DESSIN

DEMONSTRATE ECOSYSTEM SERVICES ENABLING INNOVATION IN THE WATER SECTOR

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D34.1 AN OPTIMAL CONFIGURATION SMALL PACKAGED PLANT FOR URBAN SEWER MINING

Maintenance & Operation Book

Chemitec, revised version: October 2017

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 619039

Title of the Report

D34.1: AN OPTIMAL CONFIGURATION SMALL PACKAGED PLANT FOR URBAN SEWER MINING
Maintenance & Operation Book

SUMMARY

Deliverable D34.1 is part of Task 34.1 of DESSIN Project which is related to Athens Demonstration: Sewer Mining for Urban Reuse enabled by Advanced Monitoring Infrastructure. More specifically D34.1 focuses on the installation of a small footprint packaged treatment plant. A packaged plant consisting of an advanced Membrane Bioreactor coupled with nano-filtration and reverse osmosis membranes has been installed in KEREFYT, the Sanitary Engineering Research and Development Center of EYDAP. The installation simulates direct abstraction from main sewers and is able to accept multiple types of effluent (municipal and industrial), also linked to the Metamorfosi WWTP. The reclaimed water is appropriate for irrigation purposes and will be used to irrigate the surrounding urban green area. This document aims to serve as the Maintenance and Operation Book of the proposed solution.

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List of Acronyms and Abbreviations

ADF	Average Daily Flow
AMI	Advanced Metering and Monitoring Infrastructure
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
ICT	Information and Communication Technology
MBR	Membrane Biological Reactor
MC	Maintenance Cleaning
MDF	Maximum Daily Flow
MLSS	Mixed Liquor Suspended Solids
PHF	Peak Hour Flow
RC	Recovery Cleaning
RO	Reverse Osmosis
TKj	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
UF	Ultrafiltration
VSS	Volatile Suspended Solids
WWTP	Wastewater Treatment Plant

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Executive summary

Deliverable D34.1 is part of Task 34.1 of DESSIN Project which is related to Athens Demonstration: Sewer Mining for Urban Reuse enabled by Advanced Monitoring Infrastructure. More specifically D34.1 focuses on the installation of a small footprint packaged treatment plant. A packaged plant consisting of an advanced Membrane Bioreactor coupled with nano-filtration and reverse osmosis membranes has been installed in KEREFYT, the Sanitary Engineering Research and Development Centre of EYDAP. The installation simulates direct abstraction from main sewers and is able to accept multiple types of effluent (municipal and industrial), also linked to the Metamorfosi WWTP. The reclaimed water is appropriate for irrigation purposes and will be used to irrigate the surrounding urban green area. This document aims to serve as the Maintenance and Operation Book of the proposed solution.

More specifically chapter 1 briefly presents the Athens pilot, the components of the containerised wastewater treatment plant and the influent quality characteristics. Chapter 2 explains in detail the operation of the Membrane Biological Reactor (MBR) unit. The various treatment processes and the configuration of the bioreactor and the membrane system are described. The ultrafiltration (UF) permeate characteristics are presented. Chapter 3 describes the Reverse Osmosis (RO) process and benefits and clarifies the final effluent water quality. Finally, in Annex I photos of the Athens pilot are demonstrated.

1 Introduction

An optimal configuration small packaged plant for urban sewer mining has been developed as part of the Athens Demonstration: Sewer Mining for Urban Reuse enabled by Advanced Monitoring Infrastructure. The Athens Pilot brings together two emerging technologies: Membrane based, small footprint, sewer mining technologies and distributed low energy sensor networks coupled with distributed ICT intelligence (e.g. Advanced Metering and Monitoring Infrastructure, AMIs). These technologies are (relatively) mature individually but have never been combined before. Within this task, we propose and test specific, fully automated packaged treatment trains suitable for arid and semi-arid regions combining advanced membrane types and technologies as well as processes and additives to optimize performance at minimum cost. A robust and compact WWTP for treatment of sewage from permanently inhabited buildings with a capacity of 30-200 EP or analogue capacity of 6-40 m^3/d has been installed at KEREFYT, the Sanitary Engineering Research and Development Centre of EYDAP.

The deployment of these distributed treatment solutions allows the direct mining of sewage from the network, close to the point-of-use with minimum infrastructure required and low transportation costs for the treated effluent. In the Athens pilot the reclaimed water will be used to irrigate the surrounding urban green area.

The wastewater treatment plant consists of two units; the MBR and the RO unit, which have been constructed as individual containers (modular) that are joined together in one containerized compact system offering ease of transportation. The MBR and RO units are a hybrid technological product that on the one hand employs membrane technology to treat sewage and on the other hand, in case this function fails, can operate as conventional type of WWTP. In addition this structure allows the units to be deployed either individually or in combination depending on the requirements of any potential future application.

A separate membrane filtration zone facilitates the filtration of the activated sludge. The membrane sludge circulation system is used for both the membrane sludge supply to prevent sludge over-concentration around the membranes, and as the Return Activated Sludge (RAS) stream required for denitrification. The total system follows the simple principle of pre-treatment, due to the small capacity, denitrification, nitrification, and one train membrane filtration.

This document highlights the design aspects of this new system and defines the process equipment required. The biological process and the expected effluent quality are explained, and the different features of each plant section are presented.

