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CONFIDENTIAL REPORT

DEVELOPMENT, BUILDING AND UTILISATION OF A BLACK WATER TREATMENT UNIT AT DUMONT D'URVILLE AND CONCORDIA

ESA contract (OF02.107)
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TECHNICAL NOTE 82.1

Sizing of the Black Water Treatment Unit

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1 Introduction

The Dumont-d'Urville base, located in the district of Terre Adélie, is a French settlement on the Antarctic continent. By the year 2003, a new permanent base called Concordia will be put in use in the centre of the Antarctic continent. This plan is actually carried out by the French-Italian joint.

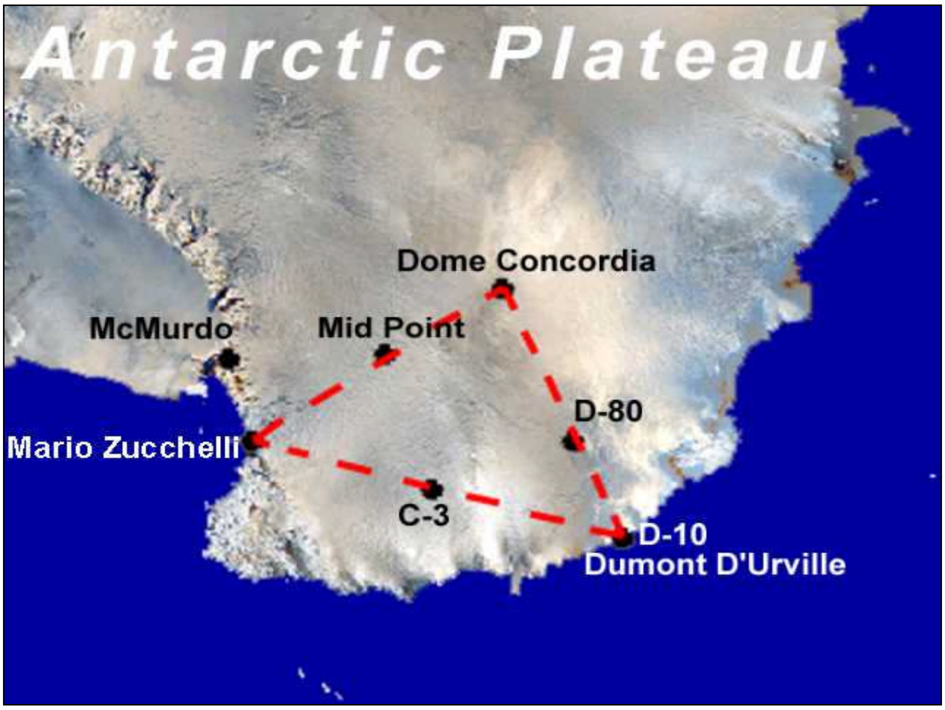

Figure 1.Map of Antarctica and the location of Dumont d'Urville and Concordia bases

Since the bases are permanently manned, the produced waste has to be managed, especially during the winter when the access to the bases is difficult. For this reason, it was decided to construct a black water treatment unit in order to process the solid waste originated from the crew and its activities.

Dumont-d'Urville base can be divided into two residences (see Figure 2): the winter residence and the summer residence. The Dumont-d'Urville summer base can be inhabited by 25 people of the Dumont d'Urville winter base during 125 days a year and will be used as a place to sleep only. The remaining days, these people will stay in Dumont d'Urville winter base, since the summer base will not be accessible (The BWT-unit will have to treat human excrements, namely urine and faecal material. Based on this number of persons and the specificity of the infrastructure at Dumont d'Urville, the sizing of the unit will be elaborated. This includes the definition of the amount of waste (faecal material and urine) that will be treated and also the amount of water that is discharged to the treatment facilities.

Figure 2 Inhabitation of Dumont d'Urville winter and summer residence

Figure 3. Dumont d'Urville base

The permanent base called Concordia is to be opened in the centre of Antarctic continent by the year 2003. There also a black water treatment unit will be elaborated to treat the waste produced by 15-16 persons for 275 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; Indeed, during the period of 365 days (12 months), the station will manned with 35 more persons for 90 days and another 20 persons for 30 days (see Figure 4).

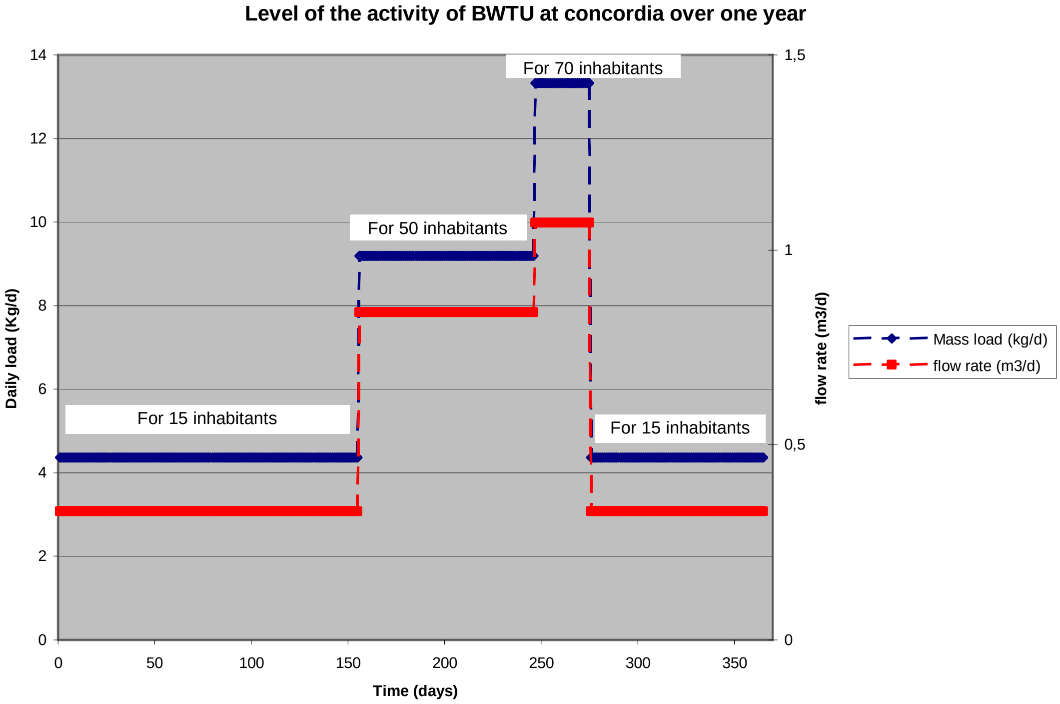

Figure 4 Inhabitation of Concordia base

Figure 5. Concordia base

2 objectives

The objectives of this work can be summarized in two main points:-

1. The determination of the process parameters values and the necessary reactor volumes in case of Concordia station and Dumont d'Urville summer residence.
2. A scenario analysis will be done to determine and define the operation limits of the units.

For the elaboration of the black water treatment units, the expertise that is gained from the research done for ESA/ESTEC in the MELISSA project (Engineering of the Waste Compartment) will be used.

3 Anaerobic degradation processes

The biological pathways in anaerobic degradation processes can be summarized as shown in Table 1. The different phases could be successively used or at least the two first phases as the case in most anaerobic digestion processes.

