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Demonstration tests results Waste Preparation Unit

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1. Introduction

In BELISSIMA Phase 1, a Waste Preparation Unit (WPU) was constructed by Packo Inox NV. The demonstration test plan for the unit including P&ID and component description was described in TN80.321.

The tests were organized in two phases. A first phase aimed to check the performance of the system in terms of homogenization, size reduction and cleaning on a mixture of vegetables and toilet paper. In a second phase, size reduction and cleaning were evaluated for the real mixture, to be used in BELISSIMA, consisting of vegetables, toilet paper, urine and fecal material.

The test record sheets were assembled in TN80.511. In this TN, the results are presented and discussed.

2. Phase 1: Demonstration test results on vegetable and toilet paper mixture

2.1. Feed composition

In TN80.16, the feed to compartment I in BELISSIMA was defined. According to Table 20 in that TN, the calculated dry matter (DM) and wet weight of the different waste materials in the feed are as shown in Table 1. To obtain a final dry matter content of 21 g/l, the total amount of 2 538 g DM has to be added to a total volume of 120 l, including urine. The BELISSIMA loop is designed to treat around 2 l/d in compartment I. It was assumed that waste mixture batches will be prepared in volumes of 40 l. The fresh loads mentioned were included in the Demonstration test plan.

Table 1: Relative amounts of waste materials and assumed dry matter (DM) contents used to calculate required wet weights in the waste mixture for BELISSIMA starting from a simulation for a 6 man crew(see also TN80.16, Table 20). The last column shows fresh loads based on actually determined DM for lettuce and red beet.

	6 man crew – 120 l volume			40 l batch		
Material	**DM/day**	**DM**	**Fresh load**	**DM**	**Fresh load**	**Fresh load recalc**
Wastes						
- Fecal material	180 g	33%	545 g/d	60 g	180 g	180 g
- Urine	306 g in 9 l	3,4%	9 l/d	102 g	3 l	3 l
- Toilet paper	108 g	100%	108 g/d	36 g	36 g	36 g
Vegetables						
- Lettuce	648 g	5%	13 kg/d	216 g	4.3 kg	*5.67 kg*
- Red beet	648 g	8%	8,1 kg/d	216 g	2.7 kg	*1.58 kg*
- Wheat straw	648 g	100%	648 g/d	216 g	216 g	216 g
Total	**2 538 g**			**846 g**		

Because moisture contents and DM contents may differ a lot between different batches of vegetables, it was decided to determine the DM for the available lettuce and red beet. The measured DM contents were 3.77% and 13.97% on average. As these values differed a lot

from the ones assumed in Table 1, it was decided to make sure that the DM contributions per type of vegetable were respected. Hence, the required fresh weights for lettuce and red beet were recalculated to 5.67 and 1.58 kg per batch.

2.2. Preparation of waste materials

Red beet and lettuce were obtained from BioFresh Belgium nv (Onze Lieve Vrouw-Waver, Belgium) and was certified to be organically grown. The material is stored at -20°C and was left to thaw for a few hours. Toilet paper was from an ecological brand (Carrefour, Eco Planet) and consisted of 100% recycled fibres.

Four crops of (still frozen) red beet were placed in the hygienic kitchen cutter (Robot Coupe vertical cutter R30) which was equipped with 3 knifes placed at optimal distances to bottom and to each other. The vegetables were cut in 4 to 5 pulses. Four additional crops were added and so on until the whole mass was processed. Then, the lettuce was added and cut per 1-2 crops, again by applying 4 to 5 pulses. During the whole process, the vegetables regularly need to be scraped away from the wall to achieve proper mixing. Finally, the toilet paper was torn into small pieces, transferred to the mixture in the kitchen cutter and processed by pulsated mixing. Introduction of toilet paper into the kitchen cutter is used to wipe the cover of the kitchen cutter and recover the vegetable parts which had accumulated there.