1.1 Wastewater characteristics

The wastewater treated in this application derives from the wastewater treatment plant of Metamorphosis. A maximum daily flow of 10,0 m^3/d is fed to the hybrid MBR system. This flow is taken upstream the primary settler of the existing wastewater treatment plant (conventional) via a new pumping station which feeds the MBR plant.

Wastewater quality tests have been carried out and results are presented in Figure 1. These parameters have been used as an input to optimise the design of the solution in order that law limits are met. Working temperatures used in these calculations are 15°C (Twinter) and 22°C (Tsummer), according to the data provided.

	Mean	Stdev	Max	maximum allowed concentration for reuse
BOD	154	58	267	10 OIK 145116
SS	146	116	530	2
COD	341	135	650	125 OIK 5673/400
TP	7,1	1,6	10	2
TN	65	10	84	15
o-PO_4^{3-}	4,42	0,38	5,00	
N-NO_3^-	1,45	1,06	2,20	
N-NO_2^-	0,11	0,10	0,23	
Cr^{6+}	0	0	0	
CN^-	0	0	0,04	
SO_4^{2-}	59	5,5	75	
Cl^-	315	234	780	
N-NH_4^+	42	15	60	
phenols	0,99	0,27	1,57	
detergent	7,0	8,1	49	
color	47	13	80	
pH	7,6	0,3	8,1	
FOG	18	13	52	

Figure 1: Wastewater quality of Metamorphosis WWTP

2 Membrane Biological Reactor unit description

The MBR unit consists of an all-plastic container divided with partitions into individual technological spaces like primary tank, denitrification tank, nitrification tank, membrane tank and excess sludge tank. The container contains an ultra-filtration module consisting of an air distribution system and aeration elements, membranes and a number of pumps. The tank is covered with a tilting cover. Wastewater flows to the primary sedimentation tank of the inlet part of the WWTP, where mechanical, floating and settling substances are removed from it and are further subjected to anaerobic decomposition (hydrolysis). From primary sedimentation tank the waste water is going to the activating space. The activation space is used for biological treatment (denitro-nitro) of wastewater and ultra-filtration through membranes. In the bottom part the aeration sector is fitted with a fine-bubble aeration system that is used to aerate the tank. Another air system exists to clean the membranes into which air is forced with a blower. An advantage of this design is that the plant works in the range between the minimum and maximum operation level, which provides it with accumulation space (buffer volume) within the entire space of the limited treatment plant and to ensure drain from the treatment plant. Activated mixture from the activation part is filtered through the membranes with the pore diameter of 0.03 µm into the drain. In case of a failure of the function of the module (pump fault, clogged module, etc.) the activated mixture from the activation part flows into the vertical final settlement tank, where at the bottom sludge is hydraulically withdrawn back to the activation part and in case of a high density of sludge into the sludge space as well (as in the case of a conventional WWTP). The proposed solution is a hybrid technological product that may operate either as conventional type of WWTP or as Membrane type one. Treated water then overflows via a submerged half pipe into the drain trough as a conventional effluent. Excessive sludge is removed with automatic control to the sedimentation and sludge sector from where in case it fills up a drain valve is actuated.

Table 1 presents the electromechanical equipment and instruments incorporated in the MBR unit.

Table 1: MBR electromechanical equipment and instruments

MBR	No of items
Physical	1
Electrical Panel MBR	2
Controller HACH LANGE	1
Screen CONTROLLER	1
Pump BORGER 1.1 KW	1
Pump GRUNDFOS CM 1-3	2
Flow meter KRONE D32	1
Flow meter KRONE D40	2
Blowers CL 220 HS	5
Pneumatic Valves FIP	2
PRESSURE TRANSMITER	2
PRESSURE SWITCH	2
Dosing Pumps GRUNDFOS DDA	1
Tank 280lit	2
Immersed pump DAB 4800 LIT/H	1
MIX PUMP	1
FILTER of waste	1
Turbidity meter HAGE LANGE	1

MBR	No of items
NO3 instrument HAGE LANGE	1
NO3 and NH4 measurement HAGE LANGE	1
MLSS meter HAGE LANGE	1
DO meter HAGE LANGE	1
PH meter HAGE LANGE	1
Waste Conductivity meter HAGE LANGE	1
Air DIFUSSER HAGE LANGE	1
INOX base for the measurement meters	
INOX construction for the pipings and pumps	

2.1 Treatment steps

2.1.1 Sand removal step

The characteristics of civil sewage coming from a unitary sewage system normally require a sand removal treatment before biological treatment. This is to preserve the electromechanical instrumentation and the membrane modules from the abrasive power of sand introduced in the influent especially during rain time. This is the reason why the efficiency required to this sand removal step is at least 97% towards all the particles with size > 200 µm.

Due to the fact that in Greece the sewage network is separate from the rain network the sand is not expected to be present in the wastewater thus the sand removal treatment is limited to the settlement in the buffer tank as well as through the filter in the pre-treatment tank of the system.

2.1.2 Oils and grit removal step

The oils and grit are among the worst enemies of polymeric membranes, because of their high fouling potential. Thus, it is mandatory that in the water line, the oil and grit removal step is able to lower the concentration of such pollutants below 10 ppm.

2.1.3 Perforated fine screen pre-treatment

The feed stream is sent to the MBR after pre-treatment of the existing WWTP which has the appropriate capacity for this purpose. The pumping station feeding the MBR is located upstream in the existing plant. Then the influent to the MBR undergoes a fine screening step before being conveyed to the biological treatment and finally to the membrane filtration step.

