CONFIDENTIAL REPORT

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

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TECHNICAL NOTE 82.3

Basic engineering

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TN	Technical note
BWTU	Black water treatment unit
GWTU	Grey water treatment unit
GAC	Granulated activated carbon
SCC	Stress cracking corrosion
AISI	American iron and steel institute
ASTM	American society for testing and materials
ASME	American society of mechanical engineers
ANSI	American national standards institute
SS	Stainless steel
CIP	Cleaning in place
H	High
L	Low
PFA	Per-fluor-alkoxy
PE	Poly-ethylene
LR	Liquefying reactor
MR	Methanogenic reactor
VFA	Volatile fatty acids
HRT	Hydraulic retention time
SRT	Solid retention time
COD	Chemical oxygen demand
PLC	Programmable logic control
(T)SS	(Total) suspended solids
ORP	Oxidation reduction potential
EC	Electro-conductivity
MT	Mettler Toledo
E+H	Endress+Hauser
f.s.d.	Full scale deflection
FU	Filtration unit
UF	Ultrafiltration
NF	Nanofiltration
RO	Reverse osmosis

Introduction

The basic engineering of the black water treatment units of Concordia base is proposed in this note. The base was constructed in 2003 and the approach for the treatment of the waste generated by the crew will be useful since the base is inaccessible during the winter time. Thanks to the biological systems proposed, which will aim to degrade the waste and produce beneficial energy, mainly in the form of methane and CO_2, the transportation of the waste will be minimised as much as possible.

The black water treatment unit (BWT-Unit) will be elaborated to treat the waste produced by 15-16 persons for 365 days. It will have 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 be manned with 35 more persons for 90 days and another 20 persons for 30 days. The waste will consist of faecal material, urine, toilet paper, kitchen rest and the rest from the dinning room. In addition to this waste, the concentrate originated from the treatment of the grey water will be included. The grey water treatment facilities were engineereed and developed by Technomembranes in collaboration with IPEV and ESA. The treatment of grey water consists of membrane filtration (ultra-, nanofiltration and two steps reverse osmosis). The collected concentrate from the ultrafiltration and nanofiltration will have to be treated by the black water treatment unit.

This technical note describes the basic engineering of the BWT-unit. The note starts defining the requirements of the needed instrumentation. Based on the requirements, a listing of measuring equipment and actuators (pumps) is given. Basic engineering also includes the design of a control concept and the needed control hardware is given.

The detailed engineering, which includes a process and instrumentation drawing, detailed listing of equipment and instrumentation, electric wiring diagram and cost price details for hardware and construction, is given in TN 82. 4.

The first chapter recapitulates the total engineering concept developed in TN 82.1 and TN 82.2. The second chapter discusses the system limitations of the BTW-unit. Basic engineering of the actual unit is discussed in the third chapter. In the last chapter, a construction plan is worked out. Finally, a listing of the required instrumentation is given as an introduction to the following technical note TN 82.4.

1 Concept engineering

The concept engineering is described in TN 82.1 and TN 82.2. The aim of this chapter is to review the general working principle of the BWT-unit. The tags next to each instrument on the figure are used in the rest of this document to refer to that specific instrument. The tag code structure is given in Table 2. The colour code is depicted in Table 1.

All waste material is collected with a pump in the influent buffer. The waste is mixed continuously, otherwise the solids settle down and foul the piping. The filter removes the coarse particles with size > 5 mm. When the level in the influent buffer gets too high (this is detected by level sensor LD-002) valve V-018 directs the flow to the liquefying reactor R-001 and the capacity of pump L-Pm-03 is adapted in such a way that the flow to the liquefying reactor varies in function of the waste produced. To monitor and control the right conditions for the anaerobic process, several devices are mounted on this reactor. The temperature sensor TS-001 measures the temperature. When the temperature gets low (under the threshold temperature of 47°C) heat is added with the heating mats HX-001. The pH sensor pHS-001 measures the pH. When the pH is high (pH > 6.8), PMP-005 pumps acid in the reactor; when the pH is low (pH < 5.2), PMP-007 pumps base into the reactor. The blender BL-001 mixes the reactor content. The two pressure sensors PD-001 and PD-002 measure the pressure at the top and the bottom of the reactor.

The formed gas of the liquefying reactor, mainly CO_2, is carried away through a back pressure regulator PR-001. This back pressure regulator keeps a slight over pressure of about 100 mbar in the liquefying reactor. This way, entry of oxygen is avoided.

To separate the liquid phase from the solid phase, the content of the reactor is ultra-filtrated. This happens via the membrane filtration unit. Pump PMP-002 re-circulates the reactor content over the liquefying reactor through the cross flow ultrafiltration unit. The transversal flow restricts fouling of the filtration membrane. Recirculation is settled to reach a targeted recovery rate to avoid solids decantation. The liquid leaves the liquefying reactor through FI-001 and flows back into the reactor through FI-002. The transmembrane pressure (the average pressure through the filtration membrane) is monitored by pressure transducer PD-001, PD-002 and PD-003. The filtration membrane can be by-passed with valve V-007 and V-008.

The filtrate is sent to the methanogenic reactor R-002. However, when the level in the liquefying reactor (detected with LD-001) is low, the effluent is sent back to the liquefying reactor with valve V-013. The methanogenic reactor is a fixed-bed reactor. The methanogenesis is realised by bacteria that live in a biofilm which is supported by beads type Polypropylene (PP). The content of the methanogenic reactor is re-circulated with pump PMP-004. The instrumentation on the methanogenic reactor is similar to that of the liquefying reactor. The produced gas (mainly CH_4), released through PR-002, can be used for energy production. To keep a constant level, valve V-014 is closed when the level gets too low.

The effluent of the methanogenic reactor can be sent to a nitrifying reactor for the conversion of NH_4^+ to NO_3^-. NH_4^+ is in equilibrium with NH_3. The latter molecule can hardly be retained in the membrane filtration systems of the GWT-unit.

To remove the yellowish colour of the effluent, a granulated activated carbon filter (GAC) can be placed at the end of the unit as option. However, since the final effluent from the nitrifying reactor is aimed to be further processed by the GWT-Unit via an ultrafiltration, nanofiltration and reverse osmosis and which indeed will remove the undesired colour, it has not added value to pre-treat it for colour removal at the end of the BWT-Unit.

Table 1: Colour code used in Figure 1.

Material	*Colour*
Untreated waste material	Brown
UF Filtrate	Blue
Produced gas	Purple

Table 2: Tagcode OK-xxx

O object		**K** kind		xxx number
T	Temperature	T	Transmitter	of the object in its kind on the drawing
P	Pressure	S	Sensor	
F	Flow	I	Indicator	
PH	pH	D	Transducer	
L	Level	R	Regulator	
S	Turbidity			
HX	Heat Exchanger			
V	Valve			
PMP	Pump			
R	Reactor Vessel			
BD	Blender			

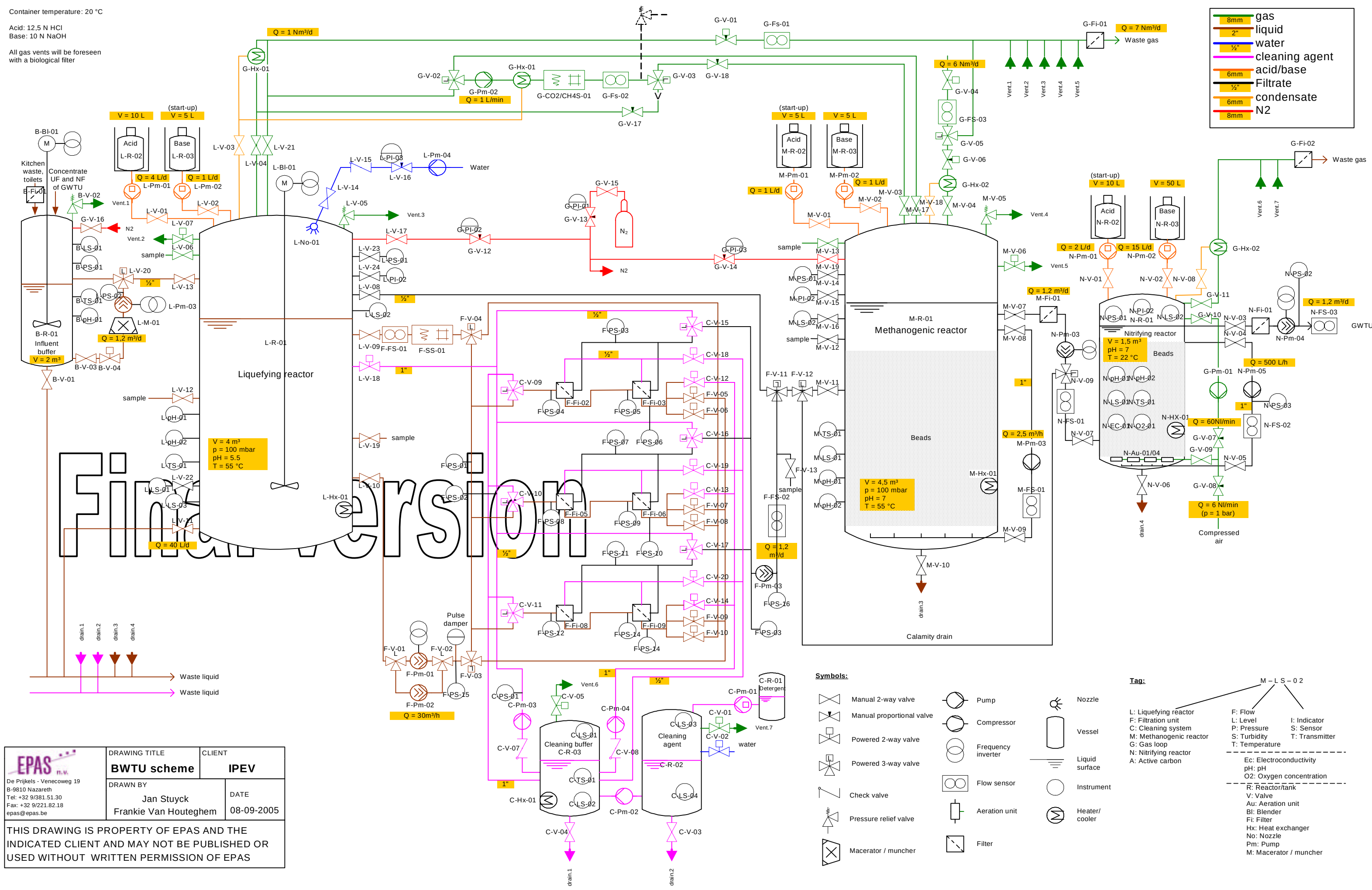


Figure 1:Concept engineering flow scheme of the BWT-Unit

2 System limitations

This chapter describes some general system limitations for the BWT-unit. These limitations are container size (paragraph 2.1), transportation restrictions (paragraph 2.2) and external influences on the materials (paragraph 2.3). Constraints and limiting factors of the process (process limitations) are extensively described in TN 82.1 (chapter 6).

2.1 Container size

The dimensions of one container are: height = 2.2 m, width = 2.2 m and length = 5.8 m. The door entry is 2.1 m high. These values were obtained from IPEV. When the two reactors and the FU must fit into one container, the size of the reactors is limited (see calculations below). It is also impossible to add GAC and a nitrification reactor. Therefore more than one container is needed. Based on a redundancy study, it will be decided if a backup reactor is needed. When the number and size of the reactors and container is known, the mechanical concept can be designed using 3D CAD (computer aided design) software. The rest of this paragraph calculates the limitations of the reactors and filtration unit when everything needs to fit in one container.

Since the reactors have an overpressure of 100 mbar, it is impossible to give the reactor a cubic form, because the flat surfaces cannot sustain any pressure, even not when it's made out of steel. The most optimal form is thus a cylinder. The bottom and top surface are smaller so a flat surface here is possible (allthough spherical surfaces are recommended). Knowing this, the maximum height of this cylinder in case of the liquefying reactor can be calculated as follows (with Figure 2):

$$h_{reactor} = h_{door} - h_{motor} - h_{flange} - h_{placement}$$
$$= 2.1 - 0.20 - 0.10 - 0.10 \text{ m}$$
$$= 1.7 \text{ m}$$

with

$h_{reactor}$ = height of reactor
h_{door} = height of container door
h_{motor} = height of blender motor or reduction house
h_{flange} = heigth of flange
$h_{placement}$ = extra height to place the 500 kg reactor in the container

The maximum diameter of the reactor is:

$$d_{reactor} = w_{container} - 2 \cdot d_{insulation} - d_{passage} - d_{placement}$$
$$= 2.2 - 2 \cdot 0.05 - 0.10 - 0.40 \text{ m}$$
$$= 1.6 \text{ m}$$

with

$d_{reactor}$ = diameter of reactor
$w_{container}$ = width of container
$d_{insulation}$ = thickness of insulation (one side)
$d_{placement}$ = space to place the reactor in the container
$d_{passage}$ = space needed for a person to pass the reactor

Hence, the maximal volume of the reactor can be calculated, using the formula of the volume of a cylinder :

$$V_{cylinder} = \frac{\pi}{4} \cdot (d_{cylinder})^2 \cdot h_{cylinder}$$

$$V_{reactor} = \frac{\pi}{4} \cdot (d_{reactor})^2 \cdot h_{reactor}$$
$$= \frac{\pi}{4} \cdot 1.6^2 \cdot 1.7$$
$$= 3.42 \text{ m}^3$$

with $V_{reactor}$ = maximum volume of liquefying reactor

In case of the methanogenic reactor (which has no blender), this becomes: $V_{reactor} = 4 \text{ m}^3$.

The total length of the unit can be estimated as follows:

$l_{unit} = 2 \cdot d_{reactor} + l_{filtration\ unit} + l_{spacing}$
$= 2 \cdot 1.6 + 1.6 + 1$ m
$= 5.8$ m

with
l_{unit} = length of BWT-unit
$d_{reactor}$ = diameter of reactor
$l_{filtration\ unit}$ = length of filtration unit
$l_{spacing}$ = length of spacing in between reactors and FU

Since the length of the container is 5.8 m, no room is left for the GAC and nitrification unit in the container. The GAC and nitrification unit will be placed in a second container.

