Grassification

D1.3.2

Demonstration of bulk anaerobic digestion of grass clippings at relevant scale (TRL 6)

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The GRASSIFICATION project

Roadside grass clippings are a problem fraction throughout the 2 Seas Programme area due to their high volume, subject to high processing costs. The industrial sector, however, is interested in the possibility of using roadside grass clippings as an alternative resource (as opposed to fossil sources or dedicated agricultural produce, e.g. isolation material). The common challenges for applying roadside grass clippings as a renewable feedstock in industrial processes are currently threefold:

• the supply chains are not yet optimal, resulting in higher costs;

• a highly variable and heterogeneous quantity;

• an unsupportive institutional framework leading to legal and political challenges.

The overall objective of the Grassification project is to apply a multi-dimensional approach to roadside grass clippings refining in order to optimize it into a viable value chain for the biobased and circular economy. The project commits itself to optimize logistics and technical aspects of the grass clippings supply chain and processing, demonstrate its market potential as well as formulate policy and legal recommendations to create a more supportive framework for the recycling of this renewable resource. These actions will increase the volume of usable material, lower costs, and generate a higher added-value for this so-called 'waste' streams. In this way, the use of roadside grass clippings as a renewable resource for the production of biobased products and hence the circular economy will become more attractive.

Context of the document

This deliverable D1.3.2 "Demonstration of bulk scale anaerobic digestion of grass clippings at relevant scale (TRL 6)" is an output of Activity 1.3 "Adopting methane production and harvesting technology from landfills for bulk (low quality) grass processing". It describes the lay-out, operation and experiences of a pilot batch anaerobic digestion cell located on the landfill site of Vanheede in Roeselare.

Roadside clippings have an important potential as a renewable energy source. So far, only part of this grass is currently removed and processed while by far the greatest part of the clippings are processed in green composting facilities, not exploiting their biogas potential. Roadside clippings are produced discontinuously, i.e. twice a year during the mowing campaigns, and in considerable amounts. However, digestion systems need a year-round stable input composition, so the clippings should be stored and added gradually to the digester. This requires considerable capacity and a good quality of storage to maintain the biogas potential of the clippings. Also, the contamination (litter, sand) of the grass clippings often requires pretreatment and makes them unsuitable for wet anaerobic digestion (AD) systems.

The batch AD cell at Vanheede tries to solve these challenges. It is designed to accept large quantities at a time without any need for intermediate storage. The system is less sensitive to

contamination, thus it can be a solution to valorize low quality grass that would not be suitable for processing into higher value products. The landfill facilities and the experience of landfill gas recuperation at Vanheede can be used for the project, while a currently unexploited landfill cell is made useful.

For the Grassification project, a batch anaerobic digestion cell with a 1750 m^3 capacity was constructed in the Vanheede landfill site in Roeselare. The cell was built with HDPE liner and included a drainage system, a leachate recirculation system and gas extraction piping. Three different grass clipping batches were fed to the system, each corresponding to a different mowing campaign: June 2019, October 2019 and June 2020.

The first batch suffered from a strong acidification, due to the high ambient temperatures during start-up, the low inoculum:biomass ratio, and the lack of buffering capacity of the system (monodigestion). By stopping the recirculation of the acid leachate, the system regained its balance with stable pH-values and biogas production.

As the first batch still had considerable biogas potential when batch 2 arrived, this second batch was added on top of batch 1. The addition of fresh biomass did not cause any disruption of the system, as evidenced by a stable pH and a more or less continuous biogas production. Maintenance issues, related to the pumping of the leachate, the extraction of the biogas and leakages in the system, caused temporary interruptions. By June 2020, the asymptotic course of the biogas production curve indicated that the digestion was coming to an end. The third batch is still underway and its follow-up and results will be added to this report in 2021.

1. System design

The system design and preparation is documented in D1.3.1 (version 2020). The cell was built on the landfill site of Vanheede in Rumbeke, separated from the ongoing landfill activities but on top of a closed landfill cel, which also insulates the digestion cell at the bottom. The project benefits from the available facilities (weigh bridge, CHP, …) and the experience of the staff. The digester cell covers a surface of 626 m^2 and is over 5 m deep. The total volume amounts to 1750 m^3. HDPE film is used as liner and top cover to create a closed reactor.

On the bottom, a drainage system is embedded in a sand layer of 50 cm thickness and protected by a layer of woodchips (Figure 1). The drainage system is connected to a central pump shaft. The collected leachate is pumped back to the top of the digester bed by means of a permeable piping system. As the digestion cell is a batch system, recirculating the leachate is the main option to homogenize the digestion process.

Figure 1. Photo of the sand bed and the drainage tubes

2. Process Control

2.1.1. Organic loading rate

The organic load was monitored by:

- Weighing the incoming cargos of grass clippings and inoculum on the weighing bridge of Vanheede;
- Determining the dry mass and the organic dry mass (VS) of the clippings, either in the control lab at Vanheede, or in the labs of Inagro or Innolab.

2.1.2. Temperature

The temperature was measured continuously by:

- Three probes:
    - TT002: located at the surface of batch 1, approximately at a depth of 80 cm below the biomass surface, not covered by batch 2 material;
    - TT003: located in the core of the biomass, in between batch 1 and 2
    - TT006: installed during batch 2 start-up, located at the surface of batch 2, approximately at a depth of 80 cm below the biomass surface.
- The inline measurement of the leachate temperature:
    - TT001: at the leachate pump in the cell;
    - TT005: input of the boiler – installed during batch 2 start-up;
    - TT004: output of the boiler – return to digester cell.

The temperature is controlled by a 21 kW heating system consisting of a 500-L boiler. It was added to the system from October onwards (batch 2) and allows to heat the leachate in order to maintain mesophilic conditions during periods of cold weather.

An additional temperature management measure consisted of putting insulation panels on top of the biomass to avoid heat losses to the environment. With an IR camera, the heat losses at the surface can be assessed (see D1.3.1).

2.1.3. Leachate

Given the batch set-up of the system, the recirculation of the leachate is the principal way to homogenize the digestion process. The recirculation also has a temperature control function and provides a picture of what is happening within the cell as, at regular intervals, leachate samples are analysed both on-site (pH, FOS/TAC) and by a certified lab (fatty acids), which allows the follow-up of the digestion process.

2.1.4. Gas production

The gas flow is monitored continuously by an ultrasonic gas flow meter (FT001).

