisture analyser. A Waste Transformer does not have an integrated dry matter content analyser.

1. If only the thin digestate fraction will be used for diluting food waste, it is mandatory to monitor the dry matter content of the digestate. The digestate can be analysed using the moisture analyser or by sending samples to an exteranl laboratory. If an ih-house analyser is to be used, please refer to the instrumentation or equipment manual that will be used for testing this parameter.
2. If thin digestate fraction and water will be used for diluting food waste, it is mandatory to monitor the dry matter content of the digestate. The digestate can be analysed using the analyser or by sending samples to an exteranl laboratory. If an ih-house analyser is to be used, please refer to the instrumentation or equipment manual that will be used for testing this parameter.
3. If water will be used for diluting food waste, it is not mandatory to measure the dry matter content of the digestate. Samples of the digestate should be sent to an external laboratory for dry matter content testing. Please consult The Waste Transformers to determine the frequency of sampling and laboratory analysis.

Optionally it is helpful to determine the following parameters.

Measuring FOS/TAC

The FOS/TAC value of the digestate is measured manually using a FOS/TAC instrument. A Waste Transformer does not have an integrated FOS/TAC instrument. Please refer to the instrumentation or equipment manual that will be used for testing this parameter.

Measuring Ammonium content

The ammonium content of the digestate is measured manually using a spectrophotometer. A Waste Transformer does not have an integrated FOS/TAC instrument.

1. If only the thin digestate fraction will be used for diluting food waste, it is mandatory to monitor the ammonium content of the digestate. The digestate can be analysed using the spectrophotometer or by sending samples to an exteranl laboratory. If an ih-house spectrophotometer is to be used, please refer to the instrumentation or equipment manual that will be used for testing this parameter.
2. If thin digestate fraction and water will be used for diluting food waste, it is mandatory to monitor the ammonium content of the digestate. The digestate can be analysed using the spectrophotometer or by sending samples to an exteranl laboratory. If an ih-house spectrophotometer is to be used, please refer to the instrumentation or equipment manual that will be used for testing this parameter.
3. If water will be used for diluting food waste, it is not mandatory to measure the ammonium content of the digestate. Samples of the digestate should be sent to an external laboratory for ammonium testing. Please consult The Waste Transformers to determine the frequency of sampling and laboratory analysis.

3. Start-up phase

3.1. Inoculum selection

An inoculum can be defined as the population of microorganisms or cells that is introduced in the fermentation reactor and medium. Before selecting a specific inoculum that will be used to seed the digester tank(s), some requirements need to be fulfilled.

1. If there is an up and running biogas installation in the vicinity of the future Waste Transformer (WT), this up and running biogas installation should be taken into account as the source of the inoculum. The requirements are:

- Operated as wet digestion (<20% dry matter content in the feedstock)
- Feedstock is food waste
- Operated at mesophilic temperatures (30-40 °C)
- Similar Organic Loading Rate to the new WT (approximately 3 kgVS/m3*day)
- Similar Hydraulic Retention Time to the new WT (approximately 44 days)
- Similar biogas production to the new WT (calculated based on a BMP test)
- Has little to no contamination (rocks, metal, plastics, clothing etc)
- Available volumes (the minimum technical volume for seeding one digester tank is 10m3 for seeding one digester tank)

If the majority of the requirements are fulfilled, this inoculum should be considered as the inoculum source for seeding a WT. Please consult The Waste Transformers to select the best inoculum source. If all the requirements are fulfilled but the available volumes cannot be found, the inoculum should still be considered. The inoculation and start-up phase will then be modified in consultation with The Waste Transformers.

2. If there is no up and running biogas installation in the vicinity of the future biogas installation or the above requirements are not met, another source of inoculum should be explored. Examples of these sources are as follows:
    - Digestate from a plant co-digesting food waste
    - Digestate from a plant co-digesting industrial waste
    - Digestate from a plant digesting manure and/or energy crops
    - Digesate from a plant digesting sewage sludge
    - Raw liquid cattle manure (fresh dung) (leaste desierd choice)

If one or multiple of these sources are to be used, please consult The Waste Transformers to select the best inoculum source.

3.2. Inoculum analysis

Whichever inoculum is selected to seed the future biogas installation, a laboratory analysis on this inoculum must be done.

1) Specific Methanogenic Production (SMP)/Activity (SMA)
2) pH
3) EC (conductivity)
4) Cl
5) NH4-N
6) TKN Ttotal Kjeldahl Nitrogen)
7) Ca
8) Norg (Organic Nitrogen)
9) Na
10) S

11) P
12) K
13) VS (Volatile Solids)
14) Mg
15) Fe
16) Al
17) TS (Total Solids)
18) Co
19) Cd
20) VSS (Volatile Suspended Solids)
21) Cr
22) Mn
23) B
24) Ni
25) Se
26) Cu
27) As
28) Hg
29) Mo
30) Zn
31) Pb

3.3. Inoculating the biogas plant Waste Transformer (WT)

The selected inoculum to seed a WT must have a TS content ideally 8 - 12 % until maximum 18%. This will enable sufficient mixing without damaging the equipment.

Whether the inoculum is delivered in a tank truck or pumped from a stationary vessel, there are two (2) entry points that can be used for seeding:

1) The bottom opening of the digester tank. If the inoculation is done through the bottom opening, it is important to open the man hole at the top of the digester tank to eliminate any pressure buildup. Make sure the valve leading to the digester tank is OPEN so that seeding material can flow from the tank truck into the digester tank. Make sure all other valves that are in the same piping line as the pipe used for seeding the digester tank are CLOSED. This way, all seeding material will be pumped into the digester tank and will not flow into other parts of the installation.
2) The man hole at the top of the digester tank. If the inoculation is done through the man hole, it is important to close the valve at the bottom of the digester tank. This way, there will be no leakeges within the installation. It is important to note that specific H&S equipemnt is needed. Please refer to the ”HSE and legal requirements” document.

3.4. Purging a Waste Transformer

Once the seeding has been finished and all the inoculum is settle in the digester tank, eliminating all air from the digester tank headspace is recommended. If purging the air from the headspace is done, it should be done using nitrogen gas (N2). In some cases, the purging step can be avoided but please contact The Waste Transformers to determine the course of action.

3.5. Preparing a Waste Transformer for feeding

Once the seeding and purging has been finished, the heating and mixing should be turned on. The heating should be adjusted to 35-38 ℃, depending on the inoculum temperature. It is important to note that the temperature should NOT INCREASE more than 1 ℃ per day. The standard mixing schedule should be adjusted using the HMI screen (mix for 5 minutes, every 30 minutes). For adjusting the mixing pattern, please refer to the “HMI Operations Manual”

3.6. Feeding a Waste Transformer

Once the WT is inoculated, purged and heated to the correct temperature, the feeding can start. Based on the substrate, inoculum volume and inoculum parameters, different feeding strategies can be followed. Please consult The Waste Transformers to select the best feeding strategy.

Table 1. Example of a feeding strategy with 22m3 active volume from a food waste biogas plant, Food Waste characteristics 30% TS and 95% VS

Day	OLR [kg VS/m3&d]	Food waste [kg/day]	Water/ dilution liquid[kg/day]	Trace metals [mL/day]	Fe [mL/day]	Time with constant OLR	Time with OLR rise
1	0.75	58	66	30	30	3 d	3 d
7	1	77	88	30	30	4 d	7 d
18	1.5	116	132	30	30	7 d	7 d
32	2	154	176	30	30	7 d	7 d
46	2.5	193	220	30	30	14 d	7 d
68	3	232	265	30	30	->	-

*After Week 10, the Organic Loading Rate (OLR) should be 3 kgVS/m3*day and the Start-up phase is completed. Proceed to the Stabilization phase.

