GEA Westfalia UCA 501-00-02
Post-treatment of digested biomass

Test report

Version 2-0

Document information

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1 TABLE OF CONTENTS

2 INTRODUCTION

This is the test report for the verification of GEA Westfalia decenter centrifuge model UCA 501-00-02. The test report is structured according to the directions defined in the AgroTech Test Centre Quality Manual.

2.1 Verification protocol reference

The test report is made to meet the requirements defined in the verification protocol for GEA Westfalia decanter centrifuge UCA 501-00-02.

2.2 Name and contact of vendor

The UCA 501-00-02 decanter centrifuge is developed and produced by GEA Westfalia Separator, Werner-Habig-Strasse 1, 59302 Oelde, Germany. Website: www.westfalia-separator.com.

UCA 501-00-02 is marketed and sold in Denmark by GEA Westfalia Separator DK A/S, Noerskovvej 1b, 8660 Skanderborg, Denmark, phone +45 8794 1000. Contact person of GEA Westfalia Separator DK is Martin Rishøj. Email: martin.rishoj@geagroup.com. Phone: +45 4030 0266.

2.3 Name of center/verification responsible

The test was performed by DANETV Verification Centre AgroTech, Udkaersvej 15, DK-8200 Aarhus N, Denmark.

Test responsible: Hans Jørgen Tellerup, AgroTech, Udkaersvej 15, DK-8200 Arhus N, Denmark. Phone: +45 8743 8406, e-mail: hjt@agrotech.dk.

2.4 Technical experts

The technical experts assigned to this test and responsible for review of test plan and test report included:

Bjørn Hjortshøj Andersen, AgroTech, Udkaersvej 15, DK-8200 Aarhus N, Denmark. Phone: +45 8743 8420, e-mail: bha@agrotech.dk.

Bjørn Malmgren-Hansen, Danish Technological Institute, Kongsvang Allé 29, DK-8000 Aarhus, Denmark. Phone +45 72201810. E-mail: bmh@teknologisk.dk.

3 TEST DESIGN

The GEA Westfalia UCA 501-00-02 decanter centrifuge was tested in full-scale on a commercial centralised biogas plant under normal operational conditions. The test was

designed so that it was possible to calculate mass balances of total dry matter, organic matter, total nitrogen, ammonium nitrogen, phosphorus and sulphur.

3.1 Test site

3.1.1 Characterization of the test site

The biogas plant of Morsoe Bioenergi was built in the period from august 2008 to April 2009. Then the first slurry was led to the digester and the biogas production started.

The GEA Westfalia decanter centrifuge was installed to treat all digested biomass leaving the digester. The purpose of the decanter centrifuge is to separate dry matter from the digested biomass thereby producing two fractions: A thin liquid fraction and a solid fraction.

Table 1. Characteristics of Morsoe Bioenergi biogasplant.

Parameter	Test site characteristics
Establishment year	2009
Capacity	119.000 tonnes of biomass per year
Process temperature	38˚C (mesophilic)
Main substrates used for biogas production	Pig slurry, cattle slurry, mink slurry Solid fractions from decentralised slurry separation units at livestock production units far from the biogas plant.

3.1.2 Addresses

The test took place at Morsoe Bioenergi, Naessundvej 234, DK-7970 Redsted Mors, Denmark. Contact person of Morsoe Bioenergi is Kurt Christensen.
Phone: +45 2343 4888. E-mail: kc@morsbioenergi.dk.

3.1.3 Description of GEA Westfalia UCA 501-00-02

In the GEA Westfalia UCA 501-00-02 decanter the centrifugal force is used to separate solids from the digested biomass. The liquid phase biomass is led into a closed horizontal cylinder with a continuous turning motion. Inside the cylinder solids and liquids are separated at the wall into an inner layer with a high dry matter concentration and an outer layer consisting of a liquid containing a suspension of colloids, organic components and salts.

The solid and liquid phases are transported to either end of the centrifuge by rotating the entire centrifuge at high speed and by simultaneously rotating the conveyor at a speed that differs slightly from the speed of the bowl [1], [2], [3].

