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DEVELOPMENT, BUILDING AND UTILISATION OF A BLACK WATER TREATMENT UNIT AT CONCORDIA

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EWC: Engineering of the waste compartment

UF: Ultrafiltration

NF: Nanofiltration

RO: Reverse osmosis

BWT-Unit: Black water treatment unit

GWT-Unit: Grey water treatment unit

TMs: Technomembranes

VFA: Volatile fatty acids

OM: Organic matter

COD: Chemical oxygen demand

GAC: Granular activated carbon

FM: Faecal material

DO: Dissolved oxygen

1. Introduction

The permanent base called Concordia is since one year open in the centre of Antarctic continent. There, a Black Water Treatment Unit (BWT-Unit) will be elaborated to treat the waste produced by 15-16 persons for 365 days. The black water treatment unit has to ensure satisfactory functioning when the load is 5 times higher than the load engendered by 15 persons (this is a waste load generated by up to 75 persons). Indeed, in addition to the 15 crew members in permanence at the Concordia station (± 12 months), the station is expected to be manned with 35 extra crew members for 90 days/year and another 20 persons for 30 days/year (see Figure 1).

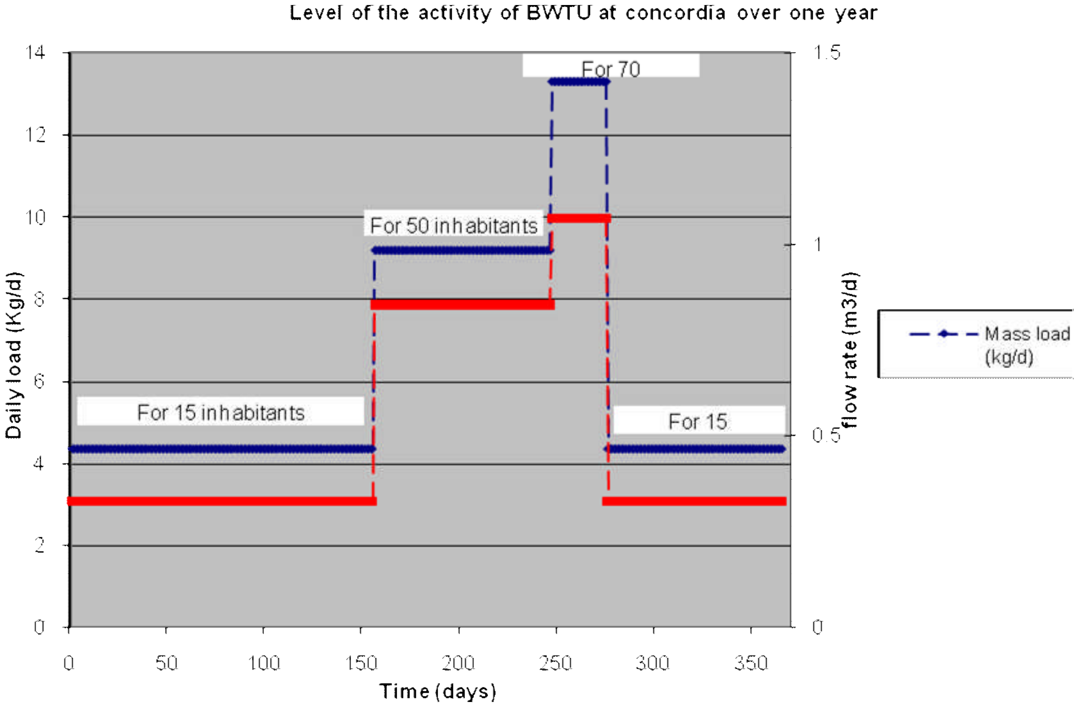


Figure 1. Inhabitation of Concordia base

Because of the high organic load and nitrogen load generated per day by the inhabitants (see Figure 1), anaerobical biological systems were considered the most appropriate. It was therefore necessary to determine the process parameters and to study the limitations of such a system for the treatment of highly loaded influents.

In this document, process parameters and system limitations are defined. Based on the biodegradation efficiencies, reactor volumes are calculated. Extreme conditions are also tested, like a sudden increase in the organic load or nitrogen load and peak increase in alcohol load in the influent, in order to determine the limitations of the system and to formulate some recommendations for the operation on-site.

2. Work plan

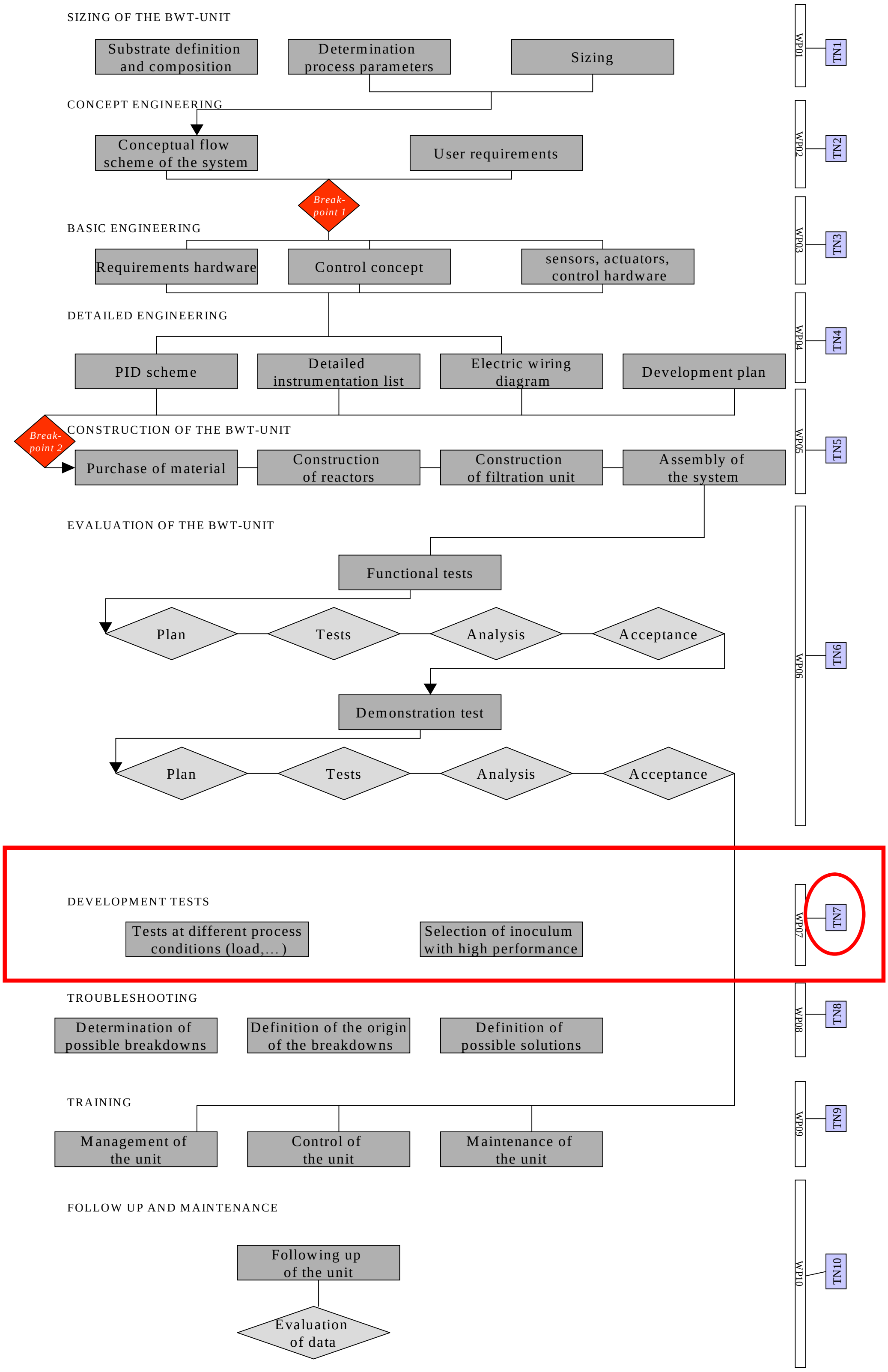


Figure 2: Work plan for the development of the BWT-Unit

3. Objectives

The objectives of this activity can be summarized into three main points:

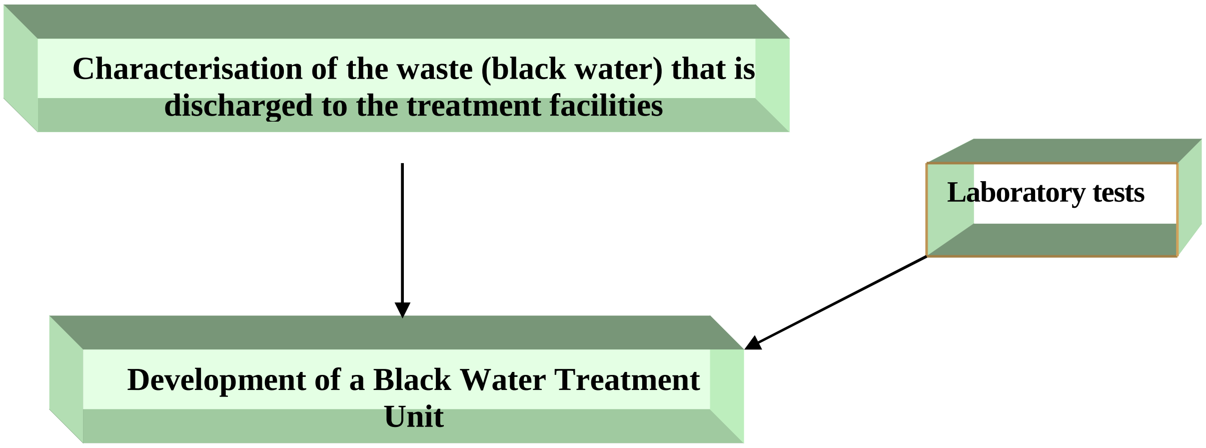
1. Development of a Black Water Treatment Unit (BWTU) at Concordia base to treat, faecal material, urine, kitchen waste (kitchen diner rests and kitchen waste) and concentrate from GWT-unit.

2. The determination of the process parameter values and the necessary reactor volumes.

3. A scenario analysis to determine and define the operation limits of the units.

Based on the infrastructure of the base, and the number of persons, the sizing of the BWT-Units was elaborated. The expertise that is gained from the research done for ESA/ESTEC in the MELISSA project (Engineering of the Waste Compartment) was used for the elaboration of the concept and engineering of the Black Water Treatment Unit.

Before initiating the construction of the BWT-Unit, some important steps should be considered as follows:



4. Influent composition of the BWT-Unit- Concept basis

In addition to faecal material, urine and toilet paper, the influent of the BWT-Unit will also contain kitchen waste (peals, rinds, etc) and rests from the dining rooms. Moreover, the concentrated streams generated from the GWT-Unit, mainly from the ultrafiltration and nanofiltration will also be directed towards the BWT-Unit. To better understand the interactions BWT-Unit and GWT-Unit, the following scheme was made (see Figure 3). Since the two units are interconnected, it is of interest to have a global overview of the total waste water treatment of the Concordia base. Indeed, the GWT unit will treat the effluent coming from the BWT unit. The concentrates from different filtration steps of the GWT unit will moreover be sent to the BWT unit. These connections were made for the nominal case of 50 persons occupation.

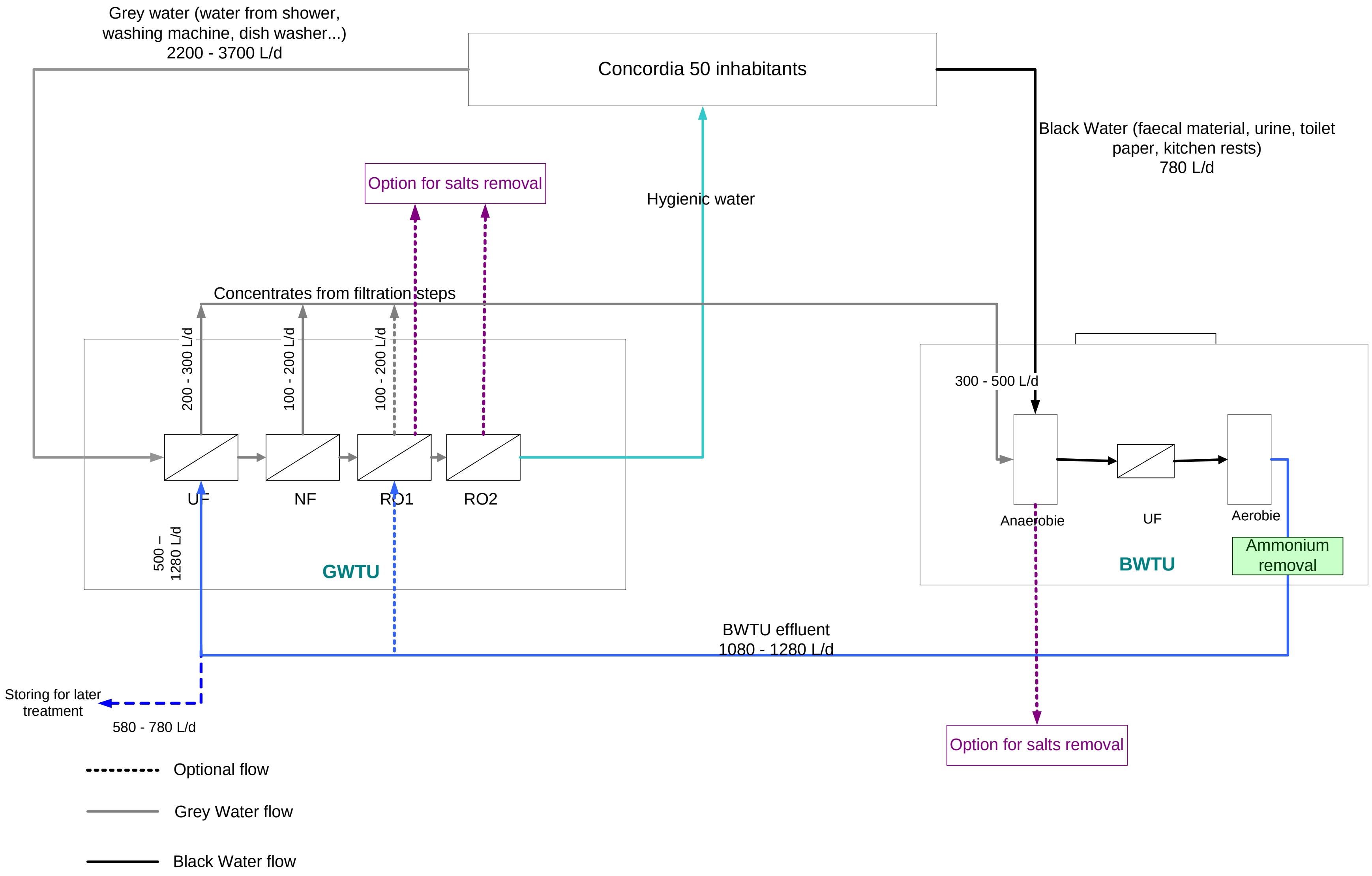


Figure 3. Interactions GWT / BWT units

4.1 Diet of Concordia inhabitants

The influent composition of the BWT-Unit will depend on the diet of the inhabitants of Concordia. Because very little is known about this diet, it was decided to select some commonly consumed vegetables to evaluate the diet. The following data are extracted from technical notes made in the framework of the MELISSA project, mainly TN 51.4 and TN 32.3. The data presented in Table 1 concern the CEEF (Closed Environmental Experiment Facility) project conceptually made for long term living in a closed system.

Table 1. Food consumed and waste generated (g) by one man a day

Plants	**Ingested food*** (g/person.d)	**water content** (%)	**Food consumed** (gDW)	**Food wasted** (%)	**Food waste** (g fresh W)	**Food wasted** (gDW)
Rice	400	13.10	350	NC (0%)	0	0
Soybean	150	8.5	122	NC (0%)	0	0
Sesame	120	13.2	104	NC (0%)	0	0
Spinach	400	91.6	33.6	30	171	14.4
Tomato	100	94.2	5.8	55	122.2	7.1
Potatoes	150	77.8	33	17	30.7	6.8
Soba (crop) or wheat	73	13.2	63	NC (0%)	0	0
Total	1393 (725 g DW)		711.4		324	28.3

NC: not considered since the food is supplied and not cultivated.*; CEEF data

For the rests from the dining room, some 10% of what is consumed by one person was considered to be wasted, this means that around **140 g fresh food** is left per person and per day (this is 73 g DW left per person and per day). The total wasted food, to be considered in this study, will include the fresh food waste **(324 g)** added to the rest of the dining room **(140g).** A total kitchen waste of **464 g fresh weight/person.d** will thus be considered to be sent to the black water treatment unit. Expressed in dry weight, the total wasted food per person and per day is (28.3 g + 73 g) = **101.3g.**

Kitchen waste produced by 15 persons = 7 kg fresh weight/d.

Kitchen waste produced by 70 persons = 33 kg fresh weight/d

According to IPEV, an average volume of 4L/person.day can be considered to dilute this food waste and process them in the available kitchen disposer.

4.2 Composition of toilet waste

Tables 2 and 3 present the average composition and amount of faecal material, urine and toilet paper generated per person and per day. The influent will be made of diluted feed since around 10 L water are used per flush and per person. The data presented on Table 2, are based on experiments carried out at EPAS and ESA and taken from technical notes (MWT TN1, MELISSA TN1).

Table 2 : Loads and flows of organic waste produced by one person and per day

Compound	Production (g/person.day)	Concentration (g/L)
Faecal Material		
DM	30	330
OM	27	300
Ash	3	33
Water	90	
N	1.5	16.7
Urine		
DM	51	34
OM	36	24
Ash	15	10
Water	1500	
N	12	8
Toilet paper		
DM	18	
Feed = Faecal Material + Urine + toilet paper		
DM	99	51
OM	63	39.6
Ash	18	28.6
Water	1590	
N	13.5	8.5

The BWTU unit will thus have to treat the following amounts of material (for 25 persons):

Table 3: Faecal Material + Urine + Toilet paper composition for the complete unit

	For 15 persons	For 70 persons
DM	1.485 kg/d	6.930 kg/d
OM	0.945 kg/d	4.410 kg/d
Ash	0.270 kg/d	1.260 kg/d
Water	23.85kg/d	111.3 kg/d
N	0.203 kg/d	0.945 kg/d

The amount of water used to flush the toilet is estimated around 10L/person.day.

4.3 Composition of concentrate from GWT-Unit

The Grey Water produced by the inhabitants of the base (waste water generated from showers, washing machine, dish washer, cleaning and cooking) is treated by a system of filtration developed by Technomembranes. These flows contain different kinds of disinfectants which are summarized in Table 4.

Table 4. Origin of Grey Water flows

Origin of the flow	Cleaning product	Dosage	Proportion in the total Grey Water flow
Washing machine	Henkel PERCROIX Henkel TRAX	2.25 g/l 0.5 ml/l	19 %
Dish washer	Yplon Fery Henkel TOPMAT	2.3 ml/l 0.44 ml/l	25 %
Hands cleaning	DEB	5.3 ml/l	15 %
Hand dish washing	Henkel TETROX	5 g/l	8 %
Showers	NEUTROGENA	0.25 g/l	23 %
Floor cleaning	GRADEX OR	10 ml/l	2 %
Cooking water	-	-	8 %

The different levels of filtration generate wastes. Given their high content in COD, these concentrates from the ultrafiltration and the nanofiltration steps are aimed to be further treated in the BWT unit. The GWT unit reaches an efficiency of 90% in these filtrations, which means that around 10% of the total grey water treated needs to be directed towards to the BWT unit. The characterization of these concentrates is presented in Table 5 (the flows are given for an occupation of 25 persons).

Table 5. Characteristics of concentrates from the GWT-Unit

	Concentrate Ultrafiltration	Concentrate Nanofiltration
T.O.C (ppm)	1400 – 3800	400 – 1500
C.O.D (ppm)	6500 - 17500	
Cond. (µS/cm)	1900 – 2500	2500 – 6000
pH	8.3 – 8.4	8.4 – 8.6
F^- (ppm)	3 – 5	10 - 20
Cl^- (ppm)	20 - 40	100 - 200
NO_3^- (ppm)	2 - 3	5 - 15
PO_4^{2-} (ppm)	50 - 300	50 - 100
SO_4^{2-} (ppm)	250 - 300	500 - 800
Na^+ (ppm)	400 - 600	600 - 1500
K^+ (ppm)	150 - 200	200 - 400
Mg^{2+} (ppm)	10 - 30	15 - 20
Ca^{2+} (ppm)	50 - 150	40 – 60
Volume (L/day)	160	100

4.4 Total loads and flows of the BWT-Unit

As mentioned above, the BWT-Unit of the Concordia base will have to treat the faecal material, urine and waste food including toilet paper, kitchen rest generated by 15 up to 70 persons during 365 days (12 months). The unit should also treat the concentrates drained from the UF and NF of the GWT-Unit.

According to IPEV, a volume of 10L is used per person a day for the toilet flush. In this volume, 1.5 L urine, 0.09 L faecal material, 18g toilet paper (data generated from EWC reports) and 464 g fresh kitchen waste generated by one person will be diluted. This consists of a total volume of ± 1.6 L/d produced by one person to be treated in the BWT-unit diluted in 10 L water. On this influent the concentrate from the grey water system will be added, with a volume of 10.4 L per person and per day. Table 6 gives an overview of the loads and flows generated by the Concordia inhabitants and which will have to be treated by the BWT-Unit.

Table 6. Feed composition of the BWT-unit of Concordia

	Toilet flush	**Toilet paper (DW)**	**Urine (DW)**	**Faecal material (DW)**	**Food waste (DW)**	**Food waste (FW*)**	**Grey water (COD)**
Load (g/person.d)	0	18	51	30	101.3	464	68- 182
Flow (L/person.d)	*10*	*0*	*1.5*	*0.09*	-	*4*	*10.4*
Load (g/15 persons.d)	0	270	765	450	1520	7000	1020 - 2730
Flow (L/.d)	*150*	*0*	*22.5*	*1.35*	-	*60*	*156*
Load (g/70 persons.d)	0	1260	3570	2100	7091	33000	4760 - 12740
Flow (L/d)	*700*	*0*	*105*	*6.3*	-	*280*	*728*

*: Fresh weight

5. Listing of the unwanted waste in the BWT-Unit

Food stuff	**DO NOT THROW IN THE UNIT**	**DOUBT => test**
From food wastes :		
- Bones	X	
- Shells	X	
- Fishbone	X	
- Cheese rinds	X	
- wine	OK	Tested for equivalent of 10L/d for few days on lab reactors
- Beer	OK	
- Distilled alcohol	OK	
- Eggshells		Tested on lab - scale unit
- Fruit skins	OK	
- Fruit stones	X	
- Packages, non food	X	
From black water :		
- Pill		Evaluate accumulation of hormones in the effluent
- Antibiotics		Test on the real unit still to perform
- Hygienic swabs	X	
- Sanitary towels	X	

6. Proposed technologies for the development of a BWTU

The black water treatment unit will have to treat ground kitchen waste, human fecal material and paper from a vacuum toilet and part of the membrane filtration concentrate from the grey water treatment system.