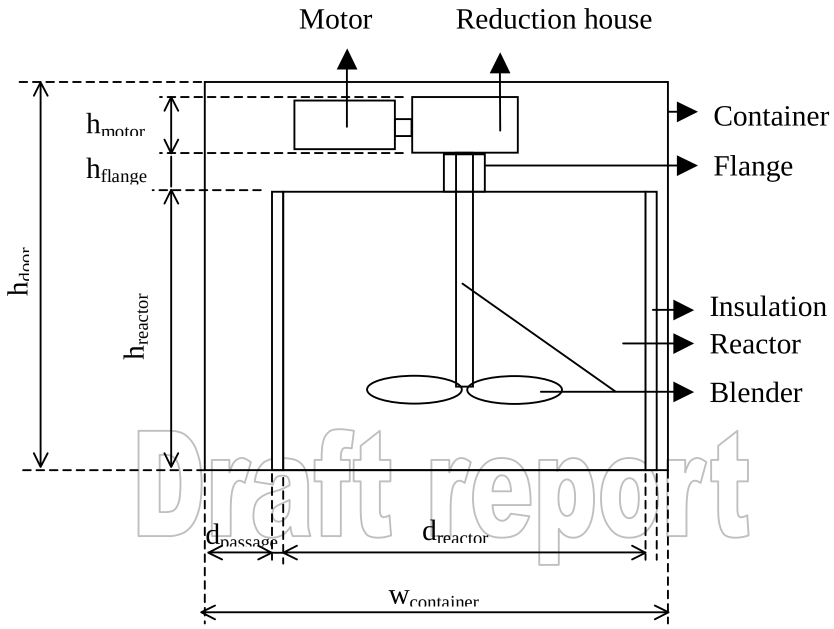


Figure 2: Side view of liquefying reactor with blender

2.2 Module based design

Since the container for the BWT-unit is already at place on the Antarctic continent, a module based design is needed. This means that the unit will consist of different modules, which can be easily dis- and reassembled, so the whole unit can be mounted in the container at Antarctica, by only connecting the different modules.

To obtain easy dis- and reassembling, Tri-Clamp® and Tri-weld® connections of Tri-Clover will be used (see Figure 3, Figure 4 and Figure 5). These connections are clamp-connections which comply with the American sanitary standard 3A®. Jensen (Swagelok) and Inoxco (the flow equipment division of Gillain & Co) meet the same standard, so these brands of clamps are interchangeable.

The clamps are made of stainless steel: material type AISI-304, AISI-316 and AISI-316L. Connections are available in 1” to 4”. The standard fittings are polished to 32 R_a.

Figure 3: Tri-Clamp – connection: elbow

Figure 4: Tri-Weld – connection: working principle

Figure 5: Clamp, which holds two pipe ends together

2.3 Mechanical and chemical resistance: material selection

Almost all materials of the unit will be in contact with the fluid, which is at elevated temperatures (± 55°C), at different pH levels and at an overpressure of 100 mbar. Furthermore, the unit must be transported to Concordia base by which it could experience temperatures down to –60 °C. A good material selection is therefore very important!

Since plastics are cheaper than steel, it is useful to consider this option. The mechanical properties of almost all plastics weaken rapidly when the temperature drops below freezing point. Secondly, due to moderate strength, plastics can only be used for piping and/or valves. For the bioreactors in this application, plastics are just not strong enough to bear the (slight) overpressure. Plastics are also thermal isolating, so external heating becomes impossible. Internal heating however, causes sticking of solids to the heating element, caused by the elevated temperature. Finally, plastics suffer chemical deterioration, even when chemical coatings are added, due to (slow) leaching out of these coatings.

Plastics are less robust than steel. In this application, where fail-proof operation is necessary in consequence of its difficult accessibility, this is hard to accept.

Based on the latter, it is decided to make all components out of steel. There are many types of alloys of steel. In this application, it is clear that stainless steel is needed. For construction of reactors and pipelines, the 300 series SS is most fit, as can be seen in Figure 6.

Stainless steel

Ferritic	Martensitic	Austenitic	Precipitation hardened
Applications			
Atmosferic corrosion	Construction components	Chemical resistance	Construction parts
Elevated temperatures	Cutting devices	Tanks/reactors	Springs
Decorative	Tools	Pipelines/piping	
Types			
400 series	400 series	200 series	17-4
		300 series	17-7

Figure 6: Most used types of stainless steel

Steels from the 300 series contain 18 % Cr and 8-10 % Ni (therefore it is sometimes called 18/8). The chromium forms a passivation layer (Cr_2O_3 which is impermeable to fluids and gases) on the surface so further corroding is inhibited. Nickle is added to promote the austenitic phase. The most used stainless steel for 'chemical applications' is AISI-304 and AISI-316. AISI-316 is used when AISI-304 doesn't suffice. To select the right type of stainless steel, something should be known about the working principle of corrosion.

The principle cause of corrosion in this application is pitting. Pitting occurs with metals that form a passivation layer (like aluminium, stainless steel) and is caused by the presence of the Cl^--ions (which are present in the reactors) . The Cl^--ions locally attack the passive layer, which causes deep localised corrosion.

In reactors under pressure, the risk of SCC (stress cracking corrosion) should be considered, but the pressure in this application is too low to form any risk of this type of corrosion.

None of the types of stainless steel corrode in the atmosphere, even not at sea. So the outside of the BWT-unit is immune to external influences. Since both reactors are anaerobic, no oxygen is present inside of the BWT-unit. Thus, oxidation cannot occur. But H_2S is present in the reactor. Sulphur can be found in the same column as oxygen in MENDELJEVS table, so both have common chemical properties. In other words, "oxidation" is also caused by sulphur. However, the amounts of H_2S are so small (~1 %) that AISI-304 suffices. The price of AISI-316 is 10 to 15 % higher than AISI-304. For the two bioreactors together, the price difference between AISI-304 and AISI-316 is ca. €2500 (less than 1 % of total cost price).

For welding purposes, special types of stainless steel exist. They are designated with an L, which means **L**ow carbon content. This way, carbon-carbide-formation is reduced during welding.

3 Basic engineering of the BWT-unit

The hardware selection is ordered in four parts:

- Frame
- Vessels and piping
- Instrumentation
- Filtration unit
- Control hardware

Important selection criteria are robustness and compatibility with the GWT-unit. The complete system should also be user-friendly.

3.1 Frame

All equipment, instruments and actuators will be mounted on or supported by a structure, which is called the frame. There will be two frames: one for the filtration unit and one for the remaining instrumentation. Both frames are based on the modular profile assembly system of Bosch Rexroth. The system exists of basic mechanic elements, which can be mounted together in a ‘meccano’-like way. Basic mechanic elements are: aluminium profiles, connections elements, joints, feet and wheels and other accessoires. Great advantages are ease of mounting and flexibility. An example is shown in Figure 7. The same system is also used for the frame of the GWT-unit.

The frame can be assembled by Bosch Rexroth itself, or separate elements can just be ordered. In the latter case, the construction will be coordinated by EPAS.

The electrical enclosure will also be mounted on the frame. The electrical drawings, will be given in TN 82.4.

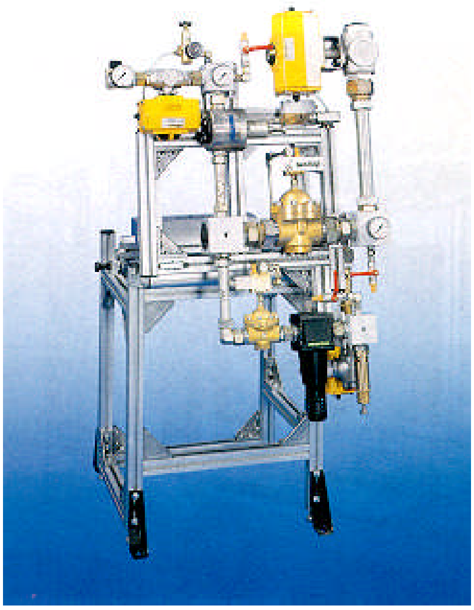


Figure 7: Structure made of Bosch Rexroth aluminium profiles

3.2 Vessels and piping

The construction of the two bioreactors will be done at SE construct in Belgium. For the instrumentation on the bioreactor, connections need to be provided.. The instrumentation itself is discussed in chapter 3.3. The following paragraphs discuss some general aspects of the bioreactors.

3.2.1 Heating of the reactors

The heating of the reactor is preferably done externally. This way, thermal energy can be added uniformly. Internal heating causes encrustment of solids on the heating elements due to the elevated temperature. External heating can be realised in two ways: by a heating cable coiled around the reactor or with heating mats. In both options, heating is realised by electrical resistances. Heating mats offer more uniform heating and are easy to install on the reactors, because they are self-adhesive. Therefore, heating mats are selected. The mats will be purchased at Dirac Industries. An example is shown in Figure 8. The mats are available in all sizes. The needed heating power is dependent on the insulation capacity: when insulation of the reactor is increased, the losses decrease and less heat has to be added. Insulation thus reduces the heating capacity of the reactor and prevents burns and fire risks. With 5 cm of insulation and a surrounding temperature of 20 °C, 1200 W of heating power is needed.

Figure 8: Flexible heating mat

3.2.2 Cleaning of the reactor

The CIP nozzles realise in-place cleaning. For manual cleaning, inspection or reparation, a manhole is provided on the reactor. A light and a sight glass makes visual inspection possible without opening the reactor.

3.2.3 Safety

Although the pressure in the bioreactors is kept constant by a back pressure regulator, pressure relief valves are added for safety. The flat surfaces at the top of the reactor are sensitive to outwards bending when the pressure inside gets too high.

To keep a constant pH, acid or base is dosed. This dosage is realised through a special tube. This way, contact between the acid or base and the reactor top and wall is avoided. This protects the reactor from corrosion. An illustration is given in Figure 9.

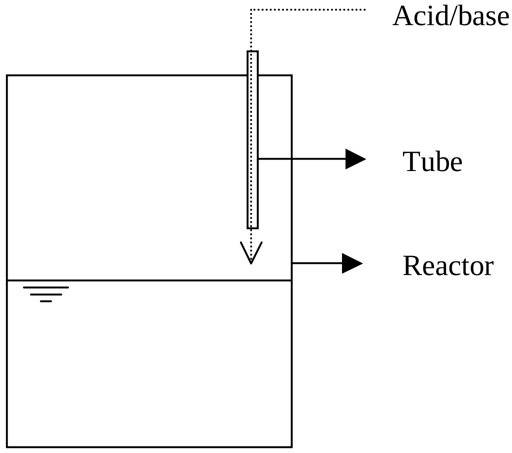
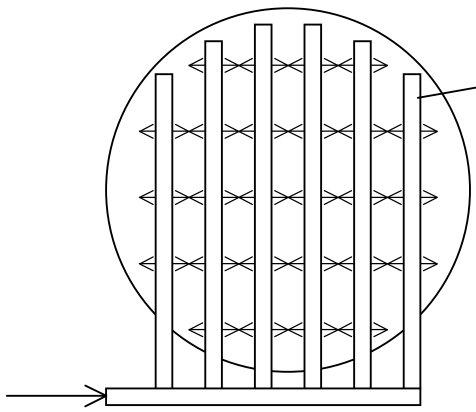


Figure 9: Acid/base input

3.2.4 Liquid distribution in the methanogenic reactor

As previously mentioned, the methanogenic reactor is a fixed bed reactor. This means that the methanogenesis is realised by bacteria that live in a biofilm which is supported by beads. The support material used is a PP type material. For an optimal working of this kind of reactor, the flow through the reactor must be as uniform as possible. This means that a good distribution system at the bottom of the methanogenic reactor is necessary. A view from above of the general principle of the distribution system is given in Figure 10. A cross section of the pipe where the fluid leaves the distribution system is shown in Figure 11. The flow out of the holes is directed downwards to the bottom of the reactor to prevent fouling.



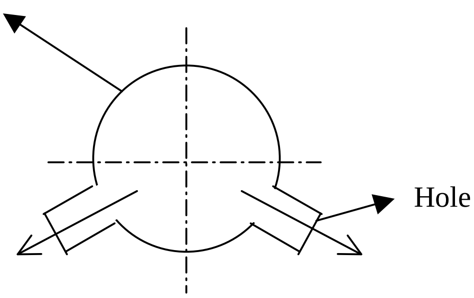


Figure 10: View from above of distribution system

Figure 11: Side view of cross section of distribution system

To realise an equal flow through all holes, the diameter size must decrease after every splitting up. The exact diameters of the pipes can be calculated if the relationship between the flow rate Q, the piezometric height difference Δh and the diameter D is known. This relationship is dependent on the type of flow regime. If the Reynolds number (Re = $\frac{U \cdot D}{\upsilon}$; for explanation of symbols: see Table 3) is lower than 2000, the flow is laminar. If Re is higher than 4000, the flow is turbulent. The transition of laminar to turbulent flow doesn't always happen at the same Re-number. There exists a transition regime in between. When an equal flow through every hole is needed, this transition regime must be avoided in the pipes. It can be proven that to the end of the distribution system the Reynolds number becomes smaller. Laminar flow through all pipes is therefore preferred. In a laminar flow, the following relationship between the flow rate Q, piezometric height difference Δh and diameter D applies:

$$Q = \dot{V} = \frac{\pi(p_1 - p_2)}{8\mu} R^4 = \frac{\pi \Delta p}{8\upsilon\rho} R^4 = \frac{\pi g \Delta h}{8\upsilon} R^4$$

This formula is called the law of (Hagen-)Poiseuille.

The local head or energy losses (from valves, bends, outlets, …) can generally be written as follows:

$$\Delta h = \zeta \frac{U^2}{2g} = \zeta \frac{Q^2}{2gA^2}$$

Values for ς can be found in the scientific literature.