The composition of the gas is monitored:

- continuously by FT001: an ultrasonic gas flow meter, equipped with a calculation tool to estimate the CH_4 content in a complex mixture of CH_4 and CO_2. Unfortunately, this proved not to be reliable in a complex mixture with the presence of N_2 and O_2;
- manually on regular intervals with a device that is calibrated once a year. These gas samples are sent to a certified lab;
- from February 2020 onwards, an automatic sampling and calibration device is active, which is linked to the portable biogas analyser, resulting in a discontinuous measurement of CH_4, CO_2, H_2S and O_2.

The extracted gas is added to the existing landfill biogas grid. The gas flow to the landfill grid is controlled by establishing a pressure difference between cell and grid.

3. Batch 1

3.1. Batch composition

The AD cell was filled in the week of 17-21 June 2019 (Figure 2). The grass clippings were all freshly mown and coming from the surrounding area of Roeselare. The clippings were inoculated with digestate from a mesophilic anaerobic digestion plant, which was only half-digested. Given the depth of the cell and the instability of the material, the only option to mix was to alternate the layers of grass and digestate during the filling. Wood chips were added in between the grass layers in order to improve the structure of the system. On Friday 21th of June, the grass drainage system was installed (Figure 3) and the cell was sealed. On July 15th, a small amount of filtered digestate was added to improve the process.

Figure 2. Grass clippings during filling

Figure 3. Gas drainage system

Five grass samples were sent to an external lab for analysis. The grass clippings had a dry matter (DM) of 32.7 ± 6.9%, an organic matter content (on fresh basis) of 24.6 ±2.6% and, therefore, an organic matter content on dry basis of 73.6 ± 13.2%. The standard deviation value shows that there is some variation, both in dry matter content, due to differences in humidity of the samples, and in organic matter content, due to contamination with soil particles. Both these values and the variation are in line with values for Flemish roadside clippings in literature (S. De Moor, 2013). Moreover, the organic matter (DW) content of the samples (varying between 65.4 and 89.0%) is in line with values of 67.0% and 68.9% found in (Aaron E. Brown, July 2020) and the values 74.5% and 87.8 from (S. De Moor, 2013). The high organic matter content of some of the samples (89.0, 82.4 and 84.2%, respectively) indicate a low(er) contamination with soil particles.

Table 1 gives an overview of the amounts of grass and inoculate. During the set-up of the system, a grass:inoculum proportion of 2:1 (fresh weight) was proposed to avoid acidification due to the high organic loading. However, for economic reasons and because of the odour nuisance from the inoculum, the grass:inoculum ratio was 3:1 (fresh weight), as can be deduced from the data in Table 1. This corresponds to a 8:1 ratio on DM, which is higher than the ones usually used for solid state AD, from 0.2:1 to 2:1 (DM) (Fuqing Xu, 2016).

Taking into account the fresh and dry matter of the input materials (grass and inoculum), the solids contents of the system can be estimated, giving a solids content of 28%. According to the classification of Vandevivere et al (P. Vandevivere, 2003), digesters in which the feedstock used consists of 20–40% dry matter are known as dry anaerobic digesters.

Table 1. Mass balance batch 1

Date	Material	Amount (ton)	
		Fresh	Dry
17-21 June	Grass clippings	270.16	88.34
17-21 June	Digestate from mesophilic AD	90.96	11.47
15 July	Filtered digestate from thermophilic AD	0.06	0.00
	Substrate : inoculum	**3:1**	**8:1**

3.2. Digestion process

The follow-up of the digestion process was done by monitoring: 1° leachate composition and pH, 2° biogas composition and production.

3.2.1. Leachate composition

The batch was inoculated with digestate from an anaerobic digester with a pH value of 8.3. The digestion process was monitored on site by regular (3 x/week) measurements of pH and FOS/TAC. After 2 weeks, a considerable drop of the pH values was observed, which corresponds to the generation of acids and is a common trend in the anaerobic digestion start-up phase (Figure 4). However, the pH drop to 5.7-5.8 is considerable and can lead to inhibition of the methanogenic bacteria. Methane formation takes place within a relatively narrow pH interval, from about 6.5 to 8.5 with an optimum interval between 7.0 and 8.0, and the process is severely inhibited if the pH decreases below 6.0 or rises above 8.5 (Weiland, 2010). The magnitude of the pH drop can be explained by two factors: (i) the use of a single substrate, i.e., mono-digestion, and (ii) the high substrate:inoculum ratio, mentioned in 3.1. Both factors lower the buffer capacity of the system.

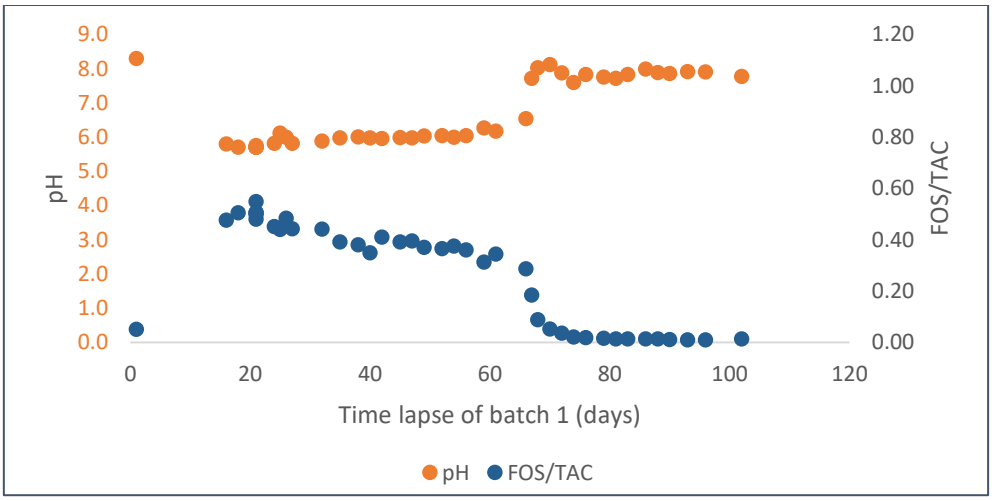

Figure 4. Leachate composition during batch 1

The FOS/TAC analysis showed very high values, of 3.32-4.12, with FOS values in the range of 15-23 g/kg CH_3COOH. This high acidity was confirmed by the analysis of a leachate sample on 16th of July by an independent lab (Table 2). Mid-July, i.e. after 20 days of inoculation, the recirculation of leachate was stopped since this was suspected to increase the acidification of the batch. Thanks to this action, the fatty acids, as indicated by the FOS/TAC value, showed a gradual decrease in the period 25-55 days with a steep decrease after 55-65 days. This is confirmed by the leachate analysis of 30/08/2019 (**Error! Reference source not found.**2).