3.7. Macro and micro element laboratory analysis

Once the start-up phase has been finalized (1st Hydraulic Retention Time is finished), a laboratory analysis of the following parameters should be done. Based on the results of the analysis, adjustments to the operating parameters, feeding strategy and feedstock composition can be made. A sample of the digestate should be taken from the WT and a laboratory analysis can be done locally or the sample can be shipped to The Waste Transformers local laboratory. Please consult The Waste Transformers when a sample will be analysed.

1) pH
2) EC (conductivity)
3) Cl
4) NH4-N
5) TKN Ttotal Kjeldahl Nitrogen)
6) Ca
7) Norg (Organic Nitrogen)
8) Na
9) S
10) P
11) K
12) VS (Volatile Solids)
13) Mg
14) Fe
15) Al
16) TS (Total Solids)
17) Co
18) Cd
19) VSS (Volatile Suspended Solids)
20) Cr
21) Mn
22) B
23) Ni
24) Se
25) Cu
26) As
27) Hg
28) Mo
29) Zn
30) Pb

4. Start-up phase process parameter monitoring

4.1. Sampling biogas from a Waste Transformer

When measuring the biogas quality with a handheld biogas analyser, it is important to define where the sampling points for different digester tanks are. The location of the biogas sampling points can be different from one installation to another installation. An example of the biogas analyser connected to the sampling point can be seen in Figure 1, highlighted in red. The manually operated valve should always be closed to eliminate gas leakages from the biogas sampling point and opened only when the

biogas analyser is securely connected to the sampling point. When sampling biogas, plug the biogas analyser hose into the opening of the valve making sure the hose is deep enough so the connection is gas tight.

Figure 1. Biogas analyser (Cubic-Ruiyi Gasboard-3200Plus) connected to sampling point when manual valve is closed

Open the manual valve to start the flow of biogas to the biogas analyser, as seen in . The analyser will measure the gas and display the biogas quality on its screen. For more information on the sampling and measurement, please refer to the biogas analyser manual. When biogas sampling is finished, disconnect the biogas analyser by pushing on the blue opening on the valve, this will release the hose.

Please make sure the manual valve is always closed (as in Figure 1) when biogas sampling is not being done. This is to avoid biogas leakages.

Figure 2. Biogas analyser connected to sampling point when manual valve is open

4.2. Interpretation of measured CO2 content in biogas

4.2.1. Waste Transformer has one digester tank

CO2 content should be measured every day using a handheld biogas analyzer (e.g. Hubei Cubic-Ruiyi or Einhorn saccharometer). If biogas is measured manually using a handheld biogas analyzer or the Einhorn saccharometer, it is important to measure this before feeding the installation. If there is an inline sensor integrated in the control container, CO2 will be measured automatically.

4.2.2. Waste Transformer has more than one digester tank

In cases where a WT has multiple digester tanks and an inline CO2 sensor, it is recommended to measure the CO2 with a handheld biogas analyzer as well. Biogas received from multiple digester tanks is collected and measured using one inline CO2 sensor but in cases where other health parameters are not in normal ranges, the CO2 of each digester tank should be measured.

Table 1. Carbon dioxide content of biogas using a handheld biogas analyzer

CO2 content in biogas [%]	Comment
41 or higher	Stop
37-40	Mode 2
35-36	Mode 1
33-34	Warning
30-33	Ok, normal operations
26-29	Ok, normal operations
25 or lower	Ok, but check measuring equipment

Table 2. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 1.

	Possible cause and action(s) to take
Warning	Important with daily measurement of biogas's CO2 content and supervision of biogas production ratio
Mode 1	CO2 is high, be vigilant. Take pH, CO2 and biogas production analysis every day and check the development of VFA as well as the FOS/TAC ratio with once per week. However still feed the same amount of material. If the process is at this CO2 content a few days to 1 week, there is a high risk that the biogas content of CO2 will increase even more as the gas ratio decreases, leading the process to Mode 2. If the Einhorn saccharometer is used for measuring CO2, repeat this measurement three times and register the average.. Please contact process management support to discuss any action programs.
Model 2	Reduce the load by 30%. Submit samples for detailed VFA analysis to an external lab. Contact process management support immediately to determine the action program. It is important to monitor the CO2 content of biogas on a daily basis as well as biogas production ratios. The frequency of analysis on own VFA analyses (FOS/TAC equipment) is increased if possible to 2 times per week to capture if the content increases and how fast. If the CO2 content tends to increase further and the VFA, FOS/TAC numbers trends upwards you will need to make preparations for STOP-mode.
Stop	Stop all feeding of material to the digester. Submit samples for detailed VFA analysis! Contact process management support immediately to determine the action program. Follow gas production, CO2 content, pH and VFA content until they have returned to values allowing for Mode 2 operations.

Warning (25% or lower)	The CO2 could have dropped because the VFA's have been consumed rapidly after reducing the loading rate. The process will stabilize and the CO2 will increase to a normal operations range. Check the measuring equipment (recalibrate it)

4.3. Interpretation of measured H2S content in biogas

4.4. Sampling biogas from a Waste Transformer

When measuring the biogas quality with a handheld biogas analyser, it is important to define where the sampling points for different digester tanks are. The location of the biogas sampling points can be different from one installation to another installation. An example of a biogas sampling point can be seen in Figure 1, highlighted in red. The manually operated valve should always be closed to eliminate gas leakages from the biogas sampling point. When sampling biogas, plug the biogas analyser hose into the opening of the valve making sure the hose is deep enough the connection is gas tight. Open the manual valve to start he flow of biogas to the biogas analyser. The analyser will measure the gas and display the biogas quality on its screen. For more information on the sampling and measurement, please refer to the biogas analyser manual.

4.4.1. Waste Transformer has one digester tank

H2S content should be tested two times per week using a handheld biogas analyzer (e,g. Hubei Cubic-Ruiyi). The H2S should be sampled and tested from two sampling points, from raw biogas and cleaned biogas. If there is an inline sensor integrated in the control container, H2S will be measured automatically. The inline H2S sensor measures cleaned biogas.

4.4.2. Waste Transformer has more than one digester tank

In cases where a WT has multiple digester tanks and an inline H2S sensor, it is recommended to measure the H2S with a handheld biogas analyzer as well. Biogas received from multiple digester tanks is collected and measured using one inline H2S sensor but in cases where other health parameters are not in normal ranges, the H2S of each digester tank should be measured.

Table 3. H2S content in raw biogas

H2S in raw biogas [ppm]	Comment
5-10	Ok, normal operations
>10 after first weekly measurement	Warning
>10 after second weekly measurement	Mode 1

Table 4. H2S content in cleaned biogas

H2S in cleaned biogas [ppm]	Comment
Ok, normal operations	Continue normal operations, measuring the H2S twice per week
Warning	Be vigilant, the H2S levels might continue increasing. Continue with normal operations and measure the H2S twice per week as planned
Mode 1	Continue normal operations but contact process management. There could be a need to increase the volumes of Fe dosed to the digester tank.

4.5. Interpretation of gas production

The biogas production should be monitored every day using a gas flow meter integrated in the Waste Transformer. An example of the biogas production can be seen Figure 3, highlighted in red.