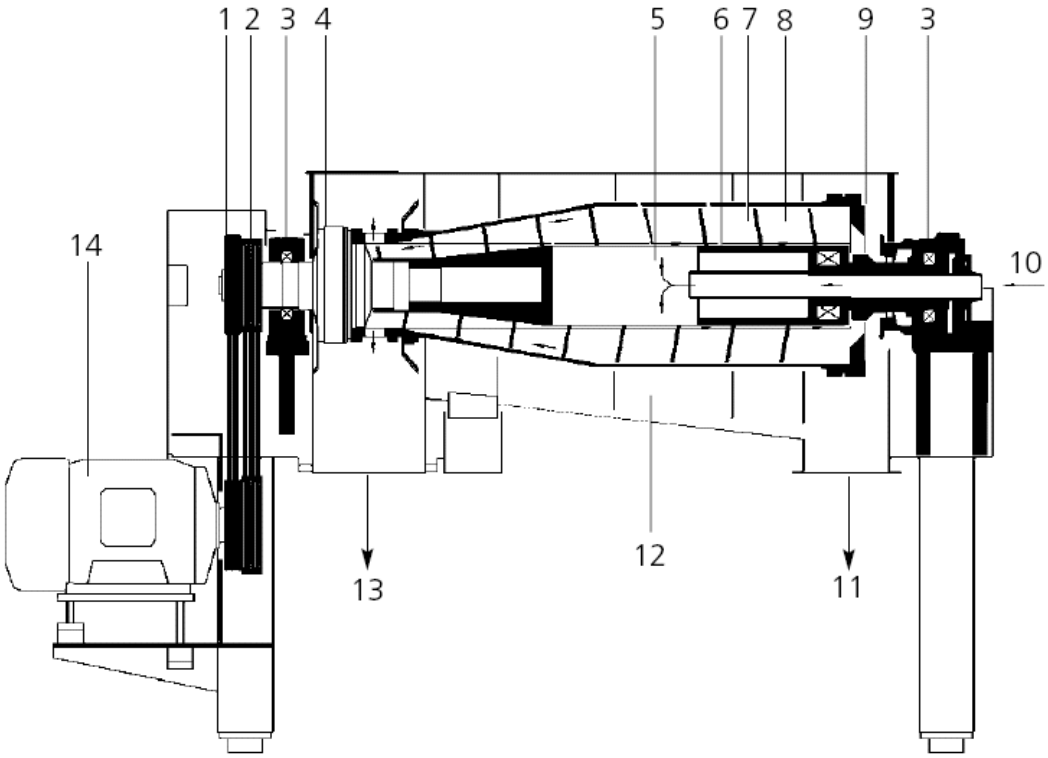

Figure 1. Constructional features of GEA Westfalia UCA 501. 1) Conveyor screw drive. 2) Bowl drive. 3) Bowl bearings. 4) Gear. 5) Distributor. 6) Conveyor screw. 7) Centrifugation space. 8) Bowl. 9) Regulating plate. 10) Feed. 11) Discharge of the clarified liquid. 12) Frame. 13) Solids discharge. 14) Drive motor.

Table 2 contains some technical data on the GEA Westfalia UCA 501 [2], [3].

Table 2. Technical data of GEA Westfalia UCA 501.

Bowl	
Diameter	500 mm
L/D ratio	4
Speed	3000 rpm
g-force, (z)	Max 2515 g
Comparative capacity	Max. 50 m^3/hour
Bowl drive	
Rating	35 kW star delta/37 kW FC
Speed at 50 Hz	3000 rpm
Speed at 60 Hz	3600 rpm
Scroll drive	
Rating at 50 Hz	11 Kw
Shipping data	
Decanter weight	3600 kg
Case dimensions	400 x 125 x 160 mm
Shipping weight	Gross 3900 kg

3.2 Tests

3.2.1 Test methods

To determine the separation efficiency of the GEA Westfalia UCA 501-00-02 a mass balance was made for total solids, volatile solids, suspended solids, total nitrogen, ammonium nitrogen, phosphorus and sulphur.

This was done by taking representative samples of all inputs to and all outputs from the decanter. Since the separation process is mechanical and no additives are used the only input is the digested biomass fed into the decanter from the digester at the biogas plant.

There are two outputs from the decanter:

- A liquid fraction with a lower content of dry matter than the input to the decanter.
- A solid fraction rich in dry matter and higher concentrations of total nitrogen.

Since the separation process takes place in a closed system (inside the decanter) and since the separation process is relatively fast, it was assumed that the amounts of nitrogen and other nutrients lost from the decanter as gaseous emissions during processing are very low. Thus, it was judged not to be relevant to measure any potential gaseous outputs from the decanter.

For the input stream and each of the two output streams the weight or volume and the concentrations of the relevant parameters were determined as part of the test in order to calculate the mass balances.

Figure 2 below illustrates schematically the input to and the two outputs from the GEA Westfalia decanter centrifuge.

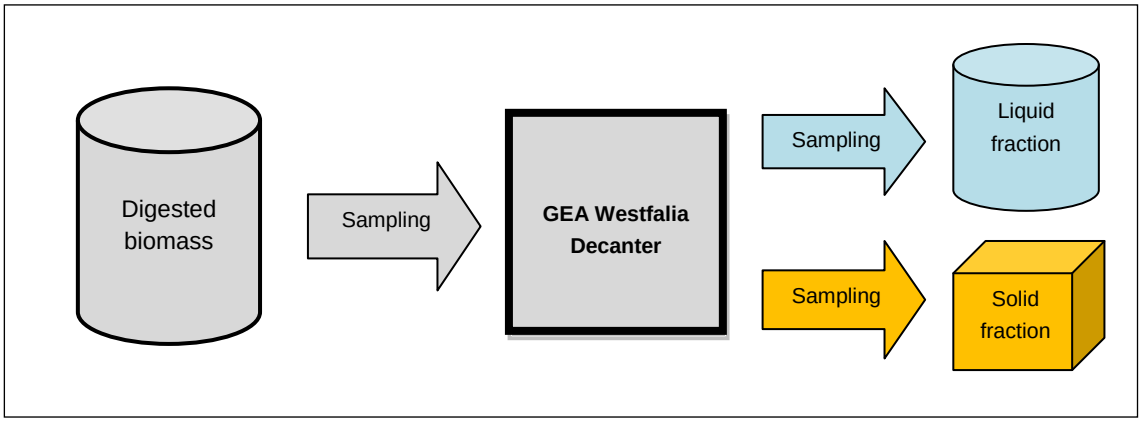

Figure 2. Illustration of the input stream and the two output streams from the GEA Westfalia decanter.

