EPAS n.v.
Eco Process Assistance
De Prijkels • Venecoweg 19 • B-9810 Nazareth
Tel. +32 9 381.51.30
Fax +32 9 221.82.18
www.epas.be • epas@epas.be

MELiSSA
ENGINEERING OF THE WASTE COMPARTMENT

ESA contract 15689/01/NL/ND

TECHNICAL NOTE 71.9.1

Test-Plan and Procedure

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	Name	Signature
Prepared by:	Noëlle Michel	
Approved by:	Dries Demey	

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1. Introduction

1.1 Objectives

The liquefying compartment of the MELiSSA loop is responsible for the biodegradation of human faecal material and other wastes (inedible parts of plant material) generated by the crew. The volatile fatty acids and ammonia produced during the anaerobic fermentation process are fed to the second photoheterotrophic compartment inoculated with the bacterium *Rhodospirillum rubrum*. The produced CO_2 is supplied to the photoautotrophic compartment inoculated with the algal strain *Arthrospira platensis* and to the higher plants compartment.

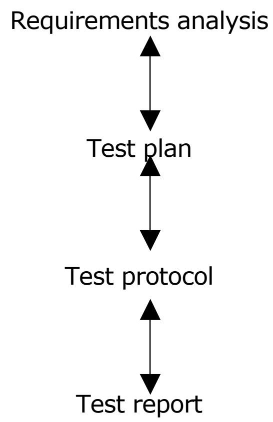
At the pilot plant of the University of Barcelona, the three compartments of the MELiSSA loop (photoheterotrophic compartment CII, nitrifying compartment CIII and photoautotrophic compartment CIVa) are already connected at lab scale and will be validated at pilot scale. In order to validate the whole MELiSSA loop, it is necessary to construct the first compartment at pilot scale (fermentation reactor) for the primary degradation of the waste produced by the crew.

However, between lab and pilot scales the construction of an intermediate prototype reactor represents an important step to evaluate and improve the theoretical concepts.

Once the prototype Waste Compartment is assembled, it is necessary to perform functional tests to evaluate the hardware and the process. A first series is performed to test individually the sensors, actuators and other instruments and equipment. After these functional tests the reactor is filled with the Melissa inoculum and fed with representative substrate. The next series of tests are performed for a period of one month, corresponding with three retention times (required for a representative process evaluation).

This technical note includes listing of requirements of the prototype and the related necessary tests. Organization of the tests and their principles and procedures are also described.

1.2 Architecture of the functional test procedure



The procedure followed to test the prototype consists first in a requirements analysis that highlights the critical points of the system to be tested. Based on this analysis, a test plan is written, organizing the tests.

Performance and evaluation of the tests can be found in the MELiSSA technical notes 71.9.3 and 71.9.4.

For a clearer structure of the work, the test plan is divided into two major levels: the hardware phase and the operation phase. The hardware phase concerns all the tests related to the instrumentation at start-up of the prototype. The operation phase consists in testing the process in a long-term running.

2. Requirements specifications

2.1 General description

The prototype reactor is aimed to perform an anaerobic digestion of a mixture composed of faecal material, toilet paper and plants, with the highest efficiency. This corresponds to the highest production of VFA and ammonium in the liquid phase, and CO_2 in the gas phase. To fill this general objective, the prototype must satisfy a certain number of criteria. These criteria vary from one phase to the other. The major part of these criteria is very specific of one type instrument. In the operation phase, more general requirements can be listed, concerning global evaluation of complete subsystems.

2.1.1 Hardware phase

Table 1 presents the main requirements of the hardware phase with the instrumentation concerned.

Table 1. Requirements of the compartment for hardware phase

Requirements	Related instrumentation
Liquid and gas tightness of the reactor	R-001, connections
Liquid tightness of the FU	FU, connections
Gas tightness of the Gas loop	Gas loop, connections
Accurate and repeatable measurements	Sensors, transmitters, PC interface
Sufficient and homogeneous mixing	Mixer
Sufficient and homogeneous heating	Heating element, warm water bath

2.1.2 Operation phase

Table 2 presents the main requirements of the operation phase with the instrumentation concerned. In this phase, the test plan includes the parallel evaluation of hardware and process during running of the prototype.

Table 2. Requirements of the compartment for operation phase

Requirements	Related instrumentation
For Hardware evaluation	
Absence of clogging of components	Membrane, pumps, connections, valves
Absence of corrosion / fouling of components	Reactors, pumps, valves and connections, sensors and actuators in contact with MELiSSA inoculum or

	biogas
Measurements continuously accurate and repeatable	Sensors, transmitters, interface
Absence of deterioration of tanks and instruments	Tanks, instruments
Correct answer of control	Controlled actuators
Correct regulation of permeate production	Filtration Unit
Correct pressure, flow and condensation regulation in gas phase	Gas Loop
Correct configurations of the sub-systems	Reactor, Filtration Unit, Gas Loop
For Process evaluation (Biological requirements)	
Optimisation of the filtration process	Filtration Unit
Optimisation of the VFA (Volatile Fatty Acids) production	Whole system
Optimisation of the NH_4^+ production	Whole system
Optimisation of the CO_2 production	Whole system
Optimisation of the OM (Organic matter) degradation efficiency	Whole system
Optimisation of the Nitrogen degradation efficiency	Whole system
Optimisation of he Fibres degradation efficiency	Whole system

2.2 Prototype instrumentation

The next schemes present the hardware specific of the prototype reactor and its sub-systems (see Figure 1, Figure 2 and Figure 3). Instrumentation in gray is not present yet on the reactor.

2.2.1 Reactor

Figure 1 presents instrumentation scheme of the reactor.