The acidifying reactor is preferably a membrane bioreactor because this concept is a very compact and efficient one for water treatment and because this allows an additional bacterial reduction of the generated water.

Tests have been performed at laboratory-scale in continuous mode with a bioreactor equipped with ultrafiltration membranes from X-Flow (Ref: WFF 4385) with 30 nm mean pore size and 5 mm internal diameter.

Boundary conditions which certainly have to be taken into account for the design of the UF-Unit are the following:

- treatment capacity: black water from 15 to 70 people, or 0.4 to 1.35 m³/d
- retention time in the bioreactor of 3 days
- treatment of 1-5% slurry
- minimal interference of membrane unit with sludge and sludge activity
- minimal cleaning requirements via optimal hydraulic conditions
- provisions for cleaning in place
- operation at 55°C
- flexibility in membrane surface area
- complete construction in stainless steel
- material choice compatible with existing treatment units at Concordia
- minimized level of automated control

7. Lab-scale set-up

In order to support the design established for the BWT-unit, tests on laboratory set-ups were performed. The general concept of the laboratory set-up is shown in Figure 4.

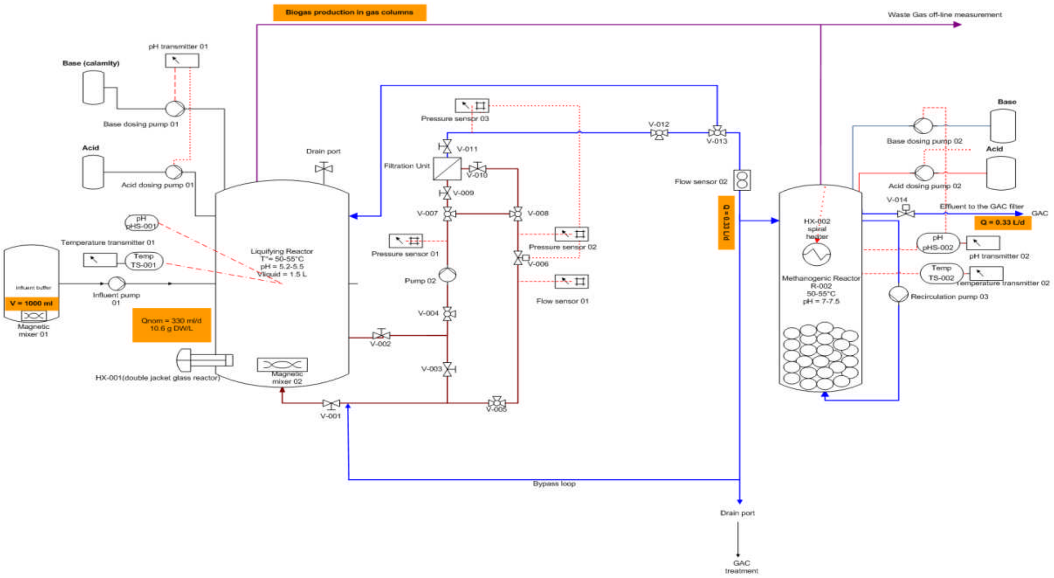


Figure 4. Conceptual design of the laboratory set-up BWTU

The coupling of the anaerobic liquefying reactor to the methanogenic reactor, via the ultrafiltration unit, was performed at lab-scale level to study the interfaces between the two reactors. These laboratory tests focussed on the selection of a high performance inoculum for given conditions. As already mentioned, the set up was operated at different process conditions to support the dimensioning and define the optimal control strategy.

The development tests on the lab-scale set-up were primarily performed on the two first sub-systems of the BWT-Unit (liquefying and methanogenic reactors) and the ultrafiltration sub-system (Figure 4). During this phase, the BWTU performances were focussing, mainly, on its ability to degrade organic matter, to produce biogas (CH_4 and CO_2) and to convert urea into ammonia via anaerobic processes. The processes are fully described in TN 1. In Figure 5, a general view of the lab-scale set-up is shown. The operation of the BWTU is described in TN 2.

Figure 5. View of the lab-scale set-up. From right to left: Liquefying reactor, Ultrafiltration unit and methanogenic reactor

7.1 Description of the process conditions

For each compartment, it is necessary to respect the process conditions at which maximum efficiencies are expected.

7.1.1 Liquefying reactor

The most important process parameters and their related values which were taken into account for process optimisation and design of the liquefying reactor are reported in Table 7.

Table 7. Process design characterisation for the liquefying reactor

Parameter	**Required value**
pH	5.5 to 6
O_2	< 0.05% (anaerobic conditions)
Heating system: Temperature	Thermophilic range 50-55°C (+/- 1°C/d fluctuations)
Hydraulic retention time: HRT	3 days

Solid retention time: SRT	∞ because of continuous recirculation of the solid back to the reactor
Volumetric loading rate: Bv	< 6.4 kg VS*/m^3.d.
Biogas production rate	0% CH_4 and > 80% CO_2 with traces of H_2 , H_2S and others at ppm level
Total nitrogen	< 3 g N/L

*: Volatile solids

The two key process parameters pH and temperature were followed on-line and controlled using a local control. pH was regulated by dosing acid or base to keep the pH between 5.2 and 5.5. The temperature in the reactor was controlled on-line via a thermostatic bath regulated to keep the temperature between 50 and 55°C.

7.1.2 Feeding procedure of the liquefying reactor

Effluent collected from the EWC lab-scale liquefying reactor was regularly collected and kept in the fridge. Since the composition of the EWC influent is different from the one of the BWT-Unit (no urine and non diversified kitchen waste), the reactor was inoculated up to 1/3 with the refrigerated EWC effluent. After re-establishing the operating conditions (temperature of 55°C, pH of 5.2 – 5.5 and ensuring anaerobic conditions by flushing the reactor with N_2 gas during the start-up for 48 hours, the feeding was initiated. Reactor conditions were as follows:

- $V_{reactor} = 1.5$ L
- Temperature = 55°C maintained by pumping warm water through the double jacket of the reactor via a thermostatic water bath..
- The reactor was completely stirred using a magnetic stirrer.
- The influent was introduced continuously using a pulse pump.
- The gas loop was connected to gas columns to measure the volume of gas produced.
- The gas composition (CO_2, CH_4, H_2, O_2) was measured daily using a portable gas analyser (type infra-red gas analyser Geotechnical instruments®). H_2S was also measured each two days, using the Gastec® kit.
- The produced effluent was pumped to the ultrafiltration unit. While the filtrate was pumped to the methanogenic reactor, the concentrate was returned back to the liquefying reactor for further processing.

7.1.3 Inoculum selection

For the inoculation of the bioreactors, it was decided to use autochthonous bacteria already present in the influent (in faeces, in urine and in kitchen waste). However, to enhance the process, biomass collected from the EWC lab-scale reactors (refrigerated inocula from liquefying and methanogenic reactors) were first grown on the reactors before feeding. Process conditions were established (see section **Fout! Verwijzingsbron niet gevonden.**) so as to allow the biomass to restore its activity and the influent was afterwards fed to the reactors.

7.1.4 Methanogenic reactor

Figure 6. View of the lab-scale methanogenic reactor

As for the liquefying reactor, the methanogenic reactor was inoculated with the biomass from the effluent of the non acidified EWC lab-scale reactor. Since the composition of the EWC influent is different from the one of the BWT-Unit (no urine and non diversified kitchen waste), the methanogenic reactor was inoculated up to its 1/3 with the refrigerated non-acidified EWC effluent (Figure 6). After re-establishing the operating conditions (temperature of 55°C, pH of 7 and anaerobic conditions by flushing the reactor with N_2 gas during the start-up) for 48 hours, the feeding was initiated.

Reactor conditions were as follows:

- $V_{reactor}$ = 1.5 L (liquid volume)
- Temperature = 55°C maintained by pumping warm water through the spiral tubing around the reactor via a thermostatic water bath.
- The reactor was an UASB (Upflow Anaerobic Sludge Blanket) type filled for 1/3 with carrying material to avoid wash out of the methanogenic bacteria from the reactor.
- Reactor content was continuously recirculated at a pump speed of 10 rpm to allow homogeneous mixing of reactor content and distribution of the influent when entering the reactor.
- The effluent coming from the liquefying reactor was introduced continuously using a pulse pump.
- The gas loop was connected to gas columns independently from the ones of the liquefying reactor to measure quantitatively and qualitatively the effective volume of gas produced from the methanogenic bacteria.
- The gas composition (CO_2, CH_4, H_2, O_2) was daily measured using a portable gas analyser (type infra-red gas analyser Geotechnical instruments®). H_2S was also measured each two days, using the Gastec® kit.
- The produced effluent was overflowed towards a granular activated carbon filter (GAC).

The process conditions in the methanogenic reactor are summarised as shown in Table 8

Table 8. Process conditions in the methanogenic reactor and related values

Parameter	**Required value**
pH	7 to 7.5
O_2	< 0.05% (anaerobic conditions)
Heating system: Temperature	Thermophilic range 50-55°C (+/- 1°C/d fluctuations)
Hydraulic retention time: HRT	3 days
Solid retention time: SRT	∞ : the bacteria are trapped in the fixed bed
Biogas production rate	80% CH_4 and ± 20% CO_2 with traces of H_2 , H_2S and others at ppm level
Total nitrogen	< 3 g N/L

7.1.4.1 Description of the support material

To serve as carrying material for the methanotrophs in the methanogenic reactor, the choice was directed towards the Davicat SP 550-10046 carrier material from Davison® Catalysts. For purification purposes, GRACE Davison is offering miniliths in a wheel-like structure as alternative to beaded molecular sieves. Such materials can be used in small reactors when a very fast adsorption kinetics needs to be combined with a low pressure drop

Miniliths zeolites are typically ¼ to ½ inch in length with a cylindrical cross-section. They are formed by pushing an extrusion paste through concentric dies such that tubes or other longitudinal voids are created. The purpose of these voids is to increase the geometric surface area to assist in diffusion-limited reactions. Miniliths are most appropriate for reactions with very fast kinetics that require high space velocities. Of the different catalyst support forms, miniliths have the lowest pressure drop with as main disadvantage of being the most expensive one as shown in Figure 7.

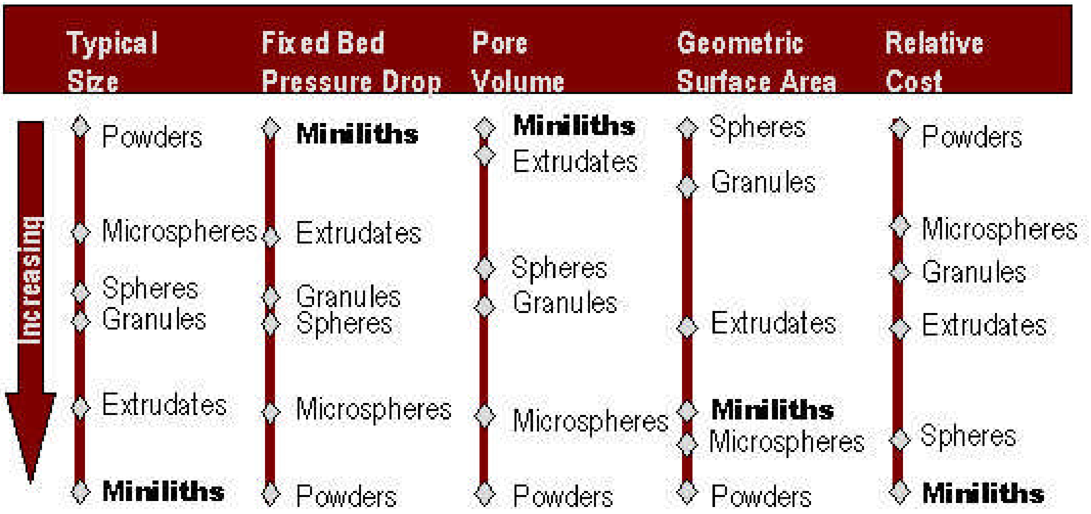


Figure 7. Characteristics of Miniliths carrying material

The primary features of Miniliths are:

1. Increased geometric surface area
2. Decreased pressure drop when compared to comparably sized solid extrudates
3. Crush strengths decrease approximately 30% in return for the improved surface area and decreased pressure drop.

Comparing Miniliths with bead based fixed beds, miniliths show the following advantages:

1. Higher equilibrium capacity per volume unit
2. Faster adsorption velocity
3. Less and constant pressure drop
4. Easier handling
5. No dust, no attrition
6. Higher stability for liquid water
7. No channelling (real fixed bed)

7.1.5 Ultrafiltration unit

Based on the expertise gained from the EWC, it was decided to adapt the same technology for the ultrafiltration system on the BWT-Unit. Nevertheless, the lab-scale set-up was operated to verify the performances of the selected filtration unit with the sludge suspension of the BWT-Unit.

During the test period, organic membranes (PVDF-type WFF 4385) from X-Flow (www.X-flow.nl) were used with the following characteristics and application fields

7.1.5.1 BASIC CHARACTERISTICS

- Hydrophilic tubular polyvinylidene fluoride membrane cast on a polyester carrier
- Tubular membrane with 5 mm diameter
- Structure asymmetric
- Developed for use in large-scale processes for water purification
- High performance and a very good anti-fouling behaviour according to the supplier
- Membranes can be supplied in a standard range of elements
- Membrane elements can be backflushed for efficient membrane cleaning resulting in a higher average

product flux

7.1.5.2 APPLICATIONS

- Pre-treatment RO and NF

- Surface water
- Drinking and process water production
- Recovery of sandfilter backwash water
- Effluent treatment
- Membrane bioreactor
- Waste water treatment
- Treatment of oil-in-water emulsions

7.1.5.3 PERFORMANCE DATA

Based on tests performed with water at X-Flow laboratories,

Parameter	**unit**	**F 4385**	**remarks**
Clean water flux	$l/m^2.h.100$ kPa	> 1000	RO-water at 25°C
Transmembrane pressure	kPa	-100 .. + 500	
Mean pore size	nm	30	
pH		2 - 10	at 25°C
Chlorine exposure	ppm.h	250000	at 25°C
Temperature	°C	1 - 70	pH 7 and 100 kPa

NOTE: Operation of membranes at any combination of maximum limits of pH, concentration, pressure or temperature, during cleaning or production, will severely influence the membrane lifetime.

7.1.5.4 SOLVENT RESISTANCE

Since the resistance of the membrane to solvents strongly depends on the actual process conditions, the indications given below should only be considered as guidelines.

Acids, pH > 2	+
Bases, pH < 11	+
Organic esters, ketones, ethers	—
Aliphatic alcohols	++
Aliphatic hydrocarbons	++
Halogenated hydrocarbons	++

Aromatic hydrocarbons	+
Polar organic solvents	—
Oils	++

7.1.5.5 CLEANING

Actually cleaning procedure tests for PVDF membranes are performed at EPAS, using as sludge suspension the content of the EWC fermentation reactor. Despite the fact that the consistence of the sludge and DM concentration are different from these of the BWT-Unit, the later being more diluted, testing cleaning procedures on EWC sludge will permit to foresee rapid solutions in worst cases in the BWT-Unit. The following cleaning agents have been chosen, according to the directives from X-Flow:

Chemical cleaning:	NaOCl (active chlorine)	500 ppm max.
	H_2O_2	1000 ppm max.
	NaOH	pH ≤ 11
	Nitric acid	pH ≥ 1
	Phosphoric acid	pH ≥ 1
	EDTA	pH ≤ 11
	Citric acid	

It is recommended from the supplier to keep the pH between 1 and 11 and not to exceed a temperature of 40 °C during cleaning and/or disinfection. If those standard cleaning techniques fail to remove the fouling compounds, more concentrated cleaning solutions could be tried.

7.1.5.6 STORAGE

New membrane modules can be stored as supplied. Membrane modules should be stored in a dry, normally ventilated place, away from sources of heat, ignition and direct sunlight. Store PVDF membranes between 0 and 40 °C.

The membrane modules should not be subjected to any freezing temperatures. After use, UF membranes need to be stored wet at all times.

To avoid biological growth during shutdowns or storage, wet membranes should be treated with a compatible biocide. The membrane is compatible with many common disinfecting agents or biocidal preservatives. For short-term shutdowns, a daily flush with permeate quality water containing up to 2.0 ppm free available chlorine for 30 to 60 minutes may be adequate for bacteria control.

In case of long-term storage, membranes should be cleaned before the disinfection step is carried out. For disinfection, a 1% sodium metabisulfite solution can be used. In either situation, modules should be stored hydraulically filled.

As major disadvantage of the PVDF membranes is clearly stated by the supplier since it was stressed, that no warranty can be given on the efficiency of any cleaning nor on the membrane performance after such cleaning attempts.

Another type of membranes are at present being tested at EPAS. For the purpose of liquid-solid separation for VFA, salts and minerals recovery from the liquefying reactor, inorganic membranes seem also to be a good alternative. The major advantage of these membranes is there long life time, resistance to highly fluctuating temperatures, sterilisability at 121°C if necessary. In the framework of the BWT-Unit project, life time of the membranes is one of the prime criteria. Therefore, selection of an adequate UF-Unit should be studied carefully.

7.1.5.7 UF-laboratory set-up

In the laboratory-scale tests performed by EPAS, mean fluxes of 14.6 l/m².h have been obtained. These were used as a starting point for the design and calculation of membrane surface area of the full-scale treatment unit (see TN 3). Based on the experience gained in MELiSSA-project (EWC) where almost similar slurries have to be treated, an optimal design was proposed.

The membrane bioreactor principle will be an external one. This means that the membrane is placed outside the bioreactor. In this case, a sufficiently high cross-flow velocity is needed along the membrane to reduce membrane fouling. For an accurate follow-up of membrane performance, the following parameters need to be measured:

- flow in the filtration loop: this allows to calculate the cross-flow velocity
- flow in the permeate line: this allows to calculate the amount of black water treated
- turbidity in the effluent line: this allows follow-up on membrane integrity
- pressure before and after the membrane module: this allows the calculation of transmembrane pressure and the evaluation of clogging and fouling problems

It is of utmost importance for proper functioning of the filtration unit that the feed to the bioreactor is free of sand and contains no large paper fragments.

7.2 Feed preparation

As mentioned previously, the feed of the BWT-Unit consists of Faecal material, urine, toilet paper, kitchen waste, rests from the dining room and concentrate UF/NF generated by the GWT-Unit. Faecal material, urine, toilet paper and toilet washing and cleaning water are mixed by means of a vacuum system in which they are mixed and grinded. Kitchen waste is selected according to the directives given by EPAS to IPEV (see section 0) which are based on tests performed in laboratory and is grinded by means of an integrated kitchen grinder, type EFAS® kitchen grinders. Toilet waste together with kitchen waste, are mixed in a collection tank together with the synthetic concentrates UF/NF from the GWT-Unit. The collection tank is provided by IPEV.

At lab-scale level, feed preparation was rather preliminary. The kitchen rests and the waste were grinded with a knife mill (from Retsch®). The faecal material as well as urine were individually collected in small vessels from donators from both sexes (men and women) and toilet paper was added afterwards in proportions as in the case of EWC feed preparation (see Table 2). The whole mixture was grinded into fine particles of about 2 to 4 mm using an IKA® mixer in a collection tank as shown in Figure 8.

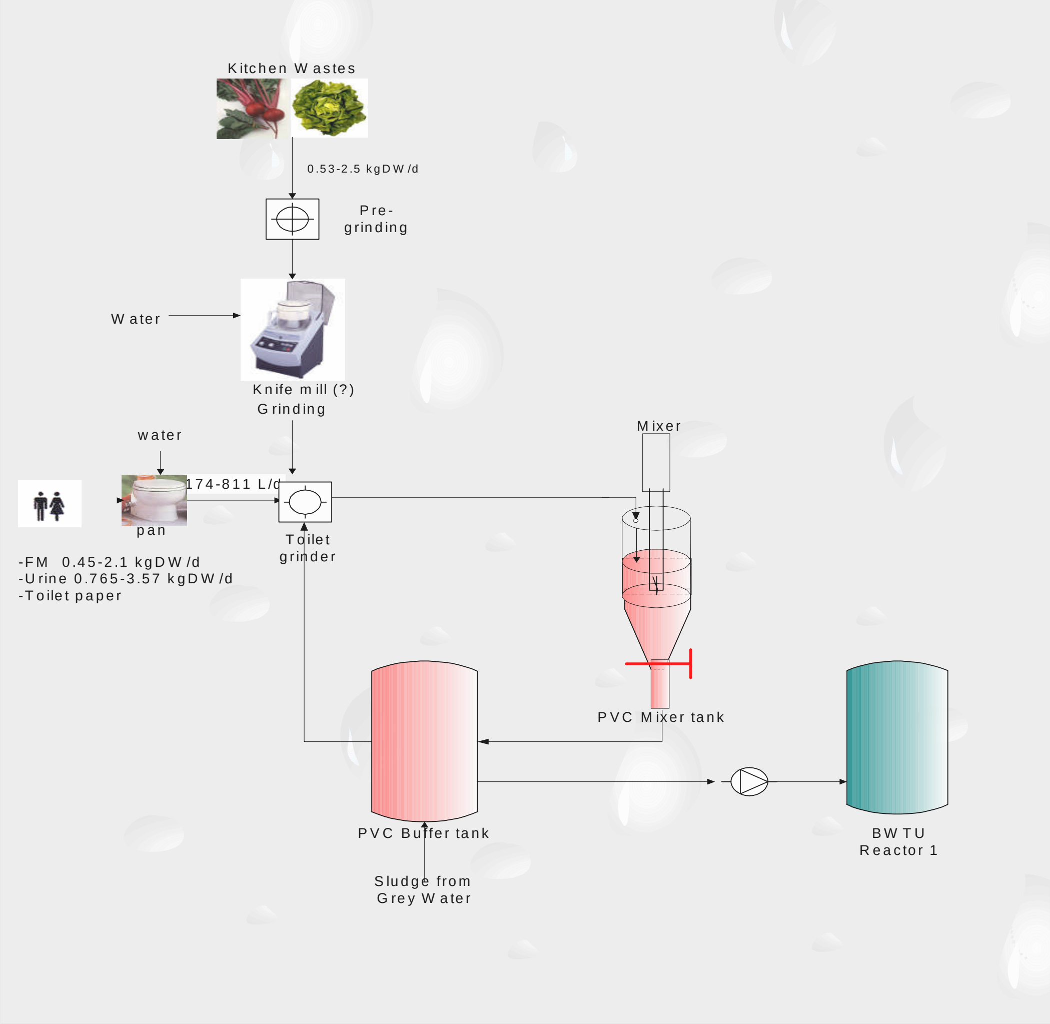


Figure 8. Feed preparation of the BWT-Unit at lab-scale level

It was not possible to provide EPAS with samples of the concentrates from the UF and NF. It was therefore decided to simulate the composition of these concentrates by making synthetic grey water concentrates. Knowing the origin of the cleaning products (provided by Technomembranes) and their proportions in the grey water flow (Table 4), a synthetic solution was made. Based on the characteristics of the concentrates generated by the UF and NF (Table 5), a COD source, in the form of acetate was added to the synthetic solution. Oxonia (0.2%) is also present in the composition of the grey water since it is introduced in the beginning of the filtration system of the GWT-Unit. In order to comply in all concentrates conditions, oxonia was also added to the synthetic grey water solution (0.2% V/V). This was corresponding to 0.5 ml Oxonia (0.2%) in 1 litre influent.