With above mentioned formulas, a system of equations can be written. The unknowns are Δh and the diameters D. The system is non-linear and is difficult to solve analytically. For calculation, a numerical method is recommended. Starting values can be obtained if the local head losses are neglected. The system of equations and its solution will be given in TN 82.4.

U	Average flow velocity
D	Diameter of pipe
R	Radius of pipe
L	Length of pipe
h	= p/ρg = piezometric height
p	Pressure
g	=9.81 N/kg = surface gravity
Q	= $\dot{V}$ = U·A = flow rate
A	Cross section of pipe
ρ	Density of fluid
μ	Dynamic viscosity coefficient
v	= μ/ρ = kinematic viscosity coefficient
Re	Reynolds number

Table 3: Explanation of symbols

3.2.5 Piping and tubing

There exist two types of 'piping': 'pipes' and 'tubes'. Pipes are used in applications with high pressure and have a thicker wall. In our case, with only a slight over pressure, tubes will do just fine. The (only) tube standard that corresponds to the Tri-Clamp weld ends is ASTM 270 or ASME BPE-1997. These tubes can be ordered in stainless steel from Sadel.

The flow velocity in the tubes should not be too low, otherwise solids could deposit. For particles size of 0.5 – 2 mm, a flow velocity of 2 – 3 m/s is recommended (Ref: Lessons Hydraulics and culture techniques, Prof. De Troch, University of Ghent). When the flow velocity is too high, the sound level increases and formation of foam occurs. This determines, together with the flow rate, the tube diameter.

For the gas tubing, PFA can be used instead of stainless steel. PFA is flexible, transparent and has good chemical resistance. PFA tubing can be purchased at Lefort. For the base and acid vessels, PE is an adequate material.

3.3 Instrumentation

This chapter discusses all instrumentation, sensors and actuators of the BWT-unit.

3.3.1 Valves (V-011, V-013, V-015)

In the final design, it must possible to replace every instrument, without having to stop the process. In addition, isolation of one part or another from the system may occur as it is wanted to make every sub-unit (buffer tank, liquefying reactor, filtration unit, methanogenic reactor, nitrifying reactor) and all the loops modular in order to facilitate their transportation and placement in the dedicated containers. To obtain this, valves are added before (and after) each instrument. Two types of on/off-valves are possible: ball valves or butterfly valves. Pictures are shown in Figure 12 and Figure 13.

Figure 12: Jensen sanitary butterfly valve

Figure 13: Jensen sanitary ball valve

Ball valves will be used in the BWT-Unit because of their advantage to provide a full passage when opened and that no clogging may happen. Butterfly valves were not selected because the chance of clogging is high.

3.3.2 Rotameter (FD-002, FD-003)

For the measurement of flow, the variable area flowmeter (also called rotameters) MT 3809 of Brooks (Figure 14) are used. They have high accuracy, a broad range of flow capacity and a versatile construction for all gas and liquid applications. The Brooks flow meter has both an indication function and an output signal of 4-20 mA. The material in contact with the fluid is AISI-316. This type of sensor is the same as used in the GWT-unit.

Figure 14: Rotameter MT 3809 (Brooks)

3.3.3 Manometer (PI-001, PI-002)

Manometers are pressure indicators. Robust pressure indicators with a good ratio of price/quality are manometers of Bogerd instrumentation. This is why they are selected for pressure indication.

In the GWT-unit, Keller sensors are used for pressure and temperature measurement, but this type of sensor is not readily available in Belgium.

3.3.4 Pressure transducer (PD-001, PD-002, PD-003, PD-004)

For the pressure measurement, the Cerabar T PMC 131 (Endress+Hauser) pressure transducers are used. A trade-off of pressure transducers can be found in TN 71.7 EWC paragraph 1.2 . The PMC 131 is based on a capacitive measurement principle. Capacitive pressure transducers have a ceramic diaphragm, which makes them very robust sensors. Furthermore, they are not expensive. The PMC 131 is available in a wide variety of pressure ranges. A picture is shown in Figure 15.

Figure 15: Cerabar T PMC 131 pressure transducers

3.3.5 Level sensor (LD-001, LD-003)

For the level measurement, several technologies exist. A contactless radar level sensor is not advised because the mixer in the fluid causes measurement errors. With ultrasonic level measurement, the turbulences at the liquid surface caused by the mixer and the vapours in the head zone cause errors. Capacitive level measurement would be a good alternative (EWC TN 71.7 par 2.1), but a capacitive level sensor is impossible to replace in situ in case of failure.

Two other possibilities are vibration limit switches or differential pressure measurement. Both systems are offered by Endress+Hauser. The performances of both systems are similar. A disadvantage of the vibration limit switch is that it cannot deal with foam which could form at the surface of the slurry. This is the reason why the differential pressure level sensor is selected. A picture is shown in Figure 16. The way it is connected to the bioreactor is shown in Figure 17.

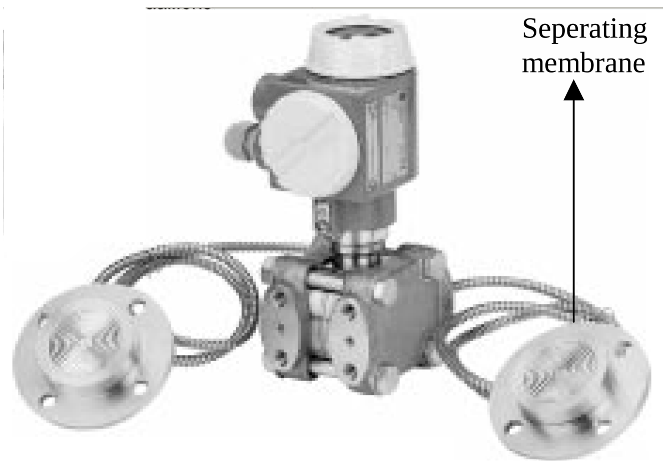


Figure 16: Endress + Hauser Deltabar S FMD 633

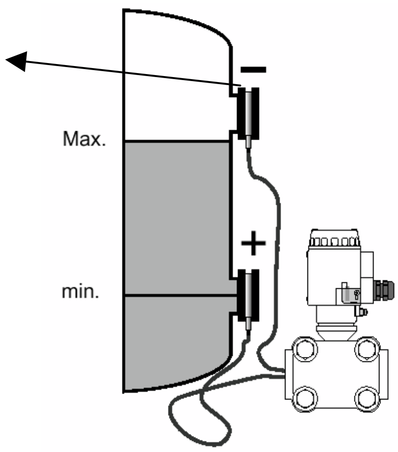


Figure 17: Connections to the bioreactor

3.3.6 pH measurement (pHS-001, pHS-002)

For the pH measurement, the Mettler Toledo Inpro 3200 is selected. A trade-off is given in TN 71.7 paragraph 2.4. The MT Inpro 3200 is a gel filled electrode. It has a long-term stability and requires little maintenance: no refilling needs to be done. This sensor is standard in biotechnical applications and is sterilisable. This is not the same sensor as in the GWT-unit: this sensor has the major advantage of being retractable: when the sensor is removed the electrode opening is cut off. This way, the sensor can be replaced or calibrated without stopping the process. A picture of the rectractable fitting can be seen in Figure 18. The same fitting can be used for gel or polymer filled pH electrodes, ORP and conductivity measurement. The fittings can be delivered with weld-in sockets. This is a connecting piece which can be welded on the bioreactor.

For the transmission of the signal, Mettler Toledo transmitters are used. They have built-in control algorithms (e.g. PID) which can be used for the control of the pH.

Figure 18: Retractable Ingold fitting: InTrac 777 with manual operation

3.3.7 Pump (PMP-001, PMP-004)

Two types of pumps are most widespread: centrifugal and volumetric pumps. The flow rates in this application however, are too small for the centrifugal pump.

Several types of volumetric pumps exists. The type selected is the progressive cavity pump. This was done for reasons of low shear rate and the presence of particles in the solution (in case of the liquefying reactor). The selected type is a Seepex pump. In the GWT-unit a centrifugal pump is selected, but as the sludge in the BWT-unit contains particles, a progressive cavity pump is preferred. A picture is shown in Figure 22. A cross-cut of a progressive cavity pump is depicted in Figure 20. An advantage of the progressive cavity pump is that the flow rate can be regulated. This can be done using a frequency inverter. The speed of the pump is dependent of the frequency of the electric voltage. A frequency inverter can change the frequency with dedicated electronics (see Figure 19). This way, the speed of the pump and thus its flow rate can be regulated. The selected frequency inverter is the same type as in the GWT-unit: Lenze ESDM 152 L4 TXA (Figure 21). A filter ESDM 2224TMF is added to filter out voltage peaks caused by the electronics of the frequency inverter. It is placed between the invertor and the electricity net. This way, the electrical equipment connected to the electricity net is protected from voltage peaks.

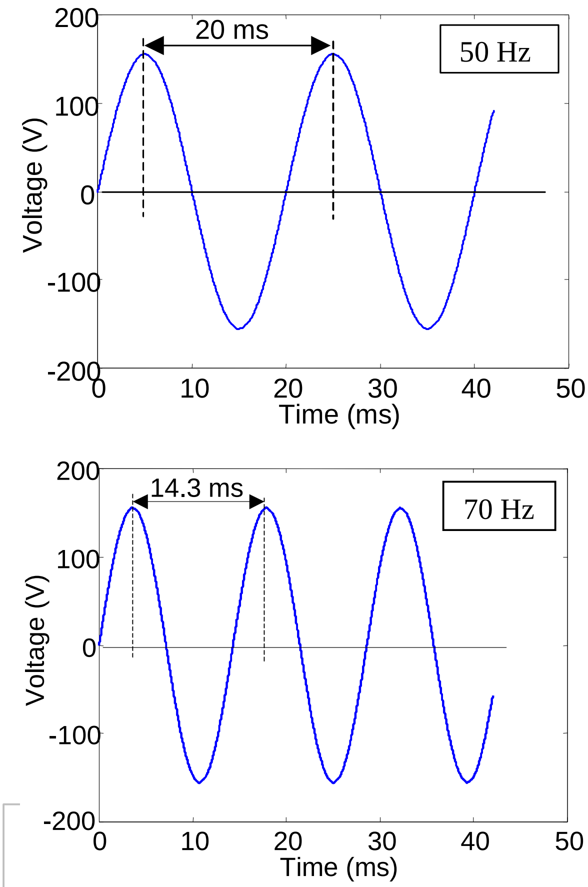


Figure 19: A frequency inverter can transform a 50 Hz signal into a 70 Hz signal

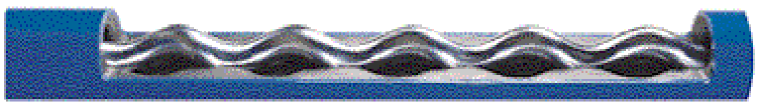


Figure 20: A cross-cut of the rotor and stator of a progressive cavity pump

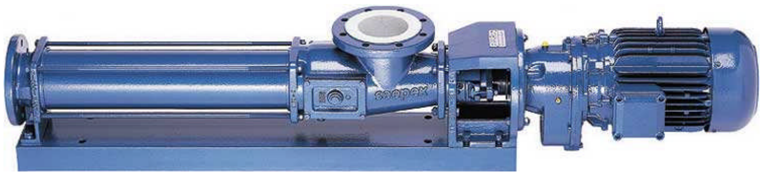


Figure 22: Seepex progressive cavity pump

Figure 21: Lenze frequency inverter

3.3.8 Pulse pump (PMP-005, PMP-006, PMP-007, PMP-008)

The selected dosing pump is the same as in the GWT-unit: LMI P153-398S3 (Dosapro). It has an output of 4 l/h, an adjustable frequency and stroke length and a accuracy of 2 % of adjusted output. A picture is shown in Figure 23.

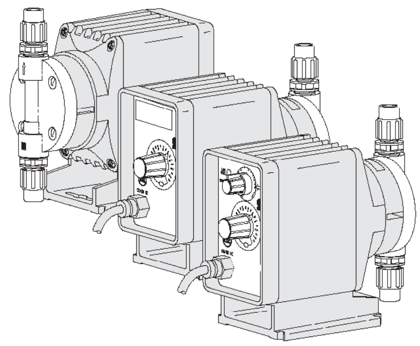


Figure 23: Dosapro dosing pump

3.3.9 Back pressure regulator (PR-001, PR-002)

There exist mechanical and electronic back pressure regulators (see TN 71.7 paragraph 4.6). The mechanical solution will provide a good pressure control without any chance of failure of electronic components, while the electronic solution will yield a more precise and accurate pressure control. Because the mechanical solution is more robust, cheaper and accurate enough for our application, a mechanical back pressure regulator is selected. This type of pressure regulator consists of a hand adjustable, spring-loaded pressure reducing regulator. For corrosion resistance, a version needs to be selected where the only materials in contact with the medium are AISI-316. The selected pressure regulator is 44-2360-24 (Tescom). The pressure can be regulated between 0 and 1.7 bar. A picture is shown in Figure 24.

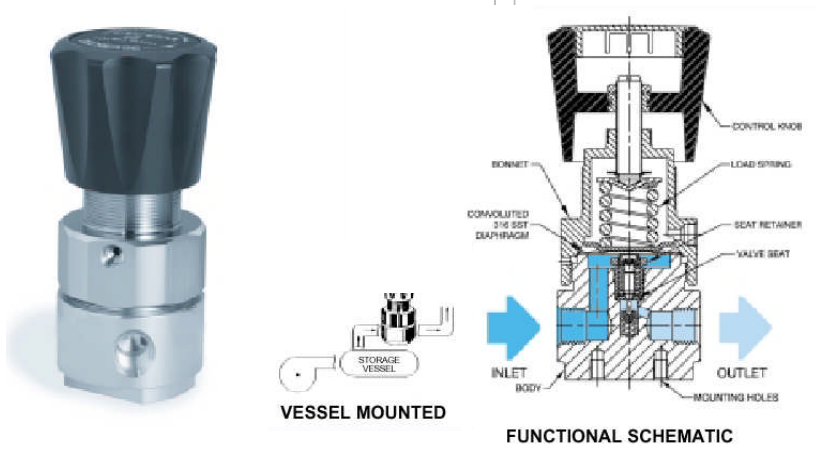


Figure 24: Tescom back pressure regulator

3.3.10 Suspended solids (SS-001)

For the estimation of the concentration of suspended solids in the liquid, turbidity will be measured. The density changes are too small to be used for the measurement of the suspended solids. See also EWC TN 71.7 paragraph 2.8. The selected turbidity measurement system is the Optek 156/AF56-N. It has high accuracy, is made of stainless steel, has Tri-Clamp process connections and can cope with a temperature of 55 °C. A picture is shown in Figure 25.