To the final mixture some 150 ml of RO (reverse osmosis) water was added to allow for continuous mixing during 4 times 5 min. In between, wall and cover were scraped to move down the waste mixture and return it to the bulk waste mixture.

Figure 1 illustrates the stepwise processing applied.

Figure 1: Illustration of the stepwise waste processing in the kitchen cutter

At the end of the mixing process, the knifes were removed from the kitchen cutter and the mixture transferred to a bucket. The wet weight amounted to 7.34 kg. This is close to the originally weighed amounts (see Table 2, total without straw). Taking into account the extra 150 ml of RO water added, this corresponds to a loss of 90 g. It is assumed that this is some thawing water from the lettuce which was not transferred with the crops to the kitchen cutter. Afterwards, the kitchen cutter was cleaned with RO water and the whole amount transferred to the homogenization tank of the Waste Preparation Unit.

Table 2: Weighed amounts of materials for the first step of the demonstration tests.

Material	Weight (kg)
Frozen red beet	1,580
Frozen lettuce	5,670
Straw	0,215
Toilet paper	0,036
Total	**7,501**
Total without straw	**7,286**

The organically grown wheat straw (certified from farm Het Eikelenhof, Neerglabbeek, Belgium) was cut to 15 cm pieces, then ground in 3 steps:

- Retsch cutting mill SM100 for raw grinding at 8 mm
- Retsch cutting mill SM100 for grinding down to 2 mm
- Retsch ultracentrifugal mill ZM200 for thin grinding to 1.5 mm.

2.3. Checking homogeneity of mixing and size reduction of the waste mixture

This part of the tests aimed at checking the homogeneity of mixing and size reduction of the waste mixture to 2 mm in a total working volume of 40 l.

Before introduction of the pretreated waste materials, some RO water was added to the homogenization tank of the Waste Preparation Unit, until the mixer was immersed in water. The volume displayed was 10 l. The mixer speed was then fixed (position 0.5-1 on a scale to 10). Nearly half of the waste mixture was transferred. The mixing speed was increased to position 1.5 and the suspension stirred for 5 min. After introduction of the remaining part of the waste material, mixing speed was further increased to position 2-3. During a few seconds, some water was introduced through the sprayball (using command ‘Start filling C-04) to clean the inside tank wall. The, the tank was filled to a level of 40 l. To ensure a correct addition of the desired water volume, the mixer was stopped and the feedwater flow decreased when approaching the setpoint. On the one hand, this avoids an overshoot. On the other, the presence of a safety filter on the exhaust of the homogenization tank leads to an additional pressure drop compared to an open exhaust. Taking into account that the level measurement is pressure based, too fast filling could lead to errors. The actual level readout was finally 38.2 l. Mixing was restarted at speed position 4. Rotation speeds were kept rather low to avoid vortex and foam formation.
Then the shear pump was switched on at a low speed and was gradually increased in 10 minutes from position 3 to 8 (again at a scale of 10). The shear pump is left to operate at this optimum for 20 min. In that period, 3 samples were collected through the sample valve,

(denominated mix 5 min, mix 10 min, mix 15 min), to determine dry weight and particle size distribution. The samples visually all looked homogeneous. The speed of the stirrer was increased to position 8, but this did not result in the anticipated foam formation. The response of the level switch LS_0004_01 thus could not be verified.
Shear pump and stirrer were stopped. After 0.5 h of settling, 2 samples were taken from the drain to determine dry weight and the fraction > 2 mm (denominated bez 1 and bez 2).
The stirrer was switched on again and the content of the tank emptied over a lab sieve with 2 mm mesh. The industrial sieve equipped with beads mentioned in the test protocol was unfortunately no longer available. Conform the experience in the MELiSSA Pilot Plant, sieving led to accumulation of suspended material on the sieve. By continuously applying soft stroking over the sieve, nearly all material passed through. The remaining material is shown in Figure 2 and amounted to 0.052 g wet weight.
All waste material was collected, weighed to be 38.12 kg (excluding around 1.5 kg losses through sampling) and frozen at -20°C.