8. Test results from the laboratory set-up

8.1 Acid base consumption in the liquefying and methanogenic reactors

Supplying the inhabitants of Concordia station with the necessary equipment and chemicals from the beginning of the installation of the BWT-Unit is important since the difficulty to access the station for at least 1 year. Estimation of the amounts of the necessary products for the running of the unit was performed. Acid will be dosed in the liquefying reactor to keep low pH values (5.2 to 5.5) and base will be dosed in the methanogenic reactor to keep the pH neutral. Based on the chemicals which, were tested on the lab-scale BWT-Unit, the necessary volumes of HCl and NaOH needed to be shipped to Concordia base were estimated. The results of the daily needs are presented in Table 9.

8.1.1 Study of the buffering capacity of the influent

The influent composition of the BWT-Unit varies depending on the daily prepared meals, on the ingested proportions and the waste produced. As a consequence of a such variations, the pH of the influent will vary leading to variations in process stabilisation in the liquefying reactor. The pH in the reactor should be stabilised between a minimum of 5.2 and a maximum of 5.6. It is therefore important in such a case to verify the buffer capacity of the influent to have an idea about the amount of chemicals necessary for pH regulation.

The buffer capacity of the influent was performed on a standard prepared sample with almost a neutral pH. The sample was titrated with an HCl solution (0.5M) and for each addition the new pH was reported with the aim to reach the minimum expected pH of 5.2 in the liquefying reactor. The results of the experiment are reported in Figure 9.

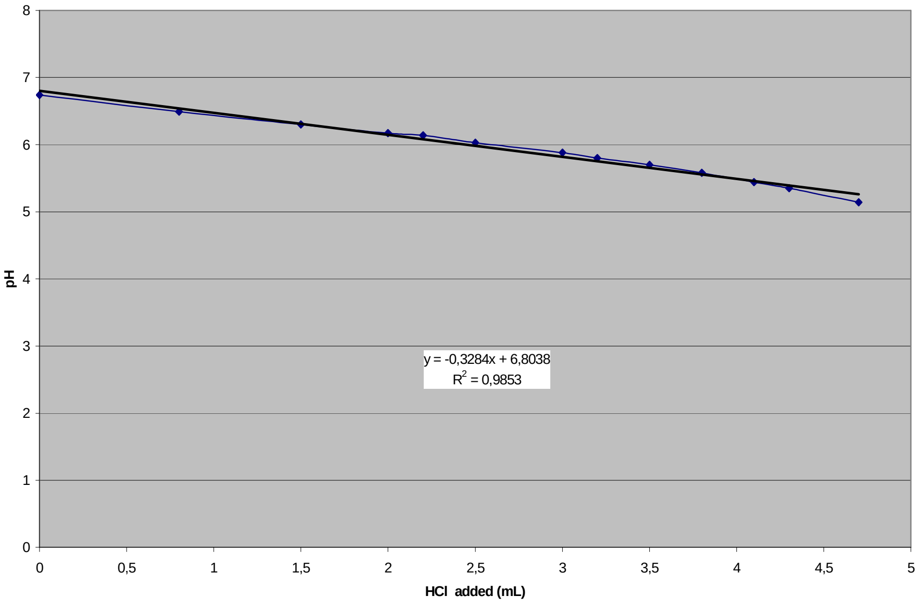


Figure 9. Correlation between pH and HCl volumes dosed in the influent BWT-Unit

The corresponding volumes of HCl needed for the BWT-Unit at large scale are reported here below:

vol sample (L) =	0,5
HCl (mol/L) =	0,5
extraplolation:	
ml HCl / unit pH	0,33
unit pH from 6,74 = >5,2	1,6
HCl (ml) /0,5L inf	2,94
HCl (mol) /0,5L inf	0,00147
HCl (mol) /L inf	0,00294

BWTU big unit	**15 inhabitants**	**50 inhabitants**	**70 inhabitants**	**Unit**

	390	1000	1350	inf L/d
	142350	365000	492750	inf L/year
	418,15	1072,19	1447,45	HCl mol/year
	42	**107**	**145**	HCl (10M) L/year

According to this experiment, for a stable influent pH of 6.8, a volume of 5.8 ml of HCl (0.5 M) per litre influent is needed to reach a pH of 5.2. This means that for a big installation of a minimum of 15 inhabitants and a maximum of 70 inhabitants, volumes in the range of 145 L (HCl 10M) will be needed to be at the site per year.

This experiment relay on the condition that the pH of the influent is stable over the year. However, this is not the case as shown in Table 9 and therefore, higher volumes of base and acid should be considered as a storage at Concordia site.

Table 9. Necessary daily acid and base volumes for the BWT-Unit

	Flow (L/d)	Influent flow (L/d)	Acid HCl 0,5M (L/d)	Base NaOH 0,1N (L/d)	Acid HCl 5M (L/d)	Base NaOH 5N (L/d)	Acid HCl 10M (L/d)	Base NaOH 12,5M (L/d)
Base occupation	15 persons	**390**	**190**	**0**	**19**	**0**		
	50 persons	**1040**	**45**	**35**	**4**	**1**	**2**	**0,5**
	70 persons	**1350**					**4**	**1**

HCl = 37% ,	Kg/L added for HCl 37%	Molarity of HCl (37%)	Kg/L added for HCl 30%	Molarity of HCl (30%)
Volumetric mass = 1,19 kg/L	**0,4403**	**12,1**	**0,357**	**10**

NaOH = 50%	Kg/L added for NaOH 50%	Molarity of NaOH (50%)
	0,5	**12,5**

In total, and considering that the station is inhabited for 365 days by 70 persons, the maximum volumes needed per year of NaOH and HCl are: 400 L and 1500 L, respectively.

During performance of the tests to determine the volume of acid (HCl) consumed per day for two different hydraulic residence times in the reactor: 7 days (referring to a 390 L/d influent flow rate and from 15 persons) and 2.6 days (referring to a flow rate of 1040 L/d influent flow rate from 50 persons), a certain equilibrium was observed after a few days of acid dosing in the reactor. The reactor has reached a buffering level at which less acid was dosed when the influent flow rate has increased from 390 L/d to 1040 L/d (for laboratory set-up the increase in influent flow rate was from 130 mL/d to 480 mL/d). This buffering capacity is an indication why less acid is expected to be dosed when the crew occupation in the Concordia station will increase from 15 to 50 persons.

In total, and considering that the station is inhabited for 365 days by 70 persons, the maximum volumes needed per year of NaOH and HCl are about 365 L (+/- 400 L NaOH 12.5N) and 1460 L (+/- 1500 L HCl 10M), respectively.

The possibility to use another chemical than HCl for pH stabilisation in the methanogenic reactor, was discussed between EPAS and IPEV. It was therefore proposed by IPEV to investigate the possibility to use another acid for safety reasons and for transportation facilities. Citric acid was proposed as potential product in its solid form. EPAS will test this chemical for acid dosage during the testing period of the BWT-Unit and will make a final decision about the selection of the most appropriate chemical for this purpose.

8.2 Performances of each sub-system of the lab-set-up BWTU

The test period for the lab-scale BWT-Unit was 9 months during which different aspects of the process were studied and simulations on the habits of the inhabitants were investigated.

8.2.1 Liquefying reactor

8.2.1.1 Organic matter degradation

For the calculation of OM degradation the following formulas were used:

Method 1:

$$\eta_{OM1} = \frac{OM_{biod}}{OM_{\inf}} = \frac{(VFA_{eff} - VFA_{\inf}) + CO_2 + CH_4}{OM_{\inf}}$$

η_{OM1} = Biodegradation efficiency for organic material

OM_{biod} = Cumulative mass of biodegraded OM fraction (mg)

OM_{inf} = cumulative mass of OM in the influent (g)

$OM_{inf} = (DM_{inf} - As_{inf}) \times$ volume fed

VFA_{eff} = cumulative mass of VFA in the effluent (mg)

$VFA_{eff} = (\text{drained volume} \times VFA_{RI}) + (\text{volume filtrate} \times VFA_{filtrate})$

VFA_{nf} = cumulative massa of VFA in the influent (mg)

$VFA_{inf} = \text{volume fed} \times VFA_{inf}$

CO_2 = cumulative mass of the produced CO_2 in the gas phase (mg)

CH_4 = cumulative mass of the produced CH_4 (mg)

Method 2

$$\eta_{OM2} = \frac{OM_{\inf} - OM_{eff}}{OM_{\inf}}$$

η_{OM2} = Biodegradation efficiency of organic material

OM_{inf} = cumulative mass of OM in the influent (g)

$$OM_{inf} = (DM_{inf} - As_{inf}) \times \text{volume fed}$$

OM_{eff} = cumulative mass of OM in the effluent (g)

$$OM_{eff} = ((DM_{RI} - As_{RI}) \times \text{drainedvolume}) + ((DM_{filtrate} - As_{filtrate}) \times \text{volume filtrate})$$

The results on the efficiency of the liquefying reactor for organic matter degradation are presented in Figure 10.

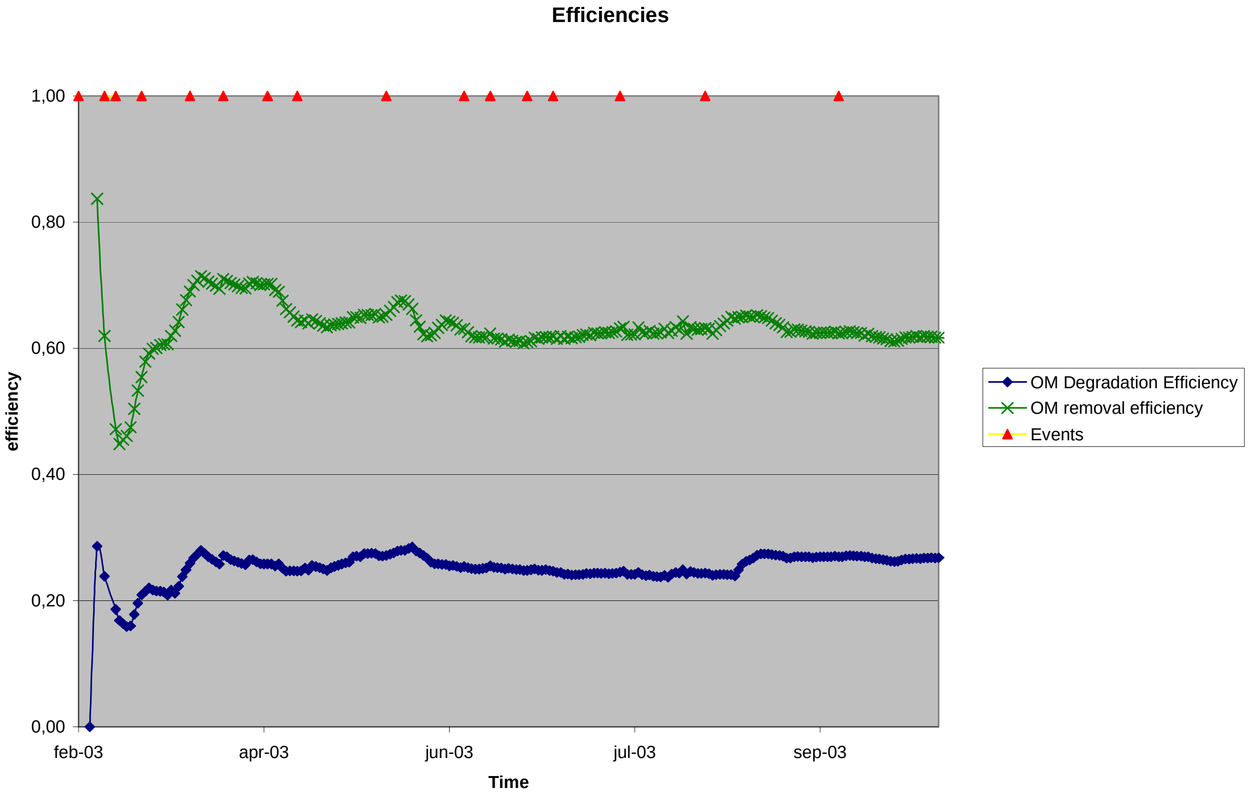


Figure 10. Performances of the liquefying reactor for organic matter degradation

Organic removal efficiency of the liquefying reactor was almost stable during the whole test period, in the range of 60 to 70% despite the fact that different substances were tested simultaneously in the influent like wine, cheese rinds and grey water concentrate containing oxonia (0.2% v/v). The estimation of the biodegradation efficiency of the organic matter was much lower because some parameters were not considered for its calculation like carbonates in soluble form and alcohols which are present in high proportions.

8.2.1.2 Urea conversion

The conversion of urea into ammonium in the liquefying reactor was complete at a minimal HRT of 3 days. Lower efficiencies were obtained at a HRT of 2.6 days. The amount of total nitrogen has increased when cheese rinds were added into the influent because of additional organic nitrogen contained in the cheese (Figure 11). This did not hinder the conversion of urea into ammonium. Moreover, due to the dilution effect exercised by the grey water concentrate stream, the amount of total nitrogen has decreased in the influent of the black water which indeed allowed to have a maximum concentration of ammonium in the filtrate stream of 300 to a maximum of 400 mg/L (Figure 12).

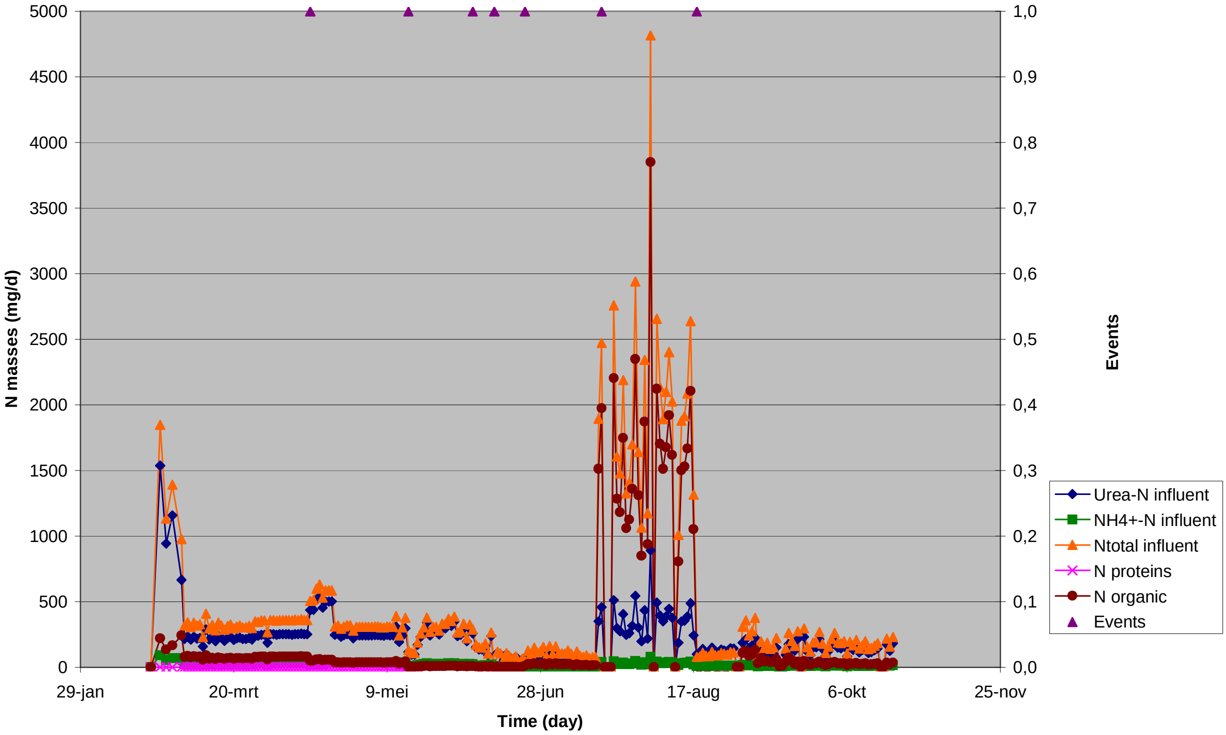


Figure 11. Nitrogen components and their masses in the influent BWT-Unit

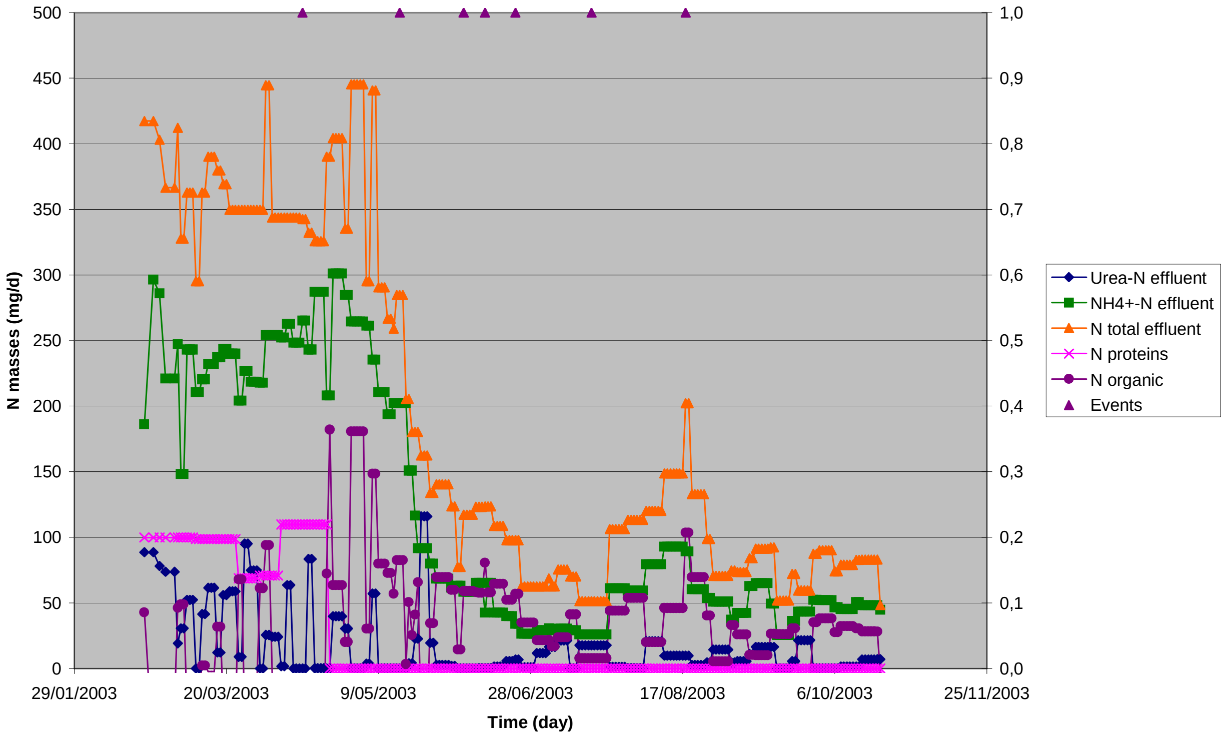


Figure 12. Nitrogen components and their masses in the effluent from the liquefying reactor

8.2.1.3 Volatile fatty acids production

The concentration of the VFA was followed in the influent and in the effluent produced from the liquefying reactor. The VFA concentration was measured in the filtrate and in the reactor content itself to verify the VFA recovery efficiency of the filtration membrane. The results of reactor for VFA production are shown in Figure 13.

After steady state was reached and process stabilisation, the concentration of the VFA produced in the filtrate stream was 5 folds the concentration of VFA in the influent with a HRT of 2.6 days. However, the composition of the VFA produced indicated that the acidification process was not complete (presence of butyric acid and valeric acid). Moreover, the COD biodegradation efficiency was low and therefore, it was decided to increase the HRT to 4 days. At this HRT, the VFA concentration produced reached 2.5 to 3 g/L and at a HRT of 3 days, the same production profile was still obtained with as major fermentation product acetic acid with small amounts of butyric acid and valeric acid. After addition of the concentrate UF/NF from grey water (synthetically prepared) and cheese rinds, the concentration of VFA produced has increased up to 8.3 g/L may be because of high COD concentrations which were converted into VFA as shown in Figure 16.

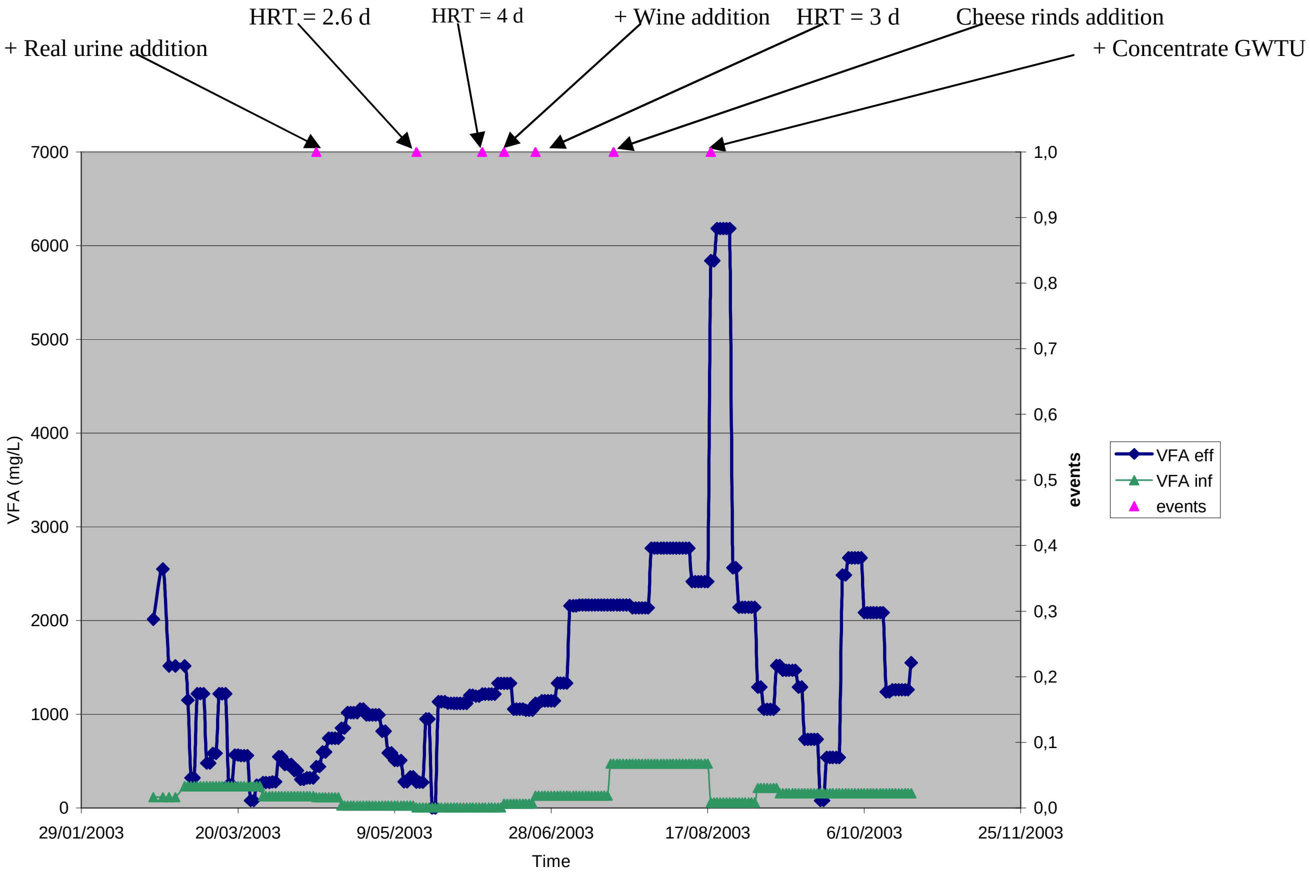


Figure 13. VFA concentrations in the influent and filtrate from the liquefying reactor

Volatile fatty acids (C_2 to C_5 straight-chain and branched) were the main soluble compounds produced during the acidogenic fermentation of the sludge. Identification of the individual acids formed during this phase is important, since it may furnish valuable information on the stability and the dynamic of the system. VFA repartition in the filtrate stream generated from the liquefying reactor is shown in Figure 14.