3.3.11 Temperature (TS-001, TS-002, TT-001, TS-002)

For the measurement of temperature, the Endress+Hauser Omnigrad M TR 45 is selected (Figure 26). It has a high accuracy (class A) and it has Tri-Clamp connections. A trade-off of temperature sensors is given in EWC TN 71.7 paragraph 2.3. The temperature sensor is a Pt100. The sensor itself is not in contact with the reactor content, but is located in a stainless steel housing, called a thermowell. The E+H TMT 187 temperature transmitter can be mounted in the head of the temperature sensor.

Figure 25: Optek turbidity meter

Figure 26: E+H Omnigrad M TR 45

3.3.12 Controlled valves (V-013, V-014, V-018)

For controlled valves, the same type as in the GWT-unit is selected, namely type 2002 angle-seat valve (Bürkert). It is available in pipe sizes from 13 to 65 mm and has a big flow opening so the chance of fouling is minimised. A picture is shown in Figure 28. The valve is operated pneumatically. Therefore a pilot valve is needed. This is also the same as in the GWT-unit: type 6012 (order code: 425 286 K). Figure 27 shows a picture of the Bürkert pilot valve. The arrow shows where the pilot valve needs to be mounted.

Figure 27: Pilot valve

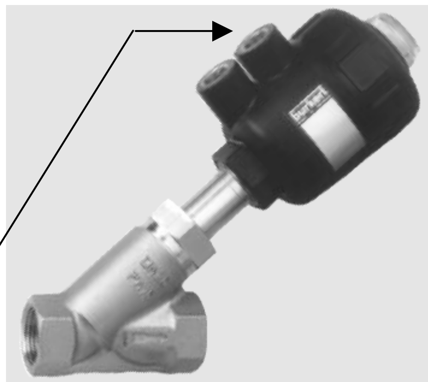


Figure 28: Type 2002 angle-seat valve

3.3.13 Additional instrumentation

This paragraph discusses the instrumentation that is useful for the operation of the BWT-unit for process follow-up.

The electro-conductivity (EC) can be measured. The conductivity is a measure representative of the ionic strength of a liquid. EC indicates the amount of dissolved salts in a given sample. As nutrients are salts, EC measurement is equivalent to total nutrient determination in this given sample. For the measurement of EC, the MT Inpro 7108/25-VP is selected (Figure 29). This is an EC sensor based on the conductive measurement principle. Allthough this sensor is more sensitive to fouling than the ones based on the inductive measurement principle, the Inpro 7108 fits in the retractable fitting MT Intrac 777. It can thus be easily cleaned without interrupting the process.

With a gas analyser, the gas composition can be measured. This can be useful for the follow-up of the process. The collected data can also be used to validate the MELiSSA technology. The Biogas 401 (ADOS) offers an accuracy of 2 % f.s.d. for a low price and is therefore selected as gas analyser. A picture is shown in Figure 30.

The oxidation reduction potential (ORP) measurement verifies the anaerobic conditions of the reactor. ORP is a potentiometric measurement in which the potential (or tendency) of the medium for electron transfer is sensed by an inert metal electrode and read relative to a reference electrode that is immersed in the same medium. This determination can also be referred to as a "redox" measurement (combination of REDuction and OXidation). The MT type Pt4805-dpa-sc-s8/255 is selected. This electrode fits in the same retractable housing as the pH sensor (InTrac 777). The transmitter is also the same as used for pH transmission.

Table 4, Table 5 and Table 6 summarise the additional equipment that can be used. EC and ORP are also discussed in TN 71.7 paragraph 2.6 and paragraph 2.5.

Figure 29: MT Inpro 7108/25-VP (EC)

Figure 30: ADOS biogas 401

Table 4: Electro-conductivity

EC-001	Electro-conductivity	Mettler Toledo	Inpro 7001/VP
	Conductivity cable	Mettler Toledo	4.6M/VP
	Retractable fitting	Mettler Toledo	InTrac 777 (manual)
	Inclined weld-in socket	Mettler Toledo	Order code: 007641014
ECT-001	Conductivity transmitter	Knick	Stratos 2402 Cond

Table 5: Gas analysis

Analyser	CO_2,CH_4,O_2 and H_2/H_2S-analyser	ADOS	Multi-channel gas monitor Biogas 401
	Compressor cooler	Kelma	Mak-6 Mini
	Analyser flowmeter 0-1000ml/min	Honeywell	AWM3300V
-	Water trap	-	-

Table 6: ORP sensor

ORPS-001	Redox sensor	Mettler Toledo	Pt4805-DPA-SC-S8/120
	Cable	Mettler Toledo	AS9/5m
	Retractable fitting	Mettler Toledo	MT InTrac 777 (manual)
	Inclined weld-in socket	Mettler Toledo	Order code: 007641014
ORPT-001	Redox transmitter	Knick	Stratos e2402 pH

3.4 Filtration unit

The main aim of using a membrane ultra-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, soluble COD and salts from the insoluble fraction. The liquid stream will be fed to 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 liquefying reactor for further biodegradation. The biomass will thus be recycled. Tests have been performed at laboratory-scale in continuous mode with a bioreactor equipped with ultrafiltration organic membranes from X-Flow.

Two phases could be distinguished in the study for the elaboration strategy of the UF-Unit:

- Phase 1: detailed design
- Phase 2: construction and functional tests

Phase 1: Detailed design

In this phase, a detailed design of the ultrafiltration unit will be elaborated. Boundary conditions which certainly have to be taken into account are the following:

- treatment capacity: black water from 15 to 70 people, or 0.4 to 1.8 m^3/d
- retention time in the bioreactor of 3 days
- treatment of 1-5 % of dry matter
- minimal interference of membrane unit with sludge and sludge activity
- minimal cleaning requirements via optimal hydraulic conditions
- provisions for cleaning in place
- operation at 50 - 55 °C
- complete construction in stainless steel
- material choice harmonized with the hardware selected for the EWC.

In the laboratory-scale tests performed by EPAS, fluxes of 14.6 $l/m^2.h$ have been obtained with PVDF organic membranes. These will be used as a starting point for the design and calculation of membrane surface area of the full-scale treatment unit. Based on the results obtained on the first MELiSSA compartment and a trade-off between organic and inorganic (ceramic) membranes, an optimal design will be 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. To achieve this cross-flow velocity, high recirculation flows are required. In order to avoid that the complete reactor content with the sensitive anaerobic biomass will be vigorously pumped through the membrane filtration loop several times per hour, an internal recirculation at very high flows will be provided in the filtration loop. Therefore two pumps will be needed, one at a high flow rate (30 m^3/h) to achieve the desired cross-flow velocity through the UF-membrane modules and the second one at a lower flow rate (0.4 to 1.8 m^3/d with a nominal flow rate of 1.2 m^3/d) to pump the produced filtrate to methanogenic reactor (see P&ID scheme in Figure 1) . For an accurate follow-up of membrane performances, 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

Furthermore, a number of valves will be required for pressure regulation, flow direction, easy access to the subunits, membrane cleaning and backwashing, etc. Additional tanks for chemical storage, buffering capacity etc. will also be included.

It is important for proper functioning of the filtration unit that the feed to the bioreactor is free of sand and contains no large fragments > 4 mm.

Phase 2: Construction and functional tests

Purchase of hardware components will be performed by EPAS. When the assembly is finished, the constructor in collaboration with EPAS, will perform hydraulic tests to evaluate the functionality of the unit. This includes checking on leaks, sensor calibration and stability, proper response of hardware units, proper operation of control, etc.

After the functional tests, the filtration unit will be delivered to EPAS and a user manual will be made in English. All required documentation for CE-conformity will be included. In Table 7, the timing needed for the construction of the UF-Unit is presented. A total period of 32 weeks will be needed for the construction.

Table 7: Time schedule

	Week 1-8	Week 9-30	Week 32
Phase 1: detailed design	X		
Phase 2: construction and functional tests		X	
Delivery to EPAS			X

Detailed tasks description for each phase are shown in Table 8.

Table 8: Task description

Phase	Task
1: Detailed design	Design
	Reporting
2: Construction and functional tests	Hardware
	Functional tests
	Reporting

3.4.1 Organic Membrane specifications

Type membranes: Compact Ultrafiltration Membrane (F 5385) from X-Flow (http://www.x-flow.com/p3.php?RubriekID=1426)

3.4.1.1 Basic characteristics

- Hydrophilic tubular polyvinylidene fluoride membrane cast on a composite polyester/polyolefine carrier
- Tubular membrane available in 8.0 mm
- Structure asymmetric
- High performance and a very good anti-fouling behaviour
- Membranes are supplied in a standard range of elements

3.4.1.2 Application fields

- Effluents treatment in Waste Water Treatment facilities
- Membrane bioreactors

3.4.1.3 Membrane composition

- Membrane material composed of polyvinylidene fluoride
- Membrane carrier is a composite polyester woven/non-woven

3.4.1.4 Performances data

Parameter	Unit	FR 5385	Remarks
Clean water flux	$\frac{l}{m^2 \cdot h \cdot 100kPa}$	> 750	RO / water at 25 °C
Transmembrane pressure	kPa	- 20 to + 500	
Mean pore size	nm	30	
pH		2 - 10	at 25 °C
Chlorine exposure	ppm.h	250000	at 25 °C
Temperature	°C	1 - 70	at pH 7 and 100 kPa

3.4.1.5 Drawbacks

It is clear that the operation of these membranes at any combination of maximum limits of pH, concentration, pressure or temperature, during cleaning or production, will severely influence the membrane lifetime. It is therefore important to study carefully these parameters and to define appropriate cleaning procedures on the UF-Unit during its testing period.

3.4.1.6 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	++

3.4.1.7 Membranes cleaning

The cleaning procedure for these type of membranes has been described in TN 82.2 according to the procedure recommended by the manufacturer (X-FLOW®) and tested at EPAS on the lab-scale UF membranes of the same type.

3.4.1.8 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 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.

3.4.1.9 Sizing of the UF-module

The most important parameters to be taken into account for the sizing of the UF-Unit are:

- The surface area of the membranes (A): m^2
- The daily nominal flow rate needed (Q): L/d
- The nominal flux: $L/m^2.h$

For the sizing of the UF module, the following values were considered:

- $A_{\text{of one membrane}}$ = 0.025 m^2 (L = 1 m, ∅ = 8 mm)

- $Q_{nominal}$ = 1200 L/d = 50 L/h. with Q_{max} = 1800 L/d = 75L/h
- Flux = 14.6 L/m^2.h at pressure operating conditions of 0.5 to 0.8 bar (This flux is deduced from the same ceramic membranes (Atech-innovations) in the framework of EWC-project and also on organic PVDF-membranes on the lab-scale BWT-Unit). This value is indicative and should be further investigated during the test period of BWTU.

Thus, the membrane surface area needed to filtrate the daily flow is:

Total surface needed A = $Q_{nominal}$ / Flux $_{nominal}$ = 3.42 m^2 with the maximum of 5.13 m^2 needed.

The number of tubular PVDF-organic membranes needed is:

5.13 m^2 / 0.025 m^2 = 205 membranes

3.4.2 Inorganic membrane specifications :

Type membranes: Ceramic membranes "-aluminium oxide" from Atech-Innovations- Germany
http://www.atech-innovations.com/ie/english/indan.htm

Due to their extremely high chemical and physical stability, their outstanding separation characteristics and their long working life, , the ceramic membranes are a perfect match for process stability, high availability, low requirements for preliminary treatment of highly loaded influents and minimum need for support and maintenance.

The supports for the membrane elements are made from -aluminium oxide with open pores - a material which not only provides maximum permeability but also fulfils high requirements regarding mechanical stability. A membrane layer of a defined texture which is only a few µm thick is applied to the inner side of the carrier tubes - of either single-channel or multi-channel design - in a sandwich-type process and connected monolithically.

Ceramic membrane elements which will be certainly selected to be used for the filtration of the black water are used in cross-flow ultrafiltration (cut-off = 50nm). They have the following characteristics:

- High pressure stability
- Resistant to concentrated dyes and acids
- Back-washing possible
- Abrasion-resistant
- Easy cleaning
- Temperature-stable
- High flux

The ceramic membranes are grouped into modules in pressure vessels as shown in Figure 31. Filter areas range from 0.05 m² for test purposes up to 20 m² per vessel for a large-scale application. Of course, when manufacturing for the food and pharmaceutical industries, account will be taken of the relevant hygienic requirements such as optimum cleaning possibility and capability of being sterilised (CIP and SIP compliant). Special plastic modules have also been especially developed for highly corrosive media. It is so that these characteristics (optimum cleaning possibility, possibility to be sterilised, inox housing and resistance to chemicals) were selected for the filtration of the organic matter from the liquefying reactor of the BWT-Unit.

Figure 31. Stainless steel modules in various designs

3.4.2.1 Application fields

Initially, ceramic membranes were used in waste water technology. Meanwhile, successful solutions and possible applications are furnished to all industries where media are filtered. In the field of environmental protection / waste water, Atech membranes are used in various applications such as:

- Filtration of cleaning solvents,
- Filtration of cooling lubricants / drilling emulsions,
- Cell separation after heavy-duty biological processes,
- Concentration of brick engobes,
- Cleansing of pickling baths,
- Recycling of paints and lacquers, and
- Recycling of water from swimming pools

In the food industry, ceramic membranes are used for:

- Filtration of bottom beer,
- Clarifying filtration of sugar syrup, fruit juice, wine and vinegar,
- Reduction of the fat content of whey, and
- Filtration of lactoferrin.