	Total	Today	Yesterday	2 days ago	3 days ago	4 days ago	5 days ago	6 days ago	7 days ago	8 days ago	9 days ago	
FT-001 water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	l
FT-002 biogas	2862.5	4.1	25.9	26.6	9.6	2.2	9.8	22.9	14.1	0.5	0.0	m³
FT-002 biogas (corrected)	2624.0	3.9	23.8	23.6	8.5	2.1	9.0	21.4	13.1	0.5	0.0	nm³
CHP Electric production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
CHP Heat production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
CHP Fuel consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
Electric power in	261.2	4.7	3.8	5.0	2.7	7.0	8.4	10.0	13.2	3.4	0.0	kWh
Electric power out	60.5	0.5	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
Power heat	1942	16	89	0	0	0	1	0	0	0	0	kWh
Volume	797	12	24	32	16	5	25	24	23	2	0	m³

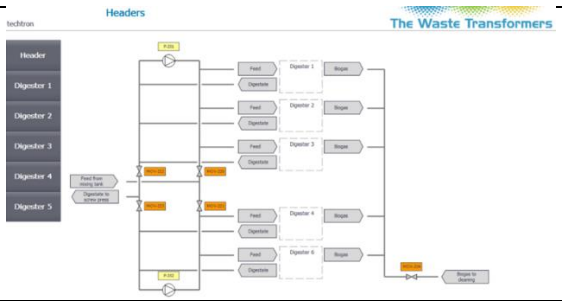
Figure 3. Biogas production on HMI screen

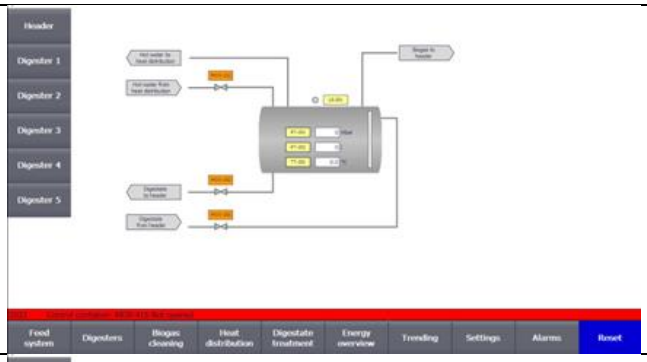
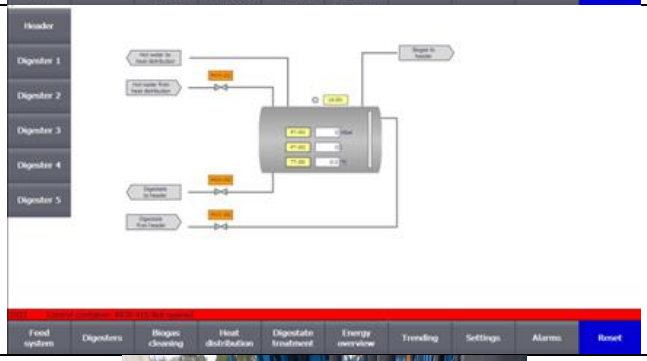
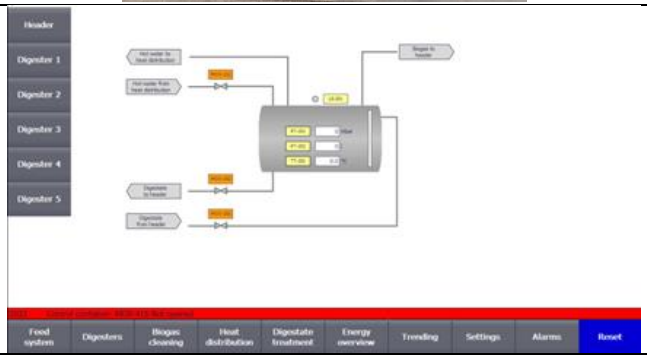
If the inoculum has not been sourced from an up and running biogas installation that has been active and gassing but rather from cattle manure or other sources, the interpretation of gas production cannot be defined. The biogas flow meter and CO2 meter might not be able to register the biogas production in the first couple of days. It is very important to measure the FOS/TAC and CO2 regularly (as defined in this document) to be sure the system is healthy, volatile fatty acids are being consumed and biogas production should be expected after 2 weeks.

4.6. Sampling sludge/digestate from a Waste Transformer

Correct sample collection is a critical step in monitoring the biogas installation and recording reliable data. When a digestate sample is collected, it is recommended to collect more sample material in case of sample lose due to spillage and repetition of analysis. It is best to sample and measure the digester health parameters approximately at the same time of the day (e.g. in the morning) to enable a reliable comparison of data. Please refer to the HMI Operations Manual for exact process steps that need to be taken for sampling digestate.

If the WT is being mixed when the sample is to be taken, wait for the mixing to finish. Freshly mixed content of the digester will provide a homogenous sample and most precise readings. Once the mixing has finished, proceed to the following steps:

Manually close the ball valve BV-228 in CC3	
On the HMI screen, press the Digesters tab at the bottom of the screen. Close valve MOV-222 on the Headers line using the HMI screen (Manual close)	
On the HMI screen, press on the Digester tank that needs to be sampled (in this case Digester 1). This will open a new tab to the digester tank that should be operated. Close bottom valve MOV-202 on the Digester tab 1 using the HMI screen (Manual close)	

	
Close all bottom valves of digester tanks that share the same mixing line as the sampled digester. For sampling Digester 1 the following steps: Close bottom valve MOV-202 on the Digester tab 2 using the HMI screen (Manual close) Close bottom valve MOV-202 on the Digester tab 3 using the HMI screen (Manual close)	
Manually open the ball valve at the sampling point on the pipe of AD1; drain the pipe and dispose of the digestate. Drain the digestate into a bucket or container. Hold the bucket close to the sample point to reduce splashing. Manually close the ball valve at the sampling point on the pipe of AD1 when the full pipe volume has been drained	
Open the bottom valve MOV-202 on the Digester tab 1 using the HMI screen (Manual open); this will fill the pipe with fresh digestate Close the bottom valve MOV-202 on the Digester tank 1 using the HMI screen (Manual open)	

Manually open the ball valve at the sampling point on the pipe of Digester 1. Take a 400 mL glass beaker and hold it near the sample point opening, slowly open the ball valve and fill 2/3 of this glass beaker. This digestate sample will be used for measuring digester health parameters. Please refer to the manual of the parameter that will be tested.	

If The Waste Transformer has multiple digester tanks, the sampling procedure will be the same for each sampled digester tank. The same sampling procedure should be done for all digestate analysis (FOSTAC, pH, EC, ammonium, dry matter).

4.7. Interpretation of pH

pH value of the sludge should be tested twice per week using a pH meter (e.g. LAQUAtwin-pH-33).

Table 5. pH value of the sludge

Sludge pH value	
>7.7	Warning 1
7.5-7.7	Ok, normal operations
7.4-7.5	Warning 2
7.3-7.4	Mode 2
7.3 or lower	Stop

Table 6. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 5

	Possible cause and action(s) to take
Warning 1	Moderately high pH. It might be time to recalibrate the pH meter or refill the internal sensor liquid.
Warning 2	Moderately low value. Measure the CO2 content of biogas daily and check the biogas production KPI. Check the development of VFA as well as the VFA/PA ratio with your own FOS/TAC analysis equipment. It is important that these VFA analyses are carried out at least once a week. Increase the pH testing from twice per week to three times per week.
Mode 2	Very low values. Contact process management support immediately to determine the action program.
Stop	Critically low values. Stop all substrate input to the digester - the process is about to crash

4.8. Interpretation of VFA and VFA/TAC ratio

VFA and VFA/TAC ratio should be tested twice per week (during normal operations) using a FOSTAC measuring equipment (e.g. Pronova FOSTAC 2000).

Table 7. VFA value and VFA/TAC ratio

VFA content [g/L]	Comment
< 3	Ok, normal operations
3-4	Warning
4-6	Mode 1
6-8	Mode 2
> 8	Stop

Table 8. VFA/TAC ratio

VFA/TAC ratio	Comment
< 0.3	Ok, normal value
0.3-0.4	Warning
0.4-0.5	Mode 1
0.5-0.85	Mode 2
> 0.85	Stop

Table 9. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 7 and Table 8.