Table 1. Anaerobic degradation processes

Biological pathways in anaerobic degradation processes	
Phase I: Prefermentation (VFA generation processes)	
Hydrolysis	Extracellular enzyme-mediated transformations, where complex soluble and particulate (insoluble) organic material is transformed into simple soluble substrate.
Acidogenesis	Acidogenic bacteria (faster growing when compared to methanogenic bacteria) ferment the hydrolysis products into long- and short-chain volatile acids, other acids, alcohols, etc.
Phase II: Methane generation (VFA consumption processes)	
Acetogenesis	High molecular fatty acids, as well as volatile acids (except for acetate), are decomposed into reaction intermediates: simple acids such as acetate, propionate and butyrate.
Methanogenesis	Methanogenic bacteria (slower growing) metabolize the VFA (decarboxylation of acetate) with methane formation.
Phase III: Additional VFA consumption processes	
Aerobic respiration	DO present: bacteria (aerobic) consume VFA
Sulfate reduction	SO_4 present: bacteria (sulfate reducing) consume VFA
Denitrification	NO_3 present: bacteria (heterotrophic) consume VFA

4 Concept of the black water treatment unit (BWT-unit)

In this work, the proposed concept will concern two stations: the Dumont d'Urville summer base and the Concordia base.

4.1 Dumont d'Urville station

The concept of the BWT-unit is shown in Figure 6. The feed will be collected in a homogeniser, where the content will be mixed and diluted with water up to the necessary concentration, depending on the amount of water, which could be managed by the users. The mixture will then be fed to the first anaerobic reactor, the liquefying reactor, for the conversion in volatile fatty acids, ammonium and other fermentation products. The fermentation products will be recovered by means of a filtration module. The recycle stream will return to the reactor. The filtrate will be introduced in a second anaerobic reactor, the methanogenic reactor, for the conversion into methane and carbon dioxide. A filtration module will separate the solids from the liquid. The solids will be recycled to the reactor and the filtrate will be send to the grey water treatment system. Depending on the final reactor configuration of the anaerobic reactor, the second ultrafiltration might be replaced by a sludge separation system based on gravitation.

The unit consists of a two-stage anaerobic degradation process. The feed will be a water phase containing particulate organic material and minerals. The feed will be introduced in the first anaerobic reactor. This liquefying reactor will be operated in thermophilic conditions (55°C) and at pH 6 to avoid methane production. A part of the fermentation products are in gaseous form like carbon dioxide.

The methanogenic reactor, proposed in paragraph 4.4, will then transform the volatile fatty acids into methane. This reactor will be operated also in thermophilic conditions (50 to 55°C), but at a pH of 7.

Both reactors will be inoculated with a consortium of anaerobic bacteria, which have already shown high efficiencies in organic matter degradation in the framework of MELISSA project: EWC (Engineering of the Waste Compartment). The bacteria will be inoculated in the reactors and allowed for adaptation for few days at low feed load to avoid irreversible environmental chocks in the allochthonous and autochthonous populations.

4.2 Concordia station

The same concept principle as for Dumont d'Urville base is proposed for the Concordia station except the fact that the latter has to treat higher loads. As shown in Table 8, in addition to faecal material and urine, the black water treatment unit of Concordia has to treat kitchen waste, kitchen rests from the dining room, toilet paper and concentrated sludge originated from the treatment of grey water (GWT unit) designed by Technomembranes. Moreover, the unit has to treat faecal material, urine and rests of at least 15 persons and a maximum of 50 to 70 persons.

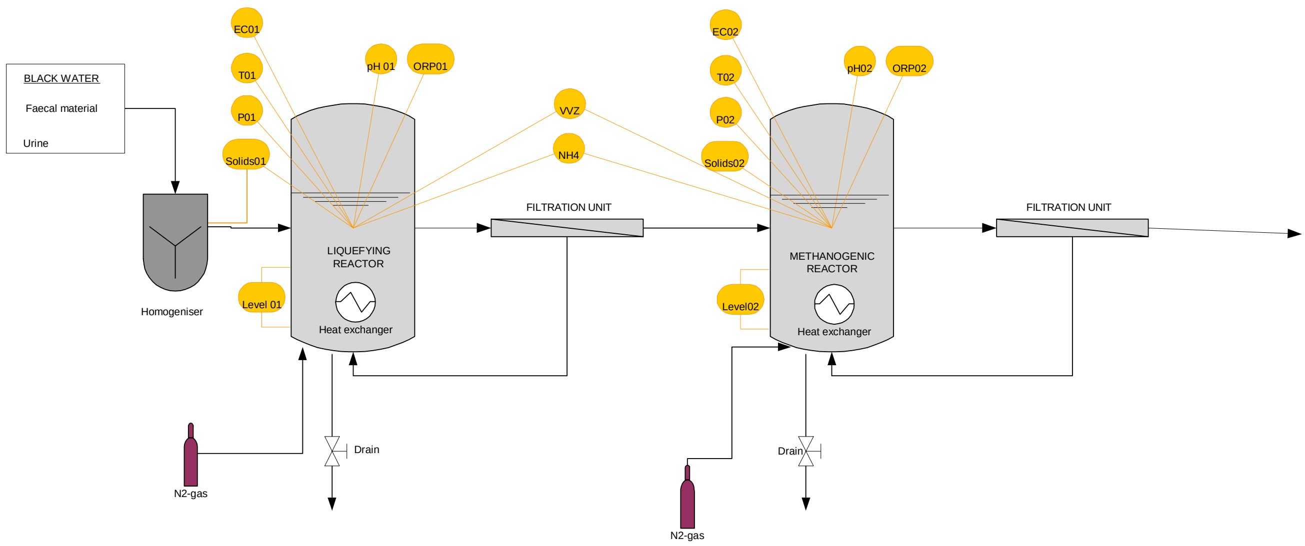

Figure 6. General concept of the BWT-unit

4.3 Liquefying reactor

This reactor needs to be operated at 55°C (thermophilic conditions) and at a pH of 6- 5.8 to avoid methane production. The reactor will be operated in anaerobic conditions. The biodegradation efficiency of the reactor needs to be at least 55 % (maximal so far obtained efficiency). The reactor needs to be provided with several interfaces among which the solid loop with the waste material and the filtration unit. The latter will be equipped with an ultrafiltration membrane. The task of the membrane is to separate the slow biodegradable fraction of organic matter from the produced VFA and ammonium. It is very important, for safety reasons and to avoid contamination in the methanogenic reactor, to retain the bacteria, present in the bioreactor by the membrane.

4.4 Methanogenic reactor

The methanogenic reactor treats the effluent of the filtration unit of the liquefying reactor. Based on the assumed efficiency of the liquefying reactor and data already collected in the framework of MELISSA-project (EWC: TN71.1), the load to the second reactor was calculated, from which the sizing of the methanogenic unit was done. Again this unit will be, probably, followed by a membrane unit to retain the sludge in the system. Another possibility is to use another type methanogenic reactor like a fixed bed reactor, from which the collected effluent will be exempt of solids and directed towards the grey water unit without passing through a second filtration unit. The methanogenic reactor will produce biogas, which should be burnt either by using a flare or by using a generator. The amount of biogas and the composition (CH_4, CO_2, H_2, H_2S,…) will be estimated. Based on the gas production and the methane concentration a heat balance will be made. Anaerobic systems have always a net production of energy.