Atech ceramic membranes were preferred among others because of the experience gained during their testing on the EWC-MELiSSA reactor. During the tests performed on the prototype-EWC (TN 71.9.4)., three type of membranes were tested: one type organic membranes PVDF from X-flow and two types inorganic ceramic membranes, the first one from Orelis and the second one from Atech. Since the performances of the Atech membranes gave satisfactory results, it was decided to select them for the operation of the filtration unit of the MELiSSA waste compartment. As already mentioned, it is of importance to validate this choice by using the same type of membranes for the filtration unit of the BWT-Unit and to test them on real conditions.

3.4.2.2 Sizing of the UF-module

For the BWTU project, the 19/8 type filter is most appropriate. The membrane material is sintered TiO_2. The membrane is a multi-channel filter element. A picture is shown in Figure 32. The internal diameter of the channels is 8 mm. The external diameter is 50 mm. The standard length is 1 m.

The inner filter surface area is: 19 x 0.008 m x π x 1 m = **0.4775 m²**

Based on this surface, the maximum needed number of membranes is 5.13 / 0.4775 = **11 membranes.** However, since the unit will rather be operated at its nominal flow rate than at its maximal flow rate, the needed membranes will be 3.42 / 04775 = **7 membranes.** For safety reasons and to guaranty optimal functioning of the filtration unit, a total membranes of **12 membranes** is proposed. The placement of the membranes and their housing as well as their disposition in the containers dedicated for the BWT-Unit will be discussed in TN 82.4. 6 extra membranes will be foreseen as back-up to allow continuous operation of the filtration unit while the cleaning of the membranes is done. Indeed, 12 membranes will perform the filtration of the slurry and 6 will undergo cleaning. The later will be sequential this means that the cleaning will always concern 6 membranes together from the moment that a decrease in the flux is registered. A decrease by 30% in the flux (information obtained from Atech-innovations) registered by the PLC will initiate the cleaning of the concerned membranes and switching on of the cleaned ones to the slurry filtration mode.

The 'cross-flow' surface is 19 x (0.008 m)² x π /4 = 0.000955 m².
With a required (average) flow velocity of 2.5 m/s (deduced from the tests performed on the prototype EWC-reactor), a flow rate of Q = 0.000955 m² x 2.5 m/s = **8.60 m³/h** is needed per multi-channel membrane filter.

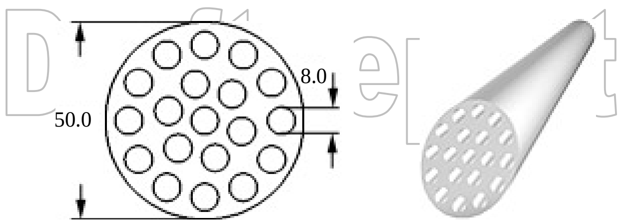


Figure 32: Atech Innovations multi-channel membrane

Different possibilities can be proposed for the organisation of the membranes in the filtration unit. They can be housed individually or organised in 2 or three membranes per housing. A trade-off of the three possibilities will be made in TN 82.4.

3.5 Estimation of weight of the BWT-Unit

Two requirements must be met concerning the weight:

1. The total mass of the BWT-Unit should not exceed 20 tons (including the sludge) because of its placement on the first floor at the Concordia site.

2. The maximum weight of each individual sub-unit should be limited to 1200 kg (maximum weight that a helicopter could transport).

An overview of the weights of the sub-units is given in Table 9.

Table 9: Mass of hardware material

Sub unit	Weight (kg)
Liquefying unit	261
Filtration unit	677
Cleaning system	363
Methanogenic reactor	181
Gas loop	971
Nitrifying reactor	54
Activated carbon (optional)	496
Miscalleneous	1019
Sub-total	***4020***

The weight of the liquid and beads can be found in Table 10.

Table 10: Mass of liquid

Sub-unit	Weight (kg)
Buffer reactor	2000
Liquefying reactor	3600
Methanogenic reactor	3600
Cleaning system	100
Nitrifying reactor	1500
Buffer vessel	1000
Activated carbon (optional)	1000
Acid/base	85
Detergent	10
Sub-total	***12885***

The total weight of the BWTU-unit during operation is **16905 kg**.

3.6 Energy requirements of the BWT-Unit

The estimated maximum power consumption is 34.5 kW. The main power consumers are the pumps (5 - 10 kW), especially F-Pm-01 and the heaters (5 - 8 kW). In operation conditions, the nominal power consumption is estimated at 23 kW.

4 Control strategy

A choice has to be made between local and global control. In global control, everything is centrally controlled with a PLC. It is therefore called software-based control. Local control is sometimes called hardware-based control. The next paragraph describes some advantages and disadvantages between the two types of control.

Reasons that plead for hardware-based control:

- Hardware controllers are designed by engineers with a lot of experience in the narrow field of their controller's work area. Their control functions are geared towards the process parameter that they are supposed to control, which ensures stability to be reached quickly.
- The control algorithm is baked in the electronics and not executed by an operating system and volatile memory, which strongly reduces chances for a crash. Therefore, hardware-based control ensures more reliability.
- When the software in the PLC crashes and its outputs do act uncontrolled, system basics like heating of the reactor content and pH control keep on working.

Reasons that plead for software-based control:

- Less hardware and simpler setup
- Less parts can fail
- All control is centralized in the PLC. During development, this means that every part of it can be altered from the same place using the same programming language and techniques. During testing and running, this means that all manipulations can be performed using the same kind of actions. All control is centralised in the PLC.
- Control laws can be adapted more flexibly to specific needs of the process.

To better cope with on-site conditions and user requirements, PLC-based control is preferred. ESA refers to this as 'level 1 automation'. More details about the control strategy are described in TN 82.4.

5 Additional treatment(s)

In the evolution of the project, on the request of IPEV, different technologies for post-treatments of the effluent were considered. Ozone, combined peroxide-UV and activated carbon technologies for colour removal from the effluent BWT-Unit were investigated at EPAS. Among the three perspectives, granular activated carbon (GAC) technique was selected as it gave the most satisfying results. The details of the tests performed for the selection of the most efficient colour removal technology are presented in TN 82.7. A column containing activated carbon has been studied at lab scale level in order to remove the colour of the effluent.

Another post-treatment that has been investigated in order to satisfy the criteria of the grey water treatment unit is the removal of ammonium. Ammonium is expected in high amounts (200 mg NH_4^+-N /L to 500 mg NH_4^+-N /L) because of the presence of urine. Since ammonium is not retained by the filtration system proposed for the treatment of the grey water, it was decided to convert it into nitrates, which, in turns can be retained by the membrane system of grey water treatment unit. In the mean while, the validation of the MELiSSA technology for the third compartment will be possible via this project.

The conceptual design of a nitrification and GAC unit is given in **Fout! Verwijzingsbron niet gevonden.**. The equipment list, and the electrical design for the nitrification reactor are given in TN 82.4.

5.1 Adsorption on GAC filter: Optional

Adsorption is the process by which fluid molecules become attached to a surface by physical or chemical forces (or a combination of both). In physical adsorption the impurities are held on the surface of the carbon by low level Van der Waals forces, while in chemisorption the forces are relatively strong and occur at active sites on the surface. Physical adsorption is predominant when using activated carbon in water purification, and the efficiency of the carbon will depend upon its accessible surface. The activated carbon actually removes the impurity in bleaching operations where a coloured impurity is chemically changed to a colourless material.

A number of factors can affect adsorption such as pore size distribution, molecular size of the impurity, particle size of the carbon, temperature of the carbon treatment, and the pH of the solution. The following relationships, however, generally apply when other variables are held constant

- Adsorption efficiency increases as the particle size of the impurity decreases.
- Adsorption efficiency increases as the temperature decreases.
- Adsorption efficiency increases as the contaminant solubility decreases.
- Adsorption efficiency increases as contact time is increased.

Three groups of pores can be distinguished in an activated carbon (Figure 33)

1. Micropores (0-20 Angstrom) (r < 0-2nm)
2. Transitional pores (20-500 Angstrom) (r = 2-50nm)
3. Macropores (> 500 Angstrom) (r > 50nm)

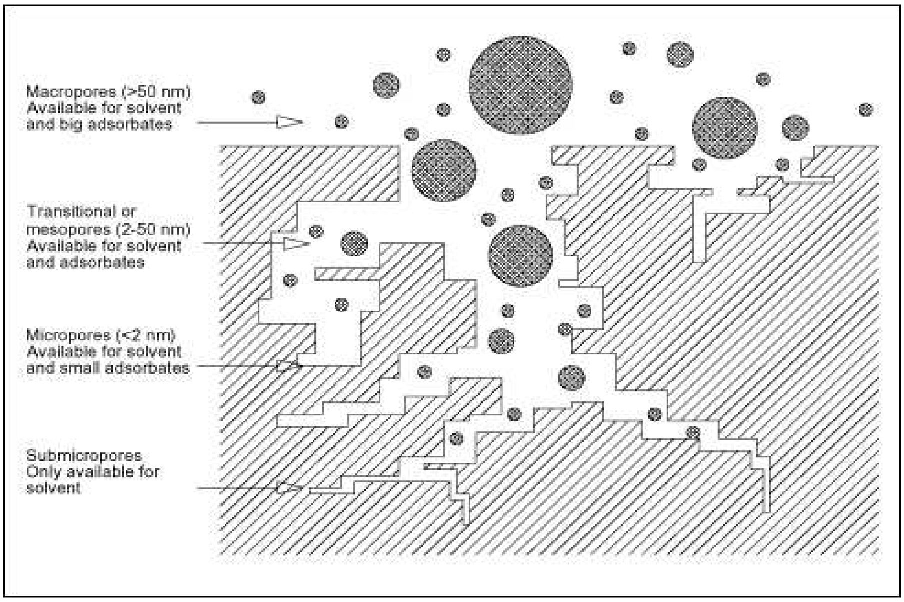


Figure 33: Pore structure in granular activated carbon

5.1.1 GAC characteristics

GAC type ORGANOSORB 10® from DESOTEC-Belgium was selected among other activated carbon types because of the satisfying results obtained on tests performed on laboratory scale. In addition, this coal based activated carbon product can be water washed to assure low dust. This minimizes the amount of backwashing required during start-up and following carbon replacement.

This Activated carbon has certain chemical and physical qualities depending on the basic material and the way of activation. These carbon qualities are characterised by certain parameters and numbers as shown in Table 11.

Table 11: Characteristics of the ORGANOSORB 10®-GAC

Parameter	Quality	Typical values
Total BET surface (m^2/g)	Min. 1000	1020
Iodine number(mg/g)	Min. 1000	1020
Methylene bleu number (mg/g)	Min. 190	192
Moisture (%)	Max. 5%	2.29
Ash (%)	Max. 12	10.79
pH	7.9	7.97
Hardness (%)	Min. 90	96
Density (g/l)	± 480	
Particle size (mesh)	8*30 (2.36 – 0.6 mm) 12*40 (1.7 – 0.425 mm)	

This activated carbon is especially developed for the purification of wastewater. Its high adsorption capacity eliminates organics to the level of traces.

Pressure drop in the GAC filters can be determined by using the following graph: Figure 34. This data is necessary to ensure proper sizing and selection of the circulation pump.

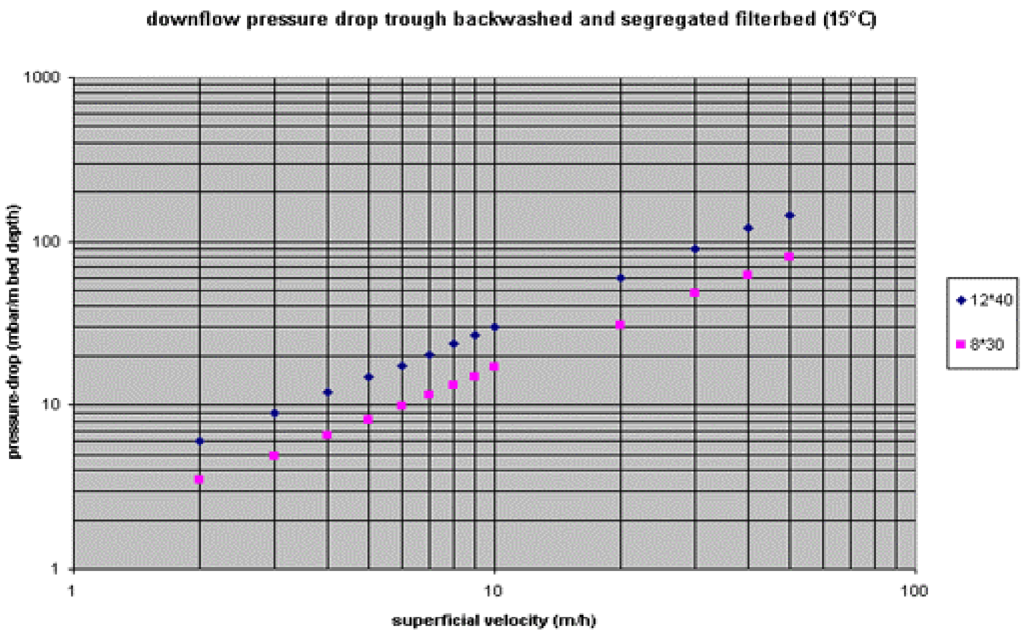


Figure 34: Down-flow pressure drop through backwashed and segregated filter-bed (at 15°C)

Two types of Granular activated carbon filters can be used for the colour removal from the effluent BWT-Unit:

1. Aerated activated carbon filter
2. Non-aerated Activated carbon filter

5.1.2 Aerated activated carbon

The system utilises the power of adsorption, oxidation, and microbiological processes. By efficient aeration of the effluent stream, recalcitrant COD's can be catalytically oxidised on the carbon surface, adsorbed by the activated carbon and digested by the micro-organisms on the activated carbon media (Figure 35). The following advantages accrue:

- Longer, even permanent lifetime of the activated carbon filter
- Lower concentration of recalcitrant, non bio-degradable molecules.