3.2.2 Test staff

The test staffs involved in the test of UCA 501-00-02 were:

Torben Ravn Pedersen, Landbo Limfjord, Resenvej 85, DK-7800 Skive, Denmark. Phone: +45 2024 2338. E-mail: trp@landbo-limfjord.dk.

Hans Jørgen Tellerup, AgroTech, Udkaersvej 15, DK-8200 Aarhus N, Denmark.
Phone: +45 8743 8406, e-mail: hjt@agrotech.dk.

3.2.3 Test schedule

The schedule for implementing the test is presented in the table below.

Table 3. Test schedule.

Task	2009				2010											
Week number	50	51	52	53	1	2	3	4	5	6	7	8	9	10	11	12
Test plan	X															
Practical planning		X	X													
Test start (28.12.2009)				X												
Period reserved for sampling				X	X	X	X	X								
Analyses by laboratory									X	X	X	X				
Test report draft													X	X		
Test report quality assurance															X	
Test report final version																X

3.2.4 Test equipment

The test included 5 batches where each batch lasted minimum 4 hours at normal operation of the decanter.

At the beginning of each batch:

- The settings of the decanter were checked on the control panel:
  - Feed: Approximately 15 m^3/hour
  - Torque: 50-60 %
  - Rotation of the bowl: around 3050 rounds per minute (RPM)
  - Differential speed: 4 - 8 rounds per minute.
- Collection of solid fraction in an empty container was prepared.
- The flowmeter was read and the actual figure was registered
- The time when the batch was started

During the batch the following was registered:

- The time when the sub-samples were taken
- The settings of the decanter were checked and the figures registered
- In case of any irregularities these were registered.

At the end of the batch it was registered:

- The time when the batch was stopped
- The flowmeter was read and the actual figure was registered
- The collection of solid output fraction in container was stopped.

After the batch ended the container was weighed using the weight at the biogas plant. Then the solid fraction was unloaded from the container and the now empty and clean container was weighed again. The result was the net weight of the produced solid fraction during the batch.

A flowmeter was installed at the inlet to the decanter when the decanter was installed. It is a Siemens MAG5000 constructed for measuring in matrices like slurry. It was calibrated when it was installed. A photo of the flowmeter is seen in figure 3.

Figure 3. Flowmeter measuring amount of treated biomass.

3.2.5 Type and number of samples

During each batch at least 3 sub-samples were taken from the input and each of the two outputs from the decanter. In each set of sub-samples the input flow is sampled first. After 10 – 20 seconds sub-samples of the two output streams were taken. The intention was to have a set of sub-samples where the two output sub-samples match a sub-sample of what is led into the separator at the same time.

For each of the 3 streams the intention was to get sub-samples that are representatives for the whole stream at the time of sampling. At the same time the sub-samples should be representative for the whole batch.

The first set of sub-samples was taken after approximately 30 minutes of the batch. The other sets of sub-samples were distributed evenly over the rest of the batch.

When the batch is completed the sub-samples are mixed and 4 pooled samples are taken:

3 pooled samples for chemical analyses:

- 0,8 L of input slurry
- 0,8 L of liquid output fraction
- 1 L of solid output fraction

1 pooled sample for particle size analysis

- 0,8 L of liquid output fraction

The 4 pooled samples were cooled down immediately (<5 degree C) and frozen within 6 hours.

Sub-samples of digested biomass led into the decanter were taken from a tap on the pipe close to the inlet of the decanter. A photo of this tap is seen on figure 4.

Figure 4. Tap for taking samples of input digested biomass.

Sub-samples of liquid output fraction were taken from a tap under the decanter. This tap is built on the decanter at the factory and it is constructed to take representatives samples of the liquid output fraction. A photo of the tap is seen on figure 5.

Figure 5. Tap for taking samples of liquid output.

Sub-samples of the solid output fraction were taken from the container in which the solid fraction from the whole batch was collected. A photo of the solid fraction in the container is seen in figure 6.

Figure 6. Collection of solid fraction in container.

3.2.6 Operation conditions

During the batch a number of operational parameters were registered from the control board of the decanter:

- Feed (m^3/hour)
- Torque (%)
- The rotation of the bowl (rounds per minute, RPM)
- Differential speed (round per minute)

Each parameter was read and registered minimum 4 times during a batch using the data reporting form included in Appendix 6 of the test plan.

In case of any irregularities or stops of the decanter during the batch these were registered, too.

3.2.7 Operation measurements

The electricity consumption was measured and logged automatically during the batch.

3.2.8 Product maintenance

The need for product maintenance was not evaluated as part of this test.

3.2.9 Health, safety and wastes

Issues related to health, safety and wastes were not evaluated as part of this test.

4 REFERENCE ANALYSIS

4.1 Analytical laboratory

For chemical analyses the 5 sets of pooled samples were transported to Eurofins Steins laboratory, Hjaltesvej 8, DK-7500 Holstebro. Website: www.eurofins.dk. E-mail: agro@eurofins.dk.