Figure 2: View of waste mixture samples (left) and remaining material on 2 mm mesh sieve (right).

The measured dry weights of all samples are summarized in Table 3. This shows that the 3 samples taken to check homogeneity of the mixtures deviated little from each other. The relative standard deviation was 1.7%, thus less than the target of 5%. The overall average value was 15.60 ± 0.27 g/l. The target put forward in the demonstration test plan was 16 g/l. The deviation is thus 2.5%, which is far below the 10% deviation allowed.
When rechecking the total dry weight expected from the vegetables and toilet paper (see Table 1), it was noted that the target should in fact be 17.1 g/l. In that case, the obtained average values deviate 8.8% from the target value, which is still within the 10% range.

Table 3: Dry weight of the various samples taken during preparation of a waste mixture (vegetables and toilet paper)

Sample	Dry weight (g/l)	Average (g/l)	Overall average (g/l)
Mix 5 min	15.4	15.75 ± 0.49	15.61 ± 0.27
	16.1		
Mix 10 min	15.7	15.65 ± 0.07	
	15.6		
Mix 15 min	15.4	15.40 ± 0	
	15.4		
Bez 1	21.8	21.95 ± 0.21	
	22.1		
Bez 2	17.2	18.15 ± 1.84	
	19.1		

It is not clear why the measured dry weight is lower than the target value.
First of all, the density of the waste mixture was checked. Indeed, the dry weights should in principle be expressed as g dry weight/g material, since they were measured by drying a predetermined mass of waste mixture, rather than from a predetermined volume. Measurements relating volumes and weights were performed for all samples and all resulted in densities between 1.00 and 1.01 g/ml. Hence, the values expressed per unit of weight would be similar to the ones expressed per unit of volume.
Secondly, a 90 g loss of waste material was observed after collecting the vegetables and toilet paper mixture from the kitchen cutter, as mentioned before. Furthermore, the total mixture volume displayed on the Waste Preparation Unit was 38.2 l instead of 40 l. The actual ratio of fresh load was thus 7.41/38.2 = 0.194 kg/l instead of 7.50/40 = 0.188 kg/l, so even somewhat higher than theoretically expected.
So it is assumed that variability in the dry weight of the different crops explains the somewhat lower dry weight.

Conform expectations, the settled samples showed a higher dry weight with a sometimes much higher standard deviation.

A second part of the evaluation concerns the particle size distribution, as determined by laser diffractometry. Since the samples were analyzed externally at Ghent University, they were conserved with sodium azide (added to a final concentration of 0.02% to avoid fermentation processes to take place) in the dark at 4°C. They were sent to Ghent and analyzed within 24 h. For each sample 2 independent subsamples (taken after homogenization) were analysed, and for each at least 3 measurements were performed. In between the duplicate samples, the equipment was cleaned, and background was measured. The particle sizes are quantified in 43 groups ranging between 0 and 3.5 mm and cumulative values calculated. Since the fractions closest to 2 mm were those > 1886 µm and > 2197 µm, the fraction < 2 mm was determined by interpolation. As shown in Table 4, average values of particle size fractions larger than 2 mm, were for all samples below 5%, conform the requirement. It was not surprising to note that the longer mixing times led to somehow better compliances, with decreasing fractions > 2 mm. Interestingly, also the settled samples showed less than 5% particles > 2 mm.

Table 4: Cumulative particle size fraction below 2 mm for the various samples taken during preparation of a waste mixture consisting of vegetables and toilet paper. Values were obtained by interpolation between the fractions > 1886 µm and > 2197 µm.