	Possible cause and action(s) to take
Ok, normal values	Continue normal operations
Warning	Important with daily measurement of the CO2 content in the biogas and biogas production KPI.
Mode 1	The frequency of analysis using our own FOS/TAC equipment is increased to three time per week to capture if the VFA-levels increases and if so, how fast. It is important to monitor the CO2 content of biogas on a daily basis as well as biogas production KPI. Please contact process management support to discuss any action program.
Mode 2	Reduce the loading rate by 30%. Submit samples for detailed VFA analysis at external lab. Contact process management support immediately to determine the action program. It is important to monitor the CO2 content of biogas on a daily basis as well as biogas production KPI. The frequency of VFA analysis using your own FOS/TAC equipment is increased to three times per week to capture if the VFA content increases and if so, how fast.
Stop	Stop all feeding of substrate to the digester. Submit samples for detailed VFA analysis. Contact process management support immediately to determine the action program. Follow gas production, CO2 content, pH and VFA content.

General advice on the meaning of rate-of-change for the VFA KPI

- An increase of VFA content by ≥1.5 units per week is an alarming signal if the total content is above 3 g/l. Submit samples for detailed VFA analysis! Contact process management support immediately to determine the action program.
- A reduction of VFA content by ≥1 unit per week is a positive signal that a reduction in substrate loading rate is having the intended effect.

4.9. Interpretation of ammonium concentration

Dilution of the substrate is done using thin fraction of the digestate. This means that a certain amount of ammonium is reintroduced into the fermentation tank with a potential of accumulation of it. The ammonium concentration should be analysed once per month, using an Merck Nova60A Spectroquant.

Table 10. Ammonium concentration of the sludge

Ammonium concentration [g/L]	
2.0-3.0	Ok, normal operations
3.0-3.5	Warning, be viginalt
3.5-4.0	Mode 1, be alert
4.0-4.5	Mode 2, carefully start to evaluate the CO2, gas production, FOS/TAC and pH and look for trends (increasing CO2, reduction of biogas production in relation to the feed and increased FOS/TAC and decreased pH)
4.5	Mode 3, ammonia levels need to stabilize

Table 11. Description of action programs associated with Mode 1 and Mode 2, Warning, and Mode 3 in Table 10.

	Possible cause and action(s) to take
Ok, normal operations	Continue with normal operations
Warning	Increase the FOS/TAC analysis to 2 times per week but continue normal operations
Mode 1	Increase the FOS/TAC analysis to 3 times per week, contact process management.
Mode 2	Increase the CO2, biogas production and pH measurements to every day. If the CO2 is increasing and biogas is decreasing, reduce the load by 30%. If none of these changes happen, continue normal operations, the system is getting used to the high ammonia loading.
Mode 3	Add water for dilution of the substrate but continue normal operations as long as CO2, biogas production, FOS/TAC and pH values are all in normal ranges. Continue operating in this mode for 2 months until the ammonia concentration stabilizes. Contact process management support for this.

4.10. Interpretation of dry matter content in the sludge

The dry matter content in the sludge should be measured once per month (during normal operations) using a dry matter or moisture analyser (e.g. VPB-10 Moisture analyser). It is important to note that if a moisture analyser is used such as the VPB-10 Moisture analyser, the dry matter content shall be calculated as:

$$100\% - \mathrm{X} = \text{dry matter content}$$

where X = the measured moisture content, presented on the screen of the VPB-10 Moisture analyser.

Whatever source of inoculum or substrate is used, the sludge dry matter content should not increase more than 1% per month. A slow and steady dry matter increase is to be expected because digestate is used for substrate dilution. If an increase of more than 1% per month occurs, contact process management but continue with normal operations. This parameter is important with monthly measurements of ammonium content and dry matter content in food waste.

4.11. Interpretation of dry matter content in the substrate

The dry matter content in the food waste should be measured once per month (during normal operations) using a dry matter or moisture analyser (e.g. VPB-10 Moisture analyser). It is important to note that if a moisture analyser is used such as the VPB-10 Moisture analyser, the dry matter content shall be calculated as:

$$100\% - \mathrm{X} = \text{dry matter content}$$

where X = the measured moisture content, presented on the screen of the VPB-10 Moisture analyser.

Table 12. Dry matter content of sludge

Dry matter content of sludge	
14%	Ok, normal operations
±2%	Warning
±3%	Mode 2
±4%	Stop

Table 13. Description of action programs associated with Mode 1 and Mode 2, Warning, and Mode 3 in Table 12.

	Possible cause and action(s) to take
Ok, normal operations	Continue with normal operations
Warning	The dry matter content in the substrate is lower or higher than it should be meaning the substrate is over diluted or under diluted. Important with monthly dry matter content and ammonium measurements. Continue normal operations.
Mode 2	The dry matter content in the substrate is too low or too high. The dilution ratio needs to be adjusted. Important with monthly dry matter content and ammonium measurements. Continue normal operations but contact process management. Fe and trace metal additions might need adjustment.
Stop	The dry matter content in the substrate is severely low or high. The dilution ratio needs immediate adjustment, contact process management. Stop all substrate input until the dilution ratio is adjusted. Continue monitoring the dry matter and ammonium content in the sludge.

4.12. Interpretation of temperature fluctuations for a mesophilic process

The target temperature of the Waste Transformer should be set to 37 degrees Celsius. Depending on the location of the Waste Transformer and the average temperature, the temperature can be slightly adjusted but please contact The Waste Transformers to determine the optimum temperature.

The temperature of the digester tank should be monitored daily and any drastic changes should be registered. For values that are not in the normal operations range, action should be taken and potential negative impact on the stability of the process should be expected. Any fast changes of temperatures should be recorded.

Table 14. Digester tank temperature fluctuations for target temperature of 37 degrees Celsius

Digester temperature fluctuations in a day	
± 1 degree	Ok, normal operations
± 1.5 degress	Warning
± 2 degrees	Mode 1
± 3	Mode 2
Under 30	Mode 3
Above 40	Stop

Table 15. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 14.

	Possible cause and action(s) to take
Warning	Continue normal operations. Important with daily measurement of the CO2 content in the biogas and biogas production. Be vigilant that the temperature can continue to increase or decrease to Mode 1.
Mode 1	Continue with normal operations but contact process management. Important with daily CO2 and biogas yield measurements.
Mode 2	Reduce the load by 30%. Important with daily CO2 and biogas yield measurements. Contact process management and try to heat or cool down the digester tank, depending on the temperature with a maximum of 1 degree Celsius change/day.

Mode 3	Digester is severely cooled, slowing down the degradation process and biogas production. Stop all substrate input and contact process management. Important with daily CO2 and biogas yield measurements.
Stop	Digester is overheating; bacteria might be dying. Stop all substrate input and contact process management.

4.13. Frequency of process parameters measurements during the start-up period

Table 16. Frequency of process parameter measurements during the start-up phase

Mode	KPI									
	CO2	H2S	Gas production	pH	VFA	VFA/PA	Ammonium concentration	DM content in the sludge	DM content in the substrate	Temperature fluctuations
Normal	5x/week	2x/week	5x/week[1]	2x/week	2x/week	2x/week	1x/month	1x/month	1x/month	5x/week
Warning	5x/week	2x/week	5x/week[1]	3x/week	2x/week	2x/week	1x/month	1x/month	1x/month	5x/week
Mode 1	5x/week	2x/week	5x/week[1]	5x/week	3x/week	3x/week	1x/month	1x/month	1x/month	5x/week
Mode 2	5x/week	2x/week	5x/week[1]	5x/week	3x/week[2]	3x/week[2]	1x/month	1x/month	1x/month	5x/week
Stop	5x/week	2x/week	5x/week[1]	5x/week	2x/week[2]	3x/week[2]	1x/month	1x/month	1x/month	5x/week

5. Stabile phase

Once the Start-up phase has been completed, the digester health parameters are within their defined boundaries and the "normal" biogas yield has been determined, the Stabile phase can be initiated. In this phase, it is paramount to feed the installation consistently, measure the digester health parameters with a frequency defined in this chapter and monitor any changes in the biogas quantity and quality. In this phase, the digester biology is maturing which means the nutrient composition in the digestate will have less fluctuations.