For particle size analysis the 5 pooled samples of the liquid output fractions were transported to AnalyTech Laboratory, Boegildsmindevej 21, DK-9400 Noerresundby, Denmark. Website: www.analytech.dk. E-mail: lab@analytech.dk.

Both Eurofins Steins laboratory and AnalyTech maintain an ISO 17025 accreditation with the quality management system required herein. Both laboratories apply accredited analytical methods, where available.

4.2 Analytical parameters

In table 4 the analytical parameters included in the test are presented.

4.3 Analytical methods

In table 4 the analytical methods of the analytical parameters are presented.

Table 4. Analytical parameters and corresponding analytical methods.

Parameter	Unit	Measured in	Analytical method
Total nitrogen	kg/ton	Input biomass Liquid output fraction Solid output fraction	Kjeldahl / Dumas
Ammonium nitrogen	kg/ton	Input biomass Liquid output fraction Solid output fraction	71/393/EØF
Total phosphorous	kg/ton	Input biomass Liquid output fraction Solid output fraction	ICP/OES
Total potassium	kg/ton	Input biomass Liquid output fraction Solid output fraction	ICP/OES
Total solids, TS	%	Input biomass Liquid output fraction Solid output fraction	EØF 103°C, 20 hours
Ashes	%	Input biomass Liquid output fraction Solid output fraction	DS204
Total sulphur	kg/ton	Input biomass Liquid output fraction Solid output fraction	ICP-OES
pH	pH unit	Input biomass Liquid output fraction Solid output fraction	Radiometer, GLP
Suspended solids, ss	mg/l	Liquid output fraction	DS207
Particle size distribution	%	Liquid output fraction	Laser diffraction (Mastersizer)

From the results of these analyses the following parameters were calculated:

- Organic nitrogen (kg/ton)
- Volatile solids, VS (%)

For all parameters except pH and particle size distribution a mass balance was calculated. The mass of each parameter pumped into and out of the decanter was calculated as the volume of the digested biomass and the liquid output fraction multiplied by the average concentration determined from the samples.

4.4 Analytical performance requirements

In this test the recovery factor expresses the proportion of a given component in the input digested biomass that end up in a specific output stream. The recovery factor is expressed as a percent.

Here the recovery factor is calculated this way:

$$\mathrm{RF_i^{S,L}} = \frac{(\mathrm{M^{S,L}} \times \mathrm{C_i^{S,L}})}{(\mathrm{M^{input}} \times \mathrm{C_i^{input}})} \times 100$$

Where:

$\mathrm{RF_i^S} =$ Percent of component *i* in input digested biomass recovered in solid fraction (S).

$\mathrm{SE_i^L} =$ Percent of component *i* in input digested biomass recovered in liquid fraction (L).

$\mathrm{M^{input,S,L}} =$ Mass of input digested biomass (input), solid fraction (S) and liquid fraction (L) respectively.

$\mathrm{C_i^{input,S,L}} =$ Concentration of component *i* in input digested biomass (input), solid (S) and liquid fraction (L) respectively.

In this test *separation efficiency* is defined as the recovery factor for the solid fraction. Thus separation efficiency is a measure of the proportion of a given component in the input digested biomass that ends up in the solid fraction.

The mass of each parameter into the decanter should equal the mass of that parameter that leaves the system in both the solid and liquid form.

To evaluate the validity of the mass balance calculations were made demonstrating to what extent the mass led into the separator was recovered in the solid and liquid output fractions (expressed as a percent).

$$\mathrm{R_i} = \frac{\mathrm{M_i^I} - (\mathrm{M_i^L} + \mathrm{M_i^S})}{\mathrm{M_i^I}} \times 100$$

Where:

$\mathrm{R_i} =$ Percent of component *i* not recovered in liquid or solid output fraction

$M_i^{I,L,S} =$ Mass of component *i* in input digested biomass (I), liquid (L) or solid output fraction (S)

In each batch for every parameter:

- R_i (per batch) has to be less than +/- 25%

In cases where R_i (per batch) was larger than +/- 25% the result had to be omitted from the calculation of separation efficiency. If possible the batch should be repeated. Verification of the separation efficiency of a given component should be based on results from minimum 4 batches.

All batches together for every parameter:

- R_i (all batches) had to be less than +/- 15%.

In cases where R_i (all batches) was larger than +/- 15% the result had to be omitted from the calculation of separation efficiency. If possible the test should have been repeated. If it was not possible to repeat the whole test the test responsible should assess whether some of the samples should be re-analyzed.

4.5 Preservation and storage of samples

The 4 pooled samples are cooled down immediately and frozen within 6 hours. When all 5 batches have been completed the samples for chemical analyses were unfrozen and sent to analytical laboratories together with written requisitions specifying what types of analyses to be performed.

5 DATA MANAGEMENT

Data management including filing and archiving procedures are described in the AgroTech Test Centre Quality Manual.

5.1 Data storage, transfer and control

Some data were collected and written down during the test at the test site. Appendix 6 of the test plan included data recording sheets to be used for registration of data at the test site.

Results from external laboratories were sent electronically by e-mail or in paper version by mail.

Table 5. Data compilation and storage summary.