Replicate	Mix 5 min	Mix 10 min	Mix 15 min	Bez 1	Bez 2
1	98.90	99.29	99.20	100	99.64
2	99.28	99.80	99.71	92.30	100
3	98.10	99.62	99.43	95.81	97.72
4	93.27	93.99	100	95.90	99.55
5	94.70	97.83	100	93.36	99.24
6	91.54	97.84	100	99.24	93.79
7	93.48	100		100	94.26
8				97.85	100
9					98.03
Average	95.61 ± 3.11	98.34 ± 2.12	99.72 ± 0.34	96.81 ± 2.96	98.03 ± 2.41

As an illustration, Figure 3 shows the particle size distributions and cumulative graphs for the sample taken after 15 min of mixing, and one for a settled sample. It is clear that the former measurement one is very reproducible, while the latter one shows more variability.

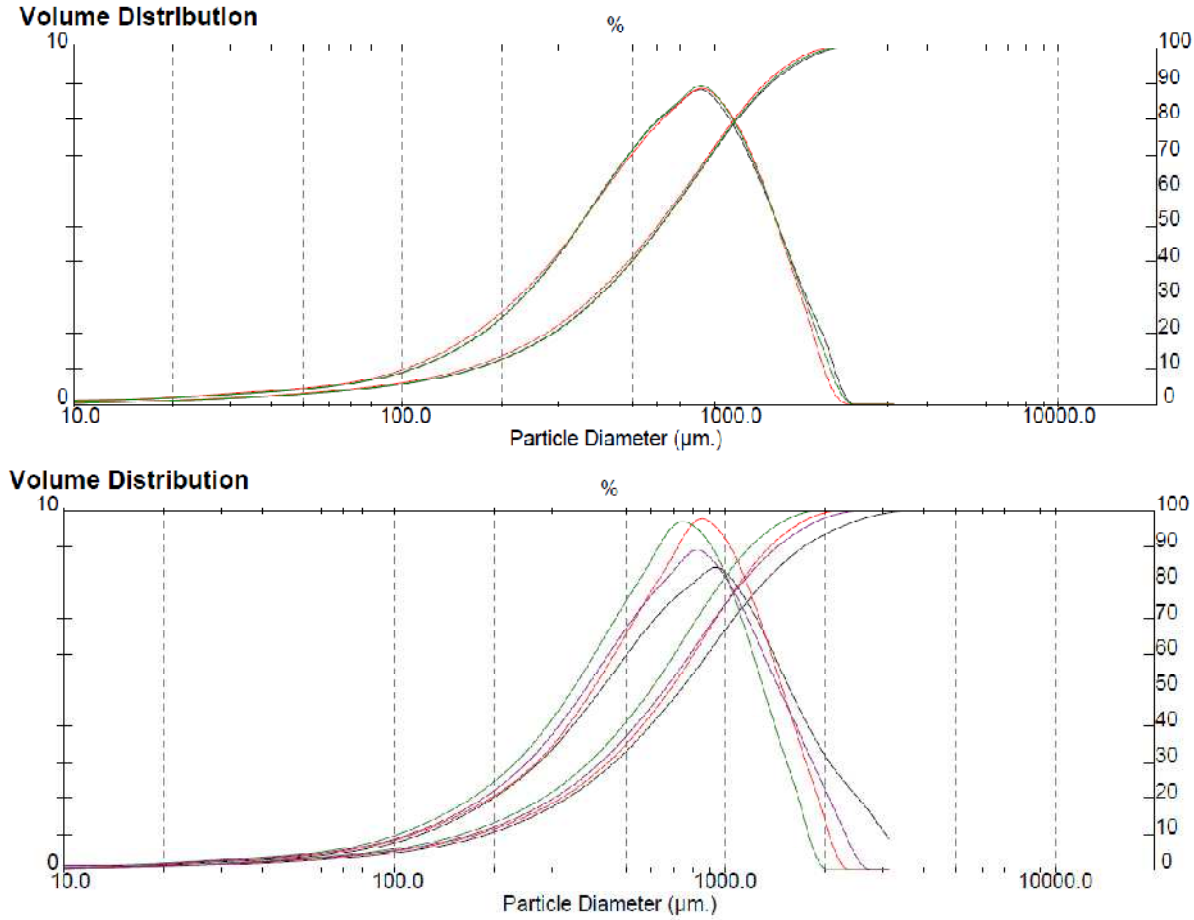

Figure 3: Example of particle size distributions for sample mixed for 15 min (top) and a settled sample (bottom).