Figure 35: Industrial aerated activated carbon filter

5.1.2.1 Application fields of the aerated activated carbon filters

As shown in Table 12, aerated carbon filters have a lot of application fields.

Table 12: Application areas for aerated GAC filters and their advantages

Application-area	Results
Landfill	Reduction of COD, hydrocarbons, etc. *Longer to permanent life-time (~load)*
Textile-industry	Reduction of COD and decolorization for wastewater-recycling *No saturation of the carbon*
Waste-treatment	Reduction of COD (500 > 200 ppm), post-nitrification *Life-time x 4*
Wood industry	Reduction of COD, BOD and N (post-nitrification) *No saturation of carbon*
Chemical industry	Elimination of phenol with double capacity (30% i.s.o. 15) and reduction of COD *with no saturation of the carbon*
Ground sanitation	Reduction of COD, hydrocarbons *Longer to permanent life-time (~load)*
Truck- and tank cleaning	Reduction of COD, detergents, hydrocarbons, etc *Longer lifetime (+ 150%)*
Food industry	Reduction of COD *Longer life-time*

The OXYCON®-technique, which will be used for the filtration of the effluent from the BWT-Unit, allows to aerate a classical activated carbon filter (even in use and partly saturated) in an efficient way, so that besides the adsorption qualities of the carbon, there happen also chemical catalytic oxidative processes and biological degradation processes (or in-situ bio-regeneration).

5.1.2.2 Principle of the technology

The effluent generated from the nitrification reactor will be directed towards an activated carbon filter (type OXYCON®) after being aerated by compressed air. The system will be kept under pressure and the effluent from the activated carbon filter will overflow in a reservoir as shown in Figure 36.

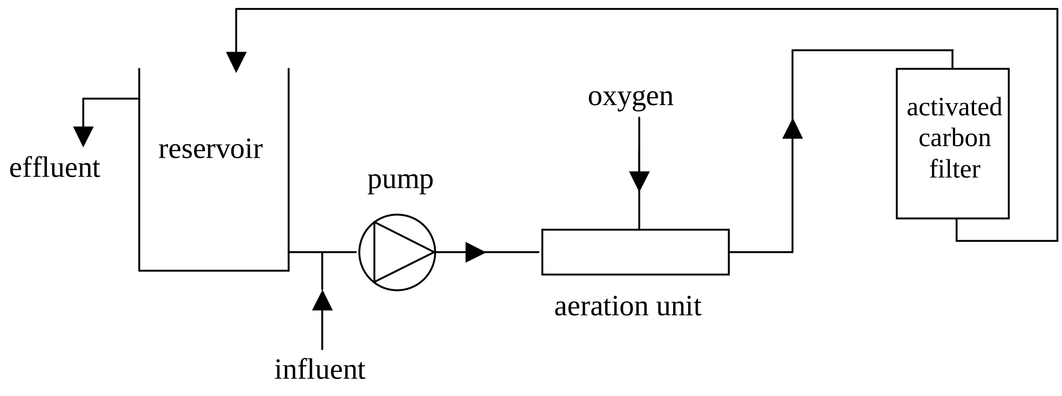


Figure 36: Principle of filtration via an aerated granular activated carbon filter

5.1.3 Non aerated activated carbon filters

The Mobicon® -DESOTEC–Belgium system was developed specifically for the treatment of industrial water and liquids (Figure 37). This mobile container can be used on-site for applications since it is easy to be transported to Concordia site. However, some inconveniences might be encountered when the filter is saturated. In this case, and after relatively a short period (see hereunder) the entire Mobicon® must be replaced by another unit, filled with fresh activated carbon. This imply the transportation of spare filters to Concordia to have at least a reserve for 1 year.

Figure 37: Non-aerated GAC mobile filters

The characteristics of this filter are shown in Table 13.

Table 13: Characteristics of mobile GAC non-aerated filters

Technical index MOBICON® 1000	**Characteristics**
effective volume	1.3/1.6 m^3 - max. charge 500 kg
weight	±580 – 600 kg
height	2300 mm
diameter	1250 mm
max. flow rate (max.)	12 m^3/h.
max. pressure (security)	5 bar - no vacuum
temperature (max.)	40 °C
materials	coated steel
connections	2" Guillemin

5.1.4 Advantages and disadvantages of aeration in GAC filters

The main disadvantages of aerated filters is the energy consumption of the system and the need of extra material installation for the purpose of aerating. This inconvenient is widely overcome because of the range of advantages of installation of a such system, especially in the case of BWT-Unit at Concordia. Due to the fact that the system is aerated, the clogging of the pores will not be immediate. Indeed, microbial growth and activity occurring because of aeration, may extend the bed life for biodegradable compounds, which have escaped from the first biological treatments, mainly the remained COD and ammonium in the effluent could be effectively removed at this level. Moreover, due to aeration, free space between the GAC particles may stay longer than in non aerated filter beds.

5.1.5 Design parameters for the activated carbon filters

Standard design conditions and data for the granular activated carbon 8*30 (0.6 - 2.36 mm) are mentioned here below:

1. Bed depth and superficial velocity

Application	bed depth m	superficial velocity m/h ($m^3/m^2/h$)
General (*)	2.0 - 3.0	10 (max 20)
Dechlorination	1.0 - 1.5	20 (max 30)
Deozonation	1.0 - 1.5	up to 50

(*) Dynamic tests (breakthrough curves) are recommended to determine the best contact-time

Calculation of the free space above the activated carbon bed

The recommended free height (space) above a carbon bed = 25% of the bed depth (e.g. for 2 m: 500 mm) + 300 mm (as a security)

Pressure drop: see Figure 34

Backwash:

Here an operating method used to remove suspended solids from the carbon bed is proposed by the supplier of the GAC filters. Water is pumped into the bottom of the adsorber, flows upward through the carbon bed, and exits through the backwash outlet. The upward flow expands the bed and removes the suspended solids, carbon fines and entrained air.

According to the supplier, rigorous backwashing of carbon beds is not recommended. Maximum backwash velocity : normally 20 to max. 30m/h (=$m^3/m^2/h$).

- *Period 1* : during the first 5 minutes : increase slowly to max. flow.
- *Period 2* : during 10 minutes : max. flow.
- *Period 3* : during the last 5 minutes : decrease the flow slowly to zero.

Take on service:

1. Fill the vessel (with the carbon) with water
2. Backwash the carbon after 24 hours under water
3. The carbon is ready to be used

5.1.6 Design of a carbon bed

In order for carbon adsorption to work well, it is important that the final design incorporate both the physical and chemical adsorption process.

5.1.6.1 Minimum Carbon Bed Mass

The carbon bed must have sufficient mass to remove the contaminants in the water stream (in our case the colour due to the COD). This is a function of many factors, most important of which being the mass rate of the contaminants (i.e. concentration of the organics expressed as COD and flow rate). The mass rate of contaminants (as an example hereunder BTEX) may be calculated from the following Equation:

$$\text{Mass rate BTEX}\left[\frac{\text{kg}}{\text{day}}\right] = \sum \text{Conc}\left[\frac{\text{mg}}{\text{L}}\right]\cdot \text{Flow}\left[\frac{\text{L}}{\text{min}}\right]\cdot 0.0952$$

Breakthrough is defined as the point when contaminants are detected in the effluent and generally occurs when the adsorption capacity of the carbon is approached. Equilibrium saturation, or the maximum usable life of a carbon bed, may be determined from the following:

$$\text{Equilibrium Saturation}\left[\text{days}\right] = \frac{\text{Carbon bed}\left[\text{kg}\right] \cdot \text{Loading}\left[\dfrac{\text{kg organic}}{\text{kg carbon}}\right]}{\text{Mass Rate (BTEX)}\left[\dfrac{\text{kg}}{\text{day}}\right]}$$

A well-designed GAC vessel should have sufficient contaminant mass removal capacity to allow for continuous operation for a significant period of time before a carbon bed replacement is required. Most non aerated systems are designed to operate for a minimum of three months between carbon changes. However, several factors must be considered when determining the minimum carbon bed mass such as the travel time to and from the site, the operation and maintenance budget, space constraints on the site and within the equipment shed, the negative consequences of a discharge violation, etc.

Loading is a function of many variables including pore size distribution of the carbon, the molecular size and concentration of the contaminants, flow rate, compound solubility in water, and the presence of functional groups such as chlorine substitutions or aromatic structures. The performance of carbon is predicted by the adsorption isotherm. The isotherm is a measure of the amount of soluble organic that is adsorbed per unit weight of carbon at varying concentrations at constant temperature. The data collected from batch tests may be plotted on a log-log graph to form a straight line based on the empirical Freundlich equation:

$$\frac{X}{M} = K \cdot c^{1/n}$$

or

$$\log\frac{x}{m} = \log k + \left(\frac{1}{n}\right) \cdot \log C$$

where,
x = amount of contaminant adsorbed (mg)
m = total bed mass of carbon (g)
c = equilibrium concentration in solution after desorption (mg/l)
k = constant
n = constant

Isotherms are available for pure compounds, but these do not take into consideration the dynamics of adsorption when multiple compounds are present. As a result, carbon adsorption modelling is not reliable. However, for the purposes of comparison, pure compound isotherms may be used to calculate the total loading for a system.

After determining the mass of carbon required for the system operating parameters, the volume of the GAC vessel may be calculated. The amount of granular activated carbon required to fill a column may be determined as follows:

$$\text{Carbon bed}\left[\text{kg}\right] = \text{Volume}\left[\text{m}^3\right] \cdot \text{AD}\left[\frac{\text{kg}}{\text{m}^3}\right] \cdot 0.85$$

where AD is the apparent density of the carbon. The above equations may be combined to determine the necessary vessel geometry to allow continued operation of the system before breakthrough as shown in the following equation:

$$\text{Radius}_{\text{min}} = \sqrt{\frac{\text{Equilibrium Saturation} \cdot \text{Conc} \cdot \text{Flow} \cdot 0.012}{\text{Height} \cdot \pi \cdot \text{AD} \cdot 0.85 \cdot \text{Loading}}}$$

5.1.6.2 Vessel Flow Configuration

Several adsorption vessel configurations are available including downflow, upflow, fixed-bed, fluidized-bed, pressure, and gravity. The downflow, fixed-bed is the simplest and most widely utilized design for water treatment applications.

The water enters the top of the vessel, is equally distributed across the carbon bed by the packed, flooded bed design, and is collected by slotted screens across the bottom of the vessel (Figure 36). The pressure type adsorber occupies less space and uses higher surface loading rates than gravity types. the System selected for the GAC for BWT-Unit offers downflow, fixed-bed, pressure rated carbon adsorption vessel.

5.1.6.3 Hydraulic Loading

Hydraulic loading, or flux, is a measure of the volume of water flowing through a given cross-sectional area in a fixed amount of time. It is defined by the following equation:

$$\text{Hydraulic Loading}\left[\frac{\text{L/min}}{\text{m}^2}\right]=\frac{\text{Flow}\left[\text{L/min}\right]}{\text{Area}\left[\text{m}^2\right]}$$

If the hydraulic loading is too high, water will move too rapidly through the GAC vessel and, as a result, the adsorption efficiency will be reduced. Empirical data indicates that the hydraulic loading should not exceed 194 to 271 $\frac{\text{L / min}}{\text{m}^2}$.

As an example, the maximum flow capacity of a 1.22 m diameter GAC may be determined by rearranging the above equation and solving for the flow:

$$\text{Flow}_{\text{max}}\left[\frac{\text{L}}{\text{min}}\right]=\text{Hydraulic Loading}\left[\frac{\text{L/min}}{\text{m}^2}\right]\cdot\text{Area}\left[\text{m}^2\right]$$

or

$$\text{Flow}_{\text{max}}\left[\text{L/min}\right]=194\left[\frac{\text{L/min}}{\text{m}^2}\right]\cdot\pi\cdot\left(\frac{1.22}{2}\,\text{m}\right)^2=227\left[\text{L/min}\right]$$

5.1.6.4 Velocity

The velocity is similar to the hydraulic loading; both terms are a measure of flux. To calculate velocity, the following equation may be used:

$$\text{Velocity}=\frac{\text{Flow}}{\text{Area}}$$

To convert hydraulic loading to velocity:

$$\text{Velocity}\left[\frac{\text{m}}{\text{s}}\right]=\text{Hydraulic Loading}\left[\frac{\text{L/min}}{\text{m}^2}\right]\cdot10^{-3}\left[\frac{\text{m}^3}{\text{L}}\right]\cdot\frac{1}{60}\left[\frac{\text{min}}{\text{s}}\right]$$

Using a maximum hydraulic loading of 271 $\frac{\text{L / min}}{\text{m}^2}$, the maximum velocity is calculated to be $4.5\cdot10^{-3}$ m/s.

5.1.6.5 Superficial Contact Time

Superficial contact time is defined as the volume occupied by the activated carbon divided by the water flow rate. It may be calculated from the following equation:

$$\text{Contact time}=\frac{\text{Height}\cdot\pi\cdot(\text{Radius})^2}{\text{Flow}}$$

The actual contact time is difficult to calculate, but is approximately one-half the superficial. Generally a superficial contact time of 10 to 15 minutes is adequate for treatment of contaminated water. Longer times, however, may be required as the types of organic compounds in water increase in number and concentration.

5.1.6.6 GAC Vessel Geometry

In addition to flux and contact time considerations, the vessel geometry must be considered when designing a GAC system. The contaminant front moves through the GAC vessel in a plug flow manner. The shape of the plug is determined by many factors some of which include the type and number of contaminants, the flow rate, the adsorption rate, and the vessel geometry. If the shape of the vessel negatively alters the shape of the contaminant front, breakthrough may occur sooner than estimated.