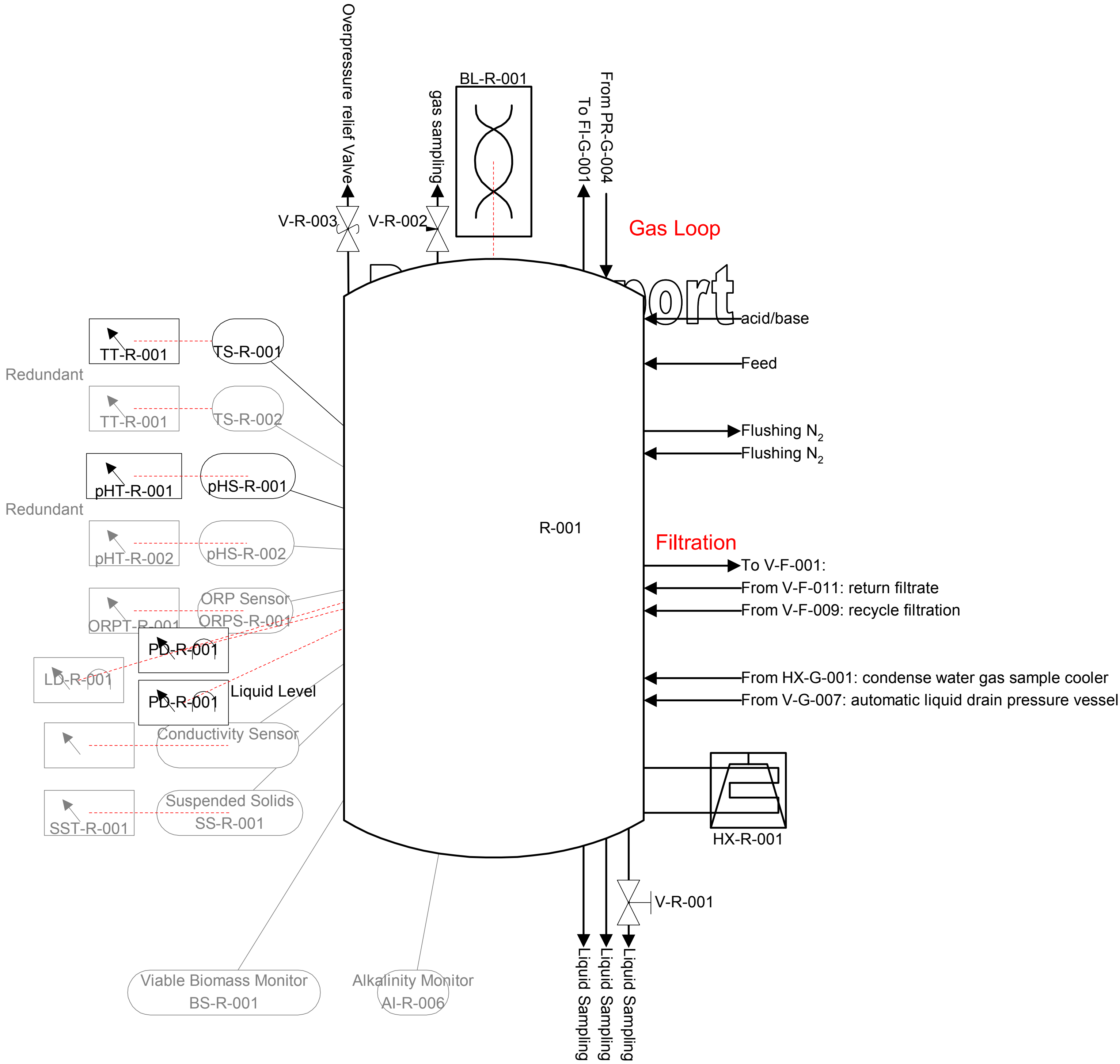
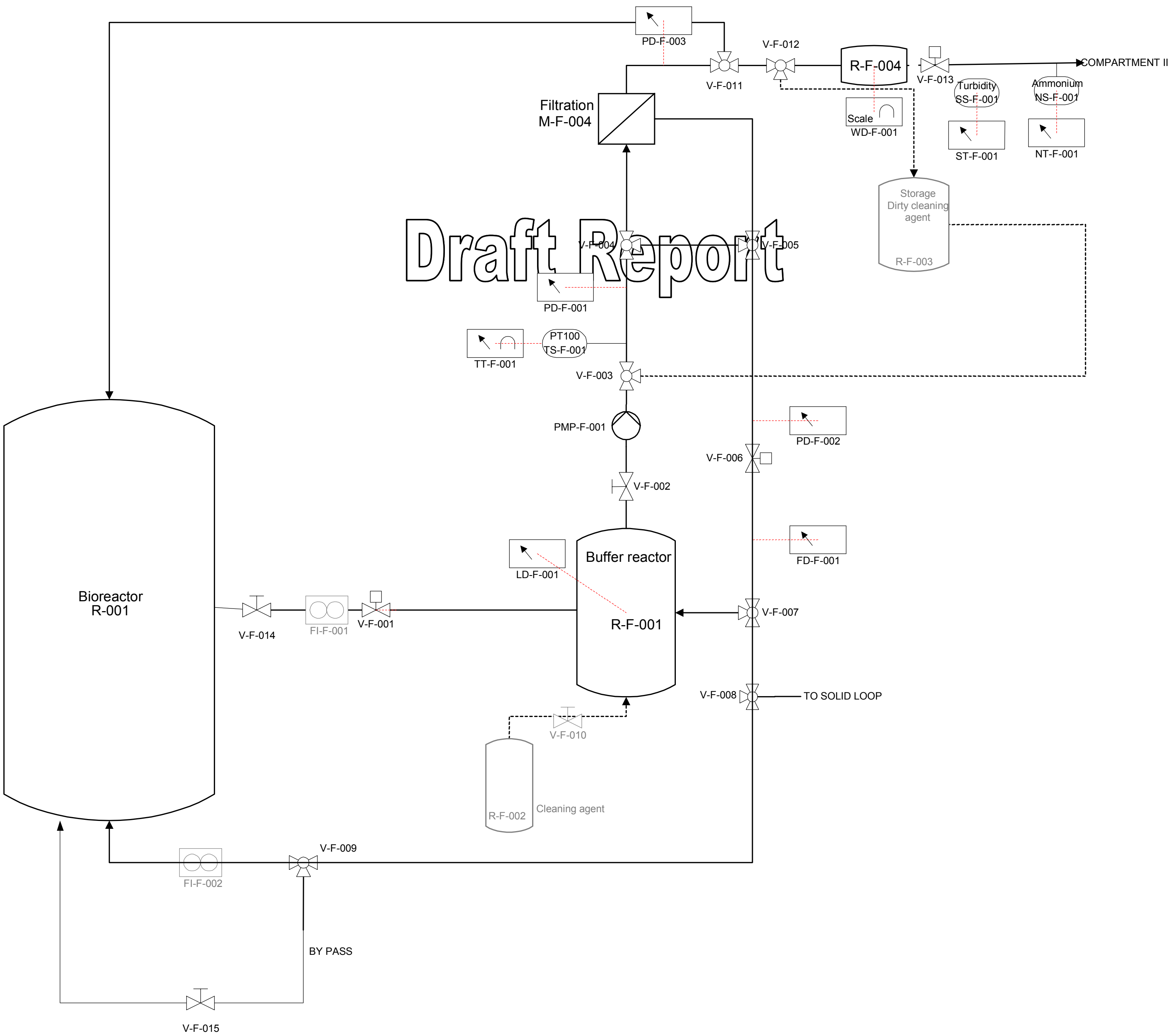


Figure 1. Instrumentation of the reactor

2.2.2 Filtration unit

Figure 2 presents instrumentation scheme of the filtration unit.

Figure 2. Instrumentation of the filtration unit



2.2.3 Gas loop

Figure 3 presents instrumentation scheme of the gas loop.

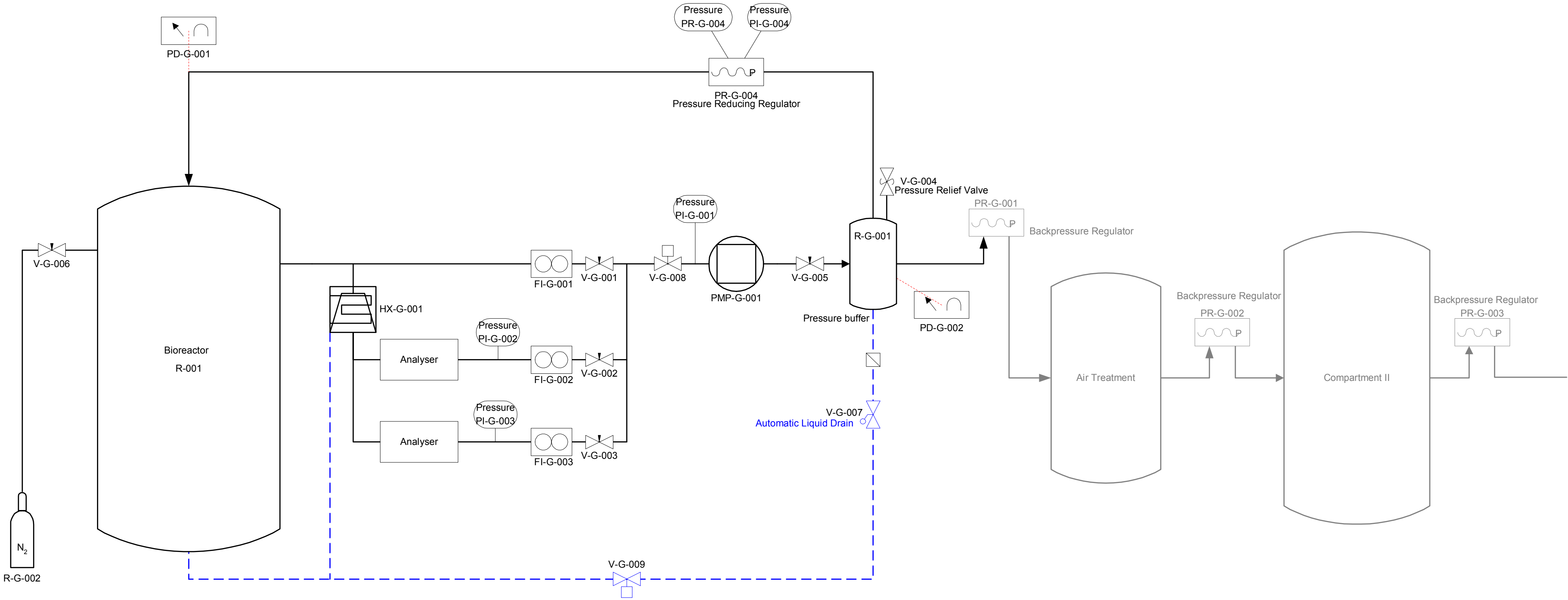


Figure 3. Instrumentation of the gas loop

2.3 Detailed system requirements and tests principles

Based on the general system requirements, a detailed list of criteria that must be satisfied by the system is established, with the general related instrumentation.