4.5 Membrane filtration

The main aim of using a membrane filtration module is to separate the liquid phase from the solid phase. In the present concept a membrane filtration unit is proposed to separate the liquid stream containing volatile fatty acids (VFA), nitrogen, COD soluble and salts from the insoluble fraction. The liquid stream will be fed the methanogenic reactor, where the VFA and COD_s will be further converted exclusively, into methane (CH_4) and carbon dioxide. The solid fraction will be retained by the membrane filter and returned back to the acidifying reactor for further transformations.

Depending on the pores size, membrane filtration systems allow or not the transfer of bacteria.. In addition, the membrane technology avoids wash out of the biomass from the bioreactors in general and thus allows longer sludge residence time in the acidifying reactor. By this means, the hydraulic residence time can be seriously shortened to less than 10 to 20 days as required in most of the anaerobic degradation systems.

Ultrafiltration is capable of concentrating bacteria, some proteins, some dyes, and constituents that have a large molecular weight, greater than 10,000 daltons. Ultrafiltration is only somewhat dependent upon the charge of the particle and is much more concerned with the size of the particle

The ultrafiltration technology proposed will retain particle with sizes up to 0.01 µm. This concerns the retention of reactor particles (organic and inorganic) with sizes higher than 0.01 µm, bacteria, colloidal material and viruses. In the proposed concept a low overpressure is needed to speed up the mass transfer process. In general an overpressure of 0.5 to 2 bars will be applied to generate the required filtrate to be fed to the methanogenic reactor.

4.6 Additional treatment

The effluent coming from the second reactor must respect some constraints to satisfy the users and to be treated in the Grey Water Treatment unit. Therefore some additional treatments will be proposed, in order to satisfy these criteria:

1. acceptable colour of the effluent (activated carbon, ozonisation, peroxide under UV light…)
2. salts composition compatible with reverse osmosis
3. ammonium content sufficiently low to respect the criteria for hygienic water after reverse osmosis (nitrification/denitrification, zeolites…).

Tests and trade-off will be performed in order to solve these problems in the most adapted way. The results of the tests will be presented in TN80.7.

5 Substrate composition

5.1 Feed composition of BWT-unit for Dumont d'Urville summer residence

The Dumont d'Urville black water treatment unit should be able to treat the excrements (urine and faecal material) produced by 25 persons every day for a period of 125 days. Tables 2 and 3 present the average composition and amount of these wastes per person and per day. The feed of the unit consists of faecal material, urine and toilet paper. The influent will be made of diluted feed. These data are based on experiments carried out at EPAS and ESA and taken from technical notes (MWT TN1, MELISSA TN1).

Table 2 : Mass flows of organic wastes produced by one person 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		
DM	81	51
OM	63	39.6
Ash	18	28.6
Water	1590	
N	13.5	8.5

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

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

Table 3: Feed composition for the complete unit

Feed = Faecal Material + Urine + Toilet paper 25 persons/day	
DM	2.475 kg/d
OM	2.025 kg/d
Ash	0.45 kg/d
Water	290 kg/d
N	0.34 kg/d

5.2 Feed composition of BWT-unit for Concordia station

5.2.1 Diet composition of the inhabitants of Concordia station

Because very little is known over the diet of the scientists leaving at Concordia station, it was decided to select some vegetables, commonly consumed on earth to evaluate the diet. The following data are extracted from technical notes made in the framework of MELISSA project, mainly the TN 51.4 and TN 32.3. The data presented in Table 4 concern the CEEF (Closed Environmental Experiment Facility) project conceptually made for long term living in a closed system.

Table 4. Food consumed and waste generated (g) by one man a day

Plants	Ingested food* (g/person.d)	water content (%)	Food consumed (gDW)	Food waste (%)	Food waste (g FW)	Food waste (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		711.4		324	28.3

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

For the rests from the dinning room, a 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 7.3 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 dinning room (140g). A total kitchen waste of 464 g fresh weight/person.d. will 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 + 7.3 g) = 35.6 g

Kitchen waste produced by 15 persons = ± 0.53 kg DW/d (this is ± 7 kg wasted fresh food per day).

Kitchen waste produced by 70 persons = ± 2.5 kg DW/d (this is ± 32.5 kg wasted fresh food per day).

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

5.2.2 Grey Water Treatment Unit concentrate composition

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 5.

Table 5. 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 waste. Given their high content in COD, the concentrates from the ultrafiltration and the nanofiltration steps are wanted to be further treated in the BWT unit. The GWT unit reaches an efficiency of 75% to 90% in these filtrations, which means that 10% to 25% of the total grey water treated needs to be sent to the BWT unit. The characterization of these concentrates is presented in Table 6 (the flows are given for an occupation of 25 persons).

Table 6. Characterisation of concentrates from the GWT-Unit: data provided by Techno-membranes (2003).

	Retentate UltraFiltration	**Retentate 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

5.2.3 Feed composition of the unit

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 and 70 persons during 365 days (12 months). The unit should also treat the sludge of the grey water generated by the membrane system designed by technomembranes from ultrafiltration and nanofiltration.

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 463 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 7 gives an overview of the loads and flows generated by the Concordia inhabitants and which will have to be treated by the unit.

Table 7. Feed composition of the BWT-unit of Concordia

	Toilet flush	Toilet paper (DW)	Urine (DW)	Faecal material (DW)	Food waste (DW)	Food waste (Fresh weight)	Grey water (COD)
Load (g/person.d)	0	18	51	30	35	463	68- 182
Flow (L/person.d)	10	0	1.5	0.09	-	4	10.4
Load (g/15 persons.d)	0	270	765	450	527	6945	1020 - 2730
Flow (L/.d)	150	0	22.5	1.35	-	60	156
Load (g/70 persons.d)	0	1260	3570	2100	2500	32410	4760 - 12740
Flow (L/d)	700	0	105	6.3	-	280	728

5.3 Influent composition for the two bases

The composition of the waste to be treated per day at each base is shown in Table 8.

Table 8. Influent composition of BWT-units of Dumont d'Urville and Concordia bases

Influent composition	Dumont d'Urville 25 persons/125 days	Concordia 15-70 persons/365 days
Faecal material (kg DW/d)	0.75	0.45 – 2.1
Urine (kg DW/d)	1.28	0.77 – 3.6
Toilet paper (kg DW/d)	0.45	0.27 – 1.26
Kitchen waste (kg DW/d)	NC*	0.43 – 2
Rest of dining room and kitchen (kg DW/d)	NC*	0.11 – 0.51
Sludge from grey water treatment (kg SS/d)	NC*	2.34 – 10.9 **
Total load (kg DW/d)	2.03	4.4 – 20.4
Total flow (m^3/d)	**0.29**	**0.39 - 1.82**

NC* : Not considered in the general concept, ** estimated from COD measurements (Techno-membranes)

6 Constraints and limiting factors of the process

The treatment unit will be composed of two following reactors, an acidogenic fermentor and a methanogenic digestor. The effluent of the acidogenic one will be fed to the methanogenic one. Several critical points have to be considered to insure a good running of the first reactor:

6.1 Nitrogen content

Anaerobic bacteria are inhibited for ammonia concentrations higher than 150 mg NH3-N/L (Malina and Pohland, 1997). In a first instance, the follow up of the process parameters will be considered in limiting conditions (nitrogen concentrations around 3 g/L) to evaluate the critical points of the process.