2.4. Cleaning of WPU

The water feed was connected to tap water and the cleaning tank filled with 15 l of water for prerinsing the homogenization tank through the nozzle. The mixer in the homogenization tank was started, the water drained and a second prerinse performed.

For prerinsing the shear pump, the cleaning tank was again filled with 15 l of tap water and the water transferred to the homogenization tank through the nozzle. Because the low level switch was not reached, the shear pump could not be activated and a second 15 l volume was added. The shear pump was started with a speed between position 5-6 for 2 min. The sampling valve was opened and closed to clean this as well. The pump was then stopped and the liquid drained. The test protocol did not mention an additional separate draining of the shear pump. We recommend to include this in the future as well. The prerinse of the shear pump was repeated.

In a final cleaning step, 2 times 15 l of RO water was transferred from the cleaning to the homogenization tank through the nozzle. The diptube from the recirculating line of the shear pump was turned 180° by hand, and the cleaning pump was activated to spray the first 15 l of RO water through the nozzle in the homogenization tank. Then the diptube was returned to its

original position and the second 15 l of RO water sprayed into the homogenization tank. This ensured that both sides of the diptube were rinsed and cleaned.
Additional rinsing steps with RO water were performed. After the second step, the conductivity and turbidity measured were similar to the ones of pure RO water (Table 5).

Table 5: Conductivity and turbidity values measured after subsequent rinsing steps with RO water and comparison to pure RO water

Condition	Turbidity (NTU)	Conductivity (µS/cm)
Pure RO water	0.40	2
1st rinse	1.77	43
2nd rinse	0.44	3
3rd rinse	0.36	2

Cleanliness was also checked visually by opening the tank, and disassembling the shear pump. The absence of particles or dirt is illustrated in Figure 4.

Figure 4: View of tank (left) and shear pump head (right) after cleaning.

Finally, the agitator flange was rinsed and the water drained through the outlet.

This test phase was thus passed successfully and no deviations were recorded. It should be noted though that no foam formation occurred and the response of the high level switch to foaming could thus not be evaluated.

3. Phase 2: Demonstration test results on real waste mixture

3.1. Preparation of waste materials

In this case, the vegetable and toilet paper mixture was prepared as described in 2.2. In addition, fecal material (180 g wet weight) and urine (3 l) stored at -20°C, were left to thaw for 1 h.
The actually weighed amounts of wastes are given in Table 6. The amount recovered from the kitchen cutter was approximately 7.29 kg compared to 7.286 kg added. So there were no losses.

Table 6: Weighed amounts of materials for the second step of the demonstration tests.

Material	Weight (kg)
Frozen red beet	1,580
Frozen lettuce	5,670
Straw	0,215
Toilet paper	0,036
Urine	3,007
Fecal material	0,180
Total	**10,688**

3.2. Checking homogeneity of mixing and size reduction of the waste mixture

This part of the tests aimed at checking the homogeneity of mixing the real waste mixture in a total working volume of 40 l. Samples for particle size distribution were not taken because the presence of urine and fecal material is not straightforward for analysis in an external lab.

The procedure followed was quite similar to the one mentioned in 2.3. After adding an initial amount of water, the vegetables-toilet paper mixture and the straw were added stepwise. In between, a small amount of water was sprayed into the homogenization tank for better mixing of the waste into the suspension. Fecal material was then added. Transfer of urine had to be delayed because the material had not thawed sufficiently to be able to remove it from the bottles. We therefore propose to thaw it at 4°C overnight when preparation of a waste batch is scheduled. After a short period of mixing, the liquid level was increased to 40 l by adding RO water. The final level readout was 39.4 l. Increasing the mixer speed and shear pump speed did not induce foam formation. So again, the level switch could not be tested. Three samples were taken through the sample valve, mixer and shear pump were stopped and after 0.5 h 2 additional samples were taken through the drain. After switching on the stirrer again, the tank content was emptied, collected and stored at -20°C. The total weight collected amounted to 37.72 kg. The difference compared to 40 l of waste mixture is mainly due to sampling.