For each phase the system requirements are listed together with the related instrumentation and the basis of the associated tests (see Table 3).

Table 3. Listing of requirements

Nber	Requirements	Related instrumentation									Test principle
		Reactor, tanks	Membrane	Pumps	Mixer	Heat exchanger	Balance	Valves and connections	Sensors, transmitters	Controller	
	Hardware phase										
1	Homogeneous mixing										Check visually + analyse and compare composition of samples from bottom and top of reactor on representative period
2	Stable heating of the reactor (55°C)										Control on representative period the stability and accuracy of temperature
3	Gas tightness										Put reactor/system under pressure and measure on representative period the pressure stability (big leaks) or check small leaks with gas detector
4	Liquid tightness										Check visually absence of leakage
5	Running of sensors and actuators										Check visually running on/ off line
	Operation phase										
	Hardware evaluation										
1	Absence of clogging										Check regularly right flow and absence of clogging through piping
2	Absence of corrosion / fouling										Regular visual check

3	Accuracy and repeatability of measurements										Regular calibration
4	Absence of instrument deterioration										Regular visual check
5	Absence of reactor deterioration										Regular visual check
6	Desired answer to user or controller action										Check right answer of instrument to one user/ controller action
7	Regulation of permeate production										Evaluate permeate production depending on selected program of the filtration unit
2	Regulation of gas loop										Check correct regulation of the gas loop on a representative period
9	Configuration of reactor										Evaluate general configuration of reactor
10	Configuration of filtration unit										Evaluate general configuration of filtration unit
11	Configuration of gas loop										Evaluate general configuration of gas loop

	Process evaluation			
	Biological requirement	*Expected value*	*Whole system*	
1	Optimisation of filtration process (quality of permeate, sludge concentration, technical performance)			Evaluate quality of filtration with regular analysis on reactor content and permeate; evaluate technical performance of filtration process with measuring the flow through speed
2	Optimisation of VFA production	min 3 g/L* in reactor		Measure regularly VFA concentration in reactor/ permeate
3	Optimisation of NH4+ production	min 0.27 g/L* in reactor		Measure regularly NH4+ concentration in reactor/ permeate
4	Optimisation of CO2 production			Measure regularly CO2 production
5	Optimisation of OM degradation efficiency**	min 20%		Evaluate regularly OM efficiency of the prototype based on regular analysis

6	Optimisation of Nitrogen degradation efficiency	min 35%		Evaluate regularly N efficiency of the prototype based on regular analysis
7	Optimisation of Fibres degradation efficiency***	min 15%		Evaluate regularly Fibres efficiency of the prototype based on regular analysis

*Expected process values are determined based on experimental data gained on Melissa lab reactors at EPAS and on model-based estimation as described in TN71.1.

**OM degradation efficiency evaluation: see section *Optimization of OM degradation efficiency*.

***Fibre degradation efficiency evaluation: see section *Optimization of Fibres degradation efficiency*.

3. Tests nomenclature and procedures

3.1 Nomenclature

The aim of the functional tests is to evaluate the prototype reactor in order to improve the system and prevent instance of identical problems on the pilot reactor. Based on the requirements listed above, the necessary tests must be established and classified.

The nomenclature used for the tests is described below in Figure 4.

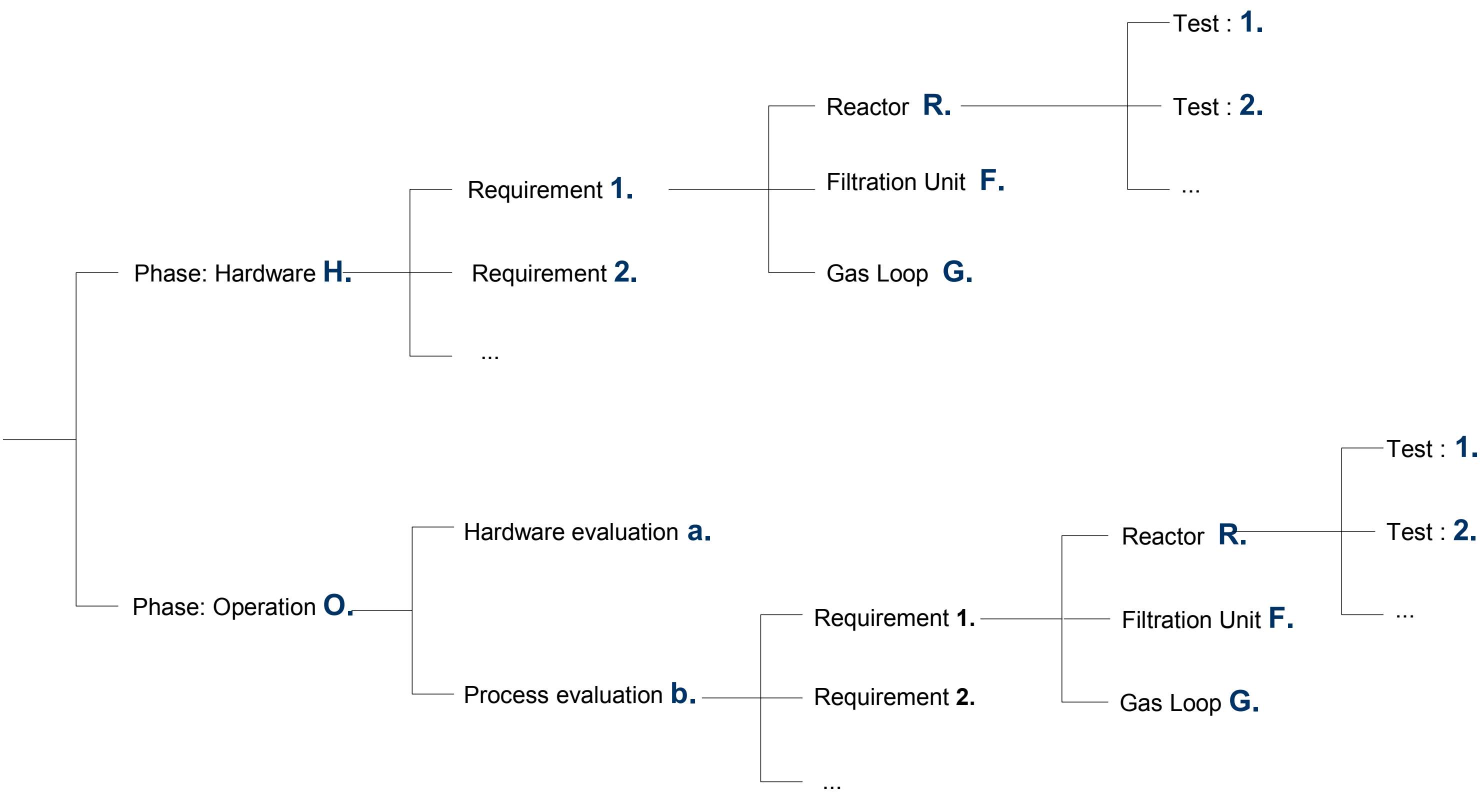


Figure 4. Test plan nomenclature

Therefore, for instance the test with number O.a.7.F.1 will concern a test in operation phase performed to check the possibility of clogging of an element from the filtration unit. The tests classification by number is presented in section 5.2. Test plan: classification by number.