2.1.4 Biological treatment

The biological calculations consider the specifications given in the Feed Water Table and they are considered average values. The peak demands are calculated based on the $10m^3/h$ at the same average concentrations, as no dilution will occur during the peak flow as it is not linked to the rain. This is a so called “first flush” and is only used to calculate the peak oxygenation demand and aeration system sizing.

2.1.5 MBR Design Data

Table 2 presents the MBR design considerations taken into account in the Athens pilot.

Table 2: MBR design data

Parameter	Units	Design values
ADF	m^3 /d	8
MDF (PHF)	m^3 /d	10 (415 l/hr)
Temperature (winter)	˚C	15
Temperature (summer)	˚C	22
Biomass Concentration	kg/ m^3	8 in aeration

2.2 Description of MBR operation

Hollow fibers ultra-filtration modules for MBR plant operate under negative pressure with a filtration direction going from the outside of the hollow fiber towards the inside. Solids are therefore withheld in the retentive on the outside of the hollow fibers while the permeate flows inside and is collected by the collection manifold in the module to be subsequently conveyed to a permeate accumulation tank and then discharged.

In MBR plants the modules are directly in contact with the aerated sludge, but not directly inside the biological reactor: the module is normally installed in dedicated filtration tank, communicating with the oxidation or anoxic tank to facilitate the control of the process and maintenance operations.

Therefore MBR plants include a feed/recycle pipeline for the aerated sludge from and to the biological tanks. The sludge flow rate fed to the filtration chamber has to be a few times higher than the permeate flow rate in order to control the suspended solids contents of the membrane tank and therefore limit membrane fouling. Normally a range of 8-12 g/l MLSS (but max 14 g/l in MT) is desired. For this reason the sludge feed flow rate to the membrane tank has to be at least 4 times the net flow rate of treated water produced.

In summary, the wastewater influent flow determines the effluent flow rate (permeate), which directly determines the flow rate of the sludge that needs to be instantly raised to the membrane compartments to avoid sludge over-concentration. Excess sludge flow rate returns to the biological reactor through an overflow/ open channel.

In the meantime the treated water to be discharged is filtered through the braided hollow fiber membrane. The filtration process consists of different cycles, which could occur either through a sequential or simultaneous procedure.

Indeed, simultaneously to the filtration process air scouring cycles are carried out to ensure sludge thickening on the membrane surface won't occur. Moreover, the standard suction required for sludge filtration is periodically interrupted by other operational mode all aimed to preserve permeability in time. It could be either a backflush cycle and/or a relaxation cycle.

Among these preventive actions backflush is the most effective and therefore preferred process to operate Puron membranes. During backflush the extraction pump inverts its rotation sense and conveys a part of permeate produced from the inside to the outside of the hollow fibres to detach any materials that may have been deposited on the outer surface of the fibres or inside the pores during the suction period. In the meantime air scouring provides the required sludge mixing to preserve as much as possible sludge concentration homogeneity in the membrane tank. Both, backflush and relaxation cycles are executed automatically by the operation software.

Moreover, since the solid-liquid suspension conveyed to the membrane tank is also saturated of air (it comes from the aerobic biological reactor, and membrane modules are subject to air scouring cyclic protocol), and during its passage through the hollow fibres, the permeate is under negative pressure, as a result, part of the air originally dissolved in the mixture is freed as bubbles. This event is completely normal in this type of filtration process, which is carried out in a slightly vacuumed atmosphere. However, it needs to be controlled to avoid huge amount of air collected in the permeate manifolds and piping negatively affecting process efficiency, pumps operation, backflush effectiveness and therefore contrasting its effect to preserve membrane permeability.

Finally, in order to preserve membrane permeability, it is also required to run membrane chemical cleaning cycles.

The membrane cleaning procedures have been designed to reduce the loss of permeability in the time (cleaning strategy based on daily or weekly, short duration and low concentration cleaning cycled followed by yearly based more aggressive recovering cycle if required), so the strategy is aimed to prevent the loss of permeability by acting in advance.

It is clear that during both types of described chemical cleans, the filtration line needs to be out of operation, and therefore the entire WWTP influent should be addressed and filtered through CAS hybrid sector. This should be taken under consideration when designing the MBR plant and sizing the filtration area.

Consequently, the following number of specific procedures are usually included in the software.

Table 3: PURON module operation

Operation	Meaning
Electrical panel	Permeate extraction
Process mode	Returns a small percentage of the produced permeates back through the membrane.
Back flush mode	Periodically stops permeate extraction to de-stress the membrane (OPTIONAL)
Relaxation mode	Dissolved air will come out of solution at a partial pressure required for permeate extraction. Venting removes this air from the pipelines.
Venting mode	Removes air from the membrane's lumen.
De-aeration mode	Maintenance Cleaning
MC	Recovery Cleaning
RC	Permeate extraction

2.3 Bioreactor configuration

The biological configuration and membrane filtration processes of the wastewater treatment plant require innovative plant infrastructure due to the low capacity of the system, especially in respect to the configuration of denitrification and nitrification. Figure 2 shows the schematics of the MBR unit. The relative filtration train is located downstream of the biological line.