6.2 Solids content

The solids concentration lower than 5% is required in the reactor to insure a good performance of the membrane filtration unit integrated to the system. For an optimal efficiency, a maximum concentration of the solids of 25 to 30 g/L is recommended (from data of the Melissa-project EWC and experimental laboratory data on the BWT-Unit at EPAS). However the filtration unit will cause an accumulation of non degraded solids in the first reactor. Therefore a strategy for draining the solids will be elaborated. The drain required from the first reactor is estimated to 10% of the flow introduced, in order to regulate the concentration around 17 gDM/L. The procedure will be developed and tested, and presented in TN80.7.

6.3 Particular elements of the influent

The diversified origins of the influent result in specific problems that must be pointed out. Indeed influence such as toxicity of some elements can be expected. The following table summarizes the suspected elements. Their impact will be evaluated using literature and practical experiments (TN 82.7).

Table 9. Problematic elements of the influent

Element	Origin	Possible problem
Ions (Na+, Cl-)	pH control	Toxicity for bacteria
Fat	Food	Inhibition of bacterial activity
Alcohol	Food	Inhibition of bacterial activity/ toxicity for bacteria
Salts	Food, grey water concentrate	Toxicity by accumulation
Tensio-actives	Grey water concentrate	Inhibition of bacterial activity
Antibiotics	Toilets	Toxicity for bacteria / users
Hormones (pill)	Toilets	Toxicity for users by accumulation

6.4 Hydraulic retention time

The hydraulic residence time HRT has to be sufficient high to allow the digestion in general (more than 10 days when the biomass is not maintained in the reactor) and could be reduced to less than 5 days if the sludge is continuously recycled to the reactor as the present case. Indeed, a HRT of 1 to 2 days will be sufficient to ensure the accomplishment of the major anaerobic phases (hydrolysis, acidogenesis and acetogenesis) of interest in the acidifying reactor. In the methanogenic reactor, where a longer phase is attended, a HRT of 2 to 3 days will be sufficient to permit the conversion of the produced volatile fatty acids into methane. The inoculated bacteria will be exclusively composed of methanogenic type consortium and therefore, will enhance the conversion of the short chain volatile fatty acids, mainly acetic acid, into methane and $CO_{2.}$

6.5 Sludge retention time

The sludge residence time SRT has to be high enough to allow sufficient contact (substrate- biomass). This is indeed the case in the actual situation since the sludge is indefinitely recycled to the acidifying reactor and the produced effluent consists exclusively of filtrate exempt of suspended material or biomass.

In the second reactor (the methanogenic reactor) will consist ofa fixed bed type reactor. It will treat the filtrated effluent generated by the acidifying reactor .The bacteria fixed to the support material and forming a biofilm structure within the voids of the support material, will not be washed out of the system together with the effluent from the metnanogenic reactor. The final effluent is expected to be poor in particulate matter, allowing thus better retention of the methanogenic bacteria within the reactor and obviously, a better biodegradation efficiency.

6.6 Volumetric loading rate

The volumetric loading rate should not exceed 6.4kgVSS/m^3.day to allow efficient degradation of the organic matter. The biodegradation efficiency has to be optimised, meaning high removal of organic matter. These points can be optimised by acting on the reactor volume and the dilution rate of the feed.

As mentioned above, a fixed-bed reactor will be used to perform the methanogenic digestion in the second reactor. The methanogenic bacteria are more sensitive to the ammonia concentration. Since the dilution of the influent will be taken into account with the water use per person and per day at the Concordia and Dumont d'Urville bases, low concentrations in total nitrogen are expected, in the average of 1.4 gN/L.

In the first case, the system will run at extreme conditions, with a total nitrogen concentration in the range of 3 g/L and low dilution rates (a maximum of 3 times dilution) in both acidifying reactor and methanogenic reactor. In these conditions, the process parameters will be followed and the mass balance established.

In a second case, dilution rates, corresponding to the user requirements will be taken into account. This means a 10 folds dilutions are allowed in the influent. The obtained data will be compared with those obtained in the worst cases and functioning limitations of the unit will be defined.

7 Substrate preparation

Since high volumes will have to be fed daily to the reactor in each configuration (see sizing of the BWT-pilot unit), an automatized toilet flush system should be integrated in the system. The faecal material and urine will be collected in the existing toilet and will be stored in a buffer tank from which the influent to the liquefying reactor will be taken. A mixing device to homogenize the preparation will be considered in the loop before feeding the reactor. The buffer tank should be covered, but not necessarily kept in anaerobic conditions, to avoid odours problems in the surrounding environment. Since the mixed influent will be kept for a least few hours in the buffer tank at room temperature, pre-digestion of organic matter may occur. Indeed, this would happen, but in less extend than in the digesters themselves. Aerobic bacteria, which could initiate bio-digestion in the buffer tank, will not survive in the anaerobic conditions inside the liquefying and methanogenic reactors.

Regular cleaning of the buffer tank will be needed, certainly when very low volumes of waste are collected . In this case an in site washing system should be integrated. A multidirectional spray water system is suitable in this case. Valves will be opened to allow up flow and down flow water streams into the tank.. Sterilisation of the buffer tank is not necessary. However, when the whole BWT-Unit will be stopped (as predicted by IPEV, for instance during winter time with only a back up Concordia crew present in the site), cleaning of the reactors will be initiated. A that time, addition of cleaning products (disinfecting agents like oxonia or Javel) in the rinsing water will be necessary. The definition of the cleaning procedure and the type of cleaning agents which will have to be used to clean the unit with its all subsystems will be presented in TN 82.7.

7.1 Extreme case

For safety reasons the extreme conditions of feeding that can be stand by the system should be identified. Then it has to be checked that the concrete set-up allows a safety margin to these extreme conditions. According to Table 2, the nitrogen concentration of the feed is around 8.5 g N/L. As the reactor concentration is wanted to be lower than 3 g N/L, this feed should be diluted a minimum of three times. In this case the organic matter content will be decreased around 13.3 g/L, which respects the filtration unit requirements. This worst case is being studied in lab scale reactor, currently running at these extreme conditions.

7.2 Dumont d’Urville Station

The feed is only made of urine, faecal material and toilet paper. According to IPEV, an average amount of water for flushing the toilet of 10L/person.day can be considered. After flushing, the substrate is sent to a mixer tank where the substrate is mechanically reduced to small particles. The influent of the reactor is pumped in this mixer tank (see Figure 7).

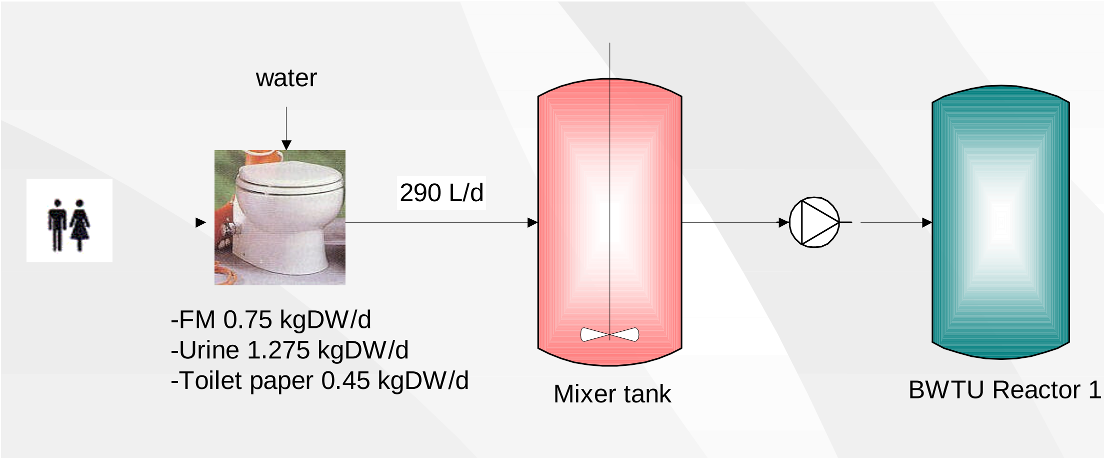

Figure 7 Dumont d'Urville feed preparation

7.3 Concordia Station

Considering the composition of the feed, the preparation can be adapted. Urine, faecal material and toilet paper can be treated in the same way as for Dumont d'Urville station. The sludge from grey water treated by Techno-membranes can join the feed in the mixer tank, as well as the food and kitchen wastes (Figure 8).