3.2 Tests procedures

All tests results will be reported under table format and presented in MELiSSA TN71.9.3.

The global procedures to be followed to perform the tests are described below. Some procedures are applicable for testing several instruments.

3.2.1 Hardware phase

- Homogeneous mixing

1. Check visually once a day that the stirrer is turning and the absence of dead zones.

2. During 10 consecutive days, take samples from bottom and top of liquid.

3. Analyze DM, ashes, NH4+, pH, EC, CODs, VFA.

4. Check statistically the absence of significant difference between the two samples groups.

5. If samples are homogeneous, mixing is accepted as homogeneous.

- Stable heating

1. Read once a day temperature inside the reactor measured continuously by the probe TS-R-001 on PC interface.

2. Temperature shall not exceed the range 53°C-57°C.

- Gas tightness

    - Test of the entire system (reactor + gas loop)

1. Fill high-pressure part of the loop with compressed air until a pressure of around 3 bars.

2. Monitor pressure in buffer tank R-G-001 over 1 hour.

3. Measure pressure in Gas loop with pressure sensors PD-G-001 and PD-G-002 and check pressure stability.

    - Test of small leaks

1. Fill the part of the loop concerned by the test with compressed air (250mbar in low pressure part, 2500mbar in high pressure part).

2. Spray water based solution with high surface tension on the tested part.

3. Check absence of leaks.

4. A leak is detected when air bubbling appears.

- Liquid tightness

1. Fill tanks with water (R-001, R-F-001).

2. Check visually, instrument by instrument, the absence of liquid leakage.

3. Re-check after 24 hours.

- Running of sensors and actuators

1. Fill tank R-001 with water.

2. Open and close all manual valves to check their operability

3. Switch on all electrical instruments and check visually one by one their operation.

3.2.2 Operation phase

3.2.2.1 Hardware evaluation

- Absence of clogging

1. Check visually once a day existence of liquid stream through membrane, pumps, valves and connections.

- Absence of corrosion/ fouling

1. Check visually and regularly the absence of corrosion or fouling on instruments.
2. Sensors shall be tested during the calibration (to avoid too much openings of the system).
3. Other elements can be checked once a week.

4. Measure nickel and iron concentrations in the prototype.
5. Filtration unit: check evolution of fouling and absence of clogging with follow up of the permeate flow through the membrane speed.
6. The flow through speed shall approximate 6L.m^{-2}.h^{-1}(Stephenson *et al*, 2000).
7. Based on its diminution, evaluate the necessary frequency for membrane cleaning and replacing.

- Accuracy and repeatability of measurements: calibration

1. Calibration shall be operated at a certain frequency, specific of the instrument and fixed by the constructor or by experimental determination.
2. Put the tested sensor off-line.

  - Calibration with standards:

3. Evaluate the degree of conformity of the output of the tested measuring instrument to the ideal value of the measured variable by some type of standard. Degree of conformity is given by the deviation from the ideal value. Acceptable deviation is fixed by the constructor.

  - Calibration without standards

3. Evaluate the degree of conformity of the output of the tested measuring instrument to the value of any medium measured by a calibrated Iso-certificated measuring instrument.

- Absence of instrument deterioration

1. Check visually and regularly the absence of physical deterioration of instruments.
2. Sensors shall be tested during the calibration.
3. Other elements can be checked once a week.

- Absence of reactor deterioration

1. Check visually once a week absence of physical deterioration of reactors.

- Desired answer to user or controller action

For each concerned instrument:

1. Execute user or controller action
2. Check adequacy of answer

- Regulation of permeate production

1. Estimate every day the flow of permeate produced (L/d) based on the volume measurement
2. Compare it to the set point of the program
3. Experimental flow should be included in the range $\left[0.1\times set;0.9\times set\right]$.

- Regulation of gas loop

1. Record pressure in the reactor on-line:
    a. Measurements every minute during a few hours to check quickness of the gas loop answer
    b. Measurements every day during 10 days to check stability of the regulation in the time
2. Estimate stability of pressure.

- Configuration of reactor

1. Evaluate during all operation time general configuration of the reactor by reporting all problems and troubleshooting

- Configuration of filtration unit

1. Evaluate during all operation time general configuration of the filtration unit by reporting all problems and troubleshooting

- Configuration of gas loop

1. Evaluate during all operation time general configuration of the gas loop by reporting all problems and troubleshooting

3.2.2.2 Process evaluation

These tests are based on regular analysis performed on the influent, the filtrate and the reactor content as described in Table 4.

Table 4. Analysis frequency

	Frequency (per week)		
	Influent	**Reactor content**	**Filtrate**
DM	1	3	3
Ashes	1	3	3
pH	1	3	*3*
EC	1	3	3
VFA	1	1	*3*
NH4+-N	1	1	3
N total	1	1	3
COD total	1	1	1
COD soluble	1	1	1
Gas		5	
H2S		1	

Once on-line analyzers are installed, the frequency of the concerned parameters can be increased.

- <u>Optimization of filtration process</u>
  - Quality of filtrate

1. Take three samples of permeate per week.
2. Measure VFA, COD total and soluble, Total nitrogen, ammonium, dry matter and ashes.
3. Evaluate filtrate quality by comparing:
   a. VFA and ammonium in permeate and in reactor content: no loss of VFA and ammonium should be detected after the filtration step since these products are further used in the MELiSSA loop
   b. COD total and soluble of permeate: they should be similar since the ultrafiltration retains the particles
   c. Total nitrogen and ammonium of permeate should be in the same range since only soluble nitrogen should be present in the filtrate (soluble nitrogen being essentially ammonium)
   d. Dry matter and ashes of permeate: they can be compared to dry matter and ashes of the reactor content. The dry matter should be constant in the time and lower than the one of the reactor content, which should increase in the time.

  - Concentration of reactor content

1. Take three samples from the reactor content per week.

2. Measure dry matter, ashes, COD total and soluble.

3. Evaluate increase of these parameters with time due to filtration and determine frequency required for drain

   - Filtration process technical performance (see also section 3.2.2.1 : clogging and fouling of membrane)

1. Measure the flow through speed once a week.

2. The flow through speed shall approximate $6 L.m^{-2}.h^{-1}$(Stephenson *et al*, 2000).

- Optimization of VFA production

1. Take three samples from the permeate produced per week.

2. Measure VFA concentration by GC analysis.

3. VFA concentration shall be upper than 3000mg/L.

4. Investigate the factors of variation of VFA production

- Optimization of NH_4^+ production

   - In absence of on-line ammonium analyzer

1. Take three samples from the permeate produced per week.

2. Measure ammonium with Dr Lange kits.

   - In presence of on-line ammonium analyzer

3. Record on-line ammonium measurements.

4. Ammonium concentration shall be upper than 270mg/L.

5. Investigate the factors of variation of ammonium production

- Optimization of CO_2 production

1. Measure every day the volume of gas produced

2. Analyze every day the composition of the gas phase

3. Evaluate the CO_2 production rate

4. Investigate the factors of variation of CO_2 production

- Optimization of OM degradation efficiency

1. Based on regular analysis, evaluate the OM degradation efficiency

The OM degradation efficiency can only be approximated since the sludge is a complex mix of products and its composition can hardly be precisely determined. Two different methods of evaluation are used to approach the effective efficiency in a simplified model:

- Using the known concentrations of the degradation products:

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

Where:

- η_{OM1} = OM biological degradation efficiency

- OM_{biod} = cumulative biodegraded OM mass (mg)

- OM_{inf} = cumulative OM mass in influent (mg)

- $VFA_{inf/eff}$ = cumulative VFA mass in influent/ effluent (mg)

- CO_2 = cumulative mass of CO2 produced (mg)

- CH_4 = cumulative mass of CH4 produced (mg)

This formula does not take into account the other possible degradation products such as lactate, ethanol... It is thus an under-estimation of the effective efficiency.