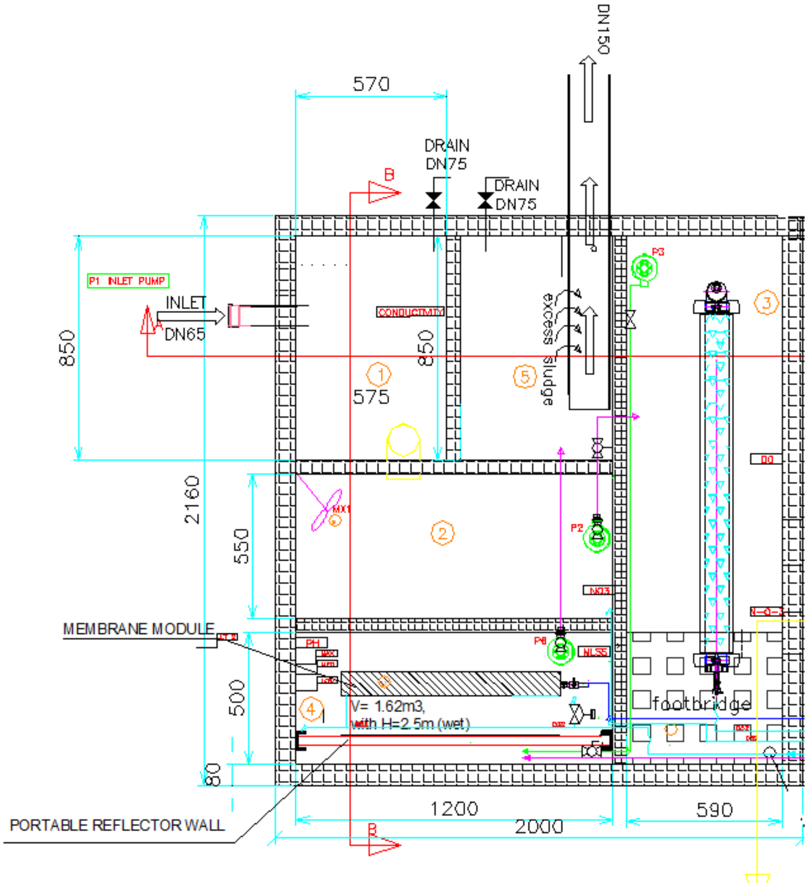

Figure 2: Bioreactor schematic

Figure 2 illustrates the treatment steps of the incoming sewage at the treatment line: after pre-treatments the waste water is conveyed to the denitrification tank where nitrate reduction takes place, thanks to the presence of the organic substrate introduced into the same tank with influent sewage. This tank is equipped with underwater mixer which keeps the sludge suspended and uniformly mixed with incoming waste water. This is actually a mixture of return sludge and raw waste water.

The following step is nitrification, where both oxidation of the organic substance and nitrification of ammonium nitrogen take place simultaneously. The nitrification zone is equipped with an air distribution system where fine bubbles have the double function of keeping the nitrification reactor in aerobic conditions and uniformly mixed. The aeration process is conducted in a non-homogenous way inside the oxidation reactor. In detail, the air distribution line is submersed into aeration tank controlled by the dissolved oxygen concentration measured by DO instrument in this section of the reactor. This makes the system more flexible towards the biological process and the measurement of dissolved oxygen concentration reduces electrical energy consumption.

The air injection line is carefully positioned upstream of the terminal section of the nitrification tank in sufficient distance from the pump feeding the membrane tanks so as not to compromise their correct operation. Indeed one immersed pump at low pressure head raises the aerated sludge from the oxidation section to the membrane tank.

When constructing an MBR plant, besides the biological reactors and the membrane tanks, a large circulation stream is required to maintain a biological solids balance in and around the membranes. This stream prevents sludge de-watering in the filtration tanks and additionally reduces the fouling of the membranes by reducing the solids loading at the membrane. The aim is to maintain the biomass concentration within a maximum threshold concentration, thereby avoiding an over-concentration in the membrane tank.

Membrane operation requires that this stream is sized at minimum 4 times the input flow (Q). The latter suggests an overall sludge MLSS circulation flow of $10m^3/d$ (PHF) x 4 (recirculation factor) = $40m^3/d$ during the peak flow. Here we design a 5 times *IR (Internal Recirculation) (*5Q) in order to catch the MLSS of about 9-10g/l in MT and to comply also the DN procedure (see also below).

Given that there is not a significant geodetic gradient level in the area where the plant will be build, the configuration of the MBR will be pumped in – gravity out. The pumps feeding the membrane tanks are regulated with level control switches, so that the sludge raised to the membrane tank can be decreased in average flow conditions.

Under normal operating conditions, a flow value equivalent to the influent flow (Q) value will exit as membranes' permeate, and the remaining part (4Q) are recycled back to the biology by overflowing between MT and Nitro tank. This means that the flow gravitating back to the biology varies depending on the flow rate entering the plant. This recirculation stream is rich in dissolved oxygen (2.5 to 5.0 mgO_2/l) and is usually returned to the nitrification zone to supplement the total oxygen demand of the biological process.

However, the design could allow an alternative approach that promotes better system robustness for the DN/N and also is more energy saving: in such cases the recirculation MLSS stream can be used to carry out the nitrates recirculation for the denitrification process, so besides the hydraulic function to maintain the membranes in a good operation, this stream can also achieve a biological function. The Dessin solution allows this approach (under the rule that 5Q, IR is sufficient to DN the MLSS in a given volume and under specific DO conditions etc. /see also above).