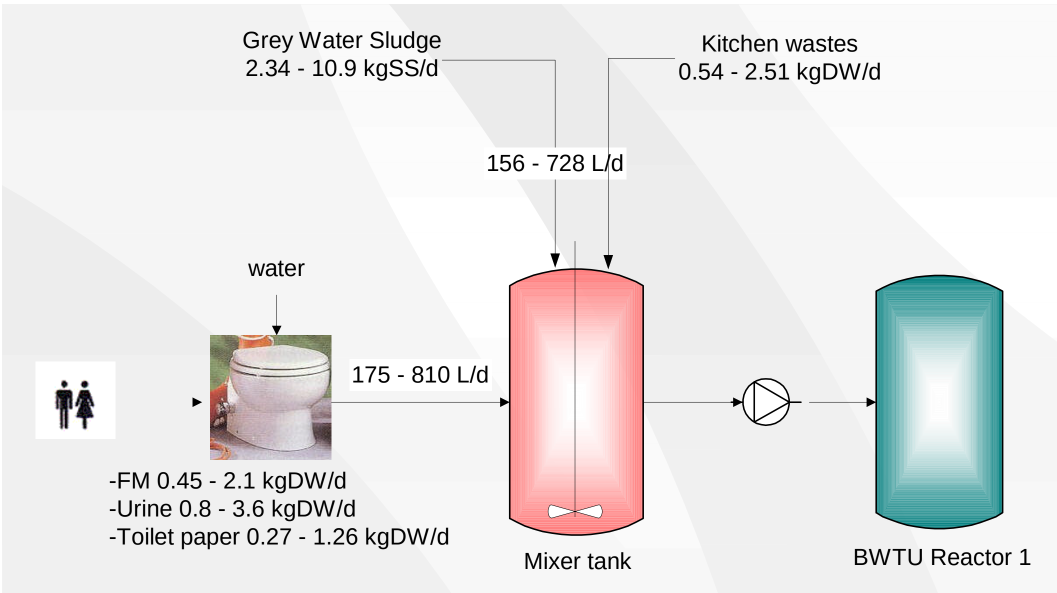

Figure 8 Concordia feed preparation

8 Determination of process parameters

According to the knowledge developed within the MELiSSA project, both reactors should be run at 55°C, in order to inhibit the eventual pathogenic strains. A pH control on the first reactor will allow to inhibit the methanogenesis by regulating the pH around 5.5 to 6. Both reactors should be completely stirred.

Concerning the feed, the BWT-Unit will be fed with all the toilet wastes produced by the inhabitants of the center. The amount of substrate fed to the lab scale reactors can be chosen in order to have a sufficient hydraulic residence time of 10 days. With a first reactor of 1L, this corresponds to an influent of 100mL/d. Thus, the corresponding load of organic matter will be around 1.3 gOM/d.

In general, the products of anaerobic digestion, depending on the type organic waste in use are the same but produced at different proportions. Some examples of anaerobic digestion products are given in Table 10. The biodegradation products in the gas loop are not always consisting of methane and CO_2. Other biogases might be formed such as H_2, H_2S, N_2…., but in much less proportions. They are mainly found in some mg/L rather than in percentages.

Table 10. Biodegradation products in anaerobic digestion

	Gas production (ml/g)	% CH_4	% CO_2
Carbohydrates	790	50	50
Proteins	700	71	29
Lipids	1250	68	32

The conditions of the system must be optimised and carefully controlled to maintain balance of the microbial groups; hydrolysis, acid and methane producing bacteria. The controlled process parameters in the BWT-Unit can be schematised as shown in Figure 9.

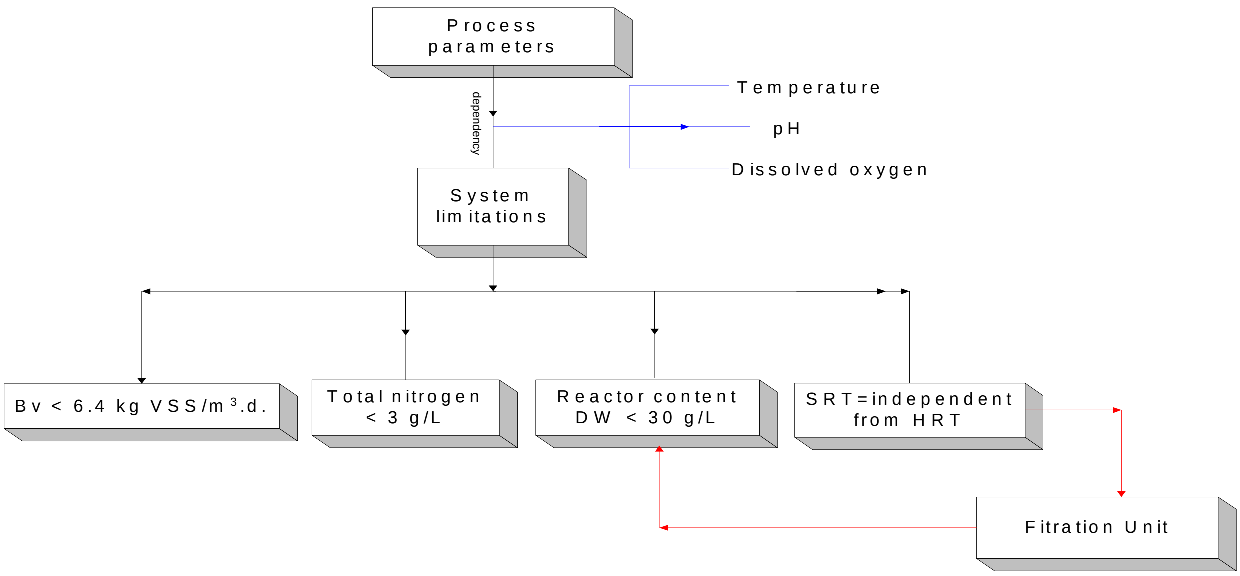

Figure 9. Process requirements for the BWT-Units in Dumont d'Urville and Concordia bases

8.1 Hydraulic Retention Time

For optimal running of an anaerobic system involving methanogenesis, a HRT of at least 10 days is needed. It is generally maintained between 10 and 20 days to ensure a degradation efficiency of around 65%. In the concept proposed from the BWT-units of Concordia and Dumont d'Urville, the hydraulic retention time could be considerably reduced to 1 to 3 days since the sludge is continuously recycled to the acidifying reactor and the thus biomass contact time optimised. The hydraulic retention time will be tested on the lab scale unit in order to validate it. Adjustments will be considered on the sizing if it appears as necessary.