The dry weights measured are summarized in Table 7.

Table 7: Dry weight of the various samples taken during preparation of a real waste mixture containing urine and fecal material

Sample	Dry weight (g/l)	Average (g/l)	Overall average (g/l)
Mix 5 min	17.7	17.82 ± 0.16	17.99 ± 0.45
	17.9		
Mix 10 min	17.7	17.62 ± 0.05	
	17.6		
Mix 15 min	18.7	18.54 ± 0.17	
	18.4		
Bez 1	12.3	12.14 ± 0.22	
	12.0		
Bez 2	11.5	11.60 ± 0.12	
	11.7		

The relative standard deviation among the different samples is 2.5%, which is below the target of 5% deviation between replicate samples. The average value is however quite different from the target value of 21 g/l, namely 14%. Similar to the previous step, the much lower value is difficult to explain. The actually added fresh weight of wastes and water volume were very close to the target values or setpoint and can thus not explain the deviation. Furthermore, the deviation is much higher than with the vegetables alone. It thus seems that mainly the urine and fecal material had much lower dry weights than estimated from other trials. It is proposed to correct this by proportionally increasing all waste fractions to the same final volume of 40 l.

Finally, it can also be observed that the 'settled' samples show a much lower dry weight than the mixed ones. It was indeed visually observed that in combination with the fecal material and urine, the straw particles have a tendency to float. The straw represented 215 g of dry weight, or 5.38 g/l on a total volume of 40 l. This corresponds to the reduction in dry weight observed between mixed and 'settled' samples.

3.3. Cleaning of WPU

Prerinsing was similar as described in 2.4. However, tank and shear pump were now prerinsed in 3 steps instead of 2. As mentioned before, 2 times 15 l of water was needed to be able to activate the shear pump. The diptube was rinsed with water as well.
The actual cleaning was performed with 30 l of 1% hypochlorite solution, which was circulated for 15 min through the unit, including diptube cleaning from both sides. Visually it could be observed that the waste material was much more sticky in this second step of the demonstration tests than without the urine and fecal material, and that the hypochlorite was effective in removing it, whereas tap water was not.
Postrinsing was performed with tap water first and then with RO water. For the future, we suggest to combine the postrinse of tank and shear pump, rather than doing it sequentially. Table 8 shows that the values of conductivity and turbidity approached those of pure RO water after 3 rinsing steps.

Table 8: Conductivity and turbidity values measured after subsequent rinsing steps with RO water and comparison to pure RO water. Each measurement was performed in duplo.

Condition	Turbidity (NTU)	Conductivity (µS/cm)
Pure RO water	0.14 – 0.25	1-1
1st rinse tank	0.27-0.29	47-53
2nd rinse tank	0.28-0.32	2-3
1st rinse pump	0.23-0.27	1-1
2nd rinse pump	0.17-0.19	1-2

Cleanliness was also checked visually by opening the tank, and disassembling the shear pump. The absence of particles or dirt is illustrated in Figure 5.

Figure 5: View of tank (left), and shear pump head (right) after complete cleaning cycle.

Finally, the agitator flange was rinsed and the water drained through the outlet.

For this test phase a deviation had to be recorded for the average dry weight values obtained. Retests were therefore planned in which all waste fractions are proportionally increased to the same final volume of 40 l, based on the dry weights determined.

4. Phase 2: Demonstration test results on real waste mixture: retests

4.1. Preparation of waste materials

As mentioned before, all waste fractions were proportionally increased. Based on the dry weights, the amounts mentioned in Table 9 were used. The amount recovered from the kitchen cutter was approximately 8.05 kg compared to 7.98 kg added (+ 100 ml of water to recover all vegetables). So there were certainly no losses.