5.1. Feeding a Waste Transformer

Feeding a WT should continue as usual, following the last day of the Start-up phase (unless there are biology disturbances that have been recorded during the Start-up phase). If there are any issues that do not allow the operations within the Stabilization phase, please contact process support.

Table 17. Example of a feeding strategy with 22m3 active volume from a food waste biogas plant, Food Waste characteristics 30% TS and 95% VS

Day	OLR [kg VS/m3&d]	Food waste [kg/day]	Water/ dilution liquid[kg/day]	Trace metals [mL/day]	Fe [mL/day]
69	3	232	264	30	30
76	3	232	264	30	30

83	3	232	264	30	30
90	3	232	264	30	30
97	3	232	264	30	30
….	3	232	264	30	30

Once the WT has been operational for one year, a revision of the operation and KPIs should be done. An assessment based on the previous operations should be made to determine if the installation can be fed with more substrate, subsequently giving more biogas. This process will introduce more risk and might destabilize the digester biology therefore please consult process management to determine the next steps.

6. Stabile phase process parameter monitoring

When measuring the biogas quality with a handheld biogas analyser, it is important to define where the sampling points for different digester tanks are. The location of the biogas sampling points can be different from one installation to another installation. An example of a biogas sampling point can be seen in Figure 1, highlighted in red. The manually operated valve should always be closed to eliminate gas leakages from the biogas sampling point. When sampling biogas, plug the biogas analyser hose into the opening of the valve making sure the hose is deep enough the connection is gas tight. Open the manual valve to start he flow of biogas to the biogas analyser. The analyser will measure the gas and display the biogas quality on its screen. For more information on the sampling and measurement, please refer to the biogas analyser manual.

6.1. Interpretation of measured CO2 content in biogas

6.1.1. Waste Transformer has one digester tank

CO2 content should be measured every day using a handheld biogas analyzer (e,g. Hubei Cubic-Ruiyi or Einhorn saccharometer). If biogas is measured manually using a handheld biogas analyzer or the Einhorn saccharometer, it is important to measure this before feeding the installation. If there is an inline sensor integrated in the control container, CO2 will be measured automatically.

6.1.2. Waste Transformer has more than one digester tank

In cases where a WT has multiple digester tanks and an inline CO2 sensor, it is recommended to measure the CO2 with a handheld biogas analyzer as well. Biogas received from multiple digester tanks is collected and measured using one inline CO2 sensor but in cases where other health parameters are not in normal ranges, the CO2 of each digester tank should be measured.

Table 18. Carbon dioxide content of biogas using a handheld biogas analyser

CO2 content in biogas [%]	Comment
41 or higher	Stop
37-40	Mode 2
35-36	Mode 1
33-34	Warning
30-33	Ok, normal operations
26-29	Ok, normal operations
25 or lower	Ok, but check measuring equipment

Table 19. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 18

	Possible cause and action(s) to take
Warning	Important with daily measurement of biogas's CO2 content and supervision of biogas production ratio
Mode 1	CO2 is high, be vigilant. Take pH, CO2 and biogas production analysis every day and check the development of VFA as well as the FOS/TAC ratio with once per week. However still feed the same amount of material. If the process is at this CO2 content a few days to 1 week, there is a high risk that the biogas content of CO2 will increase even more as the gas ratio decreases, leading the process to Mode 2. If the Einhorn saccharometer is used for measuring CO2, repeat this measurement three times and register the average.. Please contact process management support to discuss any action programs.
Model 2	Reduce the load by 30%. Submit samples for detailed VFA analysis to an external lab. Contact process management support immediately to determine the action program. It is important to monitor the CO2 content of biogas on a daily basis as well as biogas production ratios. The frequency of analysis on own VFA analyses (FOS/TAC equipment) is increased if possible to 2 times per week to capture if the content increases and how fast. If the CO2 content tends to increase further and the VFA, FOS/TAC numbers trends upwards you will need to make preparations for STOP-mode.
Stop	Stop all feeding of material to the digester. Submit samples for detailed VFA analysis! Contact process management support immediately to determine the action program. Follow gas production, CO2 content, pH and VFA content until they have returned to values allowing for Mode 2 operations.
Warning (25% or lower)	The CO2 could have dropped because the VFA's have been consumed rapidly after reducing the loading rate. The process will stabilize and the CO2 will increase to a normal operations range. Check the measuring equipment (recalibrate it)

6.2. Interpretation of measured H2S content in biogas

When measuring the biogas quality with a handheld biogas analyser, it is important to define where the sampling points for different digester tanks are. The location of the biogas sampling points can be different from one installation to another installation. An example of a biogas sampling point can be seen in Figure 1, highlighted in red. The manually operated valve should always be closed to eliminate gas leakages from the biogas sampling point. When sampling biogas, plug the biogas analyser hose into the opening of the valve making sure the hose is deep enough the connection is gas tight. Open the manual valve to start he flow of biogas to the biogas analyser. The analyser will measure the gas and display the biogas quality on its screen. For more information on the sampling and measurement, please refer to the biogas analyser manual.

6.2.1. Waste Transformer has one digester tank

H2S content should be tested two times per week using a handheld biogas analyzer (e,g. Hubei Cubic-Ruiyi). The H2S should be sampled and tested from two sampling points, from raw biogas and cleaned biogas. If there is an inline sensor integrated in the control container, H2S will be measured automatically. The inline H2S sensor measures cleaned biogas.

6.2.2. Waste Transformer has more than one digester tank

In cases where a WT has multiple digester tanks and an inline H2S sensor, it is recommended to measure the H2S with a handheld biogas analyzer as well. Biogas received from multiple digester tanks is collected and measured using one inline H2S sensor but in cases where other health parameters are not in normal ranges, the H2S of each digester tank should be measured.

Table 20. H2S content in raw biogas

H2S in raw biogas [ppm]	Comment
5-10	Ok, normal operations
>10 after first weekly measurement	Warning
>10 after second weekly measurement	Mode 1

Table 21. H2S content in cleaned biogas

H2S in cleaned biogas [ppm]	Comment
Ok, normal operations	Continue normal operations, measuring the H2S twice per week
Warning	Be vigilant, the H2S levels might continue increasing. Continue with normal operations and measure the H2S twice per week as planned
Mode 1	Continue normal operations but contact process management. There could be a need to increase the volumes of Fe dosed to the digester tank.

6.3. Interpretation of gas production

The biogas production should be monitored every day using a gas flow meter integrated in the Waste Transformer. An example of the biogas production can be seen in Figure 4, highlighted in red.