8.2 Sludge retention time

The sludge retention time is independent from the hydraulic retention time because of the presence of the filtration unit. The latter is aimed to filtrate a suitable volume of the reactor in order to feed the methanogenic reactor and to retain the sludge and return it to the acidifying reactor. The sludge retention time is thus defined as infinite compared to the hydraulic retention time.

8.3 Temperature

According to the knowledge developed within the MELiSSA project, both reactors should be run at 55°C, in order to inhibit the eventual pathogenic strains and shorten digester retention time. A pH control on the first reactor will allow to inhibit the methanogenesis by regulating the pH around 5.5 to 6. The content of both reactors should be homogeneous and therefore a good mixing in the first reactor and a good liquid dispersion in the methanogenic reactor are needed.

Specific growth rate of anaerobic bacteria increases with increasing temperature in a relatively narrow band. This means that at elevated temperatures (mesophilic and thermophilic conditions), contamination by unwanted organisms is minimised. Moreover, the minimum retention time decreases with elevated temperature, hence reducing reactor size. Although thermophilic conditions necessitate high operation costs, they show however, higher efficiencies in organic matter degradation.

8.4 pH

Methane producing bacteria are sensitive to pH. They are inhibited at relatively low pH, less than 6.0. Volatile acids accumulate in the system at this low pH and further drop in pH (pH < 5) may lead to complete inactivation of the bacteria (experimental data of the MELISSA-project EWC).

In the BWT-unit, the pH of the liquefying reactor should be maintained at 5.5 – 6 to inhibit the methanogenesis. The produced volatile fatty acids will be directed towards a methanogenic reactor (pH = 7 – 7.5) where they will be converted into methane.

8.5 Toxicity

Some biodegradation by-products may accumulate in the reactor and occasionally, if some conditions are not carefully verified, have effect on the growth rate of bacteria.

Ammonia originated from protein degradation: Free NH_3 is more toxic. Toxicity occurs at rather low concentrations. As previously mentioned, free ammonia should not exceed 150mg/L.

At pH 7.2, mostly ammonium ions are present in the reactor. Toxicity occurs from concentrations of 3 g/L as mentioned previously.

Metal ions are originated from the addition of base to control the pH. One should be careful not to exceed toxic levels. Sudden changes in pH are not suitable, but stepwise acclimatisation period, can tolerate moderately inhibitory for some time. Heavy metals are toxic to major anaerobic populations at very low concentrations. Nonetheless, they would not cause a problem in anaerobic reactors because only soluble metals have an effect and their concentrations can be reduced to non-toxic values by precipitation with sulphides, naturally occurring in the anaerobic reactors from the degradation of proteins. Similarly, heavy metals such as copper, nickel, chromium, zinc, lead, etc. in small quantities are essential for the growth of bacteria but their higher concentration has toxic effects. For example, if the concentration of soluble sulphides exceed 200 mg/L ((Malina and Pohland, 1992). the metabolic activity of methanogenic bacteria will be strongly inhibited, leading to the failure of the process Karhadkar et al., 1987; Parkin et al., 1990. Mineral ions and detergents are some of the toxic materials that inhibit the normal growth of pathogens in the digesters, which is quite positive in the case of the BWT-Unit. Small quantity of mineral ions (e.g. sodium, potassium, calcium, magnesium, ammonium and sulphur) also stimulates the growth of bacteria, while very heavy concentration of these ions will have toxic effect (for example, presence of NH_4 from 50 to 200 mg/l stimulates the growth of biomass, whereas its concentration above 1500 mg/l produces toxicity. Likewise, detergents including soap, antibiotics, organic solvents, etc. inhibit the activities of methane producing bacteria and addition of these substances in the digester should be avoided. Although there is a long list of the substances that produce toxicity on bacterial growth, the inhibiting levels of some of the major ones are given in Table 11.

Table 11. Toxic level of various inhibitors

Inhibitors	Inhibiting Concentration
Sulphate (SO4- -)	5000 ppm
Sodium Chloride or Common salt (NaCl)	40 000 ppm
Nitrate (Calculated as N)	0.05 mg/ml
Copper (Cu++)	100 mg/l
Chromium (Cr+++)	200 mg/l
Nickel (Ni++)	200 - 500 mg/l
Sodium (Na+)	3500 - 5500 mg/l
Potassium (K+)	2500 - 4500 mg/l
Calcium (Ca++)	2500 - 4500 mg/l
Magnesium (Mg++)	1000 - 1500 mg/l
Manganese (Mn++)	Above 1500 mg/l

Source: The Biogas Technology in China, BRTC, China (1989): http://www.fao.org/sd/EGdirect/EGre0022.htm

9 Control aspects

The overall process control of the BWT-unit is important to guarantee optimal operation of the system and to maximise the degradation efficiency. From the experience already gained in the Engineering of the Waste Compartment (EWC) in MELISSA-project, the load imposed to the system can be controlled. To be compatible with the requirements of the filtration unit, the total load fed to the reactor per day should be considered together with the daily flow rate to avoid clogging of the filtration unit. The follow up of the process parameters in the reactors will allow to establish a simplified model, which will give some indications about the harvesting of solids inside the first reactor. The overall follow up data and the model will be presented in TN80.7.

10 Interactions BWT/GWT-units

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. the GWT unit has been designed on IPEV request to treat the grey water generated by 25 persons and will have in addition to treat the effluent coming from the BWT unit. The concentrates generated from the UF and NF filtration steps of the GWT unit will be sent to the BWT unit. Figure 10, presents these connections for the nominal case of a 50 persons occupation. The flows of grey water concentrates (UF, NF and ROI) are calculated from the flows generated by the 13 crew actually at Concordia station and extrapolated to 25 persons.

Taking into account the results from the validation tests performed on the GWT-Unit at la Canourgue, it was possible to estimate the concentrates flows generated from the UF, NF and RO1. It was recently confirmed that the GWT-Unit could in principle treat a maximum influent flow of 4.2 m^3/d (based on the data recorded from the GWT-Unit in operation at the Concordia station). This flow includes the waste from the grey water as well as the effluent from the BWT-Unit. According to the balance on the GWT-Unit, flows between 2.20 m^3/d to 3.7 m^3/d might be expected from 25 persons (TN 6.3). This means that in worst cases (influent flow = 3.7 m^3/d), only 500 L/d effluent from the BWT-Unit could be further treated by the GWT-Unit. The non-treated fraction which consists 53.7% to 61% of the effluent BWT-Unit will have to be stored in containers (a container of 4 m^3 can hold the stored effluent for 5 to 7 days) to be later treated when waste production from the GWT-Unit is lower.

Since the GWT unit is foreseen to further proceed the effluent of the BWT unit, to generate water of hygienic quality, the composition of the effluent from the BWT unit should be compatible with the requirements of the GWT unit. One of the most important parameters, where more attention should be paid, is the ammonium. The latter will be found back in the effluent of the BWT unit at relatively high concentrations (> 200 mg/L), Its presence in the effluent is mainly justified by the conversion of urea in urine into ammonium in anaerobic conditions.

As known from the history of the membrane systems, they have limitations for the retention of ammonium. The efficiency for ammonium removal by means of this type of systems is pH dependant. Indeed, at neutral pH or elevated pH, ammonium removal is limited to some 10% (oral discussion with the experts from Technomembranes). Moreover, the stripping of ammonia gas due to high pH can seriously hinder the functioning of the filtration units due the introduction of ammonia gas in the membrane modules. Whereas, by keeping relatively low pH values of 6 to 6.5 (extra dosage of acids), the efficiencies for ammonium removal by membrane systems are higher.