Table 9: Weighed amounts of materials for the retests with the real waste mixture.

Material	Weight (kg)
Frozen red beet	1.71
Frozen lettuce	6.27
Straw	0.238
Toilet paper	0.040
Urine	3.327
Fecal material	0.201
Total	**11.786**

4.2. Checking homogeneity of mixing and size reduction of the waste mixture

This part of the tests aimed at checking the homogeneity of mixing the real waste mixture in a total working volume of 40 l. Analysis for particle size distribution was not performed because the presence of urine and fecal material is problematic for analysis in an external lab.

The procedure followed was quite similar to the one mentioned in 3.2, except that urine was left to thaw in a warm water at 30°C for several hours. Since the tests were scheduled on a Monday, it was not possible to keep them at 4°C overnight, as suggested previously. The final

level readout in the homogenization tank was 40.03 l. Increasing the mixer speed and shear pump speed did not induce foam formation. So again, the level switch could not be tested. Three samples were taken through the sample valve, mixer and shear pump were stopped and after 0.5 h 2 additional samples were taken through the drain. After switching on the stirrer again, the tank content was emptied, collected and stored at -20°C. The total weight collected amounted to 38.45 kg.

The dry weights measured are summarized in Table 10.

Table 10: Dry weight of the various samples taken during retests with the real waste mixture

Sample	Dry weight (g/l)	Average (g/l)	Overall average (g/l)
Mix 5 min	19.95	19.87 ± 0.12	20.11 ± 0.24
	19.78		
Mix 10 min	20.16	20.16 ± 0.00	
	20.17		
Mix 15 min	20.11	20.30 ± 0.28	
	20.50		
Bez 1	14.56	14.46 ± 0.15	
	14.35		
Bez 2	13.18	13.23 ± 0.06	
	13.27		

The relative standard deviation among the different samples is 1.1%, which is well below the target of 5% deviation between replicate samples. The average value is deviating 4% from the target value of 21 g/l, which is well within the allowed 10% variation.

Finally, it can again be observed that the ‘settled’ samples show a much lower dry weight than the mixed ones, caused by the floating of straw. The straw represented 238 g of dry weight, or 5.95 g/l on a total volume of 40 l. This corresponds to the reduction in dry weight observed between mixed and ‘settled’ samples.

4.3. Cleaning of WPU

Prerinsing was similar as described in 3.3. Tank and shear pump were prerinsed in 3 steps instead of 2.
The actual cleaning was performed with 2 x 30 l of 1% hypochlorite solution, which was circulated for 15 min through the unit, including diptube cleaning from both sides.
Postrinsing of tank and shear pump was now combined. Table 11 shows that the values of conductivity and turbidity approached those of pure RO water after 3 rinsing steps. Two additional rinsing steps brought the conductivity values further down to the 1 µS/cm level, originally measured for RO water. However, this is not considered necessary for future application.

Table 11: Conductivity and turbidity values measured after subsequent rinsing steps with RO water during retests and comparison to pure RO water. Each measurement was performed in duplo.

Condition	Turbidity (NTU)	Conductivity (µS/cm)
Pure RO water	0.09 – 0.10	1-1
1st rinse tank + pump	0.45-0.68	73-73
2nd rinse tank + pump	0.13-0.13	2-2
3rd rinse tank + pump	0.09-0.13	2-2
4th rinse tank + pump	0.14-0.20	2-2
5th rinse tank + pump	0.12-0.17	1-1

Cleanliness was also checked visually by opening the tank, and disassembling the shear pump. The unit was perfectly clean. Figure 5
Finally, the agitator flange was rinsed and the water drained through the outlet.

The results of the retests were in line with the targets. The tests were therefore concluded successfully.

5. Conclusions

The Demonstration test plan for the WPU was executed and showed that homogeneous waste mixtures can be obtained with the right particle size distribution. The dry weight values obtained with the real waste mixture including fecal material and urine were initially too low and retests were performed with adjusted waste fractions. This led to a result within the preset target ranges.