Data type	Data media	Data recorder	Data record timing	Data storage
Test plan and test report	Protected pdf-files.	Test responsible	When approved	Files and archives at AgroTech
Data manually recorded at test site	Data recording forms	Test staff at test site	During collection	Files and archives at AgroTech
Calculations	Excel files	Test responsible, AgroTech	During calculation	Files and archives at AgroTech
Analytical reports	Paper / pdf-files	Test responsible, AgroTech	When received	Files and archives at AgroTech

6 QUALITY ASSURANCE

The test followed the AgroTech Test Centre Quality Manual, which is ISO 9001 compliant, but not certified.

6.1 Test plan review

The test plan was subject to internal review by the verification responsible from AgroTech Test Centre.

External review of the test plan was done by the technical expert assigned to this verification task.

6.2 Performance control – reference analysis

The mass of each parameter into the decanter should equal the mass of that parameter that leaves the system in both the solid and liquid form.

To evaluate the validity of the mass balance calculations were made demonstrating to what extent the mass led into the separator was recovered in the solid and liquid output fractions (expressed as a percent).

$$R_i = \frac{M_i^I - (M_i^L + M_i^S)}{M_i^I} \times 100$$

Where:

$R_i =$ Percent of component *i* not recovered in liquid or solid output fraction

$M_i^{I,L,S} =$ Mass of component *i* in input slurry (I), liquid (L) or solid output fraction (S)

In each batch for every parameter:

- R_i (per batch) had to be less than +/- 25%

In cases where R_i (per batch) was larger than +/- 25% the result had to be omitted from the calculation of separation efficiency. If possible the batch should be repeated. Verification of the separation efficiency of a given component should be based on results from minimum 4 batches.

All batches together for every parameter:

- R_i (all batches) had to be less than +/- 15%.

In cases where R_i (all batches) was larger than +/- 15% the result had to be omitted from the calculation of separation efficiency. If possible the test should have been repeated. If it was not possible to repeat the whole test the test responsible should assess whether some of the samples should be re-analyzed.

6.3 Test system control

The stability of the test equipment was controlled continuously by supervision and recording of data. Procedures for ensuring that test facilities and equipment are calibrated and fit for the purposes are described in the Quality Manual for the Laboratories of AgroTech. These procedures are subject to internal audits from the AgroTech Management.

6.4 Data integrity check procedures

All transfers of data from printed media to digital form and between digital media have been checked by spot check undertaken by verification responsible. If errors were found in a spot check, all data transfers from the specific data collection were checked. In this test no errors were found during spot check.

6.5 Test system audits

Internal audits from AgroTech are done following the procedure described in the AgroTech Test Centre Quality Manual.

6.6 Test report review

The test report was subject to internal review by the verification responsible from AgroTech Test Centre.

External review of the test report was done by the technical expert assigned to this verification task as part of the review of the verification report.

7 TEST REPORT

The test report follows the template of the AgroTech Test Centre Quality Manual. The verification report includes the full test report as an appendix.

7.1 Test site report

No specific test site report was made. At the test site data were collected and registered on data reporting forms. Templates for data reporting forms were included in Appendix 6 of the test plan.

7.2 Test data report

No specific test data report was made since it was not judged relevant to make this as part of this test. All data recorded during the test including results from external analytical laboratories have been gathered and archived according to the AgroTech Test Centre Quality Manual.

7.3 Amendment report

In this test report there is a section (section 8.4) on amendments to and deviations from the test plan. This section compiles changes of the test plan occurring before testing with justification of deviations and evaluation of any consequences for the test data quality.

7.4 Deviations report

In the test report there is a section on amendments to and deviations from the test plan. This section compiles all changes of the test plan that occurred during testing with justification of deviations and evaluation of any consequences for the test data quality.

8 TEST RESULTS

8.1 Test performance summary

The test period started on the 28th of December 2009 with the first batch out 5 batches included in the test. The test period ended on the 27th of January 2010 when batch number 5 was completed. Table 6 shows dates for all 5 batches and the length of each batch.

Table 6. Overview of the 5 batches in the test.

Batch number	Date	Length of batch (hours:minutes)	Test staff	Treated bio-mass (m^3)	Produced solid fraction (kg)
1	28.12.2009	04:03	Torben Ravn Pedersen	55	7.580
2	28.12.2009	04:06	Torben Ravn Pedersen	61	8.460
3	29.12.2009	04:04	Torben Ravn Pedersen	61	9.080
4	21.01.2010	04:20	Torben Ravn Pedersen	55	5.409
5	21.01.2010	04:06	Torben Ravn Pedersen	51	4.840
Average batch 1–5	**---**	**04:08**	**---**	**56,6**	**7.074**

In average over the 5 batches the GEA UCA 501-00-02 was running with a capacity of 13,72 tonnes biomass treated per hour.

8.2 Test measurement summary

In table 7 are shown the average concentrations of nutrients in the digested biomass, the liquid output fraction and the solid output fraction respectively.

Table 7. Average concentrations of nutrients over 5 batches.