To avoid continuous control of the pH in the BWT unit effluent and by the mean time extra acid dosage, it was decided to look for a reliable biological technology to remove ammonium from the BWT unit effluent before processing it in the GWT unit. The most suitable technology is the aerobic nitrification of the BWT unit effluent. Here again, the selected technology could serve for the evaluation and validation of the third compartment technology (Nitrifying compartment) in MELiSSA-loop.

11 Flows calculations

Flow from the BWT-Unit generated by 50 persons = **0.780 m^3/d.**

Flow to be treated by the GWT-Unit = flow from the BWT-Unit generated by 50 persons + flow concentrate UF-GWT-Unit + flow concentrate NF-GWT-Unit.

The concentrate flows from the UF and NF are estimated according to the results obtained at la Canourgue during the validation tests of the GWT-Unit.

In optimal operating conditions of the GWT-Unit: The minimal expected flow rate = 0.78 + 0.20 + 0.10 = **1.08 m^3/d.**

In case of low performances of the GWT-Unit: The expected flow rate = 0.78 + 0.30 + 0.20 = **1.28 m^3/d**

The estimated treatment capacity of the GWT-Unit according to the data obtained during the operation of the unit at Concordia site =**4.2 m^3/d.**

The grey water generated by 25 persons as proposed in TN 6.3 is estimated at **2.2 to 3.7 m^3/d.**

Taking into account these data, it was possible to estimate the daily volumes from the BWT-Unit and which could be treated by the GWT-Unit as shown in Table 12.

Table 12. Estimation of the flows from the BWT-Unit to be treated by the GWT-Unit

	Flows grey water (m^3/d) (A)	**Flows black water + UF/NF concentrates (m^3/d) (B)**	**Flows to be treated (m^3/d) (A+B)**	**Stored flows (m^3/d) (A+B) – 4.2 m^3/d**
Minimum flow expected from 25 persons	2.2	1.08	3.28	No storage whole flow is treated
		1.28	3.48	
Maximum flow estimated from 25 persons	3.7	1.08	4.78	0.58
		1.28	4.98	0.78

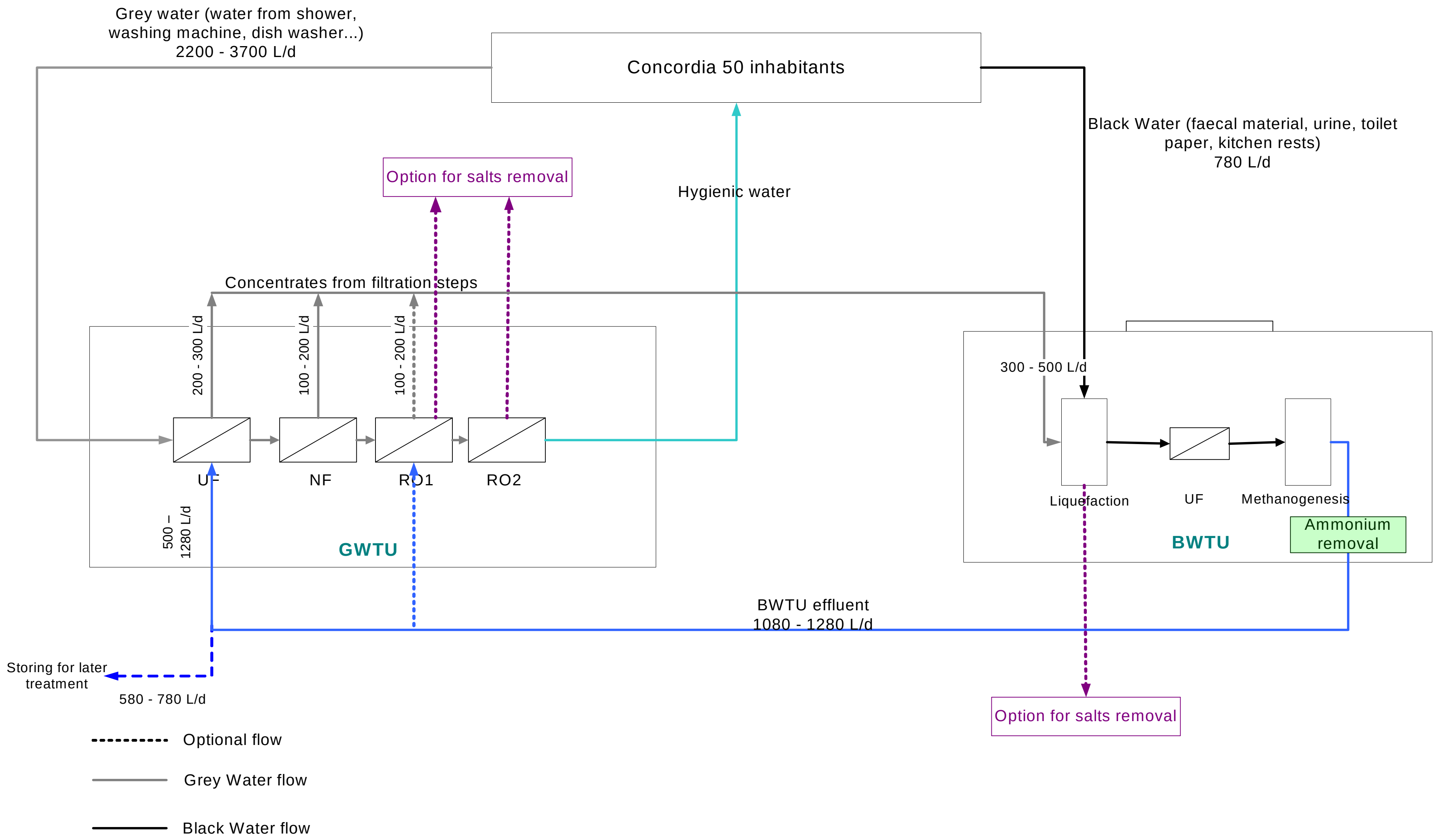

Figure 10:Interactions between GWT and BWT-units

12 Sizing of the BWT-Units

The sizing of a black water treatment unit is considered in both Dumont d'Urville and Concordia bases. Depending on the feed characteristics, volumes are proposed for the acidogenic and methanogenic reactors with respecting the constraints previously defined (see Constraints and limiting factors of the process). Biogas and VFA productions are estimated from results of lab experiments carried out at EPAS. The data obtained with the proposed system will be presented in TN 82.7, taking into account the process limitations. Both black water treatment units (Dumont d'Urville and Concordia) will be operated at worse cases in a first instance and at situation conditions in a second instance.

The sizing of the BWT-Unit of Concordia will take into account the daily loads to be treated and influent composition. Indeed, the unit should be able to treat the waste generated by a 15 persons and a maximal load generated by 70 persons. Based on the test results obtained with lab-scale set-ups (organic matter biodegradation efficiencies, urea conversion into ammonium and biogas production) the final dimensioning of the bioreactors and ultrafiltration unit was made. The results of tests performed on lab-scale BWT-Unit will be presented in TN 82.7.