- Using the global balance on organic matter:

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

Where:

- η_{OM2} = OM biological degradation and mechanical removal efficiency

- OM_{eff} = cumulative mass of organic matter in effluent (mg)

- *Accu* = accumulation (positive or negative) of organic matter in the reactor (mg)

This formula gives a simplified model closer from the reality.

2. OM degradation efficiency should be upper than 20%

3. Investigate the factors of variation of the OM efficiency

- <u>Optimization of Nitrogen degradation efficiency</u>

1. Based on regular analysis, evaluate the Nitrogen degradation efficiency

As for the organic matter efficiency, the nitrogen efficiency can only be estimated. Two estimators are used for its evaluation:

- Using the known concentrations of the degradation product:

$$\eta_{N1} = \frac{Norg_{biod}}{Norg_{\inf}} = \frac{NH4_{eff} - NH4_{\inf}}{Norg_{\inf}}$$

Where:

- η_{N1} = nitrogen biodegradation efficiency

- $Norg_{biod}$ = cumulative biodegraded organic nitrogen mass (mg)

- $Norg_{inf}$ = cumulative organic nitrogen mass in influent (mg)

- $NH4_{inf}$ = cumulative ammonium mass in influent (mg)

- $NH4_{eff}$ = cumulative ammonium mass in effluent (mg)

- Using the global balance on nitrogen:

$$\eta_{N2} = \frac{Norg_{\inf} - Norg_{eff}}{Norg_{\inf}}$$

Where:

- η_{N2} = nitrogen biodegradation and mechanical removal efficiency

- $Norg_{eff}$ = cumulative organic nitrogen mass in effluent (mg)

2. Nitrogen degradation efficiency should be upper than 35%
3. Investigate the factors of variation of Nitrogen efficiency

- Optimization of Fibres degradation efficiency

1. Based on regular analysis, evaluate the fibres degradation efficiency

The fibre degradation efficiency is approached with the assumption that the non-proteic organic matter corresponds mainly to fibres.

$$\eta_{fibres} = \frac{Fibres_{\deg}}{Fibres_{\inf}}$$

$$Fibres_{\inf} = OM_{\inf} - prot_{\inf}$$

$$Fibres_{\deg} = OM_{biod} - prot_{biod} = OM_{\inf} \cdot \eta_{OM1} - prot_{\inf} \cdot \eta_{N1}$$

Where:

- η_{fibres} = fibres biodegradation efficiency

- $Fibres_{deg}$ = cumulative degraded fibres mass (mg)

- $Fibres_{inf}$ = cumulative fibres mass in influent (mg)

- $prot_{biod}$ = cumulative biodegraded proteins mass (mg)

Proteins are determined theoretically by multiplying the amount of organic nitrogen by 6.25, which is a ratio determined based on analysis of nitrogen composition of amino-acids and classically used in protein determination (Jones, 1931).

2. Fibres degradation efficiency should be upper than 15%

3. Investigate the factors of variation of Fibres efficiency.

4. Conclusions

The functional test plan gives a structure of work to evaluate the hardware of the prototype waste compartment and the process. Based on the requirements of the reactor, an analysis of the important hardware and process requirements was performed. The test plan was established based on this analysis.

Tests on the hardware phase are performed during construction of the reactor, assembly of the prototype waste compartment and start-up.

Tests on the operation phase concern an evaluation of the prototype running on a representative period. Period for functional tests is usually defined based on the cycles of the process. To evaluate the prototype reactor, tests will be realized on a period of one month corresponding to three HRT (Hydraulic Residence Time).

Finally, evaluation of the tests results will generate an objective criticism of the prototype reactor, and thus knowledge to be transferred to the construction of the pilot reactor

5. References

Jones, D.B.: Factors for Converting Percentages of Nitrogen in Foods and Feeds into Percentages of Protein. United States Department of Agriculture, Circular No. 183. Slightly revised edition 1941 (Original version 1931).

Stephenson, T., Judd, S., Jefferson, B. and Brindle, K. (2000). Membrane bioreactors for wastewatertreatment. IWA Publishing

6. ADDENDUM

6.1 Test plan: classification by instrument

The requirements and associated test plan related to the hardware phase can be divided in 3 different groups: the hardware related to the reactor, to the filtration unit, and to the gas loop. The following tables present the requirements related to all the instrumentation.

Instruments		Requirements																					
		HARDWARE PHASE				OPERATION PHASE																	
						Hardware evaluation											Process evaluation						
Reference	**Description**	Homogeneous mixing	Stable heating of the reactor	Gas / liquid tightness	Running of sensors and actuators	Absence of clogging	Absence of corrosion / fooling	Accuracy and repeatability of measurements	Absence of instrument deterioration	Absence of reactor deterioration	Desired answer to user or controller action	Regulation of permeate production	Regulation of gas loop	Configuration of reactor	Configuration of filtration unit	Configuration of gas loop	Optimisation of filtration process	Optimisation of VFA production	Optimisation of NH4+ production	Optimisation of CO2 production?	Optimisation of OM degradation efficiency	Optimisation of Nitrogen degradation efficiency	Optimisation of Fibres degradation efficiency
REACTOR																							
R-001	Reactor																						
BL-R-001	Mixer for the bioreactor, equipped with LC-impeller																						
HX-R-001	Heat exchanger																						

PMP-R-001	Influent pump																
PD-R-001	Precision stainless steel pressure transmitter bioreactor																
PD-R-002	Precision stainless steel pressure transmitter bioreactor																
TS-R-001	Temperature sensor																
TT-R-001	Temperature transmitter																
pHS-R-001	pH sensor																
pHT-R-001	pH transmitter																
	Valves, connections																
FILTRATION UNIT																	
R-F-001	Buffer tank																
R-F-002	Permeate tank																
M-F-001	Membrane																
WD-F-001	Balance																
PMP-F-001	Pump																
PD-F-001	Pressure transducer before filtration module																
PD-F-002	Pressure transducer after filtration module																
PD-F-003	Pressure transducer on permeate flow																
TS-F-001	Temperature sensor																
TT-F-001	Temperature transmitter																
FD-F-001	Flow meter																
LD-F-001	Level sensor in buffer tank																
SS-F-001	Turbidity sensor																
ST-F-001	Turbidity transmitter																
NS-F-001	Ammonium analyser																
V-F-001	Software controlled valve between reactor and buffer tank																
V-F-006	Software controlled valve between filtration module and buffer tank																
V-F-011	Software controlled valve for permeate flow back to buffer tank																
V-F-013	Software controlled valve for effluent flow																
V-F-002	Manual controlled valve between buffer tank and pump																

V-F-003	Manual controlled valve between buffer tank and filtration module
V-F-004	Manual controlled valve before membrane module
V-F-005	Manual controlled valve after membrane module
V-F-007	Manual controlled valve between reactor and buffer tank
V-F-008	Manual controlled valve between reactor and buffer tank
V-F-009	Manual controlled valve between reactor and buffer tank
V-F-012	Manual controlled valve before permeate tank
V-F-014	Manual controlled valve between reactor and buffer tank
V-F-015	Manual controlled valve between reactor and buffer tank
	Connections
GAS LOOP	
R-G-001	Pressure vessel: buffer for produced gas at 4 bar
HX-G-001	Cooler
PMP-G-001	Master pump that generates air flow through gas loop
PD-G-001	Precision stainless steel pressure transmitter bioreactor
PD-G-002	Precision stainless steel pressure transmitter pressure vessel
GS-G-001	Gas analyser
GS-G-002	Gas analyser
PI-G-001	Pressure on suction side of PMP-G-001
PI-G-002	Pressure at outlet gas analyser 1
PI-G-003	Pressure at outlet gas analyser 2
PI-G-004	Controlled backpressure by PR-G-004
PI-G-005	Controlled pressure by PR-G-001