The most abundant component of volatile acid was acetic acid and the other component were found in the following order, butyric acid, propionic acid, caproïc acid and valeric acid. An increase in the percentage of branched VFAs (valeric acid, isovaleric acid, caproïc acid and isocaproïc acid) means that the conversion time of these VFAs into acetic acid was not sufficient and thus the HRT was low. Indeed, it was observed that the operational parameters such as HRT, SRT and environmental factors such as pH, temperature, ORP, reactor configuration and traces minerals may influence the acid phase fermentation products (Jon-Oh and Isao, 2000). This statement was confirmed with the results obtained in this study and as shown in Figure 14, the presence of elevated amounts of the branched VFAs was due to high fluctuations in pH, to accidental oxygen entry in the reactor in some cases or to a short HRT.

The aim of the study is to operate at a HRT as low as possible to minimize reactor volume and associated capital costs and space limitations in the containers dedicated for the BWT-Unit. Concurrently, high SRT is maintained due to the recirculation of the solids back to the reactor and the presence of the ultrafiltration system, in order to promote growth and proliferation of the acid-generation organisms, increase process stability without inducing growth of methane-forming bacteria.

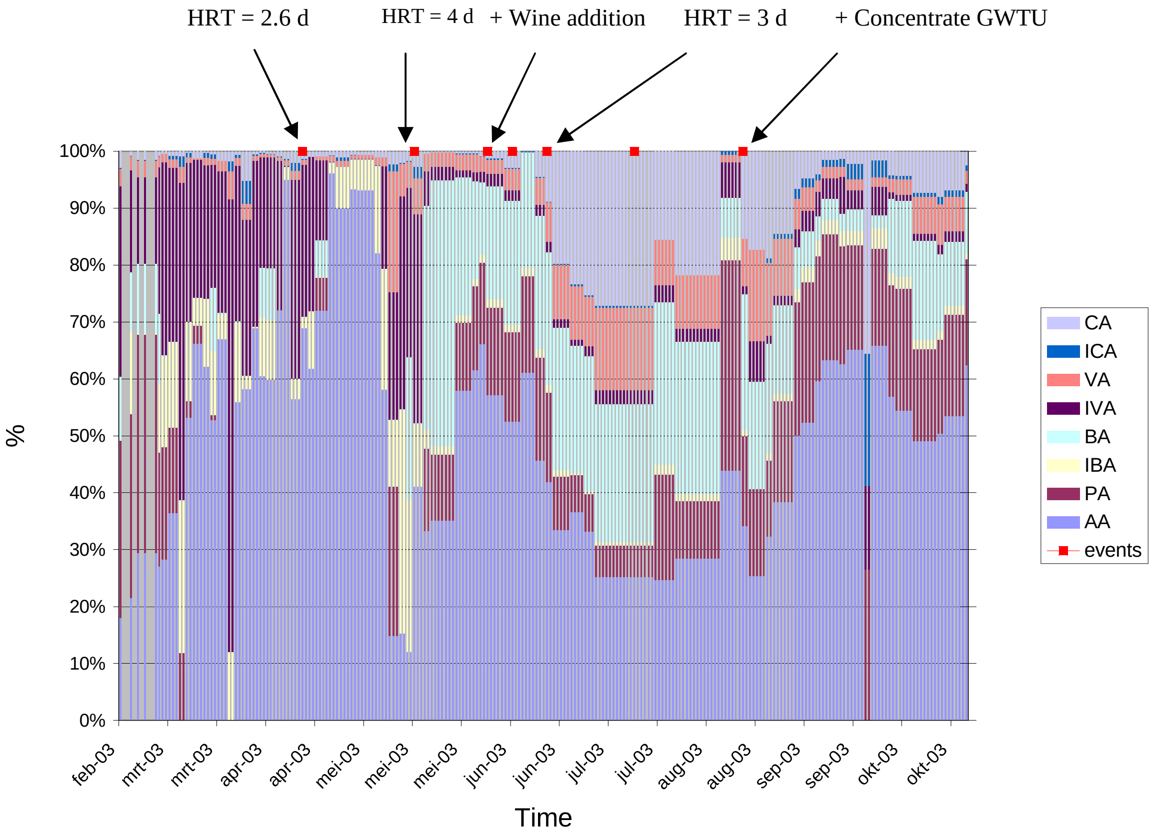


Figure 14. VFA repartition in the filtrate from the liquefying reactor

VFA production rate is expressed according to the following formula :

$$\upsilon_{\text{VFA}} = \frac{VFA_{eff}}{CODt_{\text{inf}}} \times \frac{1}{\Delta t}$$

This equation is calculated from the cumulative mass of VFA.

υ_{VFA} = Production velocity of VFA (mgCOD/gCODt.d)

VFA_{eff} = mass of the VFA in the effluent (mg COD)

VFA_{eff} = fed volume . ($\text{AA}_{\text{RI}} \times 1{,}07 + \text{PA}_{\text{RI}} \times 1{,}51 + \text{IBA}_{\text{RI}} \times 1{,}82 + \text{BA}_{\text{RI}} \times 1{,}82 + \text{IVA}_{\text{RI}} \times 2{,}04 + \text{VA}_{\text{RI}} \times 2{,}04 + \text{ICA}_{\text{RI}} \times 1{,}07 + \text{CA}_{\text{RI}} \times 1{,}07$)

CODt_{inf} = mass of CODt in the influent (gCODt)

CODt_{inf} = fed volume (L) × CODt_{inf} (mg/L)

Δt = time interval between two measurements (d)

The results of VFA production rate are shown in Figure 15. The graphs show both the daily production rate and the cumulative VFA production rate.

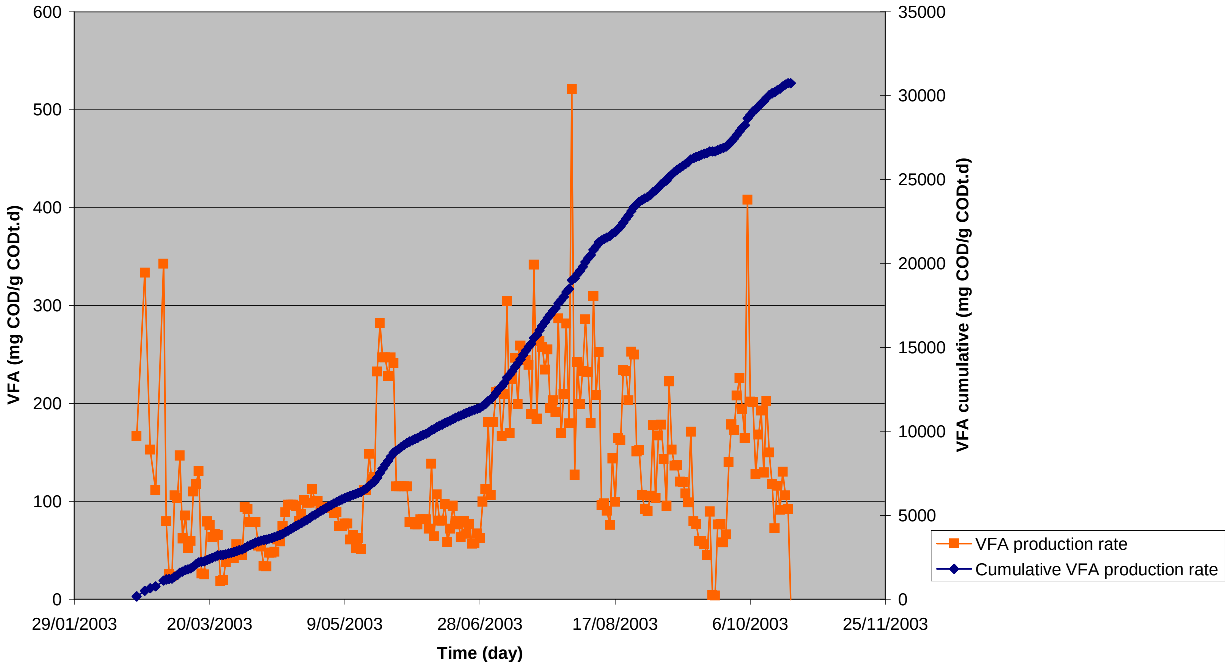


Figure 15. VFA production rate in the liquefying reactor

8.2.1.4 COD removal efficiency

The COD removal efficiency from the liquefying reactor was calculated according to the following formula:

$$\eta_{COD} = \frac{CODt_{\inf} - CODt_{eff}}{CODt_{\inf}}$$

η_{COD} = COD removal efficiency

$CODt_{inf}$ = Cumulative mass of CODt in the influent (mg)

$CODt_{inf}$ = Added volume × $CODt_{inf}$

$CODt_{eff}$ = cumulative mass of CODt in the effluent (mg)

$CODt_{eff}$ = ($CODt_{RI}$ × volume of drain) + ($CODt_{filtrate}$ × volume filtrate)

The evolution of the system for COD removal is presented in Figure 16. High COD masses were measured when cheese rinds and concentrate GWTU were added to the influent but the removal efficiency was still high around 63%.

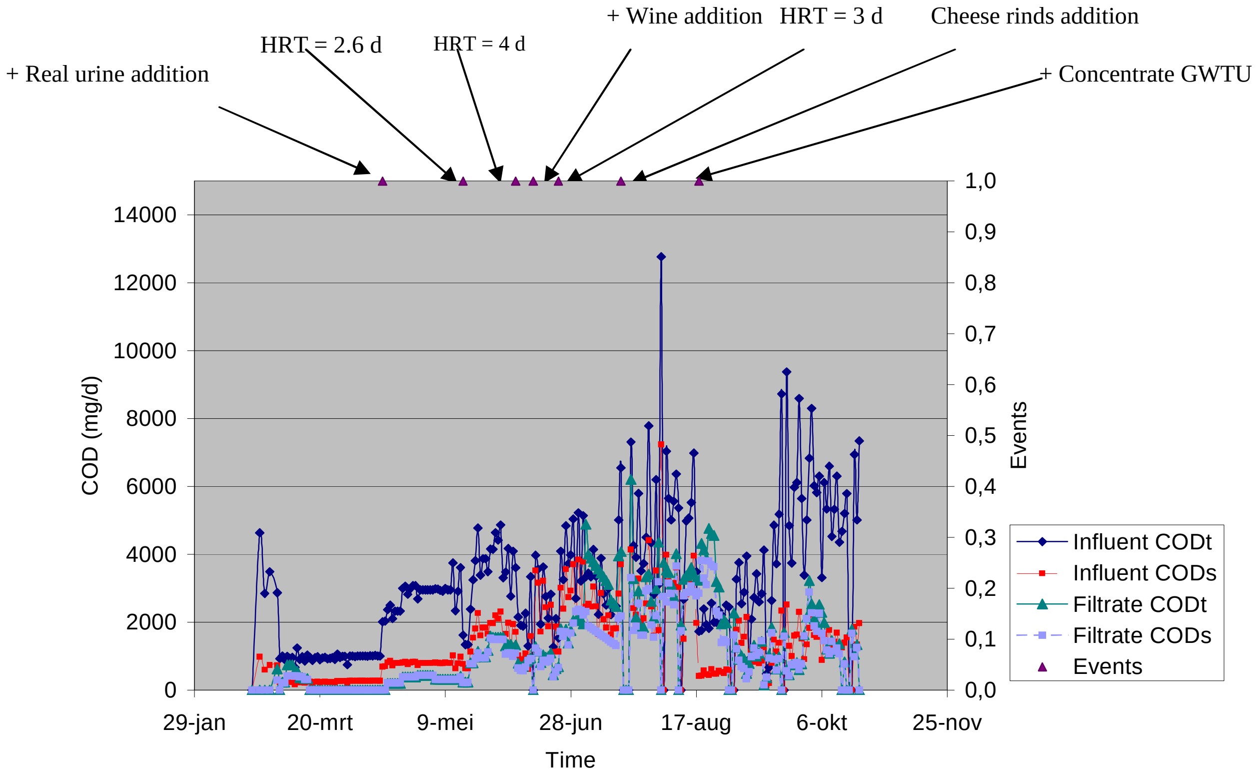


Figure 16. COD balance in the liquefying reactor

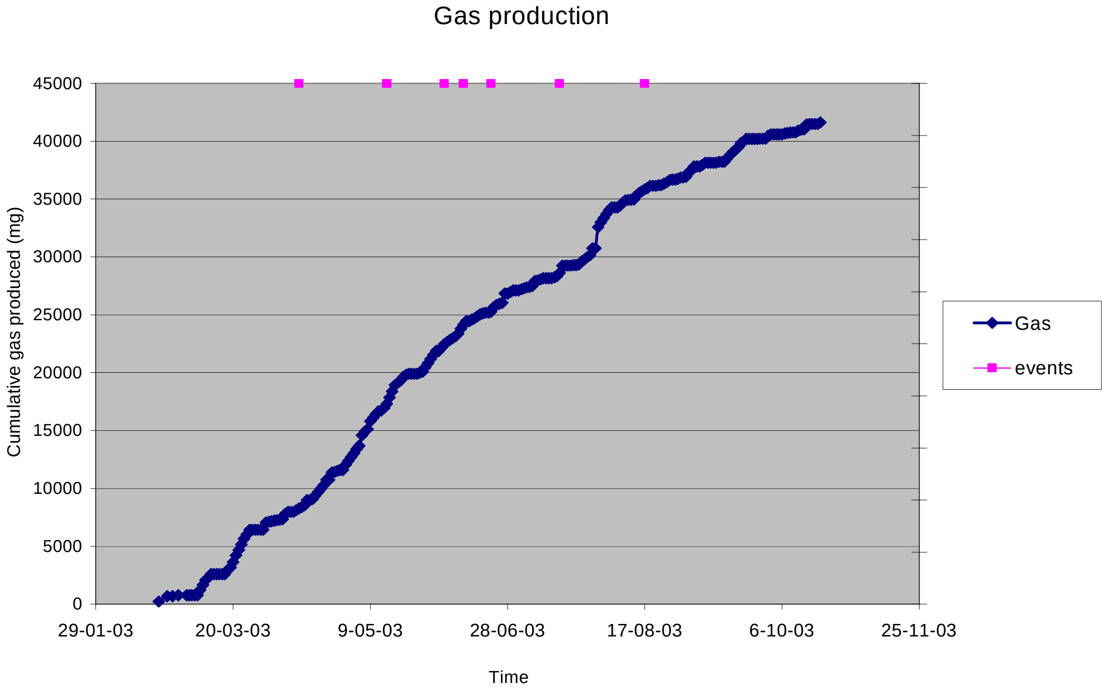


Figure 17. Amount of biogas produced from the liquefying reactor

The biogas produced mainly in the form of CO_2 over the test period as shown in Figure 17, amounted 42 g as expected. Additional to this production, the amount biogas produced from the methanogenic reactor was also considered independently (see hereunder) and measured with the aim to estimate the energy that could be generated from the system to be recovered and reused.

8.2.2 Methanogenic reactor

In this reactor, the VFA produced in the liquefying reactor will be converted into biogas mainly in the form of methane, carbon dioxide and traces hydrogen gas and hydrogen sulphite.

8.2.2.1 Biogas production

The volume of the produced gas was calculated using the following equation:

$$V_{gas} = \Pi \times r^2 \times l$$

V_{gas} = volume of the produced biogas (ml)

r = Radius of the gas column (cm)

l = level of the liquid in the gas column (cm)

The mass of the produced CO_2 was calculated as follows:

$$m_{CO2} = \frac{\%CO_2}{100} \times V_{gas} \times \frac{P \times M_{CO2}}{R \times T} \qquad (1)$$

m_{CO2} = mass of the produced CO_2 (mg)

$\%CO_2$ = percentage of CO_2 in de gas phase (%)

P = pressure = 101325 Pa

M_{CO2} = molecular mass of CO_2 (44.10^{-3} kg/mol)

R = gas constante ($8{,}314\ J.K^{-1}.mol^{-1}$)

T = temperature = 55°C = 328 K

The mass of the produced CH_4 was calculated as follows:

$$m_{CH4} = \frac{\%CH_4}{100} \times V_{gas} \times \frac{P \times M_{CH4}}{R \times T} \qquad (2)$$

m_{CH4} = mass of the produced CH_4 (mg)

$\%CH_4$ = percentage of CH_4 in de gas phase (%)

M_{CH4} = molecular mass of CH_4 (16.10^{-3} kg/mol)

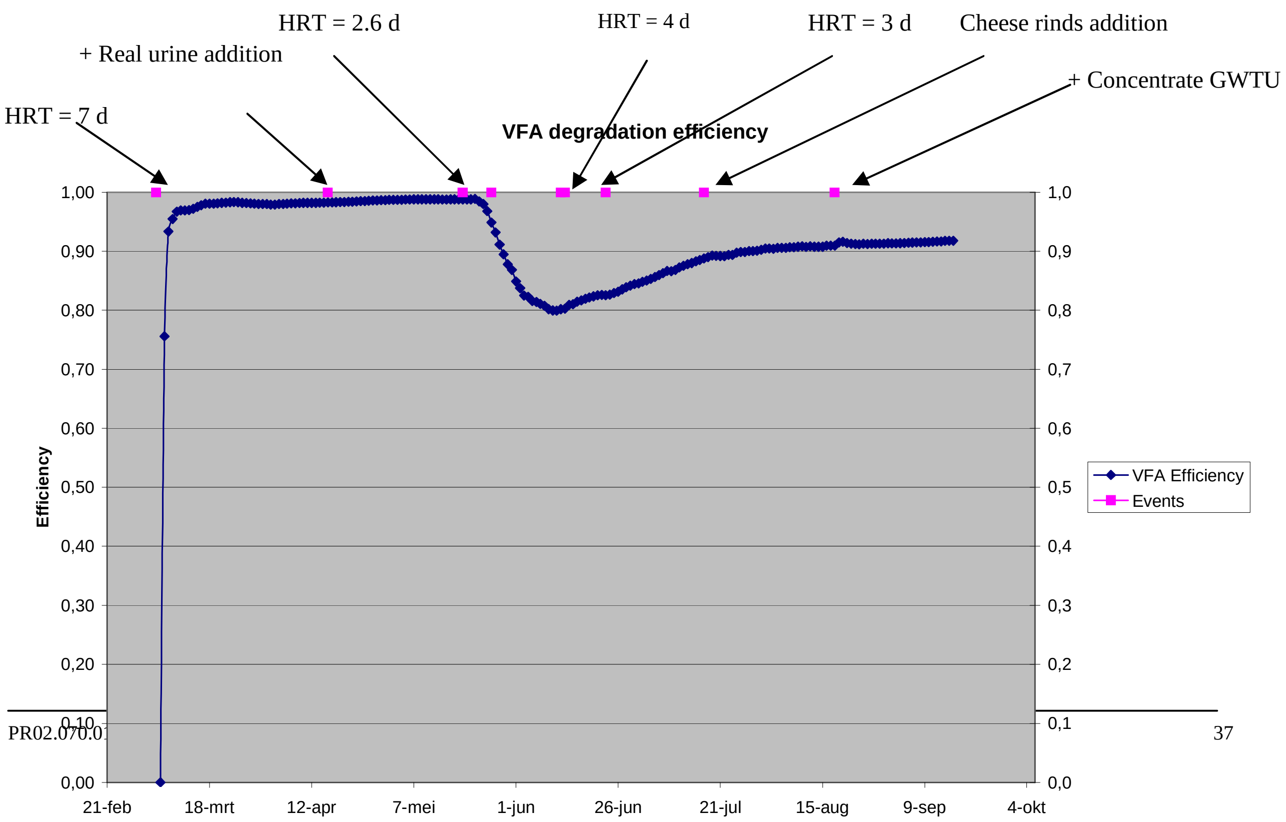
The mass of total produced biogas is:

$$m_{gas} = m_{CO2} + m_{CH4}$$

The energy balance of the system was established, taking into account the amount of biogas produced from the liquefying reactor (70 – 80% CO_2 and less than 1% CH_4) and from the methanogenic reactor (70 – 80% CH_4 and 20% CO_2). From this energy balance, the energy production capacity of the whole BWT-Unit was calculated. The results are widely discussed in section 9.

8.2.2.2 VFA conversion efficiency

The conversion efficiency of VFA by the methanotrophs was dependent on the hydraulic residence time in the



methanogenic reactor and on environmental process parameters pH, temperature and dissolved oxygen..

Figure 18. VFA degradation efficiency in the methanogenic reactor

VFA degradation efficiencies of 100% were obtained at a hydraulic retention time of 7 days. To reduce reactor volumes due to the high HRT, different lower HRT were tested. At a HRT of 3 days, degradation efficiencies of 93% were reached. This brings the volume of the methanogenic reactor equal to the volume of the liquefying reactor.

9. Energy balance of the liquefying and methanogenic reactors

The heat balance was calculated for both the liquefying and methanogenic reactor based on data collected from the lab-scale reactors. As mentioned in Figure 19, the maximum energy that is generated from the system will be around 2 kW from which only 460 W could be used for electricity production and 1.4 kW as heat. The generated energy will not be able to fulfil the requirements for the heating of the anaerobic reactors up to 50-55°C. Considering these values, IPEV decided not to make an investment to recycle the produced energy and to limit it for instance to biogas burning.