Therefore, with the proposed design, the Nitrate recirculation in anoxic zone is effectuated through the same return used by sludge coming from the membrane tank, thus providing a double advantage: it avoids a dedicated pumping step compared the traditional solution (N-DN recycle). Moreover, the biomass concentration in the membrane tank (as well as in the recirculation stream) will be slightly higher compared to that inside the nitrification and denitrification reactors in function of the extracted flow. Such lack of concentration homogeneity with the biological denitrification tank is, in fact, an advantage, because it allows counteracting the dilution caused by the influent wastewater feeding the denitrification reactor.

The specified configuration of reactors described above is designed to achieve a Total Nitrogen of less than 10mgN/l at 15°C (assuming TKj is <0.5mgN/l). The sludge age would be > 20 days at a TSS concentration of 8 g/l and fully stabilised.

2.4 Membrane System

The filtration zone is placed downstream the biological reactors. A schematic of the MBR plant is displayed in Figure 3 below.

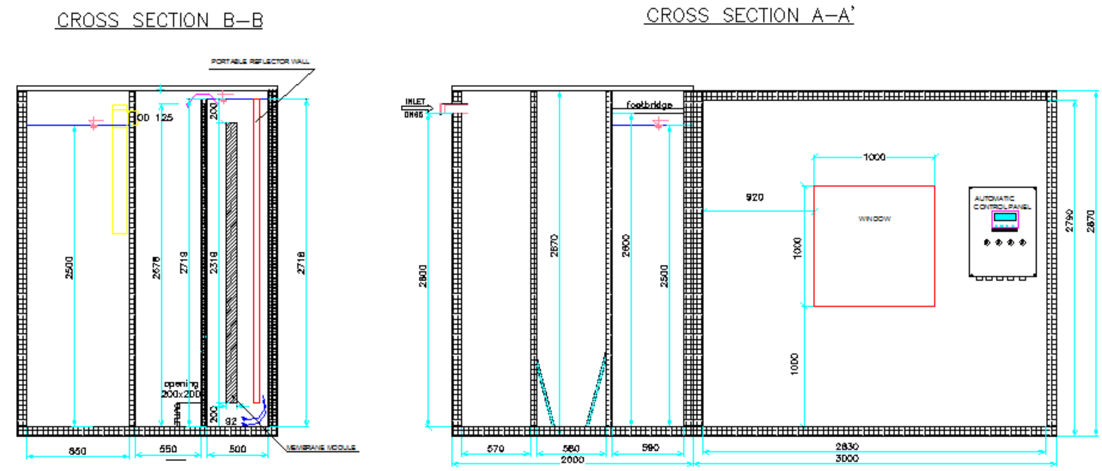

Figure 3: Membrane system schematics

The criteria used to design the filtration surface guarantees, for a limited period of time, the plant operation in average conditions. The installed surface is also designed to treat the PHF for a maximum continuous period of time of 4 hours.

The sludge flow feeding the membrane tanks is variable between 8 and 10m^3/d. A vertical pipe line feeds the mixed liquor tangently to the bottom of the membrane tank distributing it evenly throughout the whole length of the tank thus avoiding the formation of concentration gradients inside the tank and ensuring optimal module operation independently of their position. As a result, the evacuation speed, together with the upward motion induced by air injection, prevents solid sedimentation in the membrane chamber.

The water head difference created by the feed pump in the membrane tank allows the recirculation sludge stream to come back into the DN basin via gravity. A variable flow around 75% (in function of the permeate flow extracted by the membranes) of the sludge flow feeding the filtration chambers returns by gravity to the biological reactors through the open channel (overflow).

The membrane tanks have a dedicated air supply network allowing the use of the 100% PURON® aeration protocol. The membrane blower has an overall capacity of 72m^3/hr at 0.52 bar. The specific software oscillates the air flow to be sent to the module according to the extracted Flux.

Permeate (filtered effluent) is extracted through the membrane via a positive displacement lobe pump. This pump is reversible and also facilitates the periodic backflushing operation. The permeate system discharges into a common final storage permeate (UF) tank. Just 300lt storage would be sufficient to carry out the various back flushing operations of the membranes and the automatic routine maintenance cleaning steps with chemicals. Nevertheless, the same volume (300lt) will be used so that recovery cleaning procedures can also be carried out without any further water requirement. This Recovery cleaning is expected up to twice per year and consists of membrane submergence in a chemical solution. The membrane chamber would be drained of sludge and filled with permeate that will be taken from the 300lt storage. This procedure is manual and requires long soaking times from 8-12 hours. The time required to drain each membrane tank should not exceed 45 minutes as well as the filling time with clean water. Consequently, one drain pump (sludge pump) with a capacity of 3-4m^3/hr is installed to fulfil this requirement. The filling time with clean water can be easily respected because the main lobes pumps allow even higher flows.

A separate low flux wash water pump is used during chemically maintenance cleaning of the membranes. Such periodic chemical cleaning is performed at low backflush permeate flow.

The duty MC pump is also used to assist the main lobes pump in filling the membrane compartment with filtered water required to effectuate the recovery cleaning cycles of the membranes.

Oxidizing Maintenance Cleaning is expected once per day and will consist of a cleaning protocol in sludge whereby Sodium Hypochlorite is injected at low concentration (up to 200 ppm) into the low flow back flush stream. Train cleaning occurs individually. In fact, the Oxidizing dosage is also required to fill the membrane tank with high chemical concentration during recovery cleaning procedures. For this second purpose a second dosage should be foreseen.