PI-G-006	Inlet pressure to PR-G-001																
FI-G-001	Rotameter for flow through gas loop and analysers																
PR-G-001	spring loaded, diaphragm-sensed backpressure regulator: regulates pressure in buffer vessel R-G-001, relieves net gas produced																
PR-G-004	Self-contained spring loaded pressure reducing regulator with negative bias, regulates bioreactor pressure																
V-G-001	Valve regulating the flow through gas loop and gas analysers																
V-G-002	Valve regulating the flow through gas loop and gas analyser 1																
V-G-003	Valve regulating the flow through gas loop and gas analyser 2																
V-G-004	Safety pressure relief valve on pressure vessel R-G-001																
V-G-005	Valve regulating the flow through gas loop																
V-G-006	Valve regulating the addition of N_2-gas at reactor start-up																
V-G-007	Automatic liquid drain on vessel R-G-001																
	Connections																

6.2 Test plan: classification by number

Table 5. Tests classification

Test nb	Phase	Sub-Phase	Requirement nb	Tested requirement	Sub-system	Test sub-nber	Instrument ref	Instrument description
H.1.R.1	H.		1.	Homogeneous mixing	R.	1	BL-R-001	Mixer
							PLC	Control
H.2.R.1			2.	Stable heating of the reactor (55°C)	R.	1	HX-R-001	Heat exchanger
							PLC	Control
							HX-G-001	Cooler
H.3.R.1			3.	Gas tightness	R.	1	R-001	Reactor
							BL-R-001	Mixer for the bioreactor, equipped with LC-impeller
							HX-R-001	Heat exchanger
							PD-R-001	stainless steel pressure r bioreactor
							PD-R-002	Precision stainless steel pressure transmitter bioreactor
							TS-R-001	Temperature sensor
							pHS-R-001	pH sensor
							pHT-R-001	pH transmitter
								Valves, connections
H.3.F.1					F.	1	R-F-001	Buffer tank
H.3.G.1					G.	1	R-G-001	Pressure vessel: buffer for produced gas at 4 bar
							HX-G-001	Cooler
							PMP-G-001	Master pump that generates air flow through gas loop
							PD-G-001	Precision stainless steel pressure transmitter bioreactor
							PD-G-002	Precision stainless steel pressure transmitter pressure vessel
							GS-G-001	Gas analyser
							GS-G-002	Gas analyser
							PI-G-001	Pressure on suction side of PMP-G-001
							PI-G-002	Pressure at outlet gas analyser 1
							PI-G-003	Pressure at outlet gas analyser 2
							PI-G-004	Controlled backpressure by PR-G-004
							PI-G-005	Controlled pressure by PR-G-001
							PI-G-006	Inlet pressure to PR-G-001

						FI-G-001	Rotameter for flow through gas loop and analysers
						PR-G-001	spring loaded, diaphragm-sensed backpressure regulator: regulates pressure in buffer vessel R-G-001, relieves net gas produced
						PR-G-004	Self-contained spring loaded pressure reducing regulator with negative bias, regulates bioreactor pressure
						V-G-001	Valve regulating the flow through gas loop and gas analysers
						V-G-002	Valve regulating the flow through gas loop and gas analyser 1
						V-G-003	Valve regulating the flow through gas loop and gas analyser 2
						V-G-004	Safety pressure relief valve on pressure vessel R-G-001
						V-G-005	Valve regulating the flow through gas loop
						V-G-006	Valve regulating the addition of N_2-gas at reactor start-up
						V-G-007	Automatic liquid drain on vessel R-G-001
							Connections
H.4.R.1		4.	Liquid tightness	R.	1	R-001	Reactor
						BL-R-001	Mixer for the bioreactor, equipped with LC-impeller
						HX-R-001	Heat exchanger
						PMP-R-001	Influent pump
						PD-R-001	Precision stainless steel pressure transmitter bioreactor
						PD-R-002	Precision stainless steel pressure transmitter bioreactor
						TS-R-001	Temperature sensor
						pHS-R-001	pH sensor
							Valves, connections
H.4.F.1				F.	1	R-F-001	Buffer tank
						R-F-002	Permeate tank
						PMP-F-001	Pump
						PD-F-001	Pressure transducer before filtration module
						PD-F-002	Pressure transducer after filtration module

						PD-F-003	Pressure transducer on permeate flow
						TS-F-001	Temperature sensor
						FD-F-001	Flow meter
						LD-F-001	Level sensor in buffer tank
						SS-F-001	Turbidity sensor
						NS-F-001	Ammonium analyser
						V-F-001	Software controlled valve between reactor and buffer tank
						V-F-006	Software controlled valve between filtration module and buffer tank
						V-F-011	Software controlled valve for permeate flow back to buffer tank
						V-F-013	Software controlled valve for effluent flow
						V-F-002	Manual controlled valve between buffer tank and pump
						V-F-003	Manual controlled valve between buffer tank and filtration module
						V-F-004	Manual controlled valve before membrane module
						V-F-005	Manual controlled valve after membrane module
						V-F-007	Manual controlled valve between reactor and buffer tank
						V-F-008	Manual controlled valve between reactor and buffer tank
						V-F-009	Manual controlled valve between reactor and buffer tank
						V-F-012	Manual controlled valve before permeate tank
						V-F-014	Manual controlled valve between reactor and buffer tank
						V-F-015	Manual controlled valve between reactor and buffer tank
							Connections
H.4.G.1				G.	1	V-G-007	Automatic liquid drain on vessel R-G-001
							Connections
H.5.R.1		5.	Running of sensors and actuators	R.	1	PMP-R-001	Influent pump
						PD-R-001	Precision stainless steel pressure transmitter bioreactor
						PD-R-002	Precision stainless steel pressure transmitter bioreactor

						TS-R-001	Temperature sensor
						pHS-R-001	pH sensor
						pHT-R-001	pH transmitter
						PLC	Control system
							Valves, connections
H.5.F.1				F.	1	WD-F-001	Balance
						PMP-F-001	Pump
						PD-F-001	Pressure transducer before filtration module
						PD-F-002	Pressure transducer after filtration module
						PD-F-003	Pressure transducer on permeate flow
						TS-F-001	Temperature sensor
						TT-F-001	Temperature transmitter
						FD-F-001	Flow meter
						LD-F-001	Level sensor in buffer tank
						SS-F-001	Turbidity sensor
						ST-F-001	Turbidity transmitter
						NS-F-001	Ammonium analyser
						V-F-001	Software controlled valve between reactor and buffer tank
						V-F-006	Software controlled valve between filtration module and buffer tank
						V-F-011	Software controlled valve for permeate flow back to buffer tank
						V-F-013	Software controlled valve for effluent flow
						V-F-002	Manual controlled valve between buffer tank and pump
						V-F-003	Manual controlled valve between buffer tank and filtration module
						V-F-004	Manual controlled valve before membrane module
						V-F-005	Manual controlled valve after membrane module
						V-F-007	Manual controlled valve between reactor and buffer tank
						V-F-008	Manual controlled valve between reactor and buffer tank
						V-F-009	Manual controlled valve between reactor and buffer tank
						V-F-012	Manual controlled valve before permeate tank

							V-F-014	Manual controlled valve between reactor and buffer tank
							V-F-015	Manual controlled valve between reactor and buffer tank
O.a.1.F.1	O.	a.			R.	1	PMP-R-001	Influent pump
								Valves, connections
			1.	Absence of clogging	F.	1	M-F-001	Membrane
							PMP-F-001	Pump
							V-F-001	Software controlled valve between reactor and buffer tank
							V-F-006	Software controlled valve between filtration module and buffer tank
							V-F-011	Software controlled valve for permeate flow back to buffer tank
							V-F-013	Software controlled valve for effluent flow
							V-F-002	Manual controlled valve between buffer tank and pump
							V-F-003	Manual controlled valve between buffer tank and filtration module
							V-F-004	Manual controlled valve before membrane module
							V-F-005	Manual controlled valve after membrane module
							V-F-007	Manual controlled valve between reactor and buffer tank
							V-F-008	Manual controlled valve between reactor and buffer tank
							V-F-009	Manual controlled valve between reactor and buffer tank
							V-F-012	Manual controlled valve before permeate tank
							V-F-014	Manual controlled valve between reactor and buffer tank
							V-F-015	Manual controlled valve between reactor and buffer tank
								Connections
O.a.2.R.1			2.	Absence of corrosion / fooling	R.	1	R-001	Reactor
							BL-R-001	Mixer for the bioreactor, equipped with LC-impeller
							HX-R-001	Heat exchanger
							PD-R-001	Precision stainless steel pressure transmitter bioreactor