Fraction	Total nitrogen (Kg/ton)	Ammonium nitrogen (Kg/ton)	Organic nitrogen* (Kg/ton)	Total phosphorous (Kg/ton)	Total potassium (Kg/ton)	Total sulphur (Kg/ton)
Input digested biomass	4,08	2,87	1,21	0,94	2,24	0,42
Liquid output fraction	3,49	2,63	0,86	0,31	2,31	0,29
Solid output fraction	8,15	4,50	3,65	6,52	2,28	1,56

*Note: Values for organic nitrogen are calculated (difference between total-N and ammonium-N), not measured.

Table 8 presents the average content of total solids, ashes, suspended solids and the pH of the digested biomass, the liquid output fraction and the solid output fraction respectively.

Table 8. Average content of total solids, ashes, volatile solids, suspended solids and pH.

Fraction	Total solids (%)	Ash content (%)	Volatile solids* (%)	Suspended solids** (mg/l)	pH (pH units)
Input digested biomass	4,85	1,46	3,39	35.000	7,64
Liquid output fraction	2,31	0,82	1,49	8.400	7,94
Solid output fraction	27,66	6,46	21,20	Not relevant	8,12

*Note: Values for volatile solids are calculated as the difference between total solids and ash content, not measured.
**Note: It does not make sense to measure suspended solids in the solid output fraction.

For each batch a mass balance on the nutrients was calculated. The mass balances were based on the measured concentrations of the nutrients and the masses of input and the output fractions. In table 9 the results are presented.

The mass of the liquid output fraction is calculated as the mass of input minus mass of solid output fraction.

In converting the measured volume of input to mass, the density of the treated biomass was approximated to 1 ton/m^3.

The share of the nutrients recovered in the solid fraction was added to the share of the nutrient recovered in the liquid fraction as control. Due to uncertainty in sampling and analysing the samples the control value does not sum up to 100%.

It is seen in table 9 that in average for 5 batches the mass balances of total nitrogen, ammonium nitrogen and potassium sum up close to 100 %. In other words, the nutrients in the input biomass are well recovered in the liquid and solid output fractions.

There is, however, some variation between the batches. For instance, for total nitrogen it is seen that the content in liquid and solid fraction sum up to around 104 % in batch 1 to batch 3. In batch 4 and 5 the total nitrogen sum up to 92 % only.

Table 9. Mass balances for nutrients.

Batch no.	Fraction	Total Nitrogen %	Ammo-nium-Nitrogen %	Organic Nitrogen %	Total phos-phorous %	Total potas-sium %	Total sulphur* %
1	Solid output	27	22	40	85	13	49
	Liquid output	76	81	66	23	90	56
	Control	103	102	105	108	102	105
2	Solid output	27	22	40	88	13	48
	Liquid output	77	79	73	23	86	58
	Control	104	101	113	111	99	106
3	Solid output	30	24	43	107	16	57
	Liquid output	76	82	61	24	93	57
	Control	106	107	104	131	108	113
4	Solid output	19	15	28	65	11	36
	Liquid output	69	75	56	49	73	---
	Control	88	90	84	114	84	---
5	Solid output	21	15	36	86	10	42
	Liquid output	75	82	54	30	110	---
	Control	95	97	90	116	120	---
Average	***Solid output***	***25***	***19***	***37***	***86***	***13***	***46***
	Liquid output	***75***	***80***	***62***	***30***	***90***	***57***
	Control	***99***	***99***	***99***	***116***	***103***	***103***

* No data on concentrations of sulphurous in liquid output fractions in batch 4 and 5.

In table 10 the mass balances for total solids, ashes, volatile solids, and suspended solids are presented.

Table 10. Mass balances for total solids, volatile solids, suspended solids and treated biomass.

Batch no.	Fraction	Total solids %	Volatile Solids* %	Suspended solids** %	Treated biomass %
1	Solid output	70	75	82	14
	Liquid output	34	28	18	86
	Control	104	103	100	100
2	Solid output	75	81	83	14
	Liquid output	40	35	17	86
	Control	115	116	100	100
3	Solid output	88	96	82	15
	Liquid output	34	27	18	85
	Control	122	123	100	100
4	Solid output	50	55	---	10
	Liquid output	57	56	---	90
	Control	107	111	---	100
5	Solid output	74	89	---	9
	Liquid output	48	54	---	91
	Control	122	142	---	100
Average	***Solid output***	***71***	***79***	***82***	***12***
	Liquid output	***42***	***40***	***18***	***88***
	Control	***114***	***119***	***100***	***100***

*Note: Mass balances of volatile solids are based on calculated concentrations, not measures concentrations.

**Note: Share of suspended solids in solid output fraction is calculated assuming 100 % content in input biomass.

The mass balances presented in table 9 and table 10 have been adjusted so that they sum up to 100 %. The adjusted mass balances are presented in table 11 and table 12 respectively as the best estimates for the performance of the GEA Westfalia Decanter centrifuge UCA 501-00-02.

Table 11. Adjusted mass balances of nutrients to make masses of the nutrients sum up to 100 %.

Batch no. 1-5	Fraction	Total nitrogen %	Ammonium nitrogen %	Organic nitrogen %	Total phosphorous %	Total potassium %	Total sulphur* %
Average	Solid output	25	20	38	72	12	45
	Liquid output	75	80	62	28	88	55
	Control	100	100	100	100	100	100

* Note: The mass balance for sulphur is based on 3 batches only due to lacking data for batch 4 and 5.