	Total	Today	Yesterday	2 days ago	3 days ago	4 days ago	5 days ago	6 days ago	7 days ago	8 days ago	9 days ago	
FT-001 water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	l
FT-002 biogas	2862.5	4.1	25.9	26.6	9.6	2.2	9.8	22.9	14.1	0.5	0.0	m³
FT-002 biogas (corrected)	2624.0	3.9	23.8	23.6	8.5	2.1	9.0	21.4	13.1	0.5	0.0	nm³
CHP Electric production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
CHP Heat production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
CHP Fuel consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
Electric power in	261.2	4.7	3.8	5.0	2.7	7.0	8.4	10.0	13.2	3.4	0.0	kWh
Electric power out	60.5	0.5	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kWh
Power heat	1942	16	89	0	0	0	1	0	0	0	0	kWh
Volume	797	12	24	32	16	5	25	24	23	2	0	m³

Figure 4. Biogas production on HMI screen

The establishment of biogas production ratios is part of day-to-day supervision. This KPI is hard to use before you have established “normal” m3 biogas/ton food waste for a specific site over a longer period of time at stable conditions for all other KPIs. This is due to variability of specific methane yield in the substrate mix which can vary at least +/-15% from a single site depending on time of year and changes in feedstock recipes.

Table 22. Biogas production KPI in relation to the amount of food waste fed to the digester. Applies to30% DM food waste and with a variable specific methane potential

Biogas production Nm3 biogas/kg food waste		Comment
110 % of normal	Ok!	We quickly consume fatty acids in the digester.

105 % of normal	Ok!	We slowly consume fatty acids in the digester
Normal +/- 5%	Ok	Constant level of fatty acids in the digester.
95 – 85 % of normal	Warning	We slowly accumulate fatty acids in the digester. Work begins to develop action program and launch to increase the production ratio
85 – 80 % of normal	Mode 1	We accumulate fatty acids fast in the digester. The cause of low gas production must be urgently identified in order to quickly implement corrective measures.
80 – 75 % of normal	Mode 2	We accumulate fatty acids very quickly in the digester. Reduction of feed rate is required.
60 % or less of normal	Stop	Stop all feeding of food waste into the digester

Table 23. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 22

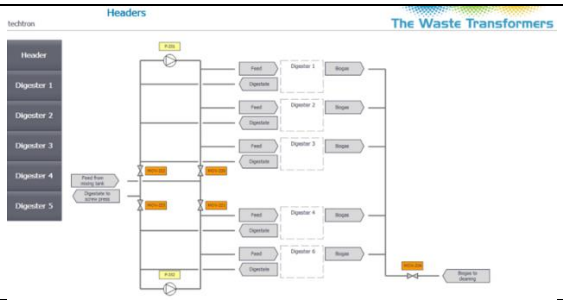
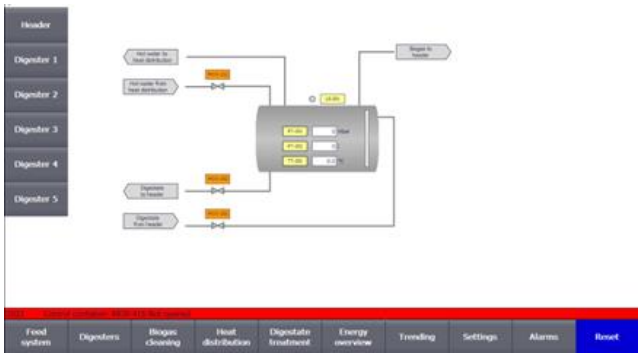
	Possible cause and action
Warning	Important with daily measurement of CO2 and pH. It is important to analyze the fatty acid content of the digestate and the FOS/TAC ratio at least once a week with your own FOS/TAC equipment. If these values increase, we are moving into "Mode 1", see below in table. Please contact process management support to discuss any action programs.
Mode 1	Important with daily measurement of CO2 and pH. The frequency of analysis of VFA/PE on your own FOS/TAC equipment is increased if possible to 2 times per week to capture if VFA is still increasing and if so, how fast. Try to identify the cause as follows: a) Analyze the DM content in the substrate: low DM content in the substrate, i.e. too much water in the substrate mixture. If this might be the case, continue one more day and see if there is any improvement. b) The load has been increased too rapidly, for example from 7 to 14 kg of food waste/m3&d in one day. Reduce the loading rate to 10 kg of food waste/m3&d in this case and see if the biogas production KPI increases. If this KPI then comes within normal range, increase the load again but in smaller increments. If the biogas production ratio does not increase or even continue to decrease, lower the load back down to 7 kg of food waste/m3&d (in this case). c) Microbiological disturbance: If the biogas production KPI decreases without any obvious cause, i.e. if not a) or b) => reduce the loading rate by about 30 %. Submit samples to external laboratory for detailed VFA analysis. Contact process management support immediately to determine the action program. If this does not lead to increased biogas production KPI, reduce the loading rate by an additional 30%.
Mode 2	Immediately reduce the load by about 30%. Submit samples for detailed VFA analysis. Contact process management support immediately to determine the action program.
Stop	Stop any feeding of new substrate into the digester. Contact process management support immediately to determine the action program. Follow gas production, CO2 content, pH and VFA content.

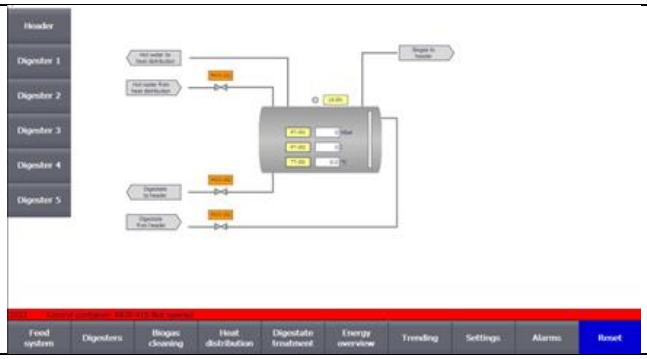
6.4. Sampling sludge/digestate from a Waste Transformer

Correct sample collection is a critical step in monitoring the biogas installation and recording reliable data. When a digestate sample is collected, it is recommended to collect more sample material in case

of sample lose due to spillage and repetition of analysis. It is best to sample and measure the digester health parameters approximately at the same time of the day (e.g. in the morning) to enable a reliable comparison of data. Please refer to the HMI Operations Manual for exact process steps that need to be taken for sampling digestate.

If the WT is being mixed when the sample is to be taken, wait for the mixing to finish. Freshly mixed content of the digester will provide a homogenous sample and most precise readings. Once the mixing has finished, proceed to the following steps:

Manually close the ball valve BV-228 in CC3	
On the HMI screen, press the Digesters tab at the bottom of the screen. Close valve MOV-222 on the Headers using the HMI screen (Manual close)	
On the HMI screen, press on the Digester tank that needs to be sampled (in this case Digester 1). This will open a new tab to the digester tank that should be operated. Close bottom valve MOV-202 on the Digester tab 2 using the HMI screen (Manual close) Close bottom valve MOV-202 on the Digester tab 3 using the HMI screen (Manual close) Close bottom valve MOV-202 on the Digester tab 1 using the HMI screen (Manual close)	
Manually open the ball valve at the sampling point on the pipe of AD1; drain the pipe and dispose of the digestate. Drain the digestate into a bucket or container. Hold the bucket close to the sample point to reduce splashing. Manually close the ball valve at the sampling point on the pipe of AD1 when the full pipe volume has been drained	

Open the bottom valve MOV-202 on the Digester tab 1 using the HMI screen (Manual open); this will fill the pipe with fresh digestate Close the bottom valve MOV-202 on the Digester tank 1 using the HMI screen (Manual open)	
Manually open the ball valve at the sampling point on the pipe of AD1. Take a 400 mL glass beaker and hold it near the sample point opening, slowly open the ball valve and fill 2/3 of this glass beaker. This digestate sample will be used for measuring digester health parameters. Please refer to the manual of the parameter that will be tested.	

If The Waste Transformer has multiple digester tanks, the sampling procedure will be the same for each sampled digester tank. The same sampling procedure should be done for all digestate analysis (FOSTAC, pH, EC, ammonium, dry matter).