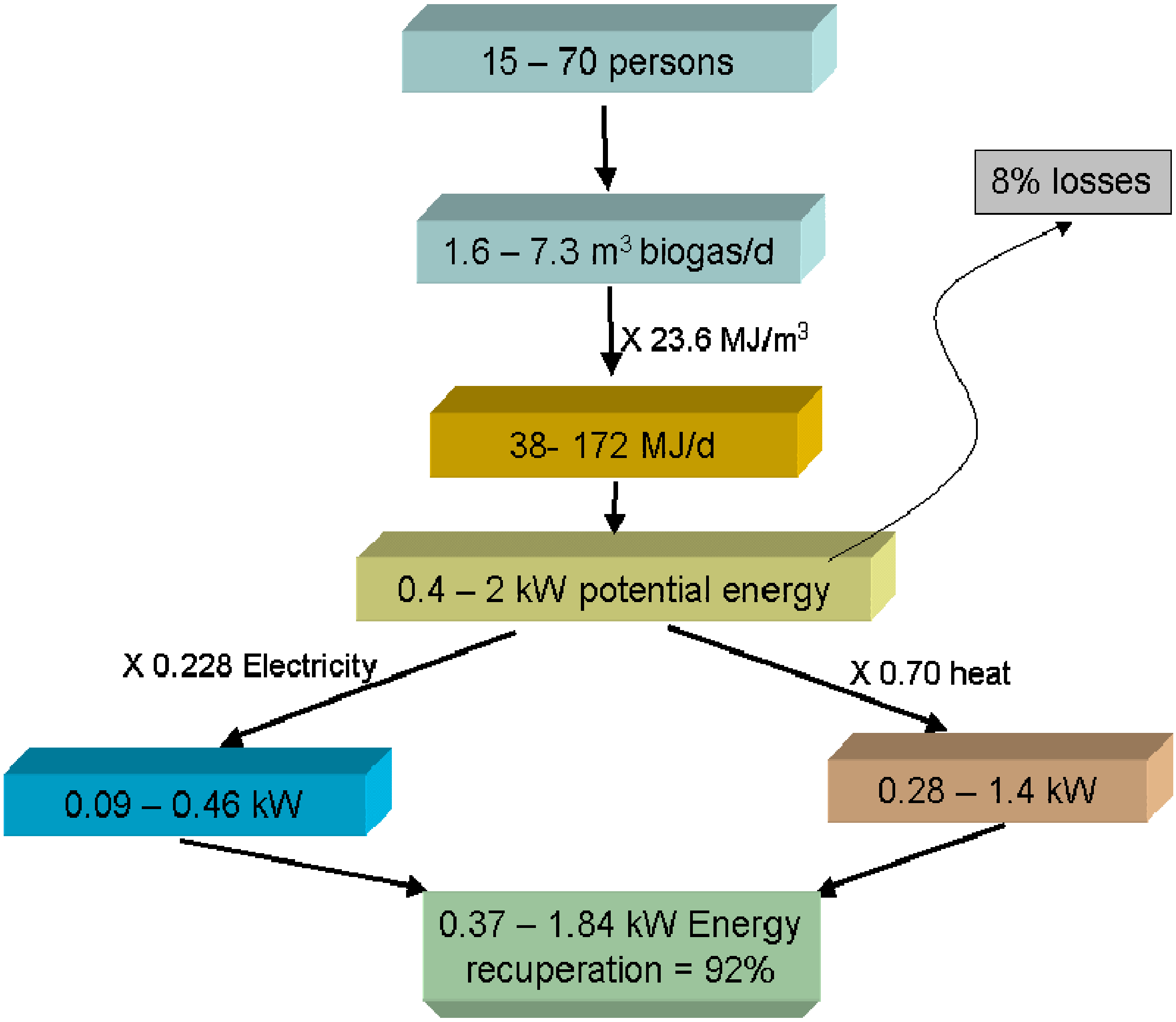


Figure 19. Heat balance of the anaerobic reactors of the BWT-Unit (Ref: lectures Prof. W. verstraete, University of Ghent)

10. Ammonium removal from the effluent of the BWT-Unit

As already mentioned above, the aim of the nitrification reactor in the BWT-Unit is to convert the ammonium mainly originated from the ureum into nitrates. Since the ammonium is a limiting factor in the functioning of the GWT-Unit, the option to avoid decreasing the separation efficiencies of the GWT-Unit was selected as being the conversion of amminum into nitrates. The latter will be easily retained by the membrane system of the GWT-Unit.

10.1 Nitrification reactor

A lab-scale set-up was tested in continuous mode to study the ammonium conversion efficiencies and to define accordingly the dimensions of the pilot nitrification reactor.

10.1.1 Inoculum selection

The reactor was inoculated with a nitrifying sludge that is cultured at EPAS. The sludge is continuously fed with ammonia as sole nitrogen source and trace elements. To familiarize the sludge with the effluent from the anaerobic reactors, low nitrogen loading rates were fed into the nitrifying reactor and gradually increased until a maximum loading rate was reached.

10.1.2 Carrying material

To avoid wash-out of the nitrifying sludge from the reactor, carrier material was introduced in the reactor. It consisted of an inert material “Biostyr” provided by ESA for the purpose. The choice was directed towards this type of carrier because the same material is actually being tested in the third compartment (nitrification compartment) of the MELiSSA loop.

10.1.3 Process conditions

The most critical environmental process parameters which were taken into account were: pH, temperature and dissolved oxygen. By dosing NaOH, the pH was regulated at 7. The temperature was around 20 to 22°C (room temperature) during the whole test period and compressed air was supplied upstream continuously to maintain dissolved oxygen concentration around 8 mg O_2/L. For feed dispersion in the reactor, allowing sufficient contact substrate-biomass, a recirculation pump was installed at a low flow rate 0.5 L/h. The EC did not exceed 4.5 mS/cm during the whole test period.

10.1.4 Test results

Nitrogen mass balance was studied to determine the conversion efficiency of ammonium into nitrates. The following compounds were followed up in the influent and the effluent: Total nitrogen, NO_3^- (mg/L) , NO_2^- (mg/L), NH_4^+ (mg/L) urea $CO(NH_2)_2$ (mg/L), SS (g/L) and VSS (g/L) at the beginning and end of the test and EC (mS/cm). The environmental parameters pH, temperature and dissolved oxygen were also in parallel measured.

To avoid acute toxicity for bacteria, Nitrogen loading rate was increased stepwise. In the beginning of the tests, the total nitrogen mass in the influent was higher than in the effluent because the steady state was not reached . The results of the nitrogen balance are reported in Figure 20.

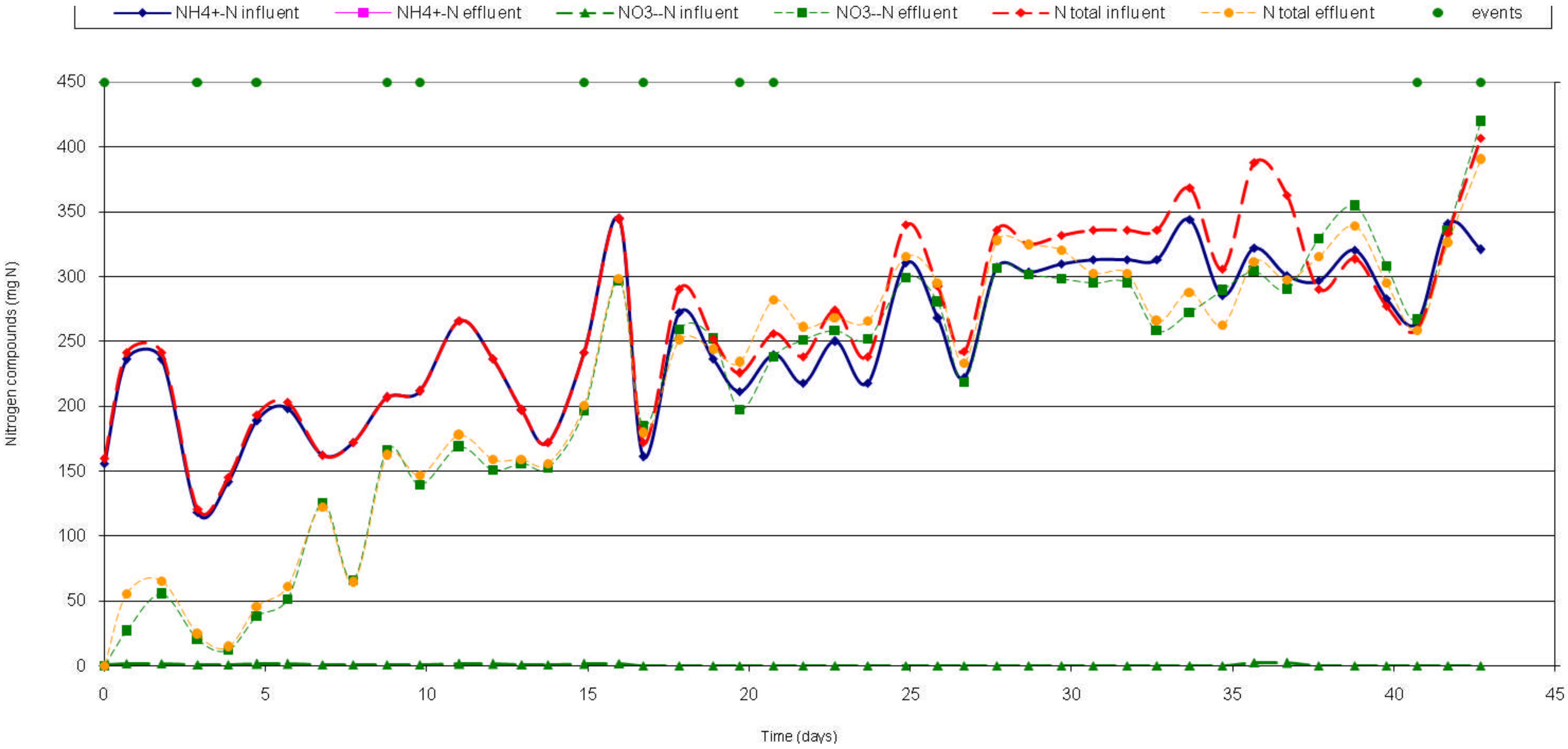


Figure 20. Nitrogen balance in the nitrification reactor

The major total nitrogen in the influent was present in the form of ammonium. This is because of an efficient conversion of urea in the anaerobic reactors into ammonium. No urea has been found back in the influent for the nitrification reactor. The conversion efficiency of ammonium into nitrates amounted 100% along the test period. In order to reduce as much as possible the volume of the nitrification reactor, different HRT were tested. In the start-up, the HRT was set at 7.5 days. By increasing the nitrogen load, the HRT was decreasing down to 1.5 days. At this HRT the conversion of ammonium into nitrates was still of 100%. Since the maximum expected ammonium concentration in the influent is of about 400 mg/L, the maximum volumetric loading rate reached was 267 mg NH_4^+-N/L.d., and the nominal influent flow to be treated by the nitrification reactor of the BWT-Unit is about 1 m^3, the volume of the reactor was calculated to be of 1.5 m^3, based on the following equation:

$$Bv = \frac{NH^+{}_4 - N_{\text{inf}} \ \ x\, Q}{V}$$

Where:

NH_4^+-N_{inf} = ammonium concentration in the influent (mg/L)

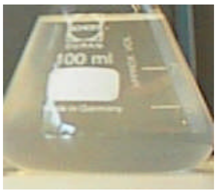
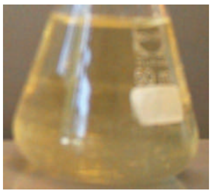
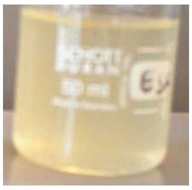
Q = influent flow rate to be treated (L/d)

V = Volume of the nitrification reactor (m^3)

11. Tests for colour removal from the effluent of the BWT-Unit

Three tests were performed to remove the undesired colour obtained in the final effluent from the nitrification reactor: UV + H_2O_2, Ozon (O_3) and granular activated carbon (GAC). For this purpose, bactch tests were performed on the effluent as shown in Table 10. Spectrophotometric analyses and COD measurements before and after the tests were performed. Visually, it is obvious that activated carbon gives better insight to the colour removal than the other technologies. After filtration of the effluent, the total COD concentration has dropped sensitively down to a maximum of 300 mg/L.

Table 10. Qualitative evaluation of the different technologies for colour removal from the effluent BWT-Unit

	ACTIVATED CARBON	OZON	UV + H_2O_2
Before treatment			
Quantities used	2 g/L* PAC & GAC for 2h & 4h	1.5 L/min 166 mg/L 250 mg/min	5 ml/L H_2O_2 (30%) UV: 486 mW.s/cm for 3 h
After treatment			

*: 2 g/L GAC was selected among other tested concentrations (0.5, 1, 1.5, 4, 8 and 10 g/L) because of the best results reached at this concentration (data not shown)

11.1.1 Type GAC

Since the satisfactory results obtained with the granular activated carbon (GAC) with more than 65% COD removal efficiency compared to the ozon (25%) and UV-H_2O_2 (< 10%) and for safety and easy handling reasons, it was decided to use GAC for the colour removal from the effluent.

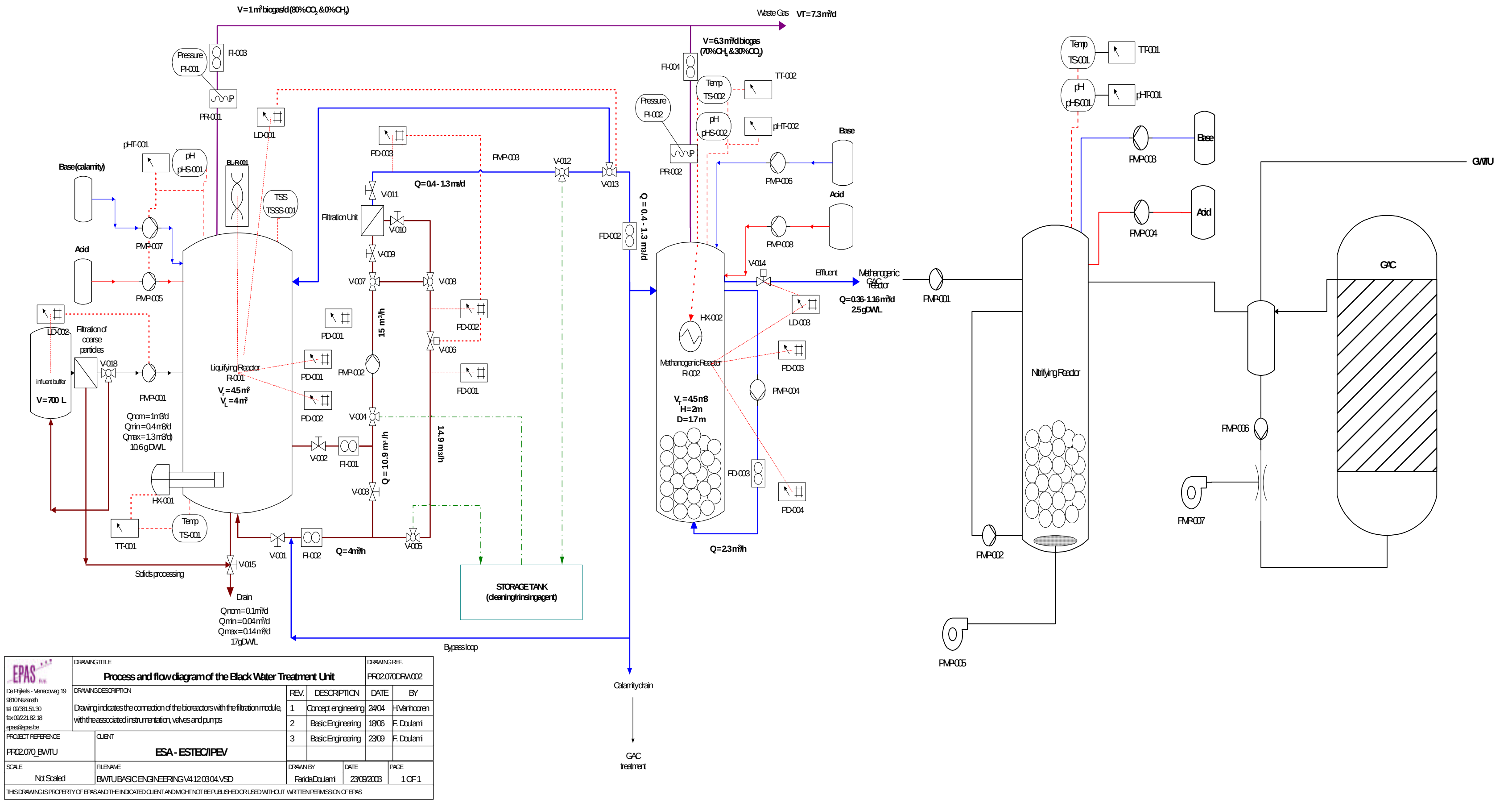
11.1.2 Test results

The GAC bed was not aerated during the test period of colour removal. 200 g GAC were placed in a PVC column to treat an effluent with 1 g total COD per day. The test period with was fixed at 60 days without changing of the GAC bed to estimate the renewal frequency of the GAC bed and by this mean to estimate the amounts of GAC needed at Concordia station.

During the 60 days, renewal of the GAC was not needed. Total COD measurements were performed each two days and the removal efficiencies were fluctuating between a minimum in the beginning of the test 93% and 65% at the end of the test. After the test period has passed, a liquid heat space above the GAC bed started to form, which is an indication of saturation of the GAC. At that moment, the GAC bed was renewed.

From these results, it was deduced that around 3.34 kg GAC would be needed per kg COD removal during two months. This means that the necessary volume to be shipped to Concordia would be 2.4 m^3/year. It is well clear that in this case the GAC bed is not aerated. However, if the choice of the GAC filtration will be directed towards an aerated bed, less amounts will be needed because of bed regeneration capacities of such a system. In this case, a 1 m^3/year GAC filtration tank would be sufficient.

12. General concept of the BWT-Unit sub-systems



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DRAWING TITLE Process and flow diagram of the Black Water Treatment Unit				DRAWING REF. PR02.070DRW002
DRAWING DESCRIPTION	REV.	DESCRIPTION	DATE	BY
Drawing indicates the connection of the bioreactors with the filtration module, with the associated instrumentation, valves and pumps	1	Concept engineering	24/04	H.Vanhooren
	2	Basic Engineering	18/06	F. Doulami
PROJECT REFERENCE PR02.070_BWTU	3	Basic Engineering	23/09	F. Doulami
CLIENT ESA - ESTEC/IPEV				

SCALE	FILENAME	DRAWN BY	DATE	PAGE
Not Scaled	BWTU BASIC ENGINEERING V4 12 03 04.VSD	Farida Doulami	23/09/2003	1 OF 1

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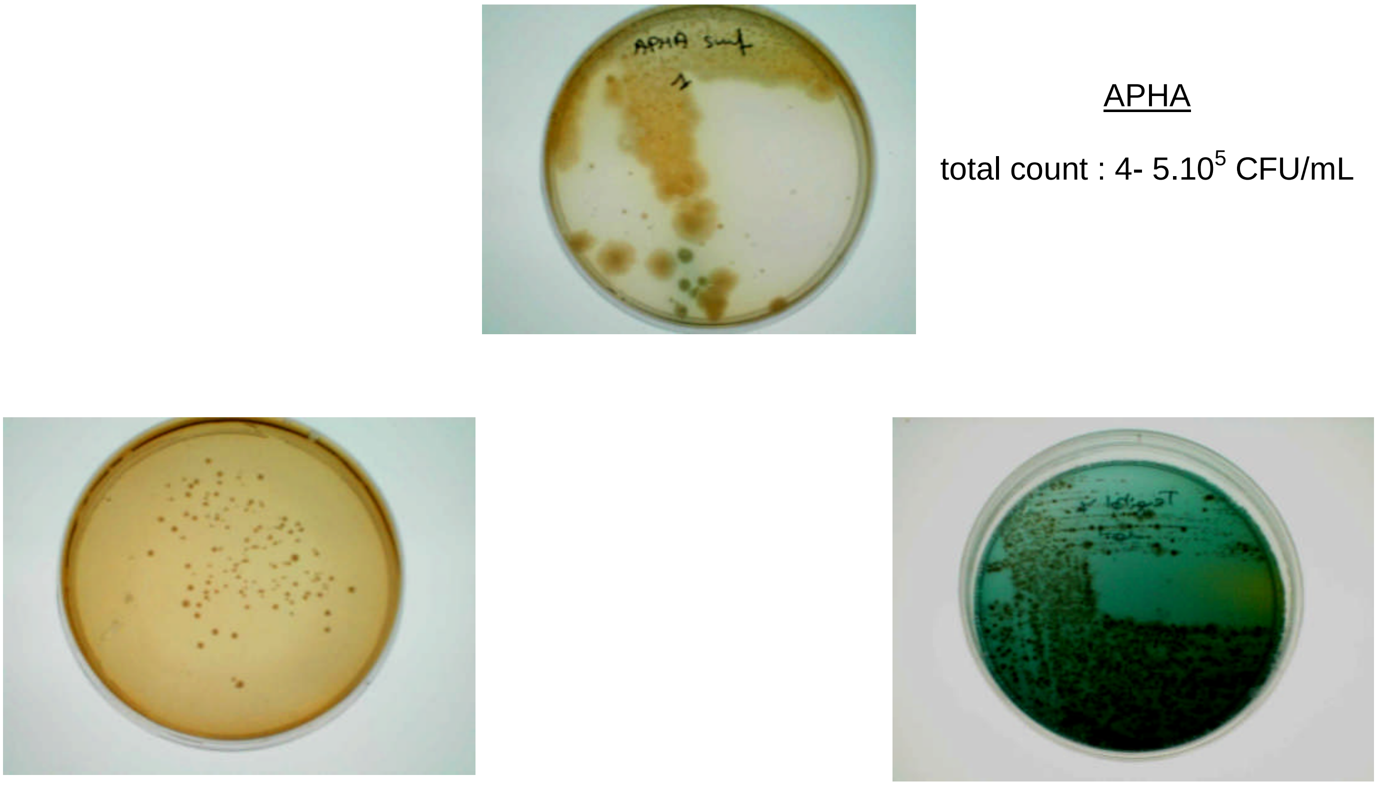
13. Evaluation of the quality of the effluent from the BWT-Unit

13.1 Microbiological quality

Samples were taken from the effluent of the BWT-Unit to be analysed for their microbiological quality using two specific media for Enterobacteria and faecal coliforms including E-coli. General medium for total bacteria count was also used to determine the total CFU in the effluent. The aim was to compare the quality of the effluent from the BWT-Unit with the quality of the grey water.

Both grey water and effluent from the BWT-Unit will be treated together in the GWT-Unit and additonal contamination from the effluent BWT-Unit will be limiting since extra concentrations of oxidantia (OXONIA) will be needed. In Figure 21, the results of plate counting are shown.