							PD-R-002	Precision stainless steel pressure transmitter bioreactor
							TS-R-001	Temperature sensor
							pHS-R-001	pH sensor
								Valves, connections
O.a.2.F.1					F.	1	R-F-001	Buffer tank
							R-F-002	Permeate tank
							PMP-F-001	Pump
							PD-F-001	Pressure transducer before filtration module
							PD-F-002	Pressure transducer after filtration module
							PD-F-003	Pressure transducer on permeate flow
							TS-F-001	Temperature sensor
							FD-F-001	Flow meter
							LD-F-001	Level sensor in buffer tank
							SS-F-001	Turbidity sensor
							NS-F-001	Ammonium analyser
							V-F-001	Software controlled valve between reactor and buffer tank
							V-F-006	Software controlled valve between filtration module and buffer tank
							V-F-011	Software controlled valve for permeate flow back to buffer tank
							V-F-013	Software controlled valve for effluent flow
							V-F-002	Manual controlled valve between buffer tank and pump
							V-F-003	Manual controlled valve between buffer tank and filtration module
							V-F-004	Manual controlled valve before membrane module
							V-F-005	Manual controlled valve after membrane module
							V-F-007	Manual controlled valve between reactor and buffer tank
							V-F-008	Manual controlled valve between reactor and buffer tank
							V-F-009	Manual controlled valve between reactor and buffer tank
							V-F-012	Manual controlled valve before permeate tank

							V-F-014	Manual controlled valve between reactor and buffer tank
							V-F-015	Manual controlled valve between reactor and buffer tank
								Connections
							M-F-001	Membrane
O.a.2.G.1					G.	1	R-G-001	Pressure vessel: buffer for produced gas at 4 bar
							HX-G-001	Cooler
							PMP-G-001	Master pump that generates air flow through gas loop
							PD-G-001	Precision stainless steel pressure transmitter bioreactor
							PD-G-002	Precision stainless steel pressure transmitter pressure vessel
							GS-G-001	Gas analyser
							GS-G-002	Gas analyser
							PI-G-001	Pressure on suction side of PMP-G-001
							PI-G-002	Pressure at outlet gas analyser 1
							PI-G-003	Pressure at outlet gas analyser 2
							PI-G-004	Controlled backpressure by PR-G-004
							PI-G-005	Controlled pressure by PR-G-001
							PI-G-006	Inlet pressure to PR-G-001
							FI-G-001	Rotameter for flow through gas loop and analysers
							PR-G-001	spring loaded, diaphragm-sensed backpressure regulator: regulates pressure in buffer vessel R-G-001, relieves net gas produced
							PR-G-004	Self-contained spring loaded pressure reducing regulator with negative bias, regulates bioreactor pressure
							V-G-001	Valve regulating the flow through gas loop and gas analysers
							V-G-002	Valve regulating the flow through gas loop and gas analyser 1
							V-G-003	Valve regulating the flow through gas loop and gas analyser 2
							V-G-004	Safety pressure relief valve on pressure vessel R-G-001

							V-G-005	Valve regulating the flow through gas loop
							V-G-006	Valve regulating the addition of N_2-gas at reactor start-up
							V-G-007	Automatic liquid drain on vessel R-G-001
								Connections
O.a.3.R.1			3.	Accuracy and repeatability of measurements	R.	1	PD-R-001	Precision stainless steel pressure transmitter bioreactor
O.a.3.R.2						2	PD-R-002	Precision stainless steel pressure transmitter bioreactor
O.a.3.R.3						3	TS-R-001	Temperature sensor
							TT-R-001	Temperature transmitter
O.a.3.R.4						4	pHS-R-001	pH sensor
							pHT-R-001	pH transmitter
O.a.3.F.1					F.	1	WD-F-001	Balance
O.a.3.F.2						2	PD-F-001	Pressure transducer before filtration module
O.a.3.F.3						3	PD-F-002	Pressure transducer after filtration module
O.a.3.F.4						4	PD-F-003	Pressure transducer on permeate flow
O.a.3.F.5						5	TS-F-001	Temperature sensor
							TT-F-001	Temperature transmitter
O.a.3.F.6						6	FD-F-001	Flow meter
O.a.3.F.7						7	LD-F-001	Level sensor in buffer tank
O.a.3.F.8						8	SS-F-001	Turbidity sensor
							ST-F-001	Turbidity transmitter
O.a.3.F.9						9	NS-F-001	Ammonium analyser
O.a.3.G.1					G.	1	PD-G-001	Precision stainless steel pressure transmitter bioreactor
O.a.3.G.2						2	PD-G-002	Precision stainless steel pressure transmitter pressure vessel
O.a.3.G.3						3	GS-G-001	Gas analyser
O.a.3.G.4						4	GS-G-002	Gas analyser
O.a.3.G.5						5	PI-G-001	Pressure on suction side of PMP-G-001
O.a.3.G.6						6	PI-G-002	Pressure at outlet gas analyser 1
O.a.3.G.7						7	PI-G-003	Pressure at outlet gas analyser 2
O.a.3.G.8						8	PI-G-004	Controlled backpressure by PR-G-004
O.a.3.G.9						9	PI-G-005	Controlled pressure by PR-G-001

O.a.3.G.10						10	PI-G-006	Inlet pressure to PR-G-001
O.a.3.G.11						11	FI-G-001	Rotameter for flow through gas loop and analysers
O.a.4.R.1			4.	Absence of instrument deterioration	R.	1	BL-R-001	Mixer for the bioreactor, equipped with LC-impeller
							HX-R-001	Heat exchanger
							PMP-R-001	Influent pump
							PD-R-001	Precision stainless steel pressure transmitter bioreactor
							PD-R-002	Precision stainless steel pressure transmitter bioreactor
							TS-R-001	Temperature sensor
							TT-R-001	Temperature transmitter
							pHS-R-001	pH sensor
							pHT-R-001	pH transmitter
							PLC	Control system
								Valves, connections
O.a.4.F.1					F.	1	M-F-001	Membrane
							WD-F-001	Balance
							PMP-F-001	Pump
							PD-F-001	Pressure transducer before filtration module
							PD-F-002	Pressure transducer after filtration module
							PD-F-003	Pressure transducer on permeate flow
							TS-F-001	Temperature sensor
							TT-F-001	Temperature transmitter
							FD-F-001	Flow meter
							LD-F-001	Level sensor in buffer tank
							SS-F-001	Turbidity sensor
							ST-F-001	Turbidity transmitter
							NS-F-001	Ammonium analyser
							V-F-001	Software controlled valve between reactor and buffer tank
							V-F-006	Software controlled valve between filtration module and buffer tank
							V-F-011	Software controlled valve for permeate flow back to buffer tank
							V-F-013	Software controlled valve for effluent flow
							V-F-002	Manual controlled valve between buffer tank and pump

							V-F-003	Manual controlled valve between buffer tank and filtration module
							V-F-004	Manual controlled valve before membrane module
							V-F-005	Manual controlled valve after membrane module
							V-F-007	Manual controlled valve between reactor and buffer tank
							V-F-008	Manual controlled valve between reactor and buffer tank
							V-F-009	Manual controlled valve between reactor and buffer tank
							V-F-012	Manual controlled valve before permeate tank
							V-F-014	Manual controlled valve between reactor and buffer tank
							V-F-015	Manual controlled valve between reactor and buffer tank
								Connections
O.a.4.G.1					G.	1	R-G-001	Pressure vessel: buffer for produced gas at 4 bar
							HX-G-001	Cooler
							PMP-G-001	Master pump that generates air flow through gas loop
							PD-G-001	Precision stainless steel pressure transmitter bioreactor
							PD-G-002	Precision stainless steel pressure transmitter pressure vessel
							GS-G-001	Gas analyser
							GS-G-002	Gas analyser
							PI-G-001	Pressure on suction side of PMP-G-001
							PI-G-002	Pressure at outlet gas analyser 1
							PI-G-003	Pressure at outlet gas analyser 2
							PI-G-004	Controlled backpressure by PR-G-004
							PI-G-005	Controlled pressure by PR-G-001
							PI-G-006	Inlet pressure to PR-G-001
							FI-G-001	Rotameter for flow through gas loop and analysers