6.5. Interpretation of pH

pH value of the sludge should be tested twice per week (during normal operations) using a pH meter (e.g. LAQUAtwin-pH-33).

Table 24. pH value of the sludge

Sludge pH value	
>7.7	Warning 1
7.5-7.7	Ok, normal operations
7.4-7.5	Warning 2
7.3-7.4	Mode 2
7.3 or lower	Stop

Table 25. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 24

	Possible cause and action(s) to take
Warning 1	Moderately high pH. It might be time to recalibrate the pH meter or refill the internal sensor liquid.
Warning 2	Moderately low value. Measure the CO2 content of biogas daily and check the biogas production KPI. Check the development of VFA as well as the VFA/PA ratio with your own FOS/TAC analysis equipment. It is important that these VFA analyses are carried out at least once a week.
Mode 2	Very low values. Contact process management support immediately to determine the action program

Stop	Critically low values. Stop all substrate input to the digester - the process is about to crash

6.6. Interpretation of VFA and VFA/TAC ratio

VFA and VFA/TAC ratio should be tested once every two weeks (during normal operations) using a FOSTAC measuring equipment (e.g. Pronova FOSTAC 2000).

Table 26. VFA value and VFA/TAC ratio

VFA content [g/L]	Comment
< 3	Ok, normal operations
3-4	Warning
4-6	Mode 1
6-8	Mode 2
> 8	Stop

Table 27. VFA/TAC ratio

VFA/TAC ratio	Comment
< 0.3	Ok, normal value
0.3-0.4	Warning
0.4-0.5	Mode 1
0.5-0.85	Mode 2
> 0.85	Stop

Table 28. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 26 and Table 27.

	Possible cause and action(s) to take
Ok, normal values	Continue normal operations
Warning	Important with daily measurement of the CO2 content in the biogas and biogas production KPI. Increase the frequency of measurements to one time per week.
Mode 1	The frequency of analysis using our own FOS/TAC equipment is increased to two times per week to capture if the VFA-levels increases and if so, how fast. It is important to monitor the CO2 content of biogas on a daily basis as well as biogas production KPI. Please contact process management support to discuss any action program.
Mode 2	Reduce the loading rate by 30%. Submit samples for detailed VFA analysis at external lab. Contact process management support immediately to determine the action program. It is important to monitor the CO2 content of biogas on a daily basis as well as biogas production KPI. The frequency of VFA analysis using your own FOS/TAC equipment should be two times per week to capture if the VFA content increases and if so, how fast.
Stop	Stop all feeding of substrate to the digester. Submit samples for detailed VFA analysis. Contact process management support immediately to determine the action program. Follow gas production, CO2 content, pH and VFA content.

General advice on the meaning of rate-of-change for the VFA KPI

- An increase of VFA content by ≥1.5 units per week is an alarming signal if the total content is above 3 g/l. Submit samples for detailed VFA analysis! Contact process management support immediately to determine the action program.
- A reduction of VFA content by ≥1 unit per week is a positive signal that a reduction in substrate loading rate is having the intended effect.

6.7. Interpretation of ammonium concentration

If the dilution of the substrate is done using the thin fraction of the digestate, it is mandatory to have ammonia measuring equipment. Because the thin digestate fraction is recirculated, a certain amount of ammonium is reintroduced into the fermentation tank with a potential of accumulation. The ammonium concentration should be analysed once every HRT cycle has been finalized (during normal operations), using an Merck Nova60A Spectroquant.

Table 29. Ammonium concentration of the sludge

Ammonium concentration [g/L]	
2.0-3.0	Ok, normal operations
3.0-3.5	Warning,
3.5-4.0	Mode 1, be alert
4.0-4.5	Mode 2, carefully start to evaluate the CO2, gas production, FOS/TAC and pH and look for trends (increasing CO2, reduction of biogas production in relation to the feed and increased FOS/TAC and decreased pH)
4.5	Mode 3, ammonia levels need to stabilize

Table 30. Description of action programs associated with Mode 1 and Mode 2, Warning, and Mode 3 in Table 29.

	Possible cause and action(s) to take
Ok, normal operations	Continue with normal operations
Warning	Increase the FOS/TAC analysis to 2 times per week but continue normal operations
Mode 1	Increase the FOS/TAC analysis to 2 times per week
Mode 2	Increase the CO2, biogas production and pH measurements to every day. If the CO2 is increasing and biogas is decreasing, reduce the load by 30%. If none of these changes happen, continue normal operations, the system is getting used to the high ammonia loading.
Mode 3	Add water for dilution of the substrate but continue normal operations as long as CO2, biogas production, FOS/TAC and pH values are all in normal ranges. Continue operating in this mode for 2 months until the ammonia concentration stabilizes. Contact process management support for this.

6.8. Interpretation of dry matter content in the sludge

The dry matter content in the sludge should be measured once per month using a dry matter or moisture analyser (e.g. VPB-10 Moisture analyser). It is important to note that if a moisture analyser is used such as the VPB-10 Moisture analyser, the dry matter content shall be calculated as:

$$100\% - \mathrm{X} = \text{dry matter content}$$

where X = the measured moisture content, presented on the screen of the VPB-10 Moisture analyser.

Whatever source of inoculum or substrate is used, the sludge dry matter content should not increase more than 1% per month. A slow and steady dry matter increase is to be expected because digestate is used for substrate dilution. If an increase of more than 1% per month occurs, contact process management but continue with normal operations. This parameter is important with monthly measurements of ammonium content and dry matter content in food waste.

6.9. Interpretation of dry matter content in the food waste

The dry matter content in the food waste should be measured once per month using a dry matter or moisture analyser (e.g. VPB-10 Moisture analyser). It is important to note that if a moisture analyser is used such as the VPB-10 Moisture analyser, the dry matter content shall be calculated as:

$$100\% - \mathrm{X} = \text{dry matter content}$$

where X = the measured moisture content, presented on the screen of the VPB-10 Moisture analyser.

Table 31. Dry matter content of sludge

Dry matter content of sludge	
14%	Ok, normal operations
±2%	Warning
±3%	Mode 2
±4%	Stop

Table 32. Description of action programs associated with Mode 1 and Mode 2, Warning, and Mode 3 in Table 31

	Possible cause and action(s) to take
Ok, normal operations	Continue with normal operations
Warning	The dry matter content in the substrate is lower or higher than it should be meaning the substrate is over diluted or under diluted. Important with monthly dry matter content and ammonium measurements. Continue normal operations.
Mode 2	The dry matter content in the substrate is too low or too high. The dilution ratio needs to be adjusted. Important with monthly dry matter content and ammonium measurements. Continue normal operations but contact process management. Fe and trace metal additions might need adjustment.
Stop	The dry matter content in the substrate is severely low or high. The dilution ratio needs immediate adjustment, contact process management. Stop all substrate input until the dilution ratio is adjusted. Continue monitoring the dry matter and ammonium content in the sludge.

6.10. Interpretation of temperature fluctuations for a mesophilic process

The target temperature of the Waste Transformer should be set to 37 degrees Celsius. Depending on the location of the Waste Transformer and the average temperature, the temperature can be slightly adjusted but please contact The Waste Transformers to determine the optimum temperature.

The temperature of the digester tank should be monitored daily and any drastic changes should be registered. For values that are not in the normal operations range, action should be taken and

potential negative impact on the stability of the process should be expected. Any fast changes of temperatures should be recorded.

Table 33. Digester tank temperature fluctuations

Digester temperature fluctuations in a day	
± 1 degree	Ok, normal operations
± 1.5 degress	Warning
± 2 degrees	Mode 1
± 3	Mode 2
Under 30	Mode 3
Above 40	Stop

Table 34. Description of action programs associated with Mode 1 and Mode 2, Warning, and Stop in Table 33.