APHA

total count : 4- 5.10^5 CFU/mL

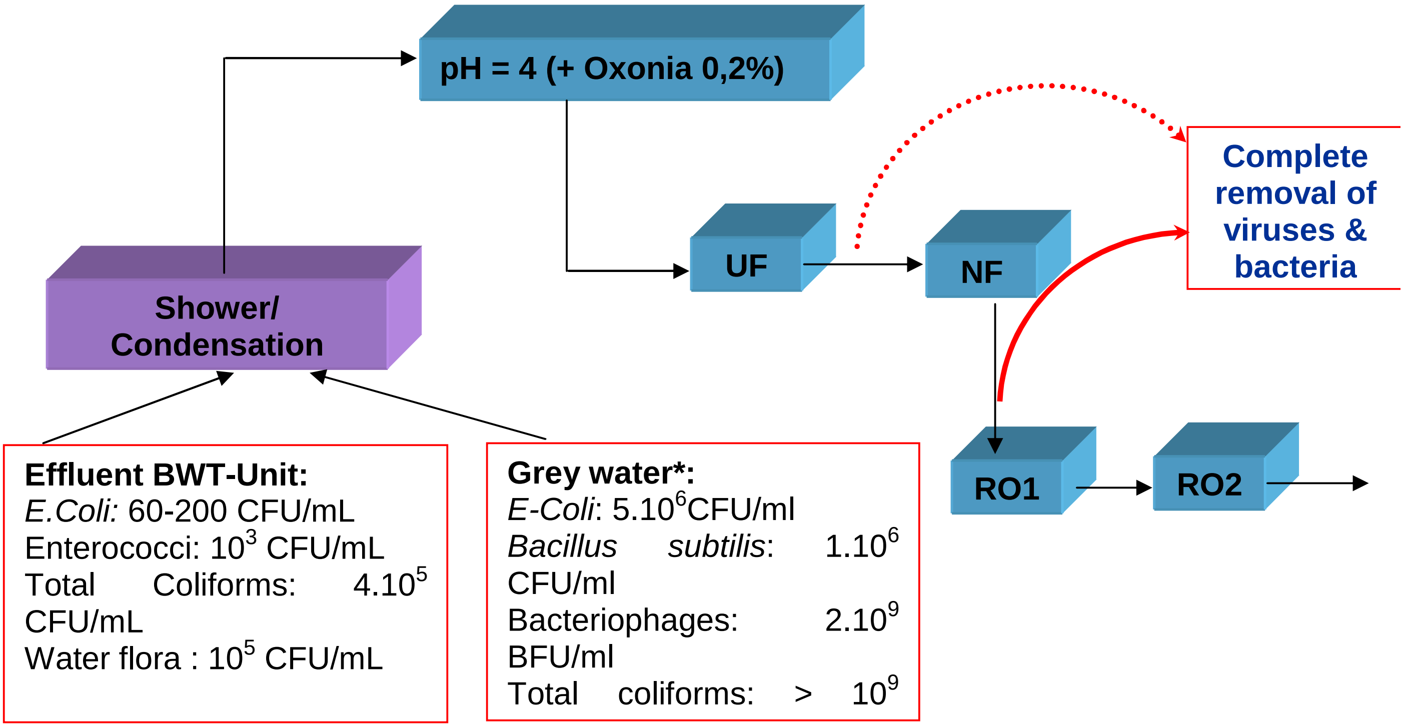
Slanetz & Bartley medium
Enterococci: 10^3 CFU/mL

Tergitol 7 medium
coliforms: 4.10^5 CFU/mL
E.Coli: 60-200 CFU/mL

Figure 21. Results of plate counting of the effluent from the BWT-Unit using general and specific media

These analyses were compared with the microbiological analyses performed on the grey water. The results are presented in Figure 22.

Compared to the microbiological quality of the grey water, the effluent from the BWT-Unit was less contaminated. The total coliforms and E-coli which is mainly originated from the gastro-intestinal tract were much lower in count.



Effluent BWT-Unit:
E.Coli: 60-200 CFU/mL
Enterococci: 10^3 CFU/mL
Total Coliforms: 4.10^5 CFU/mL
Water flora : 10^5 CFU/mL

Grey water*:
E-Coli: 5.10^6CFU/ml
Bacillus subtilis: 1.10^6 CFU/ml
Bacteriophages: 2.10^9 BFU/ml
Total coliforms: > 10^9

*: data provided by Technomembranes

Figure 22. Compatibility of the microbiological quality of the effluent BWT-Unit with the grey water quality

13.2 Physico-chemical quality

When the physico-chemical quality of the effluent from BWT-Unit was compared with the one of the grey water (Table 11), it was concluded that the effluent generated from the BWT-Unit will, in general, dilute the influent to the GWT-Unit rather than concentrating it. For instance the total COD in the effluent from the BWT-Unit is 10 times lower than the total COD of the grey water. However, two parameters linked to each other are higher in the effluent BWT-Unit and which could be limiting in the functioning of the GWT-Unit: the electroconductivity (EC) and chlorides concentration. There high concentrations are due to HCl dosage in the liquefying reactor. Nevertheless, as previously mentioned, pH regulation in the liquefying reactor can be done using another acid than HCl; like citric acid (organic acid) to decrease the EC and the chlorides concentration in the final effluent. Another parameter, which is of less impact on the performances of the GWT-Unit, is the nitrates concentration. The latter is high in the effluent BWT-Unit because of conversion of the ammonium from the urine into nitrates. Since nitrates could easily be retained in the filtration systems of the GWT-Unit, there presence is not limiting.

Table 11. Physico-chemical comparability between the effluent from the BWT-Unit and the grey water

Parameter	**Effluent**	**Grey water***
CODt (g/L)	0.07 – 0.3	2 - 3
EC (mS/cm)	**3.5 – 4.5**	1.5 - 2
pH	7- 8	8.5 – 9.5
TOC (g/L)	-	0.3 – 0.7
Sulfate (mg/L)	< 20	150 - 200
Phosphates (mg/L)	20 - 30	10 - 50
Ammonium (g/L)	0.00	-
Fluoride (mg/L)	0.12	5 - 6
Chloride (mg/L)	**200 - 300**	30 - 60
Nitrates (mg/L)	*200 - 400*	2 - 4
Mg^{2+}, K^+, Ca^{2+}, Na^+	7, 260, 15, 380	2-4, 70-90, 10-20, 300-400
Turbidity (NTU)	3.4 - 6	100 – 200

*: Data provided by Technomembranes

14. COD degradation by refrigerated BWT-Unit inoculum

Samples from the liquefying reactor were taken regularly and kept at 4°C for a period of 6 months. To estimate the degradation efficiency of the refrigerated samples, batch tests were performed. A COD source (starch) was added to the mixed samples in a 1 litre Erlenmeyer after re-establishment of the process parameters (anaerobic conditions, temperature = 50°C, pH = 6). The test period was fixed at 2 weeks. During this period, total COD, dissolved COD, VFA, pH , temperature, biogas production and biogas composition were daily measured.

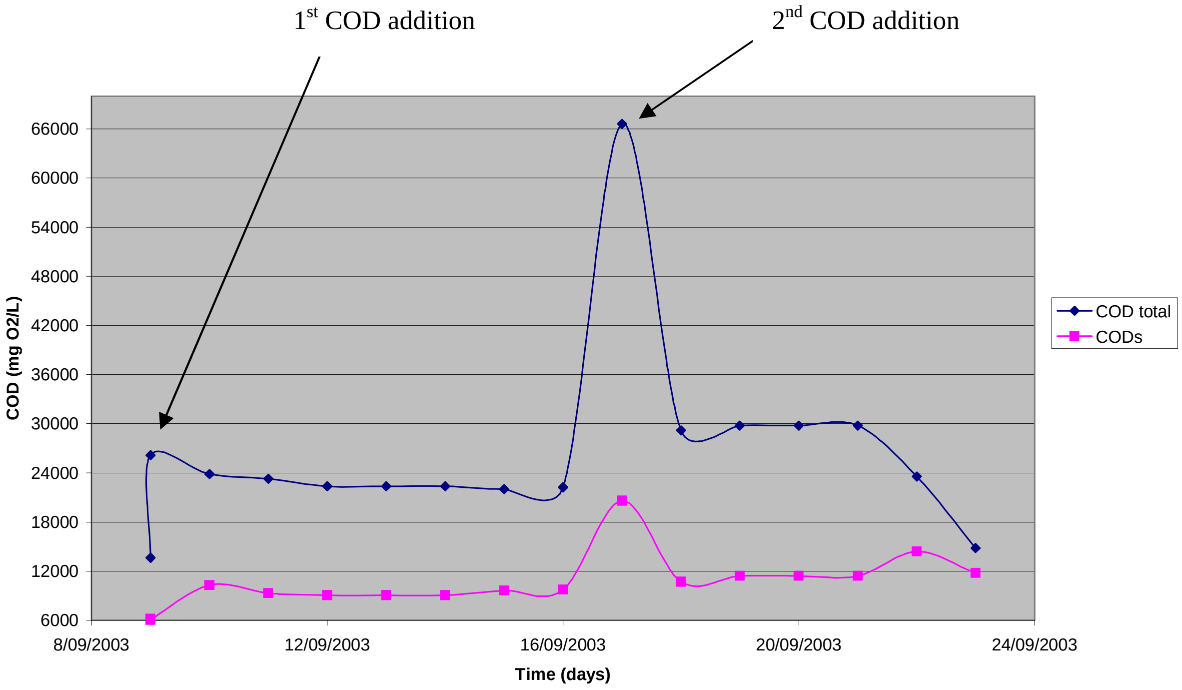


Figure 23. Evolution of CODt and CODs concentrations in the reactivated refrigerated inculum

As shown in Figure 23, The COD is relatively fast consumed. In the first instance low COD load was added to verify the efficiency of the biomass and in the second instance high COD load was added (44 g COD/L). COD consumption was very efficient since more than 56% biodegradation efficiency was reached after one day and the initial COD concentration of the sludge inoculum, before starch addition, was reached after 6 days.

The amount biogas, represented here with the CO_2 volume (since it consists of the major component in the liquefying reactor), produced during the biodegradation of the COD is presented in Figure 24.

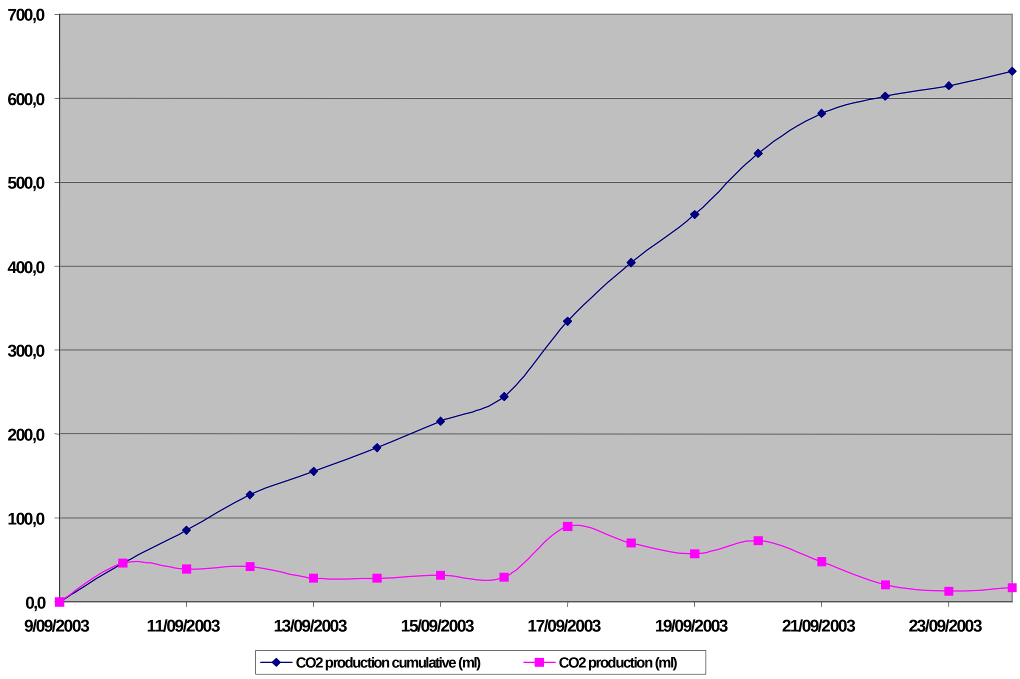


Figure 24. volume CO_2 produced during the testing of the refrigerated inoculum

The total volume CO_2 produced during the test period of 2 weeks amounted 650 ml. The production rate was around 50 ml CO_2/L.day.

The VFA production was also significant with an increase from an initial concentration of 1580 mg/L to 3660 mg/L at the end of the test.

In conclusion, the start-up of the BWT-Unit can be initiated from a refrigerated inocula kept at 2 to 4°C. This means that the sludge doe not need extra care during the transportation to the Concordia station. However, freezing of the sludge (at temperatures lower than –4°C) might lead to low performances at the start-up of the unit. It would be therefore, necessary to organise some laboratory tests using frozen inoculum to evaluate its efficiency.

15. Safety handling during the processing of the BWT-Unit

15.1 Waste collecting systems

As mentioned in section 7.2, toilet waste will be independently collected and processed from the kitchen waste. The mixing of both fractions will be done in a closed but not necessarily anaerobic buffer tank provided by IPEV. It is supposed that at this stage no direct contact (waste – operator) may occur. The grinding of the waste has therefore to be automated.

15.2 Buffer tank

As previously mentioned, the buffer tank will be provided by IPEV. However, for safety reasons, the design of the tank, its placement and cleaning procedure will be discussed together with EPAS and ESA in a preliminary step to fulfil all safety requirements.

15.3 Liquefying and methanogenic reactors

The liquefying and methanogenic reactors will not represent a real danger during there operation. They are completely anaerobic and the temperature at which they will operate is relatively high (55°C) to avoid development of pathogens. However, during the stop period of the unit, some precautions should be considered, especially when cleaning of the tanks is needed (see section 15.8). Therefore, some preliminary items were considered in the design of the reactors such as:

- In-situ cleaning of the tanks, using water spray (nozzles) and cleaning agents on the top and on the bottom of the reactors.

- Access port inside the tanks to allow the operator to check to cleanliness and status of the reactor when needed.

During the stop period of the BWT-Unit, the reactors do not have to be emptied and can be kept for a few months close and at room temperature. Low temperatures of around 4°C are advised to avoid odours development. By the start-up of the BWT-Unit, the reactors can recover there efficiencies in a short time (after 1 to 2 day) when process conditions are re-established (see section 14).

15.4 Ultrafiltration unit

To allow professional handling of the filtration unit, the latter will be built as an independent sub-unit completely automated and which can be easily mounted to and dismounted from the whole BWT-Unit. Its cleaning will be also automated in such a way that the filtration/back-washing procedures can be alternated. For safety reasons, and to avoid stopping the BWT-Unit in case of clogging of the membranes, another module of membranes unit will be placed in parallel and the flows will be switched towards it. In the mean time, the clogged module can be separately cleaned. In addition, sufficient spare capacity will be foreseen so as to guaranty continuous operation.

15.5 Nitrifying reactor

The nitrifying reactor will be inoculated with an activated sludge which is aerated continuously. Since it consists of an aerobic reactor, its handling and cleaning might not be critical. No sludge has to be drained during the operation of the unit and therefore no direct contact between the operator and the biomass. Moreover, during the standby period of the BWT-Unit, the nitrification reactor can be kept as such for a few months preferably at 4°C.

15.6 GAC tank

When the activated carbon tank will be saturated, it is not the aim to clean it, but rather to replace it by another tank. As the tank will also be mounted to the system, its dismounting will not necessitate the access to the interior of it by the operator and therefore, its handling would not present any potential danger.

15.7 Drain handling

The major safety interventions should be directed towards the drain handling from the liquefying reactor. Here again, the aim is to prevent the operator to come in contact direct with the sludge.

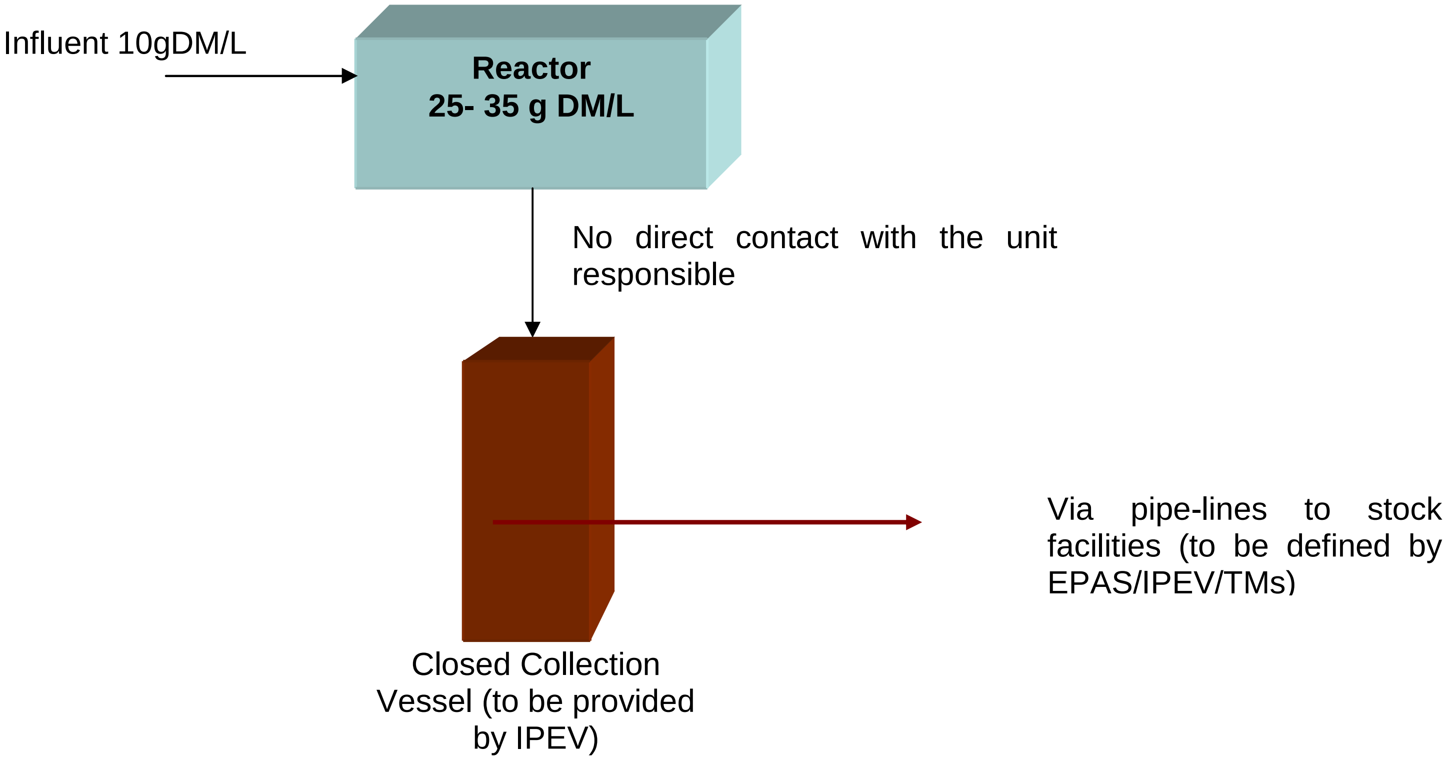


Figure 25. overview of the way established to take drains from the liquefying reactor

As shown in Figure 25, the operator may not enter in contact with the sludge since the following items will be included in the construction of the BWT-Unit:

- A drain port at the bottom of the liquefying reactor directly connected via piping to a closed vessel. The latter will be emptied at regular times by opening a manual valve and the drain will be directed outside the container where the BWT-Unit is implemented. The drain will be collected in a stock facility tank foreseen by IPEV and will freeze in thin layers at a contact of environmental temperatures (-40°C maximum). The Thermodynamic study of the incident light on drain collecting tanks and freezing temperature during summer time are actually being investigated by ESA in the framework of this study.

15.8 Tanks cleaning in case of process or system failures

Process failures are normally very limited but may occur under the following process conditions:

- High nitrogen load (> 3 g/L)
- Toxic compounds for the biology in the influent (injection of antibiotics by the crew over a long period)

Failures may also occur under specific system conditions maintained over a long period of time like:

1. Failure of the acid/base dosing control system (e.g. dosing continuously acid and keeping $pH<4.5$ over a period exceeding 5 days with as consequence irreversible biomass inactivation)

In most of the cases, process recovery is obtained when the process and system conditions are re-established. However, if no correctives actions are taken, failure may occur, leading to irreversible process stabilization. In this case, complete removal of the reactors content should be envisaged. The major safety precautions to be taken are listed hereunder. The full tanks cleaning procedure can be summarized as follows:

1. Set the whole system off during the cleaning of the nitrifying tank (cleaning procedure may take about 4 hours);

2. Foresee the operators with safety clothes (cover completely the body of the operators);

3. Remove the content of the reactors via the drain ports (The drains should be directly connected via piping to the waste collectors kept closed, PE material for the waste collectors would be adequat);

4. Introduce via the water spray nozzles water and fill the reactors;

5. Redo the procedure under point (2);

6. Redo the procedure under point (3) with addition of disinfecting agent (Oxonia?, biocides,…) in the cleaning water;

7. Redo the procedure under point (2);

8. Access of the operator inside the tanks (mainly the liquefying tank) to remove manually the excess of waste on the walls of the reactor (this action is optional and not mandatory);

9. Re-inoculate the reactor with the inoculum kept in the fridge (1/4 of the reactor volume should be filled with the inoculum. This is about 250 L inoculum);

10. Set the system (PLC) back on;

The full tanks cleaning procedure can be described after testing the developed BWTU installation. In this case, tuning on some critical items can be done and consequently, safety measures can be taken.

16. A simplified model for the BWTU

The model presented in this document is predictive and does not reflect all the inputs and outputs at each sub-system level. In order to estimate the frequency and volume of possible drain, a simple model of the acidogenic reactor can be used. In the framework of the MELISSA project, a simple model was developed by EPAS for the waste compartment. Given the similarity between the two systems, this model can be easily adapted to the BWTU configuration.

A consequence of the filtration unit following the first reactor of BWTU unit is that no output of solid matter can occur in the system. The only disappearance of solids corresponds thus to a biological degradation. Given the low level of degradation of particles usually reached in such an anaerobic process, an accumulation of solids in the reactor may occur, increasing the dry matter concentration to a value non acceptable for the filtration membrane running. In this case a drain of a part of the reactor content should be planned.

16.1 Parameters involved

The matter can be described according to the IAW nomenclature (see Table 12).

Table 12 Nomenclature describing the matter

Nomenclature	Compounds
X_S	Fibres (mainly)
S_S	Soluble organic matter
X_{ON}	Proteins (mainly)
S_F	Fermentable organic matter
S_{NO}	Urea (mainly)
S_A	VFA
S_{NH}	Ammonia

The influent is mainly constituted of urea for the urine, and of fibres and proteins for the faecal material.

16.2 Description of the process

The acidogenesis occurring in the liquefying reactor of BWTU is described in Figure 26.