12.1 Sizing of Dumont d'Urville unit

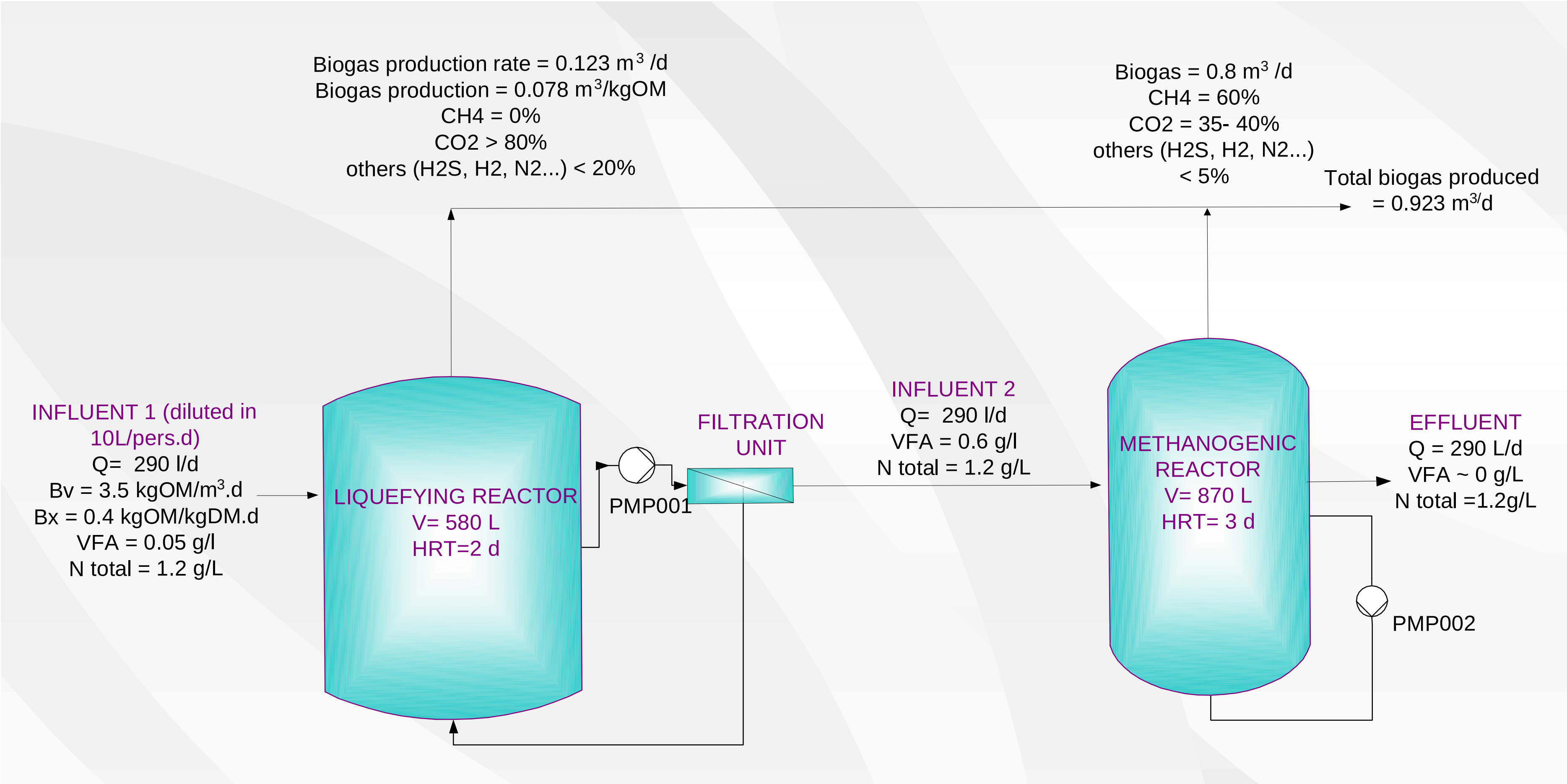

Figure 11 Sizing of Dumont d'Urville Unit

12.2 Sizing of Concordia unit

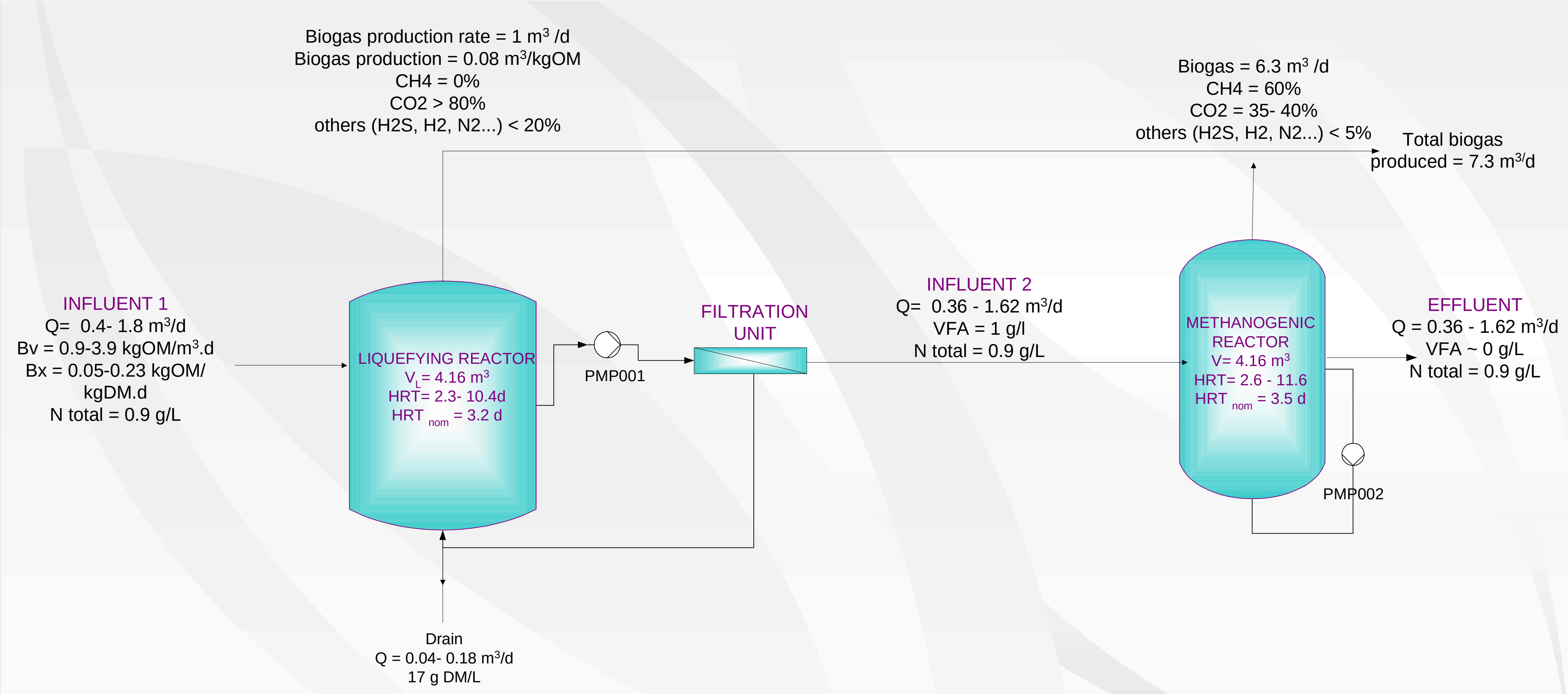

Figure 12 Sizing of Concordia unit

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