An API study determined that the optimum carbon bed height (i.e. GAC vessel height) is 1.83 m. Using 1.83 m as the minimum carbon bed height, 15 minutes as the minimum superficial contact time and the equations described above, the minimum cross-sectional area for a given set of conditions may be calculated from the following:

$$\text{Radius}_{\text{min}}[\text{m}] = \sqrt{\frac{15[\text{min}]\cdot \text{Flow}[\text{L/min}]}{6[\text{m}]\cdot \pi \cdot 10^3\left[\frac{\text{L}}{\text{m}^3}\right]}}$$

5.1.6.7 Head Loss

Hydraulic head loss is related directly to the flow rate and inversely to the average size of the carbon particles. This may be seen in the following equation:

$$\Delta P = \frac{K \cdot \nu \cdot Q \cdot L_c}{D_p \cdot D_C}$$

where,

ΔP = pressure drop [Pa = kg / ms^2]

k = constant [kg/m^3]

v = viscosity [m^2/s]

Q = flow rate [m^3/s]

LC = bed depth [m]

Dp = mean particle diameter [m]

Dc = column diameter [m]

The particle size also has a significant effect on the kinetics of the adsorption process where rates of adsorption increase with a decrease in particle size. A balance must, therefore, be reached between the optimum particle size for maximum adsorption versus minimum head loss. Commercially available particle sizes include 8 X 16, 8 X 30, 10 X 30, 12 X 40, 14 X 40, and 20 X 40, with effective sizes ranging from 0.55 mm to 1.35 mm. The recommended System for the GAC dedicated to BWT-Unit is 8 X 30 mesh carbon. This grade provides a reasonable compromise between good hydraulic characteristics and higher adsorption rates. This should be evaluated during the test period of the BWT-Unit with unusual conditions such as high TOC, low flow rates, or the presence of poorly adsorbed compounds.

5.1.7 Estimation of the GAC needs and frequency of replacements

Based on the laboratory tests with the small BWT-Unit and the theoretical data given here above in the design of the carbon bed (section 5.1.6), the necessary GAC bed mass that will be needed to filtrate a nominal effluent flow of 1 m^3/d. will be of 600 kg for a period of 6 months for non-aerated type GAC filters. In this case, the filters should be replaced at least each 3 months. In total, a volume of 2.4 m^3 GAC bed mass will be needed per year at Concordia site. For safety reasons, and due to mass and space limitations in the containers dedicated for the BWT-Unit, it was decided to operate with GAC aerated filters of 1 m^3 from the start up of the unit and to foresee an additional GAC tank as a spare part, to be used when the first GAC bed in completely saturated. The type GAC filter that was selected for this purpose is an OXICON® GAC aerated carbon filter from DESOTEC-Belgium containing GAC type "Organosorb 10" since the long life time excepted for this type of filter.

5.2 Nitrification compartment

The effluent generated from the methanogenic reactor has a concentration of 200 to 500 mg NH_4^+-N/L which will certainly hinder the efficiencies of the membrane systems of the GWT-Unit. Therefore, the nitrification step is needed in the concept of the BWT-Unit.

5.2.1 Origin of the inoculum

The sludge that will be used for the inoculation of the nitrification reactor is an inoculum that is kept in continuous operation at EPAS laboratories. The sludge is a nitrifying sludge, which will be provided together with the installation of the BWT-Unit. This inoculum has been tested on laboratory scale on the BWT-Unit and showed its high efficiency to convert ammonium into nitrates with a potential also to convert the remaining urea from the anaerobic reactors into nitrates. In addition, this sludge showed an urease positive action (reference taken from other ESA-projects: MWT Phase 2). The results of the tests on the nitrification reactor are presented in TN 82.7.

5.2.2 Type carrier

As previously mentioned, the carrier material was presented in the form of small beads of type BIOSTYR® provided by ESA for the purpose of testing the same carrier material as the one used for the third compartment of the MELiSSA loop.

5.2.3 Sizing of the reactor

Based on the results obtained from the lab-scale reactors, the sizing of the nitrification reactor was performed. The nominal reached volumetric loading rate (Bv) for which 100 % conversion efficiency was obtained was 500 mg NH_4^+-N/L.d with a maximum of 800 to 1000 mg NH_4^+-N/L.d (obtained in MWT tests). Knowing that the maximum ammonium concentration that might be expected in the effluent would be around 450 mg NH_4^+-N/L with a nominal flow rate of 1,2 m^3 par day, a HRT of 1 day was fixed for the nitrification compartment of Concordia. Therefore, the volume of the reactor was fixed at 1.5 m^3, knowing that the maximum daily flow rate to be treated is about 1.82 m^3. In this case the HRT will be reduced to 0.8 day which will always permit efficient nitrification.

5.2.4 Aeration needs

For each gram of NH_4^+-N, 4.57 g of O_2 is needed. So for a total of 500 g NH_4^+-N per day, 2.26 kg of O_2 is needed. Not all aerated oxygen will be dissolved in the nitrification reactor. With an efficiency of 10 %, 22.6 kg of O_2 per day needs to be aerated. This corresponds to 108 kg of air. The average molar mass of air is 29 g/mole, so this weight corresponds to 3724 mole or 83.4 Nm^3/day = 58 Nl/min.

6 Development plan for construction

The construction of the BWT-unit will be done partly at EPAS and partly at SE-industries. For the actual assembly, skilled workers will be put in. They will do the construction of the unit on the basis of the constructional design previously made during the first phase of the construction. The first phase is aimed to establish a detailed construction design of the BWT-Unit (hardware, software and control) with as output a detailed 3D drawing with component list and detailed cost of each selected individual item.

Phase 2 is related to the ordering of the hardware and construction of the BWT-Unit. This means that at this stage of development, all produced documents (detailed construction, material selected and technical data) should be agreed between EPAS, ESA IPEV and PNRA. The technical documents should be ready to be sent to the construction room.

Phase 1: Detailed construction design.

This phase includes the following items:

- Hardware configuration in shelter
- Control and automation design
- Hardware and supplier selection based on trade-off

To fulfil these items, a preliminary selection of material supplier, a trade-off of the existing material with as major requirement the compatibility of the selected material with the hardware selected for the EWC (Engineering of the Waste Compartment) in the MELiSSA loop and its harmonisation with the material of the grey water treatment unit.

Supplier selection

Supplier selection means looking to what is available on the market, searching and contacting of (new) suppliers. After explaining the application and asking information to suppliers, a study of the price quotations and a trade-off is made. A supplier selection is made after comparing prices and technical details.

Hardware selection

This means selecting appropriate instrumentation on the basis of online information, catalogues and the offers, verify the feasibility of the concept with technical specifications and possibly adjust the concept design. Hardware selection is strongly related to the supplier selection.

Construction design

Transfer of hardware technical details to the constructor is necessary in order for a proper 3D-design. This means that a weekly meeting for follow-up of the development of the design between the constructor and the person in charge of the technical issues of the BWTU at EPAS is needed. The end result must be user-friendly and safe. Also, the construction costs must be minimised. These contradictory characteristics make an iterative design CAD (computer aided design) necessary. The end result is a 3D drawing, which can be sent to the construction room.

Control design

Control design means: generating an input/output-list, selection of all electrical components, making the electrical drawing, generate ordering lists, placing the orders and PLC algorithm design.

Phase 2: Construction and testing of the BWT-Unit.

The duration of the phases is planned as follows:

Table 14. The two major phases needed for the construction of the BWT-Unit

Phase	Duration (months)
1	From June 2005 till September 2005
2	From October 2005 till July 2006

The workers will be supervised by the designers of the system. This way, flawless assembly is guaranteed. The technical engineers will also provide the as-built documentation. Finally, the correct working of each instrument is tested during the hardware validation. The latter also includes checking of leak-proofness of the whole system. An overview of the time estimation of construction is given in Table 14. A detailed development planning for construction is given in TN 82.4

7 Detailed hardware list for the BWT-Unit

	Reference technical schemes		BWTU scheme.vsd	
Date			08/09/2005	
Nr	Tag	Description	Supplier	Artikel
		Buffer tank [B]		
1	B-Bl-01	Blender	Mervers	
2	B-LS-01	Level sensor	E+H	Cerabar T: PMC131
3			E+H	Cerabar T: PMC131
4	B-pH-01	pH sensor	Elscolab	MT Inpro 3200
5		Retactable fitting	Elscolab	MT InTrac 777
6		pH transmitter	Elscolab	Knick Stratos E2402
7		pH cable	Elscolab	VP6-ST/5m
8		Weld-in socket		
9	B-PS-01	Pressure sensor	E+H	Cerabar T: PMC131
10	B-R-01	Buffer tank	SE	
11	B-TS-01	Temperature sensor	E+H	TST-487-1A2B
12	B-TT-01	Temperature transmitter	E+H	TMT187-A41-FE-A
13	B-V-01	Valve		
14	B-V-02	Valve		
15	B-V-03	Valve		
16	B-V-04	Valve		
		Liquefying reactor [L]		
17	L-Bl-01	Blender	Mervers	
18	L-Hx-01	Heat tracing (+isolation)	Dirac Industries	
19	L-LS-01	Levelsensor	E+H	Cerabar T: PMC131
20			E+H	Cerabar T: PMC131
21	L-LS-02	Level switch	E+H	Liquiphant T FTL260
22	L-No-01	Nozzle	PNR	
23	L-pH-01	pH sensor	Elscolab	MT Inpro 3200
24		Retractable fitting	Elscolab	InTrac 777
25		pH transmitter	Elscolab	Knick Stratos E2402 pH
26		pH cable	Elscolab	VP6-ST/5m
27		Weld-in socket	Elscolab	
28	L-pH-02	pH sensor	Elscolab	MT Inpro 3200
29		Retractable fitting	Elscolab	InTrac 777
30		pH transmitter	Elscolab	Knick Stratos E2402 pH
31		pH cable	Elscolab	VP6-ST/5m
32		Weld-in socket	Elscolab	
33	L-PS-01	Pressure sensor	E+H	
34	L-PI-02	Manometer	Bogerd Instrumentation	

35	L-PI-03	Manometer	Bogerd Instrumentation	
36	L-Pm-01	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
37	L-Pm-02	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
38	L-Pm-03	Excetric worm pump	Seepex	BN 5-6L/A2-A7-A7-F0-GA-X + Pomphuis in RVS + hardverschroomde rotor + RVS bouten, moeren, spanstangen + 1.4301 glasparelgestraalde fundatieplaat
39	L-PS-02	Overpressure safety for L-Pm-03	Seepex	PKOe 100-3, 0-6bar, DN25 PN40, M2, MSR 10, 220V /45-60Hz
40	L-M-01	Macerator	Seepex	I 25 / XX-1-*F-11-2
41	L-R-01	Liquefying reactor	SE Industries	
42	L-R-02	Acid tank	Voor 't labo	
43	L-R-03	Base tank	Voor 't labo	
44	L-TS-01	Temperature sensor	E+H	TST-487-1A2B
45	L-TT-01	Temperature transmitter	E+H	TMT187-A41-FE-A
46	L-V-01	Manual 2-way valve 6mm		
47	L-V-02	Manual 2-way valve 6mm		
48	L-V-03	Manual 2-way valve 6mm		
49	L-V-04	Manual 2-way valve 8mm		
50	L-V-05	Pressure relief valve	Ritec	
51	L-V-06	Manual 2-way valve 8mm		
52	L-V-07	Automatic 2-way valve 6mm		
53	L-V-08	Manual 2-way valve 1/2"		
54	L-V-09	Manual 2-way valve 2"		
55	L-V-10	Manual 2-way valve 2"		
56	L-V-11	Manual 2-way valve 2"		
57	L-V-12	Manual 2-way valve 2"		
58	L-V-13	Manual 2-way valve 1/2"		
59	L-V-14	Manual 2-way valve1/2"		
60	L-V-15	Check valve	Swagelok	Swagelok
61	L-V-16	Forward pressure regulator	Vesan	
62	L-V-17	Manual 2-way valve 8mm		
63	L-V-18	Automatic 2-way valve 1"		
64	L-V-19	Manual 2-way valve 2"		
65	L-V-20	Automatic 3-way valve 1/2"		
66	L-V-21	Manual 2-way valve 8mm		
67	L-V-22	Manual 2-way valve 1/2"		
68	L-V-23	Manual 2-way valve 1/2"		
69	L-V-24	Manual 2-way valve 1/2"		
Filtration unit [F]				
70	F-Fi-01	Ceramic UF membranes	Atech Innovations	

71	F-Fi-02	Ceramic UF membranes	Atech Innovations	
72	F-Fi-03	Ceramic UF membranes	Atech Innovations	
73	F-Fi-04	Ceramic UF membranes	Atech Innovations	
74	F-Fi-05	Ceramic UF membranes	Atech Innovations	
75	F-Fi-06	Ceramic UF membranes	Atech Innovations	
76		Extra ceramic membranes	Atech Innovations	
77	F-Pi-01/20	Manometer	Bogerd Instrumentation	
78	F-FS-01	Flow sensor	E+H	
79	F-FS-02	Flow sensor	E+H	
80	F-Pm-01	Excetric worm pump	Seepex	BN 52-6L / A2-A7-A7-F0-GA-X X=05A2 + RVS pomphuis + hardverschroomde rotor + RVS bouten, moeren, spanstangen, + 1.4301 glasparelgestraalde fundatieplaat
81	F-Pm-02	Excetric worm pump	Seepex	BN 52-6L / A2-A7-A7-F0-GA-X X=05A2 + RVS pomphuis + hardverschroomde rotor + RVS bouten, moeren, spanstangen, + 1.4301 glasparelgestraalde fundatieplaat
82		Pulse damper	Zilmet	Inox-Pro
83	F-Pm-03	Magnetic drive gear pump	AxFlow	model 220 GC-M25-PDS-6 + PTC sensor
84	F-PS-15	Overpressure safety for F-Pm-01 and -02	Seepex	PKOe 100-3, 0-6bar, DN25 PN40, M2, MSR 10, 220V /45-60Hz
85	F-PS-16	Overpressure safety for F-Pm-03	Seepex	PKOe 100-3, 0-6bar, DN25 PN40, M2, MSR 10, 220V /45-60Hz
86	F-PS-01	Pressure sensor	E+H	Cerabar T: PMC131
87	F-PS-02	Pressure sensor	E+H	Cerabar T: PMC131
88	F-PS-03	Pressure sensor	E+H	Cerabar T: PMC131
89	F-PS-04	Pressure sensor	E+H	Cerabar T: PMC131
90	F-PS-05	Pressure sensor	E+H	Cerabar T: PMC131
91	F-PS-06	Pressure sensor	E+H	Cerabar T: PMC131
92	F-PS-07	Pressure sensor	E+H	Cerabar T: PMC131
93	F-PS-08	Pressure sensor	E+H	Cerabar T: PMC131
94	F-PS-09	Pressure sensor	E+H	Cerabar T: PMC131
95	F-PS-10	Pressure sensor	E+H	Cerabar T: PMC131
96	F-PS-11	Pressure sensor	E+H	Cerabar T: PMC131
97	F-PS-12	Pressure sensor	E+H	Cerabar T: PMC131
98	F-PS-13	Pressure sensor	E+H	Cerabar T: PMC131
99	F-PS-14	Pressure sensor	E+H	Cerabar T: PMC131
100	F-SS-01	Turbidity sensor	Elscolab	Optek 156-AF56N
101	F-ST-01	Turbidity transmitter	Elscolab	Optek