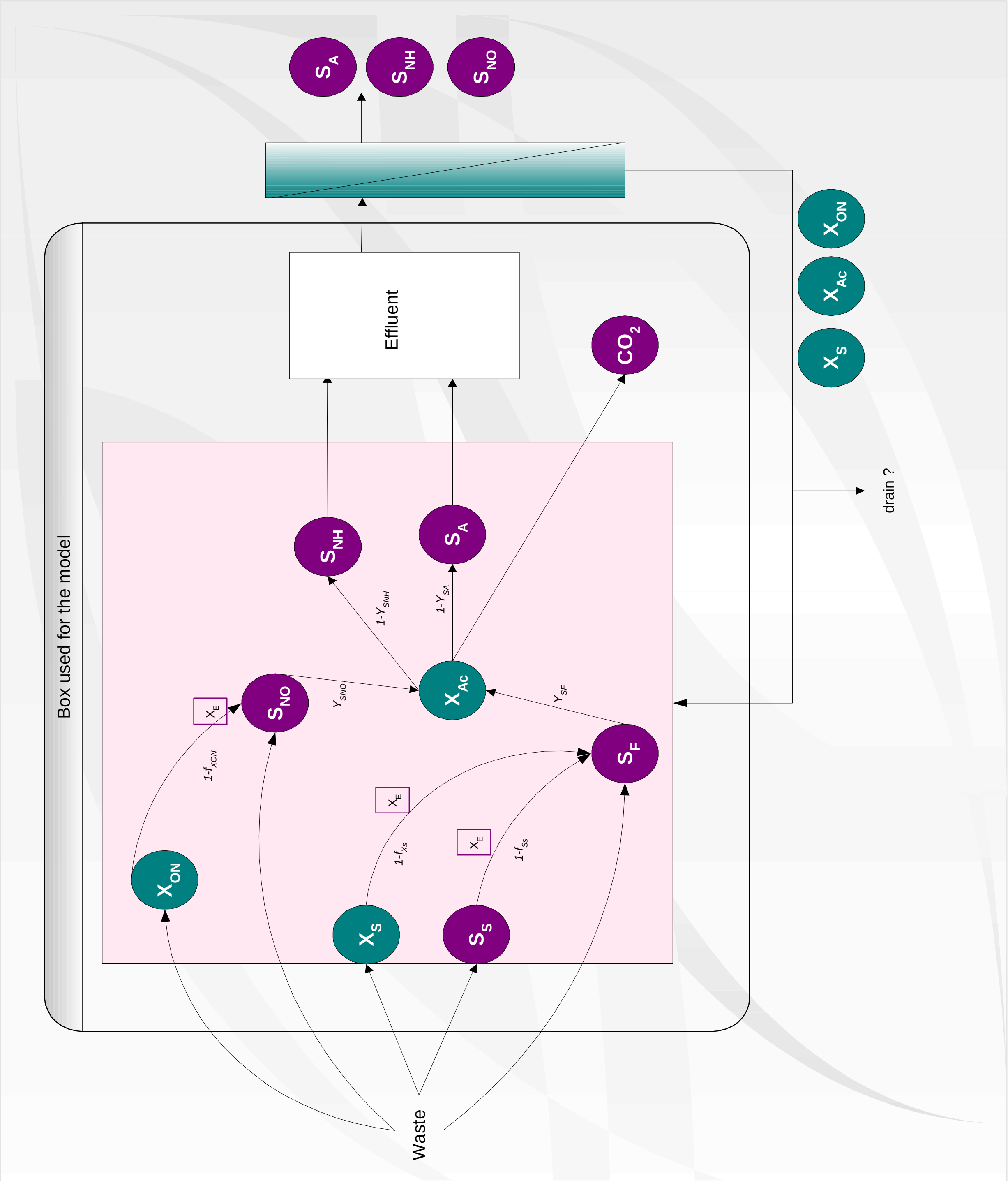


Figure 26. Description of the degradation process

The EWC model is adapted for the BWTU configuration: the parameters and basic equations describing the behaviour of the reactor are kept, only the parameters concerning the composition of feed and reactor content and the process running are modified (see TN71.1 for more details about EWC model).

16.3 Equations

Xs

$$\frac{dX_S}{dt} = -(1 - f_{XS}) \cdot k_{AcXs0} \cdot \frac{K_i}{S_A + K_i} \cdot X_S + \frac{q}{V} X_{S0} - \frac{q_{drain}}{V} X_S$$

Ss

$$\frac{dS_S}{dt} = -(1 - f_{SS}) \cdot k_{AcSs0} \cdot \frac{K_i}{S_A + K_i} S_S + \frac{q}{V} \cdot (S_{S0} - S_S) - \frac{q_{drain}}{V} \cdot S_S$$

Xon

$$\frac{dX_{ON}}{dt} = -(1 - f_{XON}) \cdot k_{AcXon0} \cdot \frac{K_i}{S_A + K_i} \cdot X_{ON} + \frac{q}{V} X_{ON0} - \frac{q_{drain}}{V} X_{ON}$$

Sf

$$\frac{dS_F}{dt} = (1 - f_{XS}) \cdot k_{AcXs0} \cdot \frac{K_i}{S_A + K_i} \cdot X_S + (1 - f_{SS}) \cdot k_{AcSs0} \cdot \frac{K_i}{S_A + K_i} \cdot S_S - \frac{\mu_m}{Y_{SF}} \cdot \frac{S_F}{K_{SF} + S_F} \cdot X_{Ac} + \frac{q}{V}(S_{F0} - S_F) - \frac{q_{drain}}{V} S$$

Sno

$$\frac{dS_{NO}}{dt} = (1 - f_{XON}) \cdot k_{AcXon0} \cdot \frac{K_i}{S_A + K_i} \cdot X_{ON} - \frac{\mu_m}{Y_{SNO}} \cdot \frac{S_{NO}}{K_{SNO} + S_{NO}} \cdot X_{Ac} + \frac{q}{V}(S_{NO0} - S_{NO}) - \frac{q_{drain}}{V} S_{NO}$$

Sa

$$\frac{dS_A}{dt} = (1 - Y_{SA}) \cdot \frac{\mu_m}{Y_{SF}} \cdot \frac{S_F}{K_{SF} + S_F} \cdot X_{Ac} + (1 - Y_{SA}) \cdot \frac{\mu_m}{Y_{SNO}} \cdot \frac{S_{NO}}{K_{SNO} + S_{NO}} \cdot X_{Ac} + \frac{q}{V}(S_{A0} - S_A) - \frac{q_{drain}}{V} S_A$$

Snh

$$\frac{dS_{NH}}{dt} = \frac{1}{2.14} \cdot (1 - Y_{SA}) \cdot \frac{Y_{SNH}}{Y_{SNO}} \cdot \mu_m \cdot \frac{S_{NO}}{K_{SNO} + S_{NO}} \cdot X_{Ac} + \frac{q}{V}(S_{NH0} - S_{NH}) - \frac{q_{drain}}{V} S_{NH}$$

16.4 Model validation

16.4.1 Simulation conditions

The BWTU model is tested in the configuration of the lab reactor nowadays running in the lab. The reactor was first inoculated with effluent from the liquefying reactor of EWC, therefore the initial concentrations inside the reactor can be determined from EWC data (see Table 13). The lab reactor was first fed with an influent made of faecal material and urine diluted three times, in a ratio corresponding to the ratio of a human production (see addendum). The concentrations of this influent was deduced from experimental data (see Table 13).

Table 13 Specific concentrations for BWTU lab acidogenic reactor

	Initial state in the reactor (g/L)	**Concentrations in the influent (g/L)**
X_S	12,82	0,7
S_S	3,2	0,28
X_{ON}	6,86	3,6
S_F	0,122	0,002
S_{NO}	1,46	4,5
S_A	2	0,16
S_{NH}	1,4	0,2

The process parameters are summarised in Table 14.

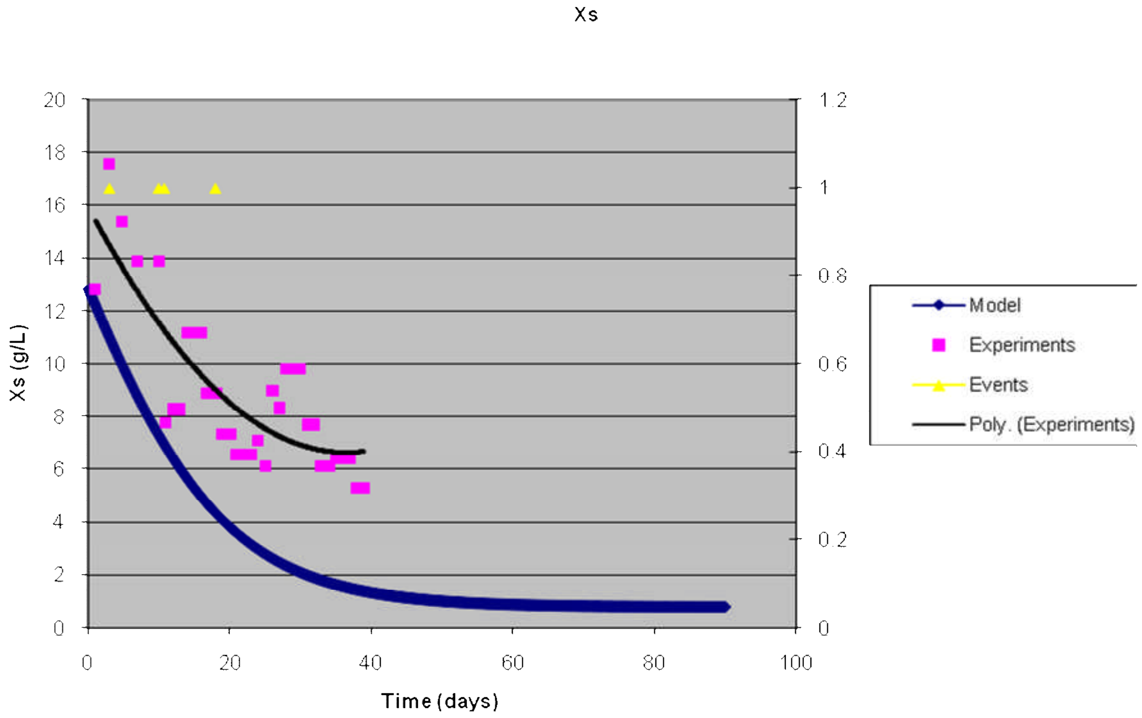
Table 14 Process parameters of lab reactor

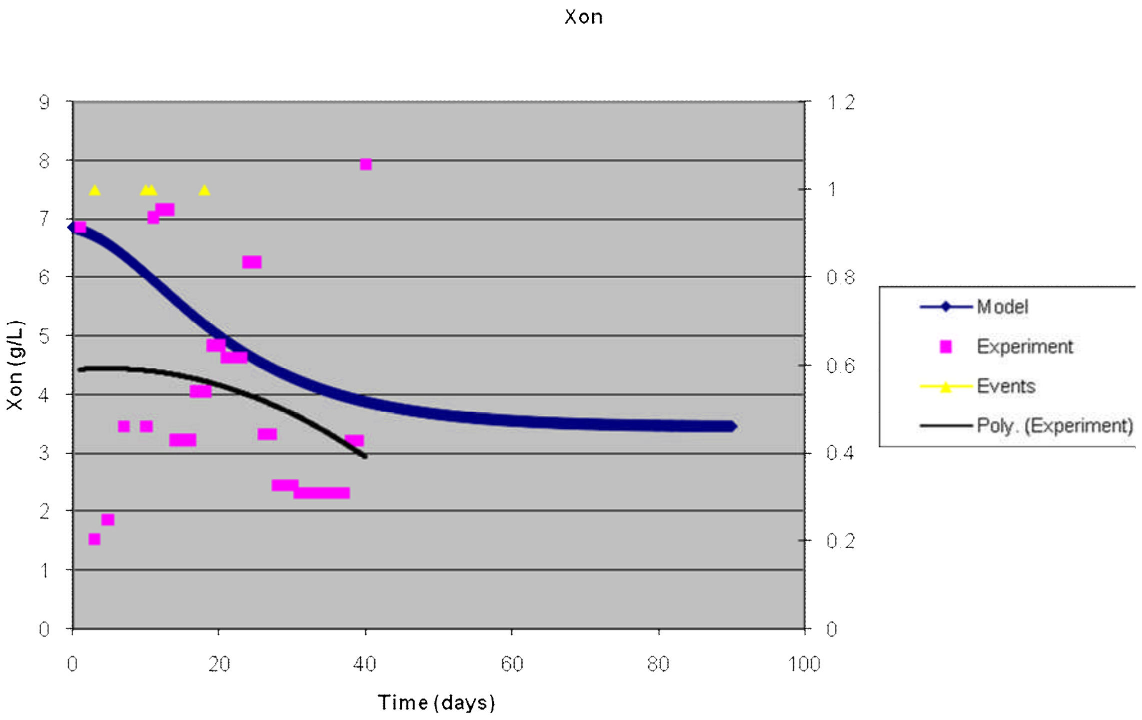
Temperature	55 °C
pH	5,8
Reactor volume	1 L
Volumetric flow rate of effluent = filtrate	115 mL/d
Volumetric flow rate of influent	115 mL/d

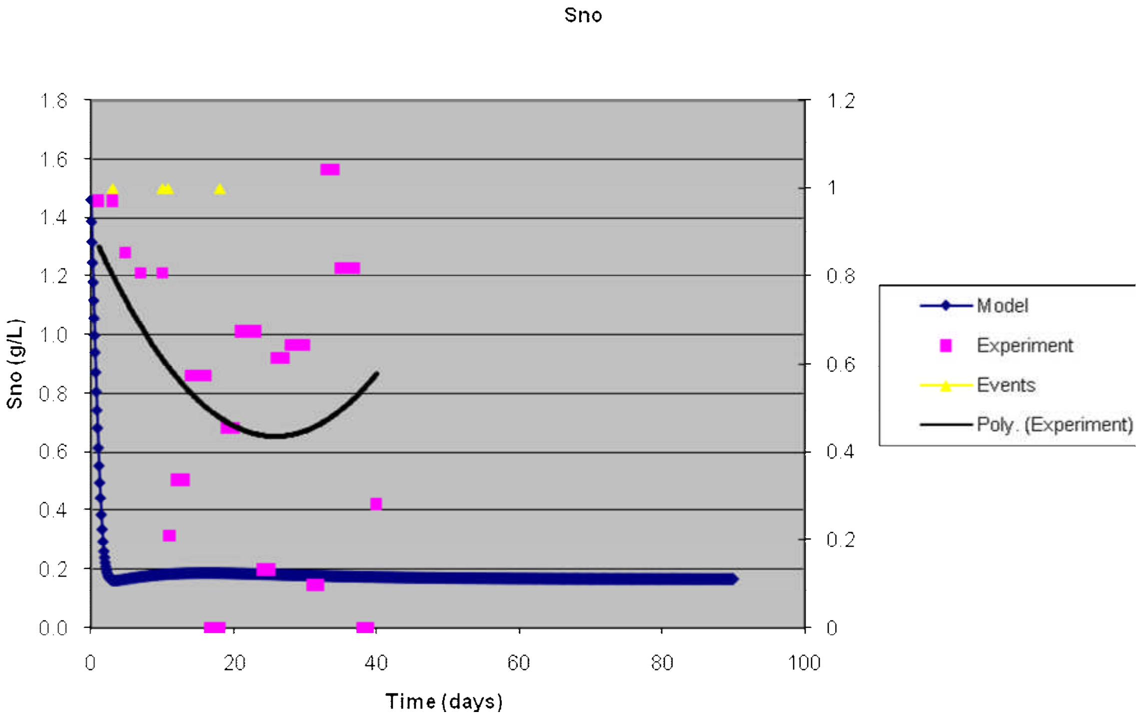
With these conditions the model is used to determine the evolution of the different compounds concentrations in the time. Then they can be compared to the experimental results obtained.

16.4.2 Comparison model – experiment results

The evolutions are presented in Figure 27.




Xon
Xon (g/L)
9
8
7
6
5
4
3
2
1
0
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time (days)
Model
Experiment
Events
Poly. (Experiment)


Sno
Sno (g/L)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time (days)
Model
Experiment
Events
Poly. (Experiment)

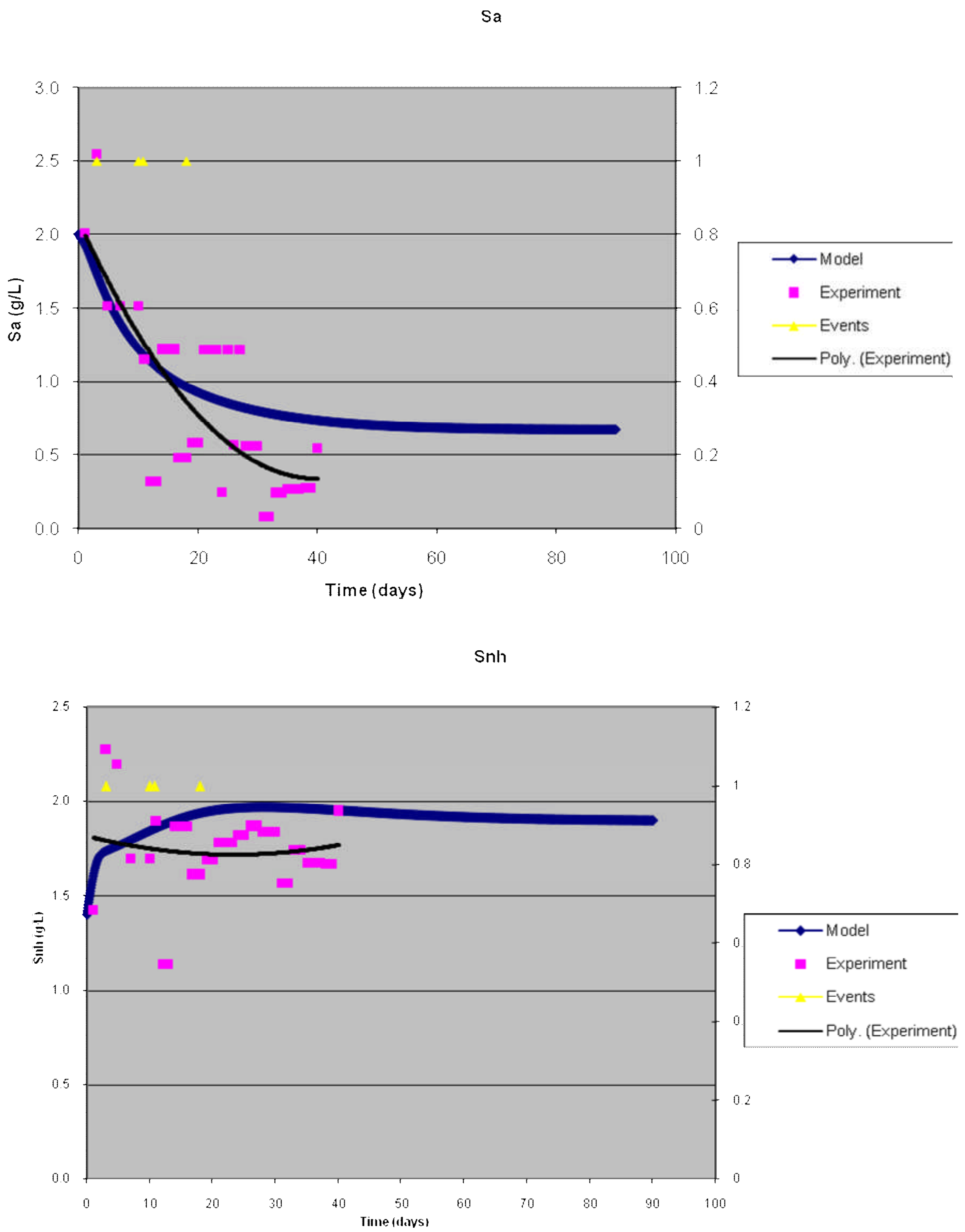


Figure 27 Comparison of compounds concentrations evolution obtained by experiments and with by modelling

As shown on these graphs the evolutions are quiet similar; differences can be explained by the approximations made in the calculations of concentrations from experimental results, and by the instability in some process parameters observed in the first weeks of the experiments (unstable pH, dilutions…). These results allow to valid the present model and use it as a tool of prediction to study the drain possibility.