	Possible cause and action(s) to take
Warning	Continue normal operations. Important with daily measurement of the CO2 content in the biogas and biogas production. Be vigilant that the temperature can continue to increase or decrease to Mode 1.
Mode 1	Continue with normal operations but contact process management. Important with daily CO2 and biogas yield measurements.
Mode 2	Reduce the load by 30%. Important with daily CO2 and biogas yield measurements. Contact process management and try to heat or cool down the digester tank, depending on the temperature with a maximum of 1 degree Celsius change/day.
Mode 3	Digester is severely cooled, slowing down the degradation process and biogas production. Stop all substrate input and contact process management. Important with daily CO2 and biogas yield measurements. Contact process management
Stop	Digester is overheating; bacteria might be dying. Stop all substrate input and contact process management.

6.11. Frequency of process parameters measurements during the stabilization period

Table 35. Frequency of process parameter measurements during stabilization phase

Mode	KPI									
	CO2	H2S	Gas production	pH	VFA	VFA/PA	Ammonium concentration	DM content in the sludge	DM content in the substrate	Temperature fluctuations
Normal	5x/week	2x/week	5x/week[1]	2x/week	1x/2 weeks	1x/2 weeks	1x/month	1x/month	1x/month	5x/week
Warning	5x/week	2x/week	5x/week[1]	3x/week	1x/week	1x/week	1x/month	1x/month	1x/month	5x/week
Mode 1	5x/week	2x/week	5x/week[1]	5x/week	2x/week	2x/week	1x/month	1x/month	1x/month	5x/week
Mode 2	5x/week	2x/week	5x/week[1]	5x/week	2x/week[2]	2x/week[2]	1x/month	1x/month	1x/month	5x/week
Stop	5x/week	2x/week	5x/week[1]	5x/week	2x/week[2]	2x/week[2]	1x/month	1x/month	1x/month	5x/week

Macro and micro element laboratory analysis

Once the WT ends the second month of operations, a laboratory analysis of the following parameters should be done. Based on the results of the analysis, adjustments to the operating parameters, feeding strategy and feedstock composition can be made. A sample of the digestate should be taken from the WT and a laboratory analysis can be done locally or the sample can be shipped to The Waste Transformers. Please consult The Waste Transformers when a sample will be analysed.

1) pH	2) EC (conductivity)	3) Cl
4) NH4-N	5) TKN Ttotal Kjeldahl Nitrogen)	6) Ca
7) Norg (Organic Nitrogen)	8) Na	9) S
10) P	11) K	12) VS (Volatile Solids)
13) Mg	14) Fe	15) Al
16) TS (Total Solids)	17) Co	18) Cd
19) VSS (Volatile Suspended Solids)	20) Cr	21) Mn
22) B	23) Ni	24) Se
25) Cu	26) As	27) Hg
28) Mo		
29) Zn		
30) Pb		

Based on the results of the macro and micro element analysis, further recommendations on process control and operations can be provided. Changes in the operation parameters or trace metals and/or iron dosing can be done but please contact process management to determine the actions.

7. Summary and conclusion

This guideline decribes the starting up and operating process of a small scale biogas process unit.

Before running the unit it is important to monitor certain parameters that will provide insight in the health of the biological system which will enable optimization or maximization of the biogas outputs.

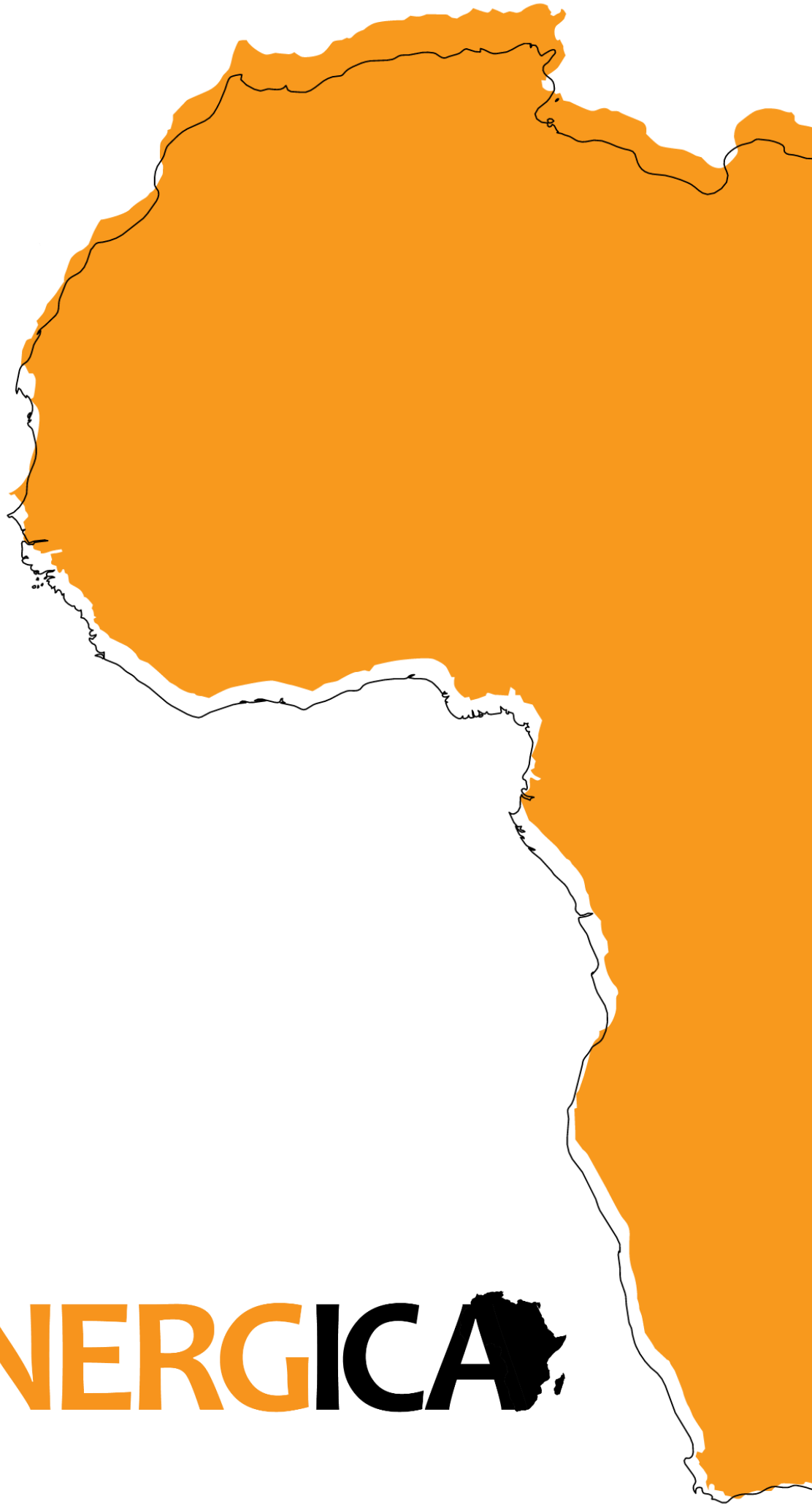
The specific health process parameters that need to be measured may change based on the input substrate, dilution liquid that will be used, operational constrains and other requirements. The selected parameters need to be monitored with a frequency defined in this document.

The feeding of the system with suitable inoculum as well as the necessary analyses and sampling steps for sensible commissioning were developed.

Furthermore running the system in a stable phase, driving styles and process monitoring for continuous operation are described.

This operating instructions should serve as a handout for the system's operating team.

1. ANNEXES



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