Acid Maintenance Cleaning is expected once per week and consists of a cleaning protocol in sludge whereby Citric Acid at 3 pH is injected at high concentration (up to max 2000 ppm) into the low flow back flush stream. The same dosage could also be used for recovery cleaning purposes.

In order to make the dosage installation more flexible the proposal for the dosing pumps is keeping them all the same size. Thus in both oxidizing and acid dosing stations pumps are installed (32l/h at 2 bar for the oxidant and 4,4l/hr at 2 bar for the acid step) that could run in parallel depending on the specific cleaning needs. In both acid and oxidizing dosing stations one pump is installed.

Sodium Hypochlorite and Citric Acid shall under no circumstance be mixed together during the automatic procedure due to the risk of chlorine gas formation.

Table 4 shows the estimated chemical reagent consumption for membrane regeneration, for the cleaning frequency mentioned above (one oxidizing maintenance cleaning per day, one acid maintenance cleaning per week and two complete recovery cleanings per year).

Table 4: Estimated chemical reagent consumption for membrane regeneration

Chemical reagent	Maintenance cleaning	Recovery cleaning
NaOCl (14%)	43g/cycle	2,10kg/cycle
Citric Acid (30%)	340g/ cycle	2,10kg/cycle

2.5 General System Control

The permeate extraction system of the train is controlled via the level of the bioreactor system. There is a level gauge in the nitrification tank used as the reference level for the permeate extraction system. At a defined lowest level in the bioreactor the permeate extraction stops. This level is approximately 0.1m under the normal operational level of the tank. The latter may occur during night time operation. At a set optimal level the permeate extraction system starts at the optimum flow.

If the level decreases the train, a switch off delay timer is used to avoid rapid switching of the train. If the level increases still further, caused by PHF, the train will ramp up from the optimum flow to the maximum overall flow of 10m^3/h net permeate production. The level to cause the Fmax situation is usually at the operational bioreactor level plus 0.1m or just under the overflow protection level. Once the peak has dissipated and the bioreactor level decreases, the system returns to optimum mode.

This type of control system is called flux minimisation – run as long as possible at optimum conditions and when a peak occurs it should be re-established as quick as possible to the optimum. The bioreactor level is used as a damping for the feed flow and a certain volume is used to buffer the feed between an optimum membrane condition and the maximum membrane condition.

2.6 Effluent quality – UF permeate

On condition of the composition and character of inlet waste water corresponds to sewage wastewater in accordance with national rules Wastewater treatment plants CHEMBOX U-30EP are able to normally achieve the drain values presented in Table 2 below. The membrane technology represents a combination of the conventional activation aeration process and very efficient separation of the solid (activated sludge) and liquid phase (treated wastewater). Mechanically pre-treated wastewater is aerated, biologically treated and then all solid substances with a larger size than the size of the membrane pores, i.e. 0.03 µm, are removed from it with the use of the membranes. Thus, particles that have a smaller size than the pores only penetrate from the filtered media into the filtrate (permeate).

Table 5: Wastewater treatment plants CHEMBOX U-30EP drain values

Parameter	Units	Drain values
BOD5	mg/l	≤10
COD	mg/l	≤ 70
TSS	mg/l	≤5
NO3	mg/l	= 14
VSS	mg/l	= 2
TN	mg/l	= 15
Non Volatiles of Effluent	mg/l	=0
TP	mg/l	=10
NH4-N	mg/l	= 0,50
Fcoli	cfu/ ml	≤100cfu /100ml

3 RO Treatment System Description - Tertiary treatment

BOX 1: WORKING TERMINOLOGY

Reverse Osmosis*: A high pressure [over 10 bar (1000 kPa)] membrane separation process used primarily for the removal of organic matter and salts from wastewater and for desalting brackish water and seawater.*

Concentrate – brine: *Flow of outlet water discharged from the Reverse Osmosis Plant having high quantity of salt (high conductivity).*

Feed water: *Flow of inlet water to the Reverse Osmosis Plant.*

Permeate: *Flow of outlet water produced by the Reverse Osmosis Plant having low quantity of salt (low conductivity).*

Conductivity: *The conductivity of an electrolytic solution is the reciprocal of the electric resistance opposed by a cubic centimetre of the same solution, at a prearranged temperature, that is the reciprocal of the resistance measured between two electrodes of 1 cm2 of surface put at the distance of 1 cm and immersed in the same solution. Usually it is expressed in μSiemens/cm.*

Recovery Rate: *The ratio between permeate and feed water.*

Total Dissolved Solids: *The total quantity of solids diluted in water and expressed in mg/lt or ppm.*

Silt Density Index: W*ater impurities index, which can be of organic or inorganic nature.*

Rejection: *The reduction percentage of salts diluted in the feed water.*

3.1 RO principles

The phenomenon of osmosis occurs when pure water flows from a dilute saline solution through a membrane into a higher concentrated saline solution, as illustrated in Figure 4a. A semi-permeable membrane is placed between two compartments. Semi-permeable means that the membrane is permeable to some species, and not permeable to others. Assume that this membrane is permeable to water, but not to salt. Then place a salt pollution in one compartment and pure water in the other compartment. The membrane will allow water to permeate through it to either side, while salt cannot pass through the membrane.