							PR-G-001	spring loaded, diaphragm-sensed backpressure regulator: regulates pressure in buffer vessel R-G-001, relieves net gas produced
							PR-G-004	Self-contained spring loaded pressure reducing regulator with negative bias, regulates bioreactor pressure
							V-G-001	Valve regulating the flow through gas loop and gas analysers
							V-G-002	Valve regulating the flow through gas loop and gas analyser 1
							V-G-003	Valve regulating the flow through gas loop and gas analyser 2
							V-G-004	Safety pressure relief valve on pressure vessel R-G-001
							V-G-005	Valve regulating the flow through gas loop
							V-G-006	Valve regulating the addition of N_2-gas at reactor start-up
							V-G-007	Automatic liquid drain on vessel R-G-001
								Connections
O.a.5.R.1			5.	Absence of reactor deterioration	R.	1	R-001	Reactor
O.a.5.F.1					F.	1	R-F-001	Buffer tank
O.a.5.F.2						2	R-F-002	Permeate tank
O.a.5.G.1					G.	1	R-G-001	Pressure vessel: buffer for produced gas at 4 bar
O.a.6.R.1			6.	Desired answer to user or controller action	R.	1	BL-R-001	Mixer for the bioreactor, equipped with LC-impeller
O.a.6.R.2						2	HX-R-001	Heat exchanger
O.a.6.R.3						3	PMP-R-001	Influent pump
O.a.6.R.4						4		Valves, connections
O.a.6.F.1					F.	1	WD-F-001	Balance
O.a.6.F.2						2	PMP-F-001	Pump
O.a.6.F.3						3	SS-F-001	Turbidity sensor
							ST-F-001	Turbidity transmitter
O.a.6.F.4						4	NS-F-001	Ammonium analyser
O.a.6.F.5						5	V-F-001	Software controlled valve between reactor and buffer tank
O.a.6.F.6						6	V-F-006	Software controlled valve between filtration module and buffer tank
O.a.6.F.7						7	V-F-011	Software controlled valve for permeate flow back to buffer tank

O.a.6.F.8						8	V-F-013	Software controlled valve for effluent flow
O.a.6.F.9						9	V-F-002	Manual controlled valve between buffer tank and pump
O.a.6.F.10						10	V-F-003	Manual controlled valve between buffer tank and filtration module
O.a.6.F.11						11	V-F-004	Manual controlled valve before membrane module
O.a.6.F.12						12	V-F-005	Manual controlled valve after membrane module
O.a.6.F.13						13	V-F-007	Manual controlled valve between reactor and buffer tank
O.a.6.F.14						14	V-F-008	Manual controlled valve between reactor and buffer tank
O.a.6.F.15						15	V-F-009	Manual controlled valve between reactor and buffer tank
O.a.6.F.16						16	V-F-012	Manual controlled valve before permeate tank
O.a.6.F.17						17	V-F-014	Manual controlled valve between reactor and buffer tank
O.a.6.F.18						18	V-F-015	Manual controlled valve between reactor and buffer tank
O.a.6.G.1					G.	1	HX-G-001	Cooler
O.a.6.G.2						2	PMP-G-001	Master pump that generates air flow through gas loop
O.a.6.G.3						3	PI-G-004	Controlled backpressure by PR-G-004
O.a.6.G.4						4	PI-G-005	Controlled pressure by PR-G-001
O.a.6.G.5						5	PR-G-001	spring loaded, diaphragm-sensed backpressure regulator: regulates pressure in buffer vessel R-G-001, relieves net gas produced
O.a.6.G.6						6	PR-G-004	Self-contained spring loaded pressure reducing regulator with negative bias, regulates bioreactor pressure
O.a.6.G.7						7	V-G-001	Valve regulating the flow through gas loop and gas analysers
O.a.6.G.8						8	V-G-002	Valve regulating the flow through gas loop and gas analyser 1
O.a.6.G.9						9	V-G-003	Valve regulating the flow through gas loop and gas analyser 2
O.a.6.G.10						10	V-G-004	Safety pressure relief valve on pressure vessel R-G-001

O.a.6.G.11						11	V-G-005	Valve regulating the flow through gas loop
O.a.6.G.12						12	V-G-006	Valve regulating the addition of N_2-gas at reactor start-up
O.a.6.G.13						13	V-G-007	Automatic liquid drain on vessel R-G-001
O.a.7.1			7.	Regulation of permeate production	R.	1	PLC	Control system
					F.		WD-F-001	Balance
							PMP-F-001	Pump
							PD-F-001	Pressure transducer before filtration module
							PD-F-002	Pressure transducer after filtration module
							PD-F-003	Pressure transducer on permeate flow
							FD-F-001	Flow meter
							LD-F-001	Level sensor in buffer tank
							SS-F-001	Turbidity sensor
							V-F-001	Software controlled valve between reactor and buffer tank
							V-F-006	Software controlled valve between filtration module and buffer tank
							V-F-011	Software controlled valve for permeate flow back to buffer tank
							V-F-013	Software controlled valve for effluent flow
O.a.8.1			8.	Regulation of gas loop	R.	1	PLC	Control system
					G.		HX-G-001	Cooler
							PMP-G-001	Master pump that generates air flow through gas loop
							PD-G-001	Precision stainless steel pressure transmitter bioreactor
							PD-G-002	Precision stainless steel pressure transmitter pressure vessel
							PI-G-001	Pressure on suction side of PMP-G-001
							PI-G-002	Pressure at outlet gas analyser 1
							PI-G-003	Pressure at outlet gas analyser 2
							PI-G-004	Controlled backpressure by PR-G-004
							PI-G-005	Controlled pressure by PR-G-001
							PI-G-006	Inlet pressure to PR-G-001

							FI-G-001	Rotameter for flow through gas loop and analysers
							PR-G-001	spring loaded, diaphragm-sensed backpressure regulator: regulates pressure in buffer vessel R-G-001, relieves net gas produced
							PR-G-004	Self-contained spring loaded pressure reducing regulator with negative bias, regulates bioreactor pressure
							V-G-001	Valve regulating the flow through gas loop and gas analysers
							V-G-002	Valve regulating the flow through gas loop and gas analyser 1
							V-G-003	Valve regulating the flow through gas loop and gas analyser 2
							V-G-004	Safety pressure relief valve on pressure vessel R-G-001
							V-G-005	Valve regulating the flow through gas loop
							V-G-006	Valve regulating the addition of N_2-gas at reactor start-up
							V-G-007	Automatic liquid drain on vessel R-G-001
O.a.9.R.1			9.	Configuration of reactor	R.	1		all instrumentation
O.a.9.F.1			10.	Configuration of filtration unit	F.	1		all instrumentation
O.a.9.G.1			11.	Configuration of gas loop	G.	1		all instrumentation
O.b.1.1			1.	Optimisation of filtration process	F.	1		Whole system- Permeate stream
O.b.2.1			2.	Optimisation of VFA production		1		Whole system- Permeate stream
O.b.3.1			3.	Optimisation of NH4+ production		1		Whole system- Permeate stream
O.b.4.1			4.	Optimisation of CO2 production?		1		Whole system- Gas stream
O.b.5.1		b.	5.	Optimisation of OM degradation efficiency		1		Whole system
O.b.6.1			6.	Optimisation of Nitrogen degradation efficiency		1		Whole system
O.b.7.1			7	Optimisation of Fibres degradation efficiency		1		Whole system

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