16.4.3 Example of results from experimental data: calculation of influent concentrations from the model

(period 3/03 27/03)

Lab measurements									
	Influent				*Effluent*				
Measurements (g/L)	Sample 1	Sample 2	Sample 3	Average	Reactor content initial	Effluent 27 d	*Sample 3 (02/1050)*	Reactor content initial	
Nt-s	2,74	2,8	3,12	2,887	*2,8*	2,8		2,800	
NH4-N s	0,135	0,198	0,2485	0,194	*1,7*	1,7		1,700	
Nt-t	2,74	2,8	3,12	2,887	*2,8*	2,8		2,800	1,465
NH4-N t	0,135	0,198	0,2485	0,194	*1,7*	1,7		1,700	
VFA	0,114	0,2308	0,1248	0,157	*1,2*	0,55		1,200	
BOD short				0,170					
CODs	1,458	2,1	2,39	1,983	*2,6*	1,6		2,600	
DM	18,3	11,9	11	13,733	*23*	15,6		23,000	28,36333
ashes	6,2	6,2	5,4	5,933	*6,7*	5,3		6,700	
CODt	6,88	8,25	8,75	7,960	*17,8*	8,3		17,800	25,80833
Urea-N	2,28	1,91	2,173	2,121	0,4	0,2		*0,400*	
Gas (g/L)								*0,412*	

Compounds concentrations				
Measurements (g/L)	Influent	Initial reactor	Effluent 25d	
Xs	0,896	9,002	5,626	
Ss (gCOD/L)	1,813	1,313	1,009	
Ss (g/L)	1,813	1,639	0,943	
Xon (cf sigma meas)	0,060	4,800	3,300	
Sf (gCOD/L)	0,003	0,003	0,003	
Sf (g/L)	0,002	0,003	0,003	
Sno	5,029	0,856	0,428	
Sno (gCOD/L)				
Sa (g/L)	0,157	1,200	0,550	
Sa (gCOD/L)	0,167	1,284	0,589	
Snh	0,250	2,193	2,193	
total	8,050	16,300	10,300	

(OM inf = 6g/L! super)

🟦 Use the COD prog to convert

Fraction of inert matter (%)
10,05017799
0,724347186
0,904083179
80
1,195536663
1,195536663
0,170214797
7,666098807
7,666098807
8,770421324

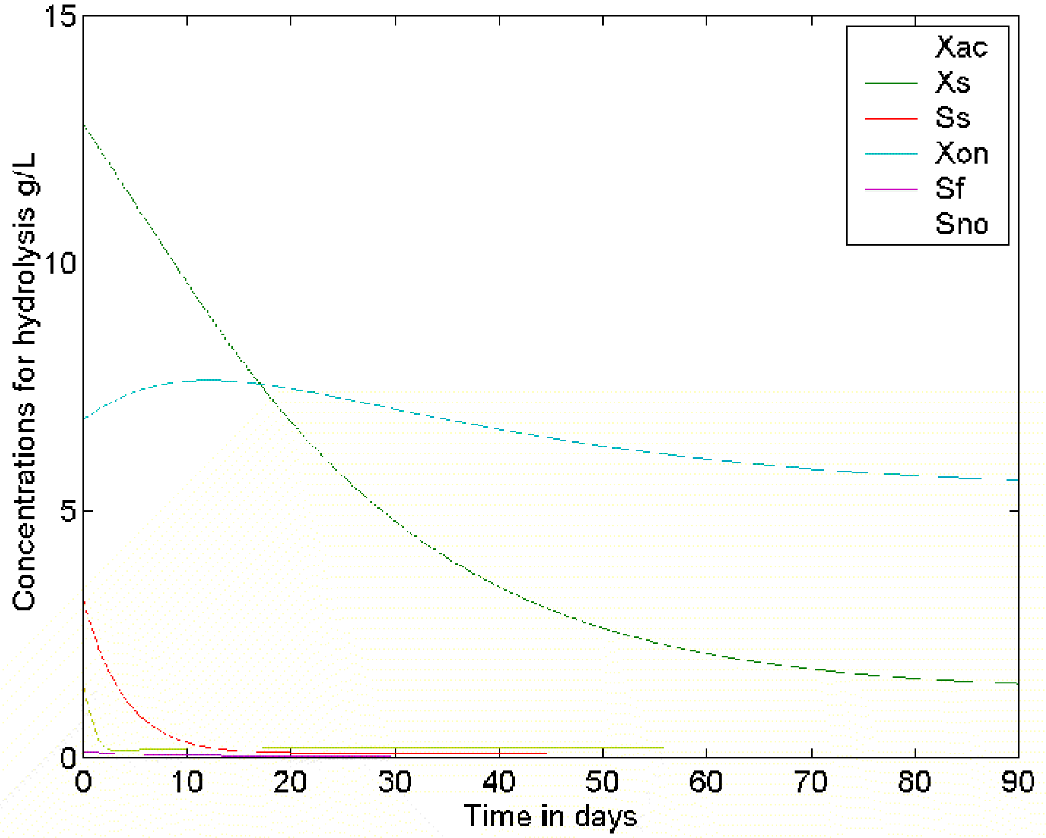
Sno=Urea-N * 2,14

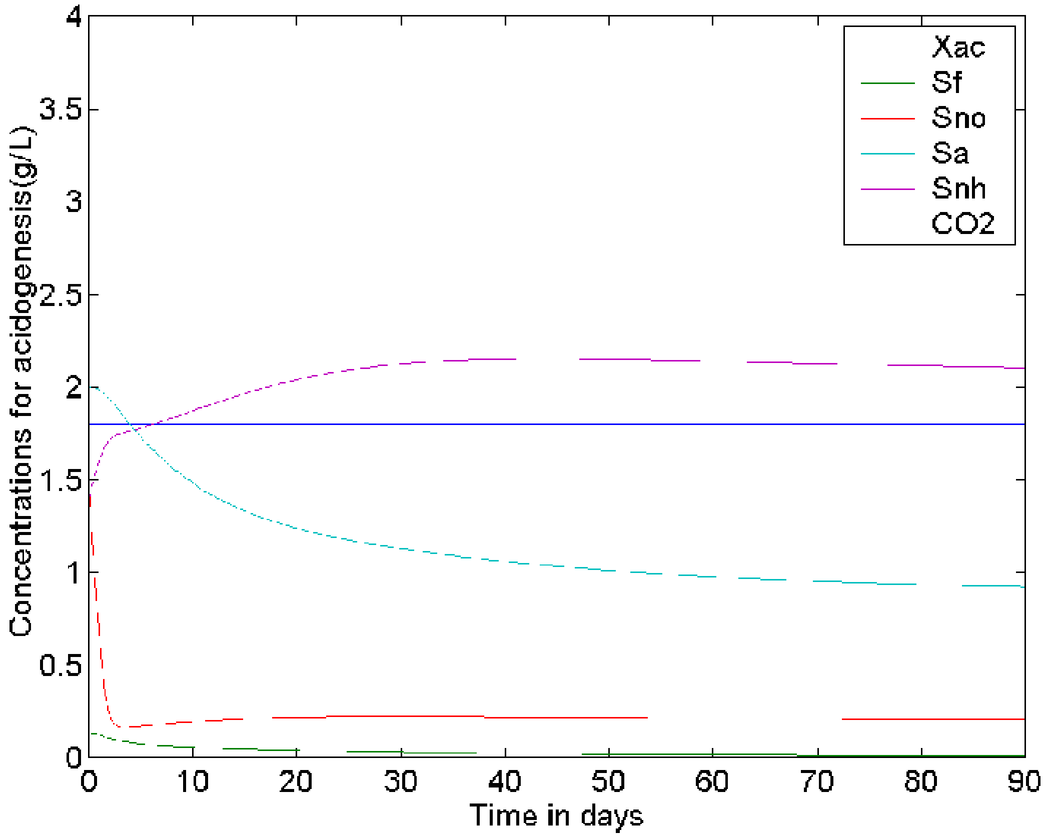
Check		
Measurements (g/L)	Influent	*Effluent*
COD t	7,96	*17,8*
Sa+Sf+Ss+Xon+Sno+Xs	7,9565	*17,5*

Lab measurements					
	Influent-Concordia composition (16/05)	*Effluent*			
Measurements (g/L)	**Sample 1**	**Reactor content initial**	**Effluent 27 d**	***Sample 3 (02/1050)***	**Reactor content initial**
Nt-s	0,76				
NH4-N s	0,06				
Nt-t	0,76				
NH4-N t	0,06				
VFA	0,005				
BOD short					
CODs	4,54				
DM	9,7				
ashes	1,7				
CODt	9,55				
Urea-N	0,7				

Gas (g/L)

Compounds concentrations			
Measurements (g/L)	**Influent**	**Initial reactor**	**Effluent 25d**
Xs	1,938	-4,800	-2,750
Ss (gCOD/L)	-0,008	-0,003	-0,592
Ss (g/L)	4,500	-0,003	-0,553
Xon (cf sigma meas)	0,061	4,800	3,300
Sf (gCOD/L)	0,003	0,003	0,003
Sf (g/L)	0,003	0,003	0,003
Sno	1,498	0,000	0,000
Sno (gCOD/L)	0,000		
Sa (g/L)	0,005	0,000	0,550
Sa (gCOD/L)	0,005	0,000	0,589
Snh	0,077	0,000	0,000
total	8,077	0,000	0,000


15
10
5
0
0
10
20
30
40
50
60
70
80
90
Concentrations for hydrolysis g/L
Time in days
Xac
Xs
Ss
Xon
Sf
Sno


4
3.5
3
2.5
2
1.5
1
0.5
0
0
10
20
30
40
50
60
70
80
90
Concentrations for acidogenesis(g/L)
Time in days
Xac
Sf
Sno
Sa
Snh
CO2

17. Drain specifications

Because the liquefying reactor is coupled to a membrane filtration unit, the non-degraded solids are retained in the reactor and are accumulated, creating an increase in the dry matter content after a certain period of time, which is dependent on the degradation efficiency of these solids. To ensure an optimal operation of the BWT unit both in terms of hardware operation and biodegradation efficiency, it is necessary to regulate the dry matter content under a certain value that was fixed at 5%. This can be performed by draining the reactor at regular intervals of time.

One possibility to estimate the necessary drain frequency and amplitude consists to simulate the solids accumulation in the time, based on different parameters (dry matter content of reactor at time 0 and influent, load of influent). It is assumed that about 25% of the dry matter fed in the reactor is accumulated, based on the experimental results. The drain specifications were calculated in order to regulate the dry matter under 35 g/L (Figure 28). Each peak corresponds to a drain of around 3000 L, for a reactor volume of 4160 L in maximal load of 70 persons. This corresponds to an average of about 43 L/d of drain. The average daily volume of drain depending on the number of inhabitants is presented in

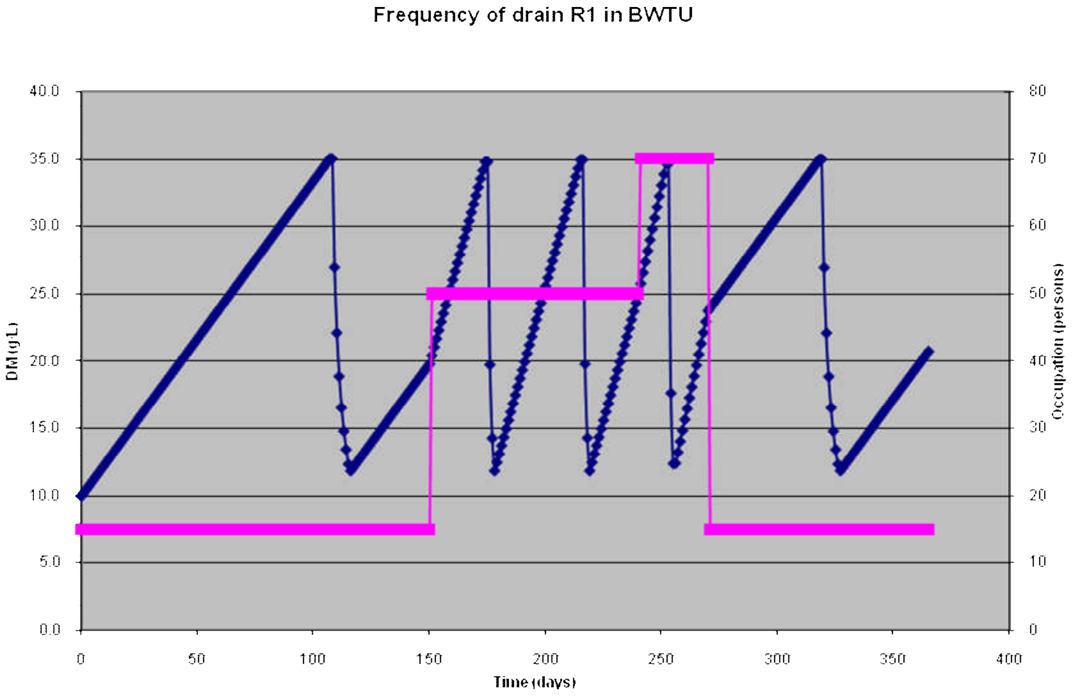


Figure 28. Drain frequency

Table 15. Drain estimation from the liquefying reactor

Occupation	Estimated average drain (L/d)
15	14
50	30
70	43

18. Addendum

18.1 Details about tests performed with lab-scale reactors

The lab experiments are performed within different steps:

1. with influent of DDU in worst case (FM + urine diluted 3 times)
2. -with influent of Concordia in real case, without grey water sludge, with a HRT of 7.6 days
3. -with influent of Concordia in real case, with grey water sludge, with a HRT of 7.6 days
4. -with influent of Concordia in real case, with grey water sludge, with a HRT of 2 days
5. -with influent of Concordia in real case, with grey water sludge, with a HRT of 3 days

DDU Worst case: FM + Urine diluted 3 times

Period: 03/03/2003 to 15/03/2003

In a first approach a dilution of 3 is proposed, in order to study the worst case that can be stand by the unit. Table 16 shows the volumes of urine and faecal material for one sample.

Table 16. Feed preparation

	Unit	**Urine**	**Faecal material**
DM	g/person.d	51	30
[DM]	g/L	34	330
Volumetric flow	L/person.d	1.5	0.09
Total flow of the unit (V = 1200L)	L/d	37.5	2.25
Lab flow (V = 1L)	mL/d	31	1.88
Lab flow diluted 1/3	mL/d	93	5.64
Volumes for one sample (3 samples/week)	mL	217	13.16

Concordia without grey water sludge, occupation of 15 persons

Period: 22/04 to 16/05/2003

Before the grey water sludge samples are available to perform the tests, the unit can work with the rest of the Concordia substrate and the same composition.

Table 17. Feed preparation

	Volume (L)	Urine (L)	Faecal Material (L)	Food waste = Plants (kg fresh)	Daily volumetric load (L/d)
Concordia	810	105	6,3	32,41	810
Lab	1	0,13	0,0078	0,04	0,13
			2,6g fresh	15,4g beet 24,6 g lettuce	

Concordia feed, occupation of 50 persons (HRT = 2.6 d), V = 2700L

Period: 16/05 to 06/06/2003

	Concordia base (2700 L)	Lab reactor (1L)	Feed lab reactor
Flow (L/d)	1040	0,385	for 1L
Toilet paper	900 g/d	0,33 g/d	0,86 g
Urine	75 L/d	28 mL/d	72,2 mL
Faecal material	1,5 kg/d	0,56 g/d	1,45 g
Grey Water sludge	260 L/d	96 mL/d	250 mL
Food wastes*:	10 kg/d	3.7 g/d	9,6 g
-meat/fish/egg			1,7 g
-vegetables/fruits			3,2 g
-"starch food"			3,2 g
-milk products			1,5 g

As the efficiency decreases sensitively, it was decided to re-size the unit in order to have a HRT of 4 days with an occupation of 50 persons.

Concordia feed, occupation of 50 persons (HRT = 4 d), V = 4160L

Period: 07/06 to 13/06/2003

	Concordia base (4160 L)	Lab reactor (1L)	Feed lab reactor
Flow (L/d)	1040	0,250	for 1L
Toilet paper	900 g/d	0,22 g/d	0,88 g
Urine	75 L/d	18 mL/d	72 mL
Faecal material	1,5 kg/d	0,36 g/d	1,45 g
Grey Water sludge	260 L/d	62,5 mL/d	250 mL
Food wastes*:	10 kg/d	2,4 g/d	9,6 g
-meat/fish/egg			1,7 g
-vegetables/fruits			3,2 g
-"starch food"			3,2 g
-milk products			1,5 g

Concordia feed, occupation of 50 persons (HRT = 4 d), V = 4160L, test with wine

Period: 13/06 to 23/06

In order to test the possible influence of throwing wine in the system, wine will be added in the feed based on a throwing of 10L/d during 8 days for an occupation of 50 persons.

	Concordia base (4160 L)	Lab reactor (1L)	Feed lab reactor	Feed lab reactor
Flow (L/d)	1040	0,250	for 1L	for 2 L
Toilet paper	900 g/d	0,22 g/d	0,88 g	1.76 g
Urine	75 L/d	18 mL/d	72 mL	144 mL
Faecal material	1,5 kg/d	0,36 g/d	1,45 g	2.9 g
Grey Water sludge	260 L/d	62,5 mL/d	250 mL	500 mL
Food wastes*:	10 kg/d	2,4 g/d	9,6 g	19.2 g
-meat/fish/egg			1,7 g	3.4 g
-vegetables/fruits			3,2 g	6.4 g
-"starch food"			3,2 g	6.4 g
-milk products			1,5 g	3 g
-wine	10 L/d	2.4 mL/d	9.6 mL	19.2 ml

Concordia feed, occupation of 70 persons (HRT = 3 d), V = 4160L, test with wine

Period: 23/06 to 17/07

***: pH correction stopped the 30/06

Same composition of the influent

	Concordia base (4160 L)	Lab reactor (1L)	Feed lab reactor	Feed lab reactor
Flow (L/d)	1350	0,325	for 1L	for 2 L
Toilet paper	1260 g/d	0.3 g/d	0,88 g	1.76 g
Urine	105 L/d	25 mL/d	72 mL	144 mL
Faecal material	2.1 kg/d	0.5 g/d	1,45 g	2.9 g
Grey Water sludge	260 L/d	62.5 mL/d	250 mL	500 mL
Food wastes*:	14 kg/d	3.4 g/d	9,6 g	19.2 g
-meat/fish/egg			1,7 g	3.4 g
-vegetables/fruits			3,2 g	6.4 g
-"starch food"			3,2 g	6.4 g
-milk products			1,5 g	3 g
-wine	14 L/d	3.4 mL/d	9.6 mL	19.2 ml

Concordia feed, occupation of 70 persons (HRT = 3 d), V = 4160L, test with cheese breeds

Period: 17/07 to 18/08

Still no pH correction

	Concordia base (4160 L)	Lab reactor (1L)	Feed lab reactor	Feed lab reactor
Flow (L/d)	1350	0,325	for 1L	for 2 L
Toilet paper	1260 g/d	0.3 g/d	0,88 g	1.76 g
Urine	105 L/d	25 mL/d	72 mL	144 mL
Faecal material	2.1 kg/d	0.5 g/d	1,45 g	2.9 g
Grey Water sludge	260 L/d	62.5 mL/d	250 mL	500 mL
Food wastes*:	14 kg/d	3.45 g/d	9,6 g	19.2 g
-meat/fish/egg				
-vegetables/fruits				
-"starch food"				
-milk products				
-cheese breeds	4 kg/d	1 g/d	3 g	6 g

Concordia feed, occupation of 70 persons (HRT = 3 d), V = 4160L, Test with concentrate of grey water treatment

Period 18/08 to 10/09

The tests will be performed for a period of 3 weeks to verify the influence of the used detergents in the grey water on the anaerobic bacteria in the BWTU.

Still no pH correction: pH reactor 1 = 6

	Concordia base (4160 L)	Lab reactor (1L)	Feed lab reactor	Feed lab reactor	Feed lab reactor
Flow (L/d)	1350	0,325	for 1L	for 2 L	For 5L
Toilet paper	1260 g/d	0.3 g/d	0,88 g	1.76 g	4.4 g
Urine	105 L/d	25 mL/d	72 mL	144 mL	360 ml
Faecal material	2.1 kg/d	0.5 g/d	1,45 g	2.9 g	7.25 g
Grey Water sludge	260 L/d	62.5 mL/d	250 mL	500 mL	1250ml
1.Xyplon	400 ml	0.096 ml	0.288 ml	0.57 ml	1.44 ml
2.Neutrogena	34.2 g	8.22 mg	24.66 mg	49.32 mg	123.3 mg
3.DEB	318 ml	0.076 ml	0.23 ml	0.46 ml	1.15 ml
4.Percroix	213.5g	51.32 mg	154 mg	308 mg	770 mg
5.Tetrox	80g	19.23 mg	57.69 mg	115.38 mg	288.45 mg
6.Gradex OR	10 ml	2.4 µl	7.2 µl	14.4 µl	36 µl
7. OXONIA (0.2%)	0.52 L	0.125 ml	0.5 ml	1ml	2.5 ml
Food wastes*:	14 kg/d	3.45 g/d	9,6 g	19.2 g	48 g
-meat/fish/egg					
-vegetables/fruits					
-"starch food"					
-milk products					

In this case, cheese breeds and wine were removed from the influent composition

Concordia feed, occupation of 70 persons (HRT = 3 d), V = 4160L, Test with concentrate of grey water treatment unit (higher volume of concentrate GW)

Period 01/09 to 05/09

The tests will be performed for a period of 1 week to verify the influence of the used detergents in the grey water on the anaerobic bacteria in the BWTU. The flows of the concentrate from the GWTU are higher than the previous case since the BWTU could treat the grey water generated by 70 persons.

Still no pH correction: pH reactor 1 = 6

	Concordia base (4160 L)	Lab reactor (1L)	Feed lab reactor	Feed lab reactor	Feed lab reactor
Flow (L/d)	1350	0,325	for 1L	for 2 L	For 5L
Toilet paper	1260 g/d	0.3 g/d	0,88 g	1.76 g	4.4 g
Urine	105 L/d	25 mL/d	72 mL	144 mL	360 ml
Faecal material	2.1 kg/d	0.5 g/d	1,45 g	2.9 g	7.25 g
Grey Water sludge 1.Xyplon 2.Neutrogena 3.DEB 4.Percroix 5.Tetrox 6.Gradex OR 7. OXONIA (0.2%)	700 L/d 1076 ml 116.3 g 1023 ml 574.8 g 215.38 g 27 ml 1.4 L	168.27 mL/d 0.25 ml 28 mg 0.24 ml 0.14 g 51.7 mg 6.48 µl 0.33 ml	250 mL 0.75 ml 84 mg 0.72 ml 0.42 g 155 mg 19.44µl 1 ml	500 mL 1.5 ml 168 mg 1.44 ml 0.84 g 310 mg 39 µl 2 ml	1250ml 3.75 ml 420 mg 3.6 ml 2.1 g 775 mg 97.2 µl 5 ml
Food wastes*: -meat/fish/egg -vegetables/fruits -"starch food" -milk products	14 kg/d	3.45 g/d	9,6 g	19.2 g	48 g

18.2 Data obtained from Technomembranes for the characterisation of the grey water

Eaux à traiter

Capacité de traitement : 2.4 à 2.8 m^3 par jour.

Cette quantité est estimée pour environ 25 personnes.

Le tableau ci dessous indique l’origine de l’effluent, le produit à utiliser, le dosage du produit, et la proportion du rejet spécifique dans l’effluent total.

Origine du rejet	Produit utilisé	Dosage du produit	Proportion du rejet
Machine à laver le linge	Henkel PERCROIX Henkel TRAX	2.25 g/l 0.5 ml/l	19 %
Lave-vaisselle	Yplon Fery Henkel TOPMAT	2.3 ml/l 0.44 ml/l	25 %
Lavage des mains	DEB	5.3 ml/l	15 %
Vaisselle à la main	Henkel TETROX	5 g/l	8 %
Douches	NEUTROGENA	0.25 g/l	23 %
Lavage des sols	GRADEX OR	10 ml/l	2 %
Eaux de cuisson	-	-	8 %

Les caractéristiques sont les suivantes :

COT :	300 – 700 ppm
DCO :	2000 – 3000 ppm
Turbidité :	100 – 200 NTU
Conductivité :	1500 – 2000 µS/cm
pH :	8.5 – 9.5
Fluorure :	5 – 6 ppm
Chlorure :	30 – 60 ppm
Nitrate :	2 – 4 ppm
Phosphate :	10 – 50 ppm
Sulfate :	150 – 200 ppm
Sodium :	300 – 400 ppm
Potassium :	70 – 90 ppm
Magnésium :	2 – 4 ppm
Calcium :	10 – 20 ppm

L’installation doit permettre d'obtenir une eau traitée de qualité "hygiène" avec un taux de récupération de l'ordre de 90 %.

Quantité des différents rejets

Nombre de personne :	25	
Lavage vaisselle machine :	700	l/jour
Eaux de douche :	600	l/jour
Lavage des mains :	400	l/jour
Lavage du linge :	500	l/jour
Lavage vaisselle manuel :	200	l/jour
Eaux de cuisson :	200	l/jour
Lavage des sols :	50	l/jour
Total :	2650	l/jour

Estimation de la consommation électrique

Puissance installée : 19 kW

Puissance consommée estimée : 15 kWh

Encombrement général

Longueur : 15.5 mètres

Largeur : 2 mètres

Poids : 1500 kg

Utilités

Une cuve de 3000 litres est prévue pour la collecte des effluents.
La production doit être collectée dans une autre cuve (à prévoir). Si l’on souhaite réalimenter les machines à laver le linge et la vaisselle, ainsi que les douches, il faut prévoir un surpresseur.

19. Reference documents

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System study life support in space Microbial Water Treatment ,TN 1, February 2002