Overall, the pH followed a similar pattern, i.e. increasing with the decrease of the acids, to a stable value of 7.8-8 after 60 days. During the transition period (25-55 days), the gradual decrease in fatty acids was not yet reflected in the pH value, probably due to the buffer capacity of the leachate (Figure 4).

Table 2. Analysis of the leachate

Acid (mg/kg)	16/07/2019	30/08/2019
acetic acid	6 270	2 041
propanoic acid	2 459	1 171
isobutyric acid	353	47
butyric acid	2 693	9
isovaleric acid	687	114
valeric acid	1 385	<12
caproic acid	2 057	<24

3.2.2. Biogas production

3.2.2.1. Biogas potential

For batch 1, only a theoretical biogas potential, i.e. based on the composition of the grass sample, was calculated. The potential was determined to be 107 ± 6 Nm^3/t with 54% CH_4 content. This is in line with the biogas potential (82.1 and 115.9 Nm^3/t) of 2 roadside samples in (S. De Moor, 2013).

The biogas potential of the inoculum was not determined at the start-up phase of the digestion cell; a sample of the inoculum from the same digester was, nevertheless, analysed in April 2020. The lab fermentation test gave a result of 10.2 Nm^3/ton and a CH_4 content of 63.8%, which is quite high and can be explained by the low OLR during the test. It is suggested that a CH_4 content between 58 and 63% would correspond more to reality. We therefore assumed a CH_4 content of 60.5% for the inoculum. When receiving the inoculum, Vanheede noted that it still had considerable digestion potential. The determined potential of 10.2 Nm^3/ton therefore seems an underestimation of the actual biogas potential of the inoculum.

Using the mass balance of Table 1, a total theoretical biogas potential of 29 835 Nm^3 was calculated, of which 16 200 Nm^3 would be of methane. This is a rough estimate, since this

potential is based on only one theoretical analysis of the grass clippings and a inaccurate estimation for the inoculum.

3.2.2.2. Biogas production

The initial biogas production was very limited, as can be seen from **Error! Reference source not found.**5. After 2 months, only ± 5 000 m^3 was generated. This low production can be explained by several factors:

- The high acidification, as explained in 3.2.1;
- The high H_2 percentage in the gas (as H_2 is a reaction product of the hydrolysis reaction of the fatty acids, high H_2 values could inhibit methanogenesis);
- The lack of pressure build-up in the digestion cell. The produced gas is probably "captured" in the digestate "matrix". So a negative pressure is required to extract the biogas. Both in July and August, the biogas extraction was out of order for a long period due to technical problems.

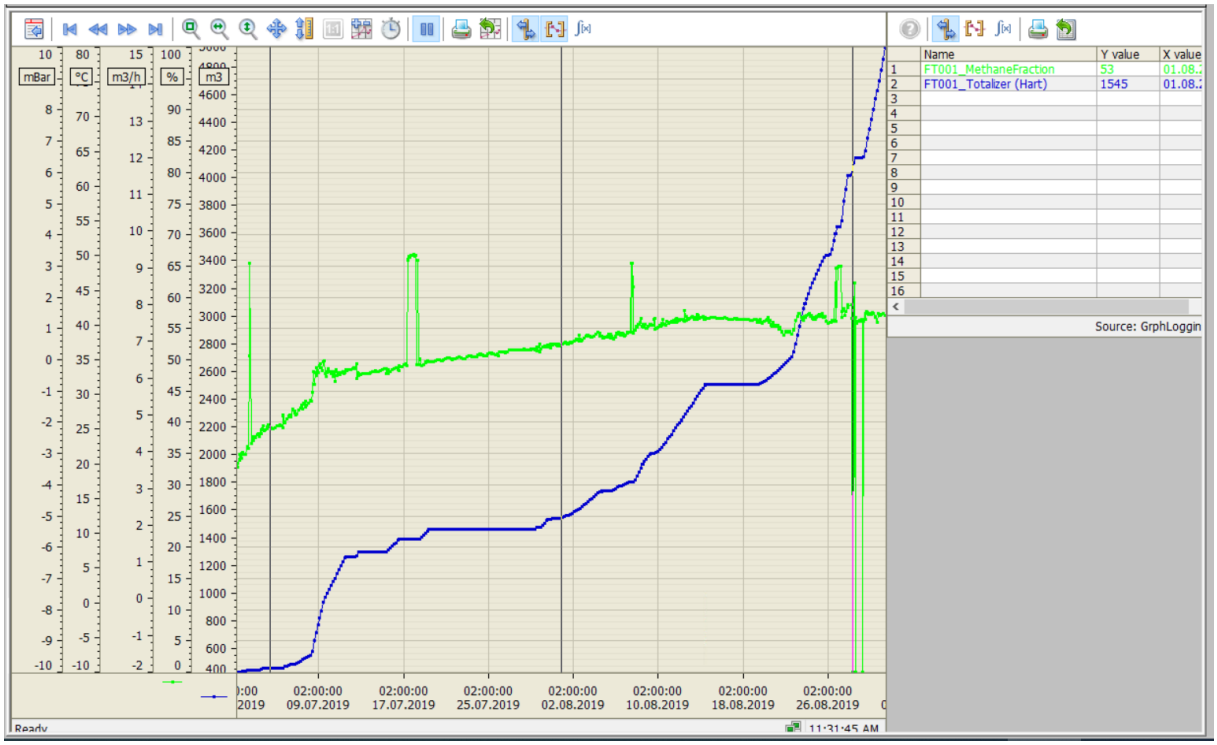

Figure 5. Cumulative amount of biogas extracted from day 1-60 (blue line)

Once the digestion conditions (acidification) normalized and the negative pressure increased (-3 mbar, see purple line in Figure 6), the biogas capture increased substantially. On 6th of October, i.e. before opening the cell for batch 2 start-up, ± 24 000 Nm^3 biogas had been produced, which corresponds to 74 % of the theoretical estimated biogas potential.