Table 12. Adjusted mass balances of solids to make masses of the solids sum up to 100 %.

Batch no. 1 - 5	Fraction	Total solids %	Volatile Solids* %	Suspended solids** %	Treated biomass %
Average	Solid output	63	68	82	12
	Liquid output	37	32	18	88
	Control	100	100	100	100

*Note: The mass balance for volatile solids is based on data from 4 batches only.

**Note: The mass balance for suspended solids is based on data from 3 batches only.

Table 13 presents the results of the particle size analysis. It is seen that over 5 batches in average 92 % of the total particle volume are particles with diameters less than 40 µm.

Furthermore, it is seen that in none of the 5 batches particles with diameters more than 40 µm constitute more than 10 % of total particle volume.

Table 13. Particle size distribution in liquid output fraction from GEA Westfalia UCA 501-00-02.

Batch No.	Share of particle volume with increasing particle diameters						
	<1 µm	< 5 µm	< 10 µm	< 15 µm	< 20 µm	< 40 µm	< 65 µm
1	11 %	36 %	58 %	72 %	81 %	96 %	100 %
2	10 %	33 %	54 %	67 %	76 %	92 %	97 %
3	11 %	35 %	55 %	67 %	75 %	90 %	96 %
4	18 %	49 %	65 %	74 %	79 %	90 %	96 %
5	20 %	52 %	66 %	74 %	79 %	90 %	95 %
Average	***14 %***	***41 %***	***60 %***	***71 %***	***78 %***	***92 %***	***97 %***

In table 14 the measured capacity of the decanter centrifuge during test is presented together with the results of the electricity consumption measurements.

Table 14. Capacity and electricity consumption.

Batch no. 1 - 5	Capacity Tons of input digested biomass treated per hour	Electricity consumption* kWh / ton input digested biomass treated
Average	13,72	1,67

* Note: Results on electricity consumption are based on data logged electronically by GEA Westfalia during test period.

8.3 Test quality assurance

In calculation of the average mass balances the following batches have been omitted because the analytical performance requirements have not been met:

- Phosphorous, batch 3.
- Suspended solids, batch 4 and batch 5.
- Volatile solids, batch 5
- Sulphur, batch 4 and batch 5.

Consequently, separation efficiencies for phosphorous and volatile solids are based on results from 4 batched only. Calculation of separation efficiencies for suspended solids and sulphur are based on results from 3 batches only.

8.4 Amendments to and deviations from test plan

According to the original test schedule batch 4 and batch 5 were planned to end of December 2009. However, since the biogas plant used as test site was not in normal operation the original schedule for the test could not be followed. Instead batch 4 and batch 5 were postponed to 21.01.2010. The operational problems at the biogas plant were not related to the GEA Westfalia UCA 501-00-02.

Since the analytical performance requirements were not met the pooled samples of liquid output fraction from batch 4 and batch 5 were re-analyzed at analytical laboratory. The results from the re-analyses have been used for calculation of average concentrations of nutrients and solids in the input and output streams and for calculation of mass balances and separation efficiencies.

A P P E N D I X 1

Terms and definitions used in the test plan

Word	DANETV
Analytical laboratory	Independent analytical laboratory used to analyse test samples
Application	The use of a product specified with respect to matrix, target, effect and limitations
DANETV	Danish center for verification of environmental technologies
(DANETV) test center	Preliminary name for the verification bodies in DANETV with a verification and a test sub-body
Effect	The way the target is affected
(Environmental) product	Ready to market or prototype stage product, process, system or service based upon an environmental technology
Environmental technology	The practical application of knowledge in the environmental area
Evaluation	Evaluation of test data for a technology product for performance and data quality
Experts	Independent persons qualified on a technology in verification
Matrix	The type of material that the product is intended for
Method	Generic document that provides rules, guidelines or characteristics for tests or analysis
Liquid fraction	Liquid or thin fraction derived from the separation of slurry.
Performance claim	The effects foreseen by the vendor on the target (s) in the matrix of intended use
Performance parameters	Parameters that can be documented quantitatively in tests and that provide the relevant information on the performance of an environmental technology product
Procedure	Detailed description of the use of a standard or a method within one body
Producer	The party producing the product
Recovery factor	Expresses the proportion of a given component in the input slurry that end up in a specific output stream. The recovery factor is expressed as a percent.
Separation efficiency	In this verification separation efficiency is defined as the recovery factor for the solid fraction. Thus separation efficiency is a measure of the proportion of a given component in the input slurry that ends up in the solid