As a fundamental rule of nature, this system will try to reach equilibrium. That is, it will try to reach the same concentration on both sides of the membrane. The only possible way to reach equilibrium is for water to pass from the pure water compartment to the salt containing compartment, to dilute the salt solution.

Figure 4a also shows that osmosis can cause a rise in the height of the salt solution. This height increases until the pressure of the column of water (salt solution) is so high that the force of this water column stops the water flow. The equilibrium points of this water column height in terms of water pressure against the membrane are called osmotic pressure.

If a force is applied to this column of water, the direction of water flow through the membrane can be reversed (Figure 4b). Note that this reversed flow produces pure water from the salt solution, since the membrane is not permeable to salt.

Osmosis-
Reverse Osmosis

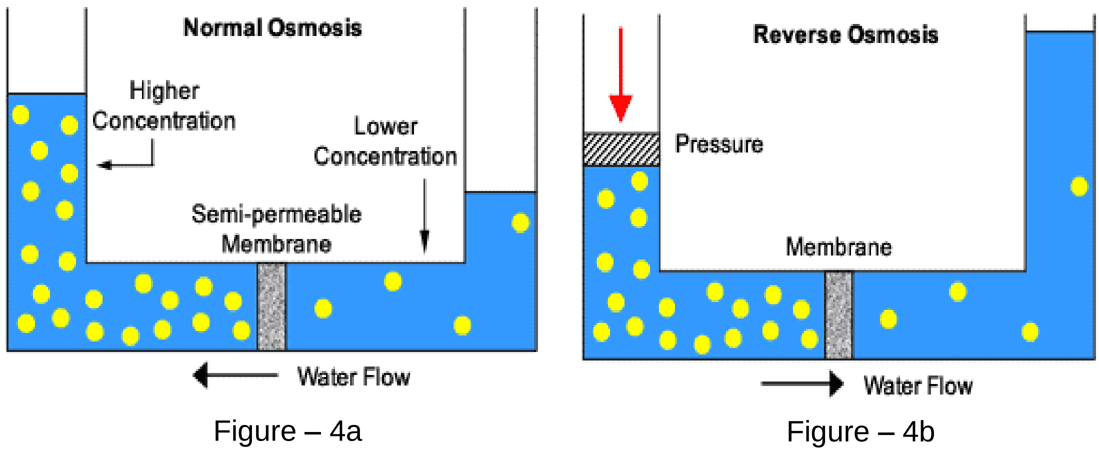

Figure 4: Representation of normal osmosis and reverse osmosis

3.2 RO in practice

With a high pressure pump, pressurised saline feed water is continuously pumped to the module system. Within the module, consisting of a pressure vessel (housing) and a membrane element, the feed water will split in a low saline product, called permeate and a high saline brine, called concentrate or reject (Figure 5). A flow regulation valve, called concentrate valve, controls the percentage of feed water that is going to the concentrate stream and permeate which will be obtained from the feed.

In case of a spiral wound module (Figure 6) consisting of a pressure vessel and several spiral wound elements, pressurised water flows into the vessel and through the channels between the spiral windings of a spiral wound elements. Up to seven elements are connected together within a pressure vessel. The feed water becomes more and more concentrated and will enter the next element, and at last exists from the last element to the concentrate valve where the applied pressure is collected in the common permeate tube installed in the centre of each spiral wound elements and flows to a permeate collecting pipe outside of the pressure vessel.