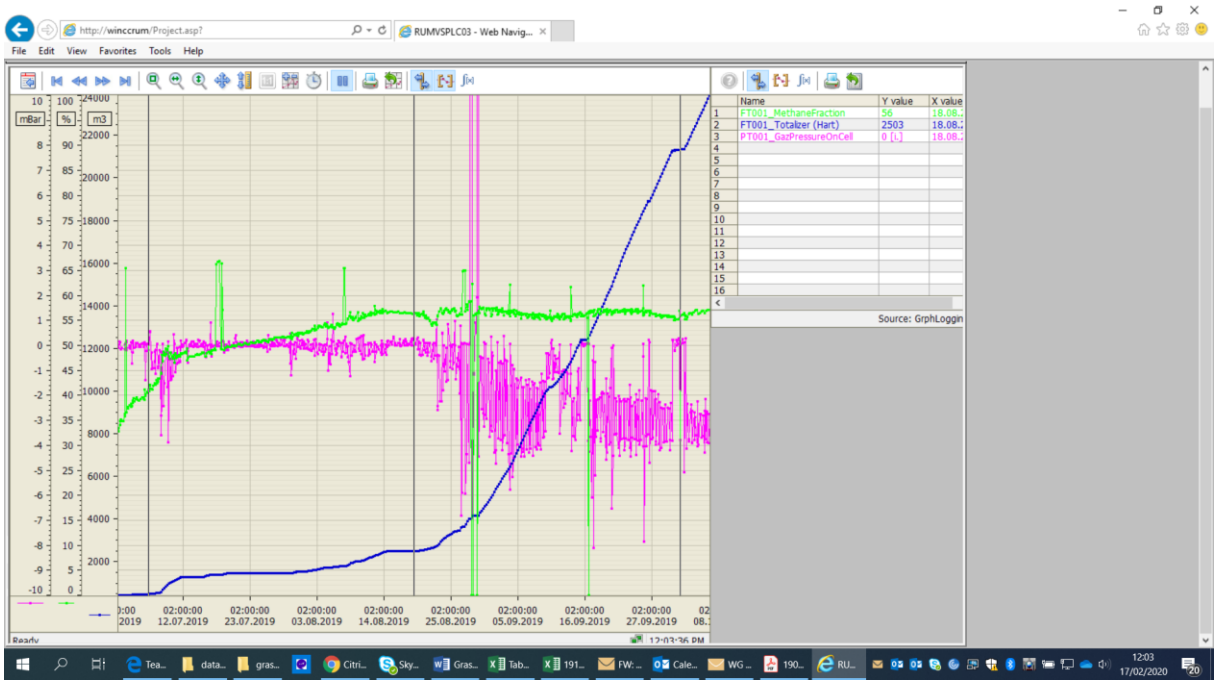

Figure 6. Cumulative amount of biogas extracted day 1-90 (blue line)

3.2.2.3. Biogas composition

As the online monitoring turned out to show systematic deviations, an external laboratory was used for biogas analyses (Table 3). As the July samples were taken while the system was not stable (due to acidification), these measurements are not fully representative. The deviant value on 20 September is caused by a leakage in the system, as the O_2 and N_2 values indicate the entry of air. If we recalculate the CH_4 and CO_2 values of these samples by excluding the air, a CH_4 concentration of 54% is found, in line with the concentration of 56.5 % measured on 30/08/2019. Based on these two samples, the average methane content of the biogas produced was 55%.

Table 3. Biogas composition at an external laboratory (Innolab)

Date	CH_4 (%)	CO_2 (%)	O_2 (%)	N_2 (%)	H_2 (%)	H_2S (ppm)
16/07/2019	49.6	50.4	<0.05	<0.05		179
18/07/2019	67.7	31.3	0.5	0.4	>2	710
30/08/2019	56.5	41.0	0.9	1.6	>2	337
20/09/2019	38.1	31.4	4.7	25.8	>2	222
20/09/2019 (corrected)	54.0	44.5	0.2	0.8		

3.2.3. Temperature

During batch 1, both TT002 and TT003 were located just below the surface of the biomass and show a similar, slightly downward trend, corresponding to the decreasing outside temperatures from August onwards (Figure 7). The shaft water temperature, measured at the core of the cell

(and thus surrounded and buffered by the biomass), is constant due to the exothermic digestion process.

The temperature of the return water pipe corresponds to the outside temperature: the peak at the end of August clearly corresponds to peak in the temperatures during that period (Figure 8). The temperature drop of all probes from the 6th of October onwards corresponds to the opening of the cell for the start of batch 2.

Overall, since all three probes in the cell indicate temperatures in the range of 30-40 °C, it is possible to say that the digestion occurred under mesophilic conditions.