102		Housing	Elscolab	IP 65 type 19-21
103		Cable	Elscolab	5 m
104	F-V-01	Manual 3-way valve 2"		
105	F-V-02	Manual 3-way valve 2"		
106	F-V-03	Automatic 3-way valve 2"		
107	F-V-04	Automatic 3-way valve 2"		
108	F-V-05	Automatic 2-way valve 2"		
109	F-V-06	Automatic 2-way valve 2"		
110	F-V-07	Automatic 2-way valve 2"		
111	F-V-08	Automatic 2-way valve 2"		
112	F-V-09	Automatic 2-way valve 2"		
113	F-V-10	Automatic 2-way valve 2"		
114	F-V-11	Automatic 3-way valve 1/2"		
115	F-V-12	Automatic 3-way valve 1/2"		
		Cleaning system [C]		
116	C-Hx-01	Heating spiral	Dirac Industries	
117	C-LS-01	Level switch	E+H	
118	C-LS-02	Level switch	E+H	
119	C-LS-03	Level switch	E+H	
120	C-LS-04	Level switch	E+H	
121	C-Pm-01	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
122	C-Pm-02	Pump	Vesan	JetInox 70/50 M
123	C-Pm-03	Magnetic drive gear pump	AxFlow	model 220 GC-M25-PDS-6 + PTC sensor
124	C-PS-01	Overpressure safety for F-Pm-01 and -02	Seepex	PKOe 100-3, 0-6bar, DN25 PN40, M2, MSR 10, 220V /45-60Hz
125	C-Pm-04	Pump	Vesan	VLRX2B30SM
126	C-R-01	Detergent tank	Voor 't labo	
127	C-R-02	Cleaning agent tank	SE Industries	
128	C-R-03	Cleaning agent buffer tank	SE Industries	
129	C-TS-01	Temperature sensor	E+H	TST-487-1A2B
130	C-TT-01	Temperature transmitter	E+H	TMT187-A41-FE-A
131	C-V-01	Automatic 2-way valve 8mm		
132	C-V-02	Automatic 2-way valve 1/2"		
133	C-V-03	manual 2-way valve 1"		
134	C-V-04	Manual 2-way valve 2"		
135	C-V-05	Automatic 2-way valve 8mm		
136	C-V-06	Automatic Proportional valve	ASCO	
137	C-V-07	Check valve	Swagelok	
138	C-V-08	Check valve	Swagelok	
139	C-V-09	Automatic 3-way valve 2"		
140	C-V-10	Automatic 3-way valve 2"		
141	C-V-11	Automatic 3-way valve 2"		

142	C-V-12	Automatic 2-way valve 1"		
143	C-V-13	Automatic 2-way valve 1"		
144	C-V-14	Automatic 2-way valve 1"		
145	C-V-15	Automatic 3-way valve 1/2"		
146	C-V-16	Automatic 3-way valve 1/2"		
147	C-V-17	Automatic 3-way valve 1/2"		
148	C-V-18	Automatic 2-way valve 1/2"		
149	C-V-19	Automatic 2-way valve 1/2"		
150	C-V-20	Automatic 2-way valve 1/2"		
Methanogenic reactor [M]				
151	M-Hx-01	Heat tracing (+isolation)	Dirac Industries	
152	M-LS-01	Level sensor	E+H	
153	M-LS-02	Level switch	E+H	
154	M-pH-01	pH sensor	Elscolab	MT Inpro 3200
155		Retractable fitting	Elscolab	InTrac 777
156		pH transmitter	Elscolab	Knick Stratos E2402 pH
157		pH cable	Elscolab	VP6-ST/5m
158		Weld-in socket	Elscolab	
159	M-pH-02	pH sensor	Elscolab	MT Inpro 3200
160		Retractable fitting	Elscolab	InTrac 777
161		pH transmitter	Elscolab	Knick Stratos E2402 pH
162		pH cable	Elscolab	VP6-ST/5m
163		Weld-in socket	Elscolab	
164	M-PI-02	Manometer	Bogerd Instrumentation	
165	M-Pm-01	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
166	M-Pm-02	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
167	M-Pm-03	Centrifugal pump	AxFlow	Waukesha Purity C216 + Inox hood
168	M-PS-01	Pressure sensor	E+H	
169	M-R-01	Methanogenic reactor	SE Industries	316 - 4 m³
170		Beads	PP-Holvoet	
171	M-R-02	Acid tank	Voor 't labo	
172	M-R-03	Base tank	Voor 't labo	
173	M-TS-01	Temperature sensor	E+H	TST-487-1A2B
174	M-TT-01	Temperature transmitter	E+H	TMT187-A41-FE-A
175	M-V-01	Manual 2-way valve 6mm		
176	M-V-02	Manual 2-way valve 6mm		
177	M-V-03	manual 2-way valve 8mm		
178	M-V-04	manual 2-way valve 8mm		
179	M-V-05	Pressure relief valve	Ritec	
180	M-V-06	Automatic 2-way valve 8mm		
181	M-V-07	Manual 2-way valve 1/2"		
182	M-V-08	Manual 2-way valve 1"		

183	M-V-09	Manual 2-way valve 1"		
184	M-V-10	Manual 2-way valve 2"		
185	M-V-11	Manual 2-way valve 1/2"		
186	M-V-12	Manual 2-way valve 1/2"		
187	M-V-13	Manual 2-way valve 8mm		
188	M-V-14	Manual 2-way valve 1/2"		
189	M-V-15	Manual 2-way valve 1/2"		
190	M-V-16	Manual 2-way valve 1/2"		
191	M-V-17	manual 2-way valve 8mm		
192	M-V-18	manual 2-way valve 6mm		
193	M-V-19	manual 2-way valve 8mm		
		Gas loop [G]		
194	G-FS-01	Mass flow meter	Gefran	M+W Instruments D-5110
195	G-FS-02	Mass flow meter	Gefran	M+W Instruments D-5110
196	G-FS-03	Mass flow meter	Gefran	M+W Instruments D-5110
197	G-Hx-01	Gas cooler	AGT Thermotechnik	MAK
198	G-Hx-02	Cooler	Fryka	DLK 400
199	G-Pm-01	compressor/blower	Rietschle Thomas	?
200	G-Pm-02	Gas pump	Rietschle Thomas	202,1
201	G-Fi-01	Flow meter	Ecotechnic	Rotameter
202	G-Fi-02	Flow meter	Ecotechnic	Rotameter
203	G-CO2/CH4S-01	Gas Analyser	Kelma	Biogas 401 Multi-channel gas analyser
204	G-PI-01	Manometer	Bogerd Instrumentation	
205	G-PI-02	Manometer	Bogerd Instrumentation	
206	G-PI-03	Manometer	Bogerd Instrumentation	
207	G-V-01	Automatic proportional valve 8mm	ASCO	
208	G-V-02	Automatic 3-way valve 8mm		
209	G-V-03	Automatic 3-way valve 8mm		
210	G-V-04	Automatic 2-way valve 8mm		
211	G-V-05	Automatic 3-way valve 8mm		
212	G-V-06	automatic proportional valve 8mm		
213	G-V-07	manual proportional valve 8mm		
214	G-V-08	manual proportional valve 8mm		
215	G-V-09	manual 2-way valve 8mm		
216	G-V-10	manual 2-way valve 8mm		
217	G-V-11	manual 2-way valve 8mm		
218	G-V-12	Forward pressure regulator	Air Liquide	
219	G-V-13	Forward pressure regulator	Air Liquide	
220	G-V-14	Forward pressure regulator	Air Liquide	

221	G-V-15	manual 2-way valve 8mm		
222	G-V-16	manual 2-way valve 8mm		
223	G-V-17	manual proportional valve 8mm		
224	G-V-18	manual proportional valve 8mm		
Nitrifying reactor [N]				
225	N-Au-01	Aeration unit		
226	N-Au-02	Aeration unit		
227	N-Au-03	Aeration unit		
228	N-Au-04	Aeration unit		
229	N-EC-01	Electro-conductivity sensor	Elscolab	Inpro 7108
230		Weld-in socket	Elscolab	Inclined weld-in socket
231		EC transmitter	Elscolab	Knick Stratos E2402
232		Retractable fitting	Elscolab	InTrac 777
233	N-FS-01	Flow sensor	E+H	Promag
234	N-FS-02	Flow sensor	E+H	Promag
235	N-FI-03	Flow indicator	Bogerd Instrumentation	
163	N-Fi-01	Washable filter	Satorius	
164	N-LS-01	Level sensor	E+H	Cerabar T: PMC131
			E+H	Cerabar T: PMC131
165	N-LS-02	Level switch	E+H	Liquiphant T FTL20-0020
166	N-O2-01	Dissolved oxygen sensor	Elscolab	MT Inpro 6800
167		DO transmitter	Elscolab	Knick Stratos
		Weld-in socket	Elscolab	
168	N-pH-01	pH sensor	Elscolab	MT Inpro 3200
169		Retractable fitting	Elscolab	InTrac 777
170		pH transmitter	Elscolab	Knick Stratos E2402 pH
171		pH cable	Elscolab	VP6-ST/5m
172		Weld-in socket	Elscolab	
173	N-pH-02	pH sensor	Elscolab	MT Inpro 3200
174		Retractable fitting	Elscolab	InTrac 777
175		pH transmitter	Elscolab	Knick Stratos E2402 pH
176		pH cable	Elscolab	VP6-ST/5m
177		Weld-in socket	Elscolab	
122	N-Pm-01	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
123	N-Pm-02	Membrane dosing pump	DOSAPRO MILTON ROY S.A.	LMI Series P1
19	N-Pm-03	Magnetic drive gear pump	AxFlow	model 220 GC-M25-PDS-6 + PTC sensor
	N-PS-02	Overpressure safety for N-Pm-03	Seepex	PKOe 100-3, 0-6bar, DN25 PN40, M2, MSR 10, 220V /45-60Hz
19	N-Pm-04	Magnetic drive gear pump	AxFlow	model 220 GC-M25-PDS-6 + PTC sensor

	N-PS-03	Overpressure safety for N-Pm-04	Seepex	PKOe 100-3, 0-6bar, DN25 PN40, M2, MSR 10, 220V /45-60Hz
182	N-PS-01	Pressure sensor	E+H	Cerabar T: PMC131-A11F1
183	N-PI-02	Manometer	Bogerd Instrumentation	
184	N-R-01	Nitrifying reactor	SE Industries	
185		Beads		Biostyr
186	N-R-02	Acid tank	Voor 't labo	
187	N-R-03	Base tank	Voor 't labo	
188	N-TS-01	Temperature sensor	E+H	TST-487-1A2B
189	N-TT-01	Temperature transmitter	E+H	TMT187-A41-FE-A
190	N-V-01	Manual 2-way valve 6mm		
190	N-V-02	Manual 2-way valve 6mm		
191	N-V-03	Manual 2-way valve 1/2"		
192	N-V-04	Manual 2-way valve 1"		
193	N-V-05	Manual 2-way valve 1"		
194	N-V-06	Manual 2-way valve 2"		
195	N-V-07	Manual 2-way valve 1/2"		
196	N-V-08	Manual 2-way valve 6mm		
196	N-V-09	manual 2-way valve 1/2"		

The energy consumption for each instrumentation reported in this list is assumed as maximal and should not be taken as such for the energy consumption estimation of the whole BWT-Unit. Based on inputs from the suppliers and depending on the needs for the operation of the BWT-Unit, a total nominal energy of 15 KW would be needed. This represents 30% of the maximal energy capacity.

8 Conclusion

TN 82.1 and TN 82.2 studied all process-technical details of the BWT-Unit. This research was conducted with lab-scale experimental set-ups. The results of the lab-scale set-up are presented in TN 82.7. This leads to the conceptual design with calculation of the necessary volumes and flow rates. Based on the conceptual design, the basic engineering was performed in this technical note. Basic engineering includes the study of general aspects, material selection, estimation of sizes and energy consumption, instrumentation selection and a general plan for construction. This technical note provides all necessary elements to take into account to make a detailed design. This final design is the subject of TN 82.4. It will include a detailed instrumentation list, electric wiring diagram, calculation of cost price and the development plan for construction.

9 References

MELiSSA-Engineering of the Waste Compartment. ESA contract n° 15689/01/NL/ND. TN 71.9.4 : Test results evaluation. N. Michel, H. De Wever, C. Dotremont and V. Van Hoof. July, 2005.

MELiSSA-Engineering of the Waste Compartment. ESA contract n° 15689/01/NL/ND. TN 71.7 : Instruments review, trade-off and selection. F. Van Houteghem and F. Doulami. May, 2004.

Development, building and utilisation of a black water treatment unit at Dumont D'Urville and Concordia. ESA contract n° 15689/01/NL/ND. TN 82.1. Sizing of the black water treatment unit. F. Doulami and N. Michel. August, 2005.

Development, building and utilisation of a black water treatment unit at Dumont D'Urville and Concordia. ESA contract n° 15689/01/NL/ND. TN 82.2. Concept engineering . F. Doulami and N. Michel. August, 2005.