Word	DANETV
	fraction (expressed as a percent).
Slurry	Faeces and urine produced by housed livestock, usually mixed with some bedding material and some water during management to give a liquid manure with a dry matter content in the range from about 1 – 10%. A slurry is a mixture of liquid and solid materials, where typically the solid materials are not dissolved in the liquid phase, and will precipitate out of the slurry under a prolonged period of storage.
Slurry additive	Manufactured or naturally occurring products or substances that are added to manures to modify their biological, chemical or physical properties. Many additives are commercially available but most have not been subjected to independent testing so their effectiveness has not been assessed.
Slurry separator	Slurry separators (separation technologies) are here defined as technologies that divide liquid livestock manure (slurry) into one or more solid fractions and one or more liquid fractions.
Solid fraction	A fraction from separation with a higher content of solids (e.g. dry matter or phosphorus) than the input material. Normally the solid fraction is stackable.
Standard	Generic document established by consensus and approved by a recognized standardization body that provides rules, guidelines or characteristics for tests or analysis
Target	The property that is affected by the product
Test center, test sub-body	Sub-body of the test center that plans and performs test
Test center, verification sub-body	Sub-body of the test center that plans and performs the verification
Test/testing	Determination of the performance of a product for parameters defined for the application
Vendor	The party delivering the product to the customer
Verification	Evaluation of product performance parameters for a specified application under defined conditions and adequate quality assurance

A P P E N D I X 2

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[8] AgroTech (2009): AgroTech Test Centre Quality Manual. Not published.

A P P E N D I X 3

References methods

The reference methods are presented in section 4 Reference methods.

A P P E N D I X 4

In-house test methods

Test methods are described in section 3.2 Tests.

A P P E N D I X 5

In-house analytical methods

In this test all analyses are made by external laboratories.

A P P E N D I X 6

Test data report

Analytical results from Eurofins Steins Laboratory are presented in the table below.

				Results from analyses of samples										
Batch	Date	Code	Fraction	Total-N	NH4-N	Org N	P	K	TS	Ashes	VS	S	SS	pH
no.				kg/t	kg/t	kg/t	kg/t	kg/t	%	%	%	kg/t	mg/l	Unit
1	28.12.2009	B1	Input	4,28	3,02	1,26	1,10	2,40	5,67	1,60	4,07	0,45	41.000	7,67
1	28.12.2009	B1	Liquid output	3,78	2,82	0,96	0,29	2,50	2,21	0,88	1,33	0,29	8.500	7,99
1	28.12.2009	B1	Solid output	8,34	4,72	3,62	6,80	2,20	28,92	6,70	22,22	1,60	---	8,19
2	28.12.2009	B2	Input	4,24	3,02	1,22	1,10	2,40	5,18	1,50	3,68	0,43	43.000	7,69
2	28.12.2009	B2	Liquid output	3,81	2,78	1,03	0,29	2,40	2,38	0,87	1,51	0,29	8.400	7,94
2	28.12.2009	B2	Solid output	8,28	4,72	3,56	7,00	2,30	28,07	6,70	21,37	1,50	---	8,16
3	29.12.2009	B3	Input	4,18	2,90	1,28	1,00	2,20	4,95	1,50	3,45	0,42	39.000	7,67
3	29.12.2009	B3	Liquid output	3,73	2,81	0,92	0,28	2,40	1,96	0,85	1,11	0,28	8.300	7,92
3	29.12.2009	B3	Solid output	8,41	4,75	3,66	7,20	2,30	29,22	7,00	22,22	1,60	---	8,31
4	21.01.2010	B4	Input	4,06	2,78	1,28	0,88	2,10	5,09	1,50	3,59	0,44	28.000	7,60
4	21.01.2010	B4	Liquid output	3,12	2,33	0,79	0,48	1,70	3,23	1,00	2,23	0,11	1.000	7,92
4	21.01.2010	B4	Solid output	7,83	4,20	3,63	5,80	2,30	25,91	6,00	19,91	1,60	---	7,94
5	21.01.2010	B5	Input	3,64	2,65	0,99	0,64	2,10	3,37	1,20	2,17	0,34	24.000	7,60
5	21.01.2010	B5	Liquid output	3,01	2,42	0,59	0,22	2,55	1,79	0,50	1,29	0,11	450	7,92
5	21.01.2010	B5	Solid output	7,87	4,10	3,77	5,80	2,30	26,20	5,90	20,30	1,50	---	7,99

Results from particle size distribution analyses in liquid output fraction from GEA Westfalia UCA 501-00-02.

Batch No.	Share of particle volume with increasing particle diameters						
	<1 µm	< 5 µm	< 10 µm	< 15 µm	< 20 µm	< 40 µm	< 65 µm
1	11 %	36 %	58 %	72 %	81 %	96 %	100 %
2	10 %	33 %	54 %	67 %	76 %	92 %	97 %
3	11 %	35 %	55 %	67 %	75 %	90 %	96 %
4	18 %	49 %	65 %	74 %	79 %	90 %	96 %
5	20 %	52 %	66 %	74 %	79 %	90 %	95 %
Average	***14 %***	***41 %***	***60 %***	***71 %***	***78 %***	***92 %***	***97 %***

A P P E N D I X 7

Amendment and deviation reports for test

According to the original test schedule batch 4 and batch 5 were planned to end of December 2009. However, since the biogas plant used as test site was not in normal operation the original schedule for the test could not be followed. Instead batch 4 and batch 5 were postponed to 21.01.2010. The operational problems at the biogas plant were not related to the GEA Westfalia UCA 501-00-02.

Since the analytical performance requirements were not met the pooled samples of liquid output fraction from batch 4 and batch 5 were re-analyzed at analytical laboratory. The results from the re-analyses have been used for calculation of average concentrations of nutrients and solids in the input and output streams and for calculation of mass balances and separation efficiencies.