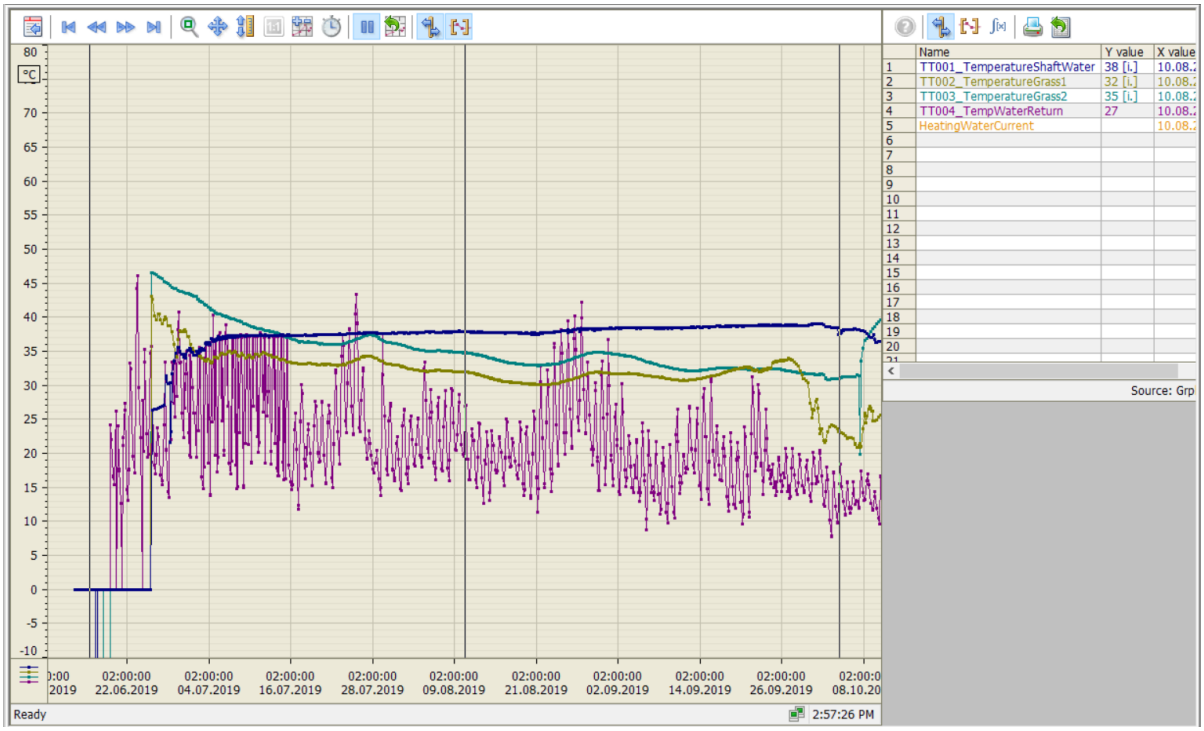

Figure 7. Temperature during batch 1

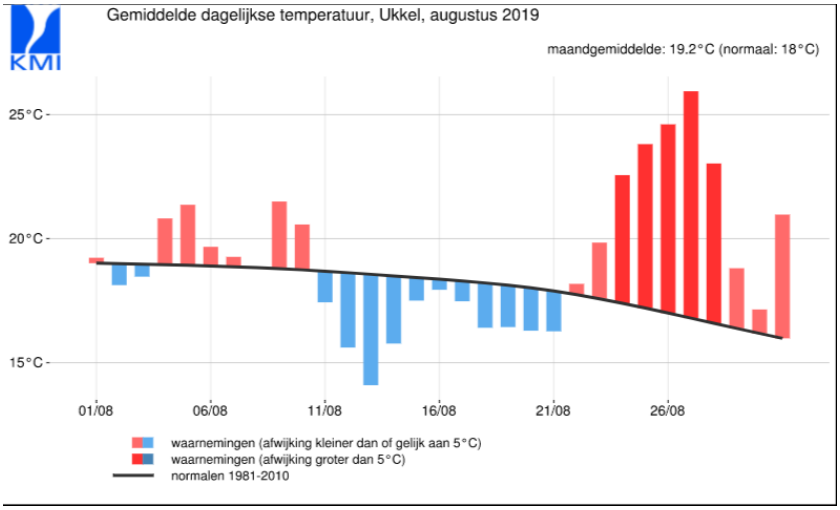

Figure 8. KMI temperature curve August 2019 (source: www.meteo.be, 2019)

3.3. Opening of batch 1

3.3.1. Digested clippings

The opening of the batch offered the opportunity to analyse samples of the digested clippings (Figure 9). Upon opening of the batch, several samples were taken and the residual biogas potential was assessed. A theoretical biogas potential was calculated, based on the composition of the samples; since this is based on a chemical analysis, the test results are quickly available and give a first idea of the biogas potential. For the digestion lab test, the substrate of the sample was inoculated with mesophilic anaerobic sludge with an organic load of 4.0-4.5 g DM/L. All four samples were taken from the top layer of the batch. For stability reasons, it was impossible to sample the core of the cell.

The results summarized in **Error! Reference source not found.**4 show:

- The biogas potential is only slightly lower than the biogas potential of the initial sample, indicating that these samples still have a substantial digestion potential;
- The theoretical biogas potential is systematically higher than the potential measured by a lab digestion test that rather approaches the "real" conditions;
- The percentage of CH_4 is higher than what is measured in the gas samples from the digestion cell, probably because lab conditions are more controlled;
- The pH of the samples is very low and does not correspond with the overall pH measured in the batch (see 3.2.1) nor with the leachate sample (see table 5).

Table 4. Biogas potential of digested grass samples after batch 1

Location of the grass sample	**DM**	**ODM**	**Raw Fat**	**Raw protein**	**Carbohy drates**	**Theoretical biogas potential[1]**		**pH**	**Biogas potential lab[2]**	
	%	**%DM**	**(kg/t)**			**Volume (Nm^3/t)**	**CH_4%**		**Volume (Nm^3/t)**	**CH_4%**
upper layer, side part	28.2	67.74	5.93	21.8	93	93	55	5.3	86.8	66.0
upper layer, middle part	29.5	64.36	5.84	20.9	97	97	54	4.6	78.2	66.1
80 cm depth	25.1	79.81	5.58	19.6	96	96	54	5.2	90.9	67.6
mixed sample	29.5	62.75	5.35	19.0	101	95	54	5.1	64.0	65.5

Although the samples are located close to the top layer, thus close to the leachate recycling tubes, these zones do not seem to be reached by the leachate. The leachate probably flows through low hydraulic resistance channels, thus failing to reach part of the digestion material, especially in the upper, unsaturated zone. The recirculation of the leachate, as a mean to homogenize the digestion process, is thus not fully successful. Both the low pH and the high residual biogas potential indicate that these samples were rather subjected to an ensiling

[1] Theoretical biogas potential, calculated on the composition
[2] Biogas potential lab: lab fermentation test

process. Unfortunately, it was not technically feasible to take samples from the deeper, saturated zone of the cell. Those samples are expected to be digested to a certain extent, and are expected to have a lower residual biogas potential.

Figure 9. Image of the digested grass

3.3.2. Leachate

The analysis of the leachate served to get an idea of its potential use as fertilizer. Table 5 gives an overview of the most relevant parameters. The concentrations of heavy metals and organic pollutants are low and do not pose a problem. The liquid contains some K, but the N-content is low and the Cl-content seems too high for irrigation.

Table 5. Analysis of leachate from batch 1

DM (%)	1.37
pH	7.51
Cl^- (mg/l)	2 810
HCO_3^- (mg/l)	10 900
NO_3^- (mg/l)	0.84
NO_2^- (mg/l)	-
SO_4^{2-}(mg/l)	15.2
NH_4-N (mg/l)	1 350
K (mg/l)	3 640
Na (mg/l)	695
BOD (mg O_2/l)	870
COD (mg O_2/l)	4 940

The leachate was also tested on its methanogenic potential. Leachate samples were incubated at 38 °C and sodium acetate and ethanol were added in a 50:50 ratio. Different organic loads were tested and the biogas production was monitored during 10 days. Although the different loading rates show different patterns in biogas production, they all show a methanogenic activity of 0.01 g COD/g OM.d, which is extremely low compared to a normal 0.14 g COD/g OM.d activity rate of an anaerobic sludge. During the test, the pH remained stable at about 8,

so this discards the hypothesis that the low activity was caused by acidification. This result indicates that the wood chips and sand bed base layer in the cell functions as a filter, so that the sampled leachate hardly contains any microorganisms.

3.3.3. Conclusions and lessons learnt

The experience of batch 1 led to the following conclusions:

- The complete start-up of a (pilot)plant for anaerobic batch digestion is challenging: it is difficult to mix the material and the addition of the inoculum causes considerable odour nuisance so the cell has to be quickly sealed. The fact that the plant was started mid-June was particularly challenging since the high outdoor temperatures increased the speed of the fermentation process and thus the acidification of the system.
- The process conditions are difficult to steer and even to follow up. There seems to be a gradient in the digestion process, with low digestion in the upper layers and advanced digestion in the lower, saturated zones. The leachate recirculation seems to homogenise the system only to a certain extent since the water probably follows certain preferential channels and the methanogenic microbes are not recirculated. The best way to homogenise the cell would be by adding more liquid in order to have the cell fully saturated. However, this means more leachate to dispose of once the digestion ends and thus extra logistics, handling and costs.
- Although the follow-up of a batch digestion process with a relatively high solids content and high volume will always be challenging, but the lack of biogas potential assessment of the initial samples made it even more difficult to evaluate the digestion process. Therefore, it was decided to start a lab scale digestion test with grass samples for batch 2.
- The high biomass load led to a strong acidification of the leachate, with recirculation enhancing this acidification. Stopping the recirculation stabilised the system. Since the leachate of the first batch was now stable, it was decided to re-use it as inoculum for the second batch. Moreover, as the first batch still showed considerable residual biogas potential, it was decided to add batch 2 on top of batch 1 and recirculate the leachate through both batches.
- In order to be able to maintain the mesophilic conditions during autumn and winter, insulation panels were laid on top of the biomass (Figure 10) and a heating boiler was added to the leachate recirculation circuit.
- The layout of the cell requires quite some maintenance. As the grass ferments, the mass settles. The pulling forces caused by this settling can lead to unleashing of the seams and the formation of puddles on the surface. Reparation and maintenance of the cell is not easy, since the HDPE surface is very slippery.
- The high risk of leakages has led to the installation of an automatic sampling and calibration device in order to periodically monitor the biogas quality. This monitoring enables an early detection of eventual leakages.

Figure 10. Insulation panels on top of batch 2 – view before closing the HDPE sealing

4. Batch 2

4.1. Batch 2 composition

Since batch 1 still had considerable residual biogas potential, it was kept in the cell and batch 2 was added on top of batch 1. However, batch 2 was not evenly spread but concentrated on 2/3 of the batch 1 surface. Although no survey was done at the start of batch 2, the attached cross section, especially the difference between the January and July measurement, clearly shows a heap on the right side (Figure 11), which corresponds to the location of batch 2.

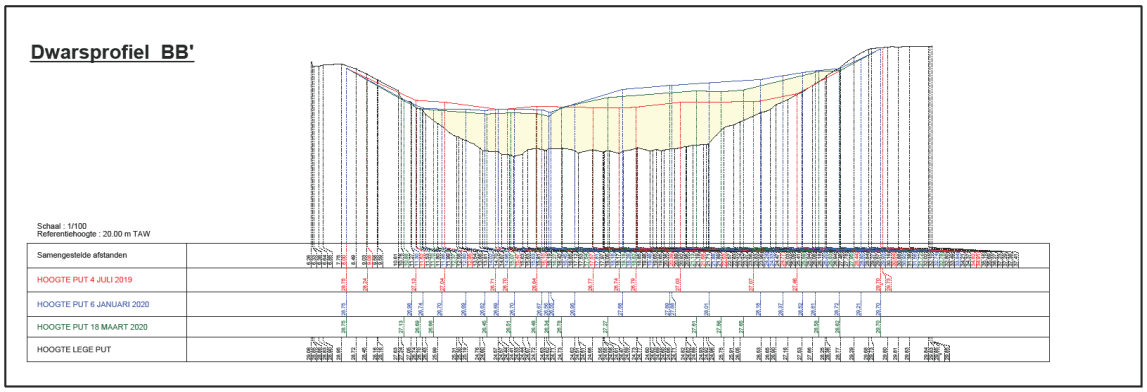

Figure 11. Cross section of the digestion cell

The batch 2 clippings originated from a 2-week mowing campaign in the surroundings of the facility. 292.6 ton of grass were added to the digestion cell with a dry mass of 34.1 ± 8.4% (average of 3 samples) together with 30.64 ton of digestate from an operating AD digester to improve the microbiology of the cell. The lack of better information regarding the biogas potential of batch 1 prevented the calculation of the mass balance for batch 2. To improve the follow-up of batch 2, three samples from the grass clippings were analysed for their biogas potential (Table 6).

Table 6. Analysis of the grass clippings of batch 2

	DM	ODM	Raw Fat	Raw protein	Carbohydrates	Theoretical biogas potential[3]		pH	Biogas potential lab[4]	
	%	%DM	(kg/t)			Volume (Nm^3/t)	CH_4%		Volume (Nm^3/t)	CH_4%
Sample 1, lightbrown color	35.4	71.72	7.51	23.9	140	130	54.0	4.72	113.4	63.4
Sample 2, freshly mown	25.2	77.78	6.39	32.8	82.6	91	57.0	7.41	89.4	60.5
Sample from intermediate storage	41.8	77.02	7.35	36.9	169	160	54.0	6.28	144.7	58.9
Average	34.1	75.5	7.1	31.2	130.5	127.0	55.0	6.14	115.8	60.9
Standard deviation	8.4	3.3	0.6	6.6	44.0	34.6	1.7	1.40	27.7	2.3

It is important to note that the lower biogas potential per ton fresh material of sample 2 can be explained by the high humidity of the sample. The value of CH_4 potential Nm^3/t_{ODM} is therefore a more reliable parameter. The values measured, between 265 and 283 Nm^3/t_{ODM}, are in the lower end of values found in literature, of 286 and 324 Nm^3/t_{ODM} (Weiland, 2010). The CH_4 content of the biogas, as measured in the lab digestion tests, is rather high and not fully representative for a full scale installation where values of 55% seem more realistic.

When comparing the CH_4 potential/t_{ODM} of the fresh grass samples (274 Nm^3/t_{ODM} on average) with the corresponding values of the "digested" samples from batch 1 (around 280 Nm^3/t_{ODM}), the CH_4 potential is similar. This supports earlier conclusions by (Aaron E. Brown, July 2020) that there is no significant difference in biomethane potential of fresh and ensiled grass. This also supports the hypothesis that the top part of batch 1 was rather subject to an ensiling than to a digestion process.

4.2. Digestion process

4.2.1. Leachate composition

In the period October-December, the FOS/TAC and pH were analysed on-site in order to follow up the system and especially detect eventual acidification. The addition of batch 2 did not seem to alter the system parameters: FOS/TAC remained at 0.1 and the pH at 8.0-8.5. The buffer capacity was thus high enough to neutralize the acids formed by the fermentation process. The

[3] Theoretical biogas potential, calculated on the composition
[4] Biogas potential lab: lab fermentation test

lower outdoor temperatures during the start-up of the fermentation might also have play a role (lower fermentation rate – lower acid load).

4.2.2. Biogas production

4.2.2.1. Biogas potential

Table 7 shows the biogas potential of batch 2. As the values for the different samples taken were quite different, a range was calculated using min, max and average values.

Table 7. Total biogas potential of batch 1 and batch 2

	min	average	max
Total amount of biogas potential batch 2 (Nm^3)	27 384	35 118	43 565
Total biogas potential batch 1[5] + 2 (Nm^3)	57 219	64 953	73 400
Total CH_4 production *(49.4% CH_4)* (Nm^3)	**28 266**	**32 087**	**36 259**

4.2.2.2. Biogas production

Figure 12 shows the steady production of biogas (blue line) by keeping the negative pressure more or less constant. The small plateaus in the biogas curve correspond to temporary shutdowns caused by maintenance activities on the grid. Gradually, the slope indicates a decrease of biogas production rate.

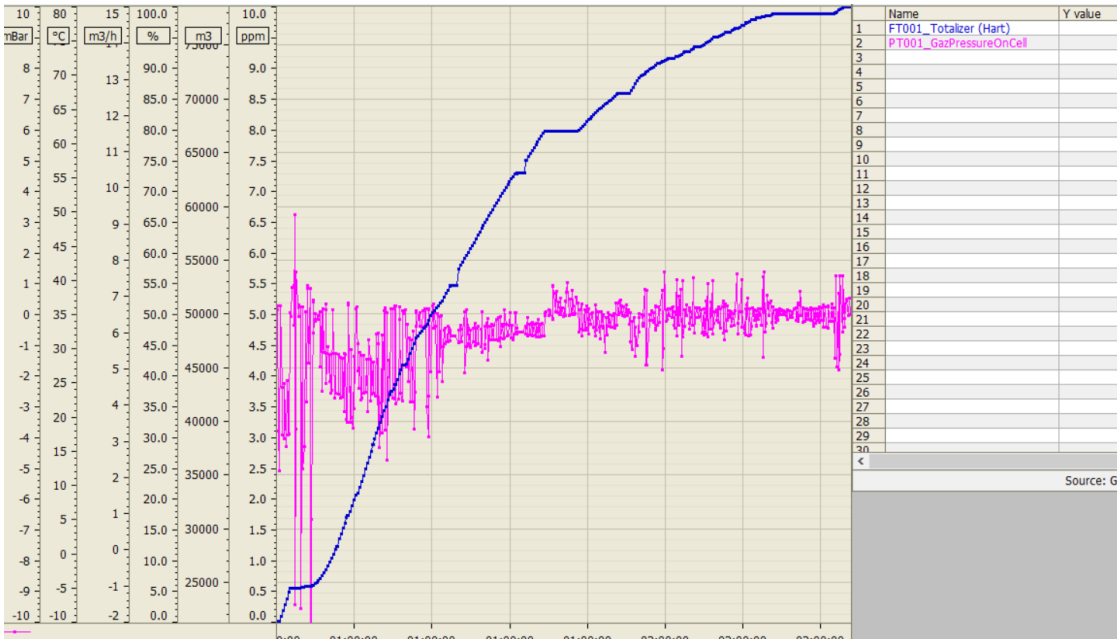

Figure 122. Biogas production from 10/10/2019 till 30/06/2020 (blue line)

[5] The estimated theoretical biogas potential for batch 1 was 29 835 Nm^3, which corresponded to a CH_4 potential of 17 575 Nm^3, when assuming a 54% CH_4 content.

On 30 March, a total of 71 600 Nm^3 biogas was registered. On 30 June, before opening the cell, the total amount had increased to 78 550 Nm^3. This amount corresponds to 107 % of the maximum estimated biogas potential calculated (Table 7). Both the asymptotic course of the biogas curve and the amount produced indicate that the digestion was coming to an end.

4.2.2.3. Biogas composition

As the online biogas monitoring did not seem to register the gas composition correctly, this parameter was monitored by external analysis. Again, high O_2 and N_2 values indicate the entry of air. Therefore, the CH_4 content of the sample was recalculated by excluding the air, giving a value of 51.8%, which is in line with the concentrations measured during batch 1.

Table 8. Biogas composition (Innolab analysis)

Date	CH_4 (%)	CO_2 (%)	O_2 (%)	N_2 (%)	H_2 (%)	H_2S (ppm)
22/11/2019	43.6	39.5	1.4	15.5	<0.05	<2
22/11/2019 Corrected	51.8	47.0	0.2	0.8	-	-

In March 2020, a new online gas analyser was installed. CH_4 concentrations in the range 45-53% were measured (Figure 13). The CH_4-values were more or less stable in the period 01/04/2020 – 30/06/2020. During this period the online gas analyser measured a CH_4 value of 49.4 ± 3.7%. The analysed sample (after correction) also lies in this interval (Table 8).

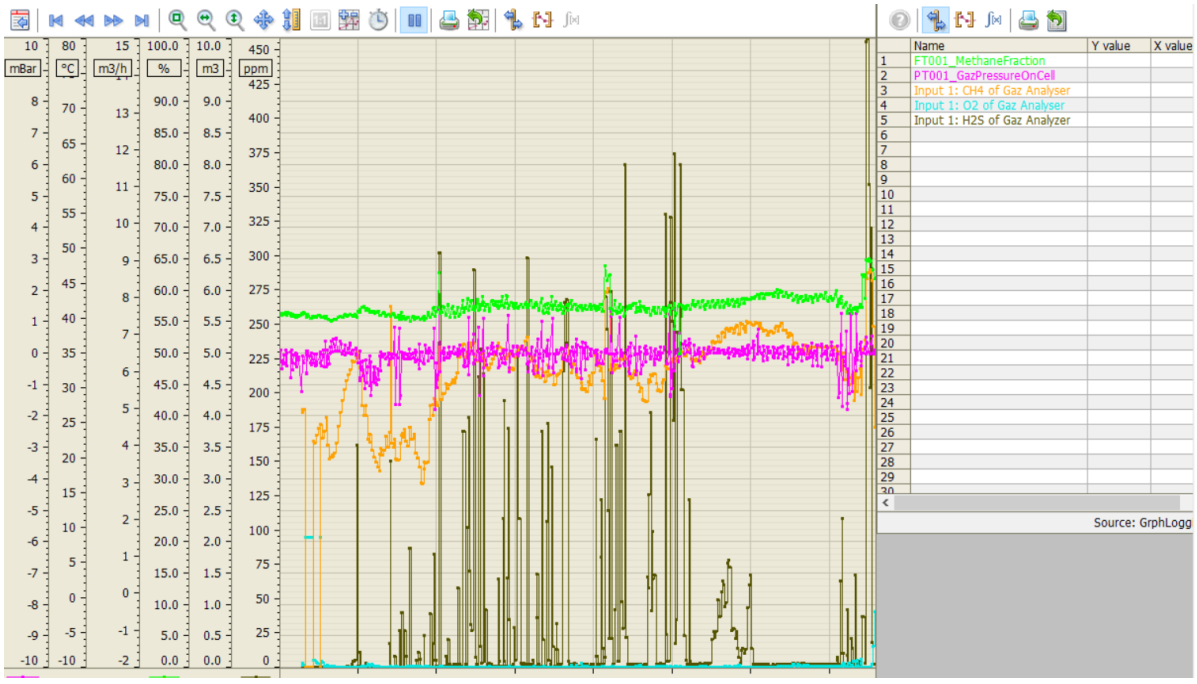

Figure 133. Gas composition (01/03/2020 - 30/06/2020) – orange line

4.2.3. Temperature

During this second digestion period, the temperature in the core of the cell (probe TT003) remained stable at ± 45 °C, which is at the high end for mesophilic digestion. The temperatures measured near the surface (TT002 and TT006, at a depth of ca 20-80 cm below the surface) were much lower.

During this period, batches of 500 L of pumped leachate were heated. This is shown by the light blue curve. However, only the surface probe TT006 seemed to register the effect of the heating. Seen the limited volume of leachate heated compared to the total volume of the batch (700-800 m^3), the effect of the heating is shown only after a few days of pumping. This is confirmed by the temperature curve of probe TT003. The exothermic reaction of the fermentation process explains the stable temperature at the core of the batch.

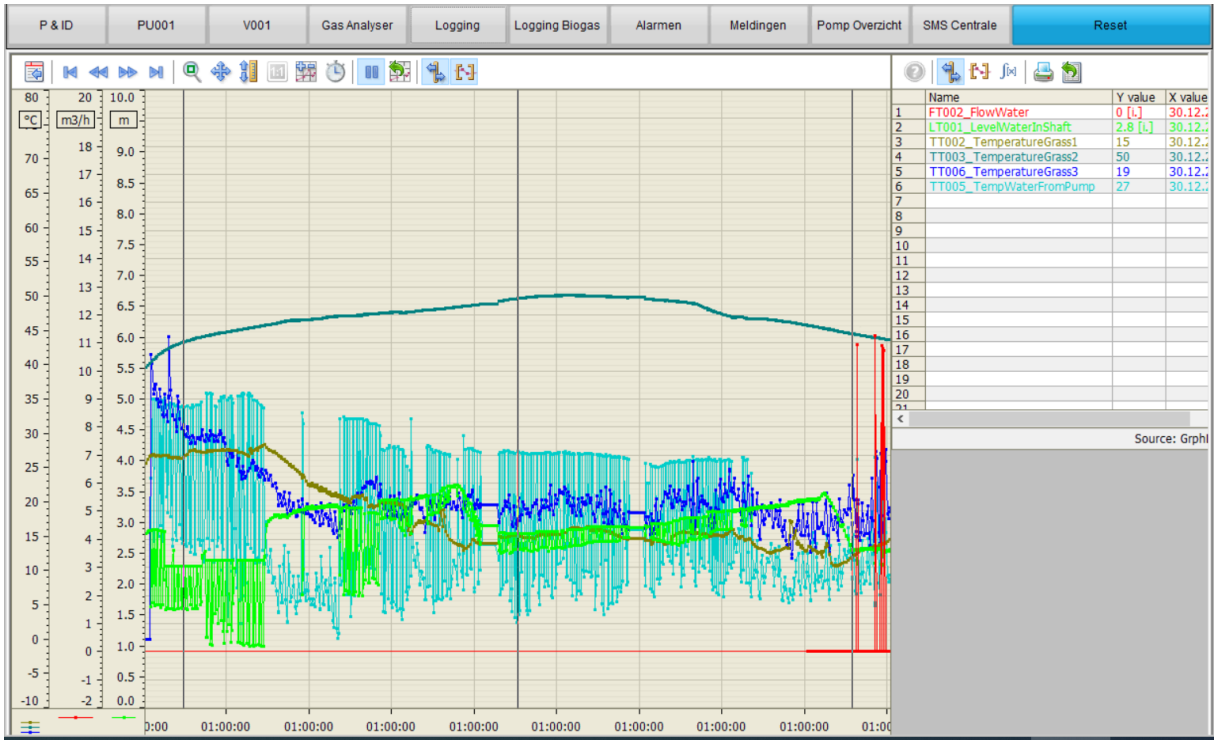

Figure 144. Temperature curves from 10/0/2019 till 20/03/2020

4.2.4. Batch 2: conclusions and lessons learnt

Both the experience built up during batch 1 and the fact that batch 2 was added to a buffered and more established system led to a more stable system during this second period. The time lapse between batch 1 and 2 was only 4 months. In this second batch, the digestion was maintained unchanged for about 8 months.

From an operational point of view, a large batch digester remains challenging. The monitoring devices (pH, temperature, gas flow and composition) give information but this might not always be representative for the whole system, given the dimensions of the cell.

The settling of the biomass during digestion entails a risk of leakage since the tensions can cause the seals to detach. Continuous monitoring of O_2 in biogas is useful to detect eventual leakages and to adjust the max pressures that can be applied to the digester cell. Too high negative pressures have to be avoided since this could enhance the introduction of air in the system. For the same reason, rain water puddles on the cell have to be avoided, since the water could enter the cell through occasional leaks and influence the leachate levels and composition.

The cell therefore requires a continuous follow-up and quite some maintenance. Maintenance activities are difficult to perform, both when the cell is open due to the instability of the grass mass and when the cell is closed due to the slippery conditions of the foil.

From an economic point of view, it seems that the investment in the construction and the costs for maintenance only make sense if the digested grass (including the percolate) generates added value.

The digested grass samples from batch 1 had a very strong smell, which jeopardized further processing options. At the current stage of the project, valorisation options are still under investigation. When re-opening the cell, samples will be taken to investigate different pathways.

It was decided to leave the digested grass of batch 1 and 2 in the cell in order to avoid the additional cost for discharging (gate fee at the composting facility for the grass fibres). The leachate will be recycled as inoculum for batch 3.

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