Mainly treatment -

Reject of salts = Desalination

Reverse Osmosis membranes provide water almost without salts and brine

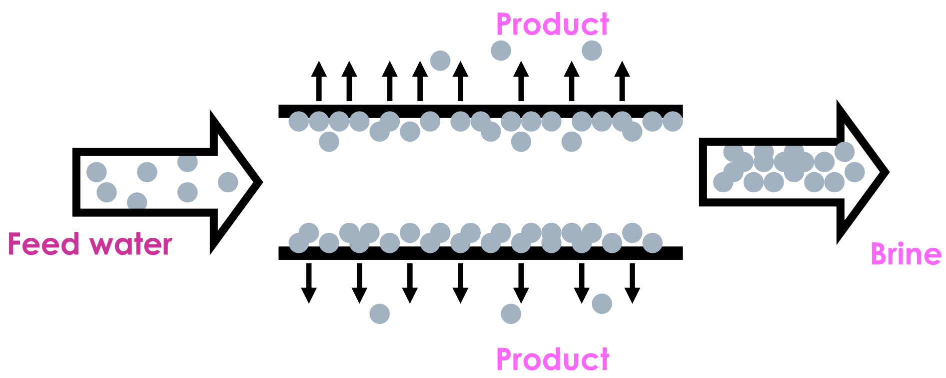

Figure 5: RO operation

Spiral wound membranes

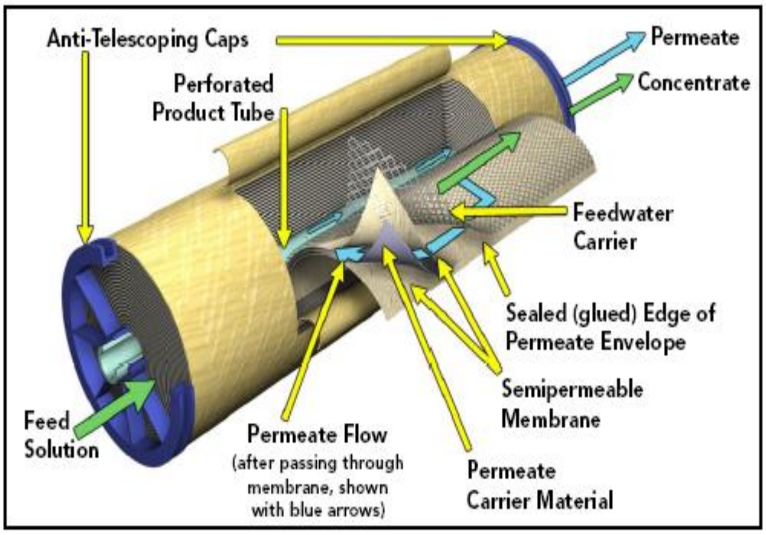

Figure 6: Spiral wound membranes

3.3 RO benefits

Reverse Osmosis (R.O.) process provides several benefits. The R.O. technology is an advanced high efficiency rate water treatment process and represents the finest level of liquid filtration available today. Whilst ordinary filtration systems use a screen to remove particles from a water stream, Reverse Osmosis utilizes a membrane to remove dissolved minerals. Therefore R.O. is a membrane process for desalting saline water by the application of hydrostatic pressure to drive the feed water through a semi permeable membrane while a major portion of its impurity content remains behind and is charged as waste.

The largest and most important application of reverse osmosis is the production of pure water from seawater and brackish water. In most cases, the membrane is designed to allow only water to pass through this dense layer, while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–82 bar (600–1200 psi) for seawater, which has around 27 bar (390 psi) natural osmotic pressure that must be overcome.

A number of benefits derive from the use of Reverse Osmosis Systems:

- Small Foot-Print Area
- Suitable for sea and brackish water (depend on the applications)leachate of landfill, industrial water, tertiary treatment
- Friendly to the environment, as they are not produce or use any harmful chemicals during the process

- Production of purified water, colour free, without minerals and other contaminants that cause water to smell unpleasant
- Very Compact design and robust operation
- Fully automatic operation with remote monitoring is possible (Minimum Attendance)
- Low energy requirements and low running cost
- Excellent Treatment Efficiency and Effluent Quality
- Easy transportation, fast installation and quick start up

Because of its efficiency, the Reverse Osmosis technology can be used for Sea and Brackish water as well as for treated waste water post treatment, raw water pretreatment, tertiary treatment and Industrial wastewater (food & drink industry, process water, etc).

Here in our application The Reverse Osmosis Treatment Unit is part of an integrated Treatment Facility commonly referred to as Waste Water Compact Integrated Treatment Plant.

Table 6 presents the electromechanical equipment and instruments incorporated in the RO unit and Table 7 presents the final effluent quality.

Table 6: RO electromechanical equipment and instruments

RO	No of items
Electrical panel	1
HP pump GRUNDFOS CRN 3-23	1
Pumps GRUNDFOS CM1-6	2
Automatic valves SIRCA ADP 12	4
Flow meters KINETIC STUBE	3
Conductivity meters HANG LANGE	2
PRESSURE TRANSMITER	2
PRESSURE SWITCH	1
Vessel CIP 120 lit	1
Membrane vessels wave cyber	4
Manometer 0-10 bar WIKA	1
Cartridges filter	1
INOX SKID RO	1
Dosing pumps GRUNDFOS DDE	2
Chemicals' Vessel 100lit	2
Air Compressor TOROS 24 LIT 2 HP	1
Flow meter KHRONE D32	1

Table 7: Final Effluent Quality (RO Permeate)

Parameter	Units	Values
BOD	mg/l	≤1,0
COD	mg/l	≤5,0
TSS	mg/l	nil
CONDUCTIVITY	μS/cm	≤ 200

Normally the UF permeate still contains dissolved salts, colour and some microorganisms. Depending on the end using destination the effluent must or must not go for further treatment (tertiary treatment).

In our case the MBR effluent is led to further treatment in the Reverse Osmosis. The Reverse Osmosis including the E/M equipment and the MBR + RO controllers are placed into a second ISO Box and located nearby MBR.

A HP pump sends the feed inside the membrane vessels. The feed is separated into a low salt concentrated product (which is the permeate) and a high salt solution (which is the concentrate). The correlation between permeate and feed is called Recovery Rate (RR).

Table 8: RO membrane specs

Type	Polyamide Thin-Film composite
Active surface	8,1m^2
Applied pressure	6,9 bar
Permeate flow	9,8m^3/d
Maximum operation temperature	45oC
Maximum operation pressure	41 bar
pH Range during operation	2-11
Dimensions	4'' D x 100 cm L

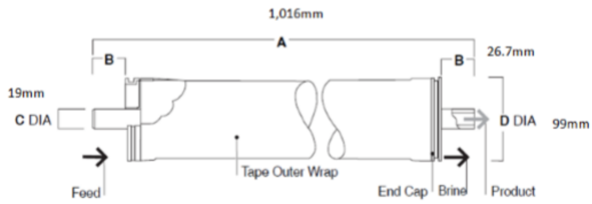

Figure 7: RO Mebrane scheme

Automatic remote monitoring

Instruments for data acquisition have been incorporated in an online platform including sensors for waste and treated water. Temperature sensors, pH, DO, conductivity, NH4 and NO3 meters, SS and energy meters have been placed into the system. For more information please check D22.2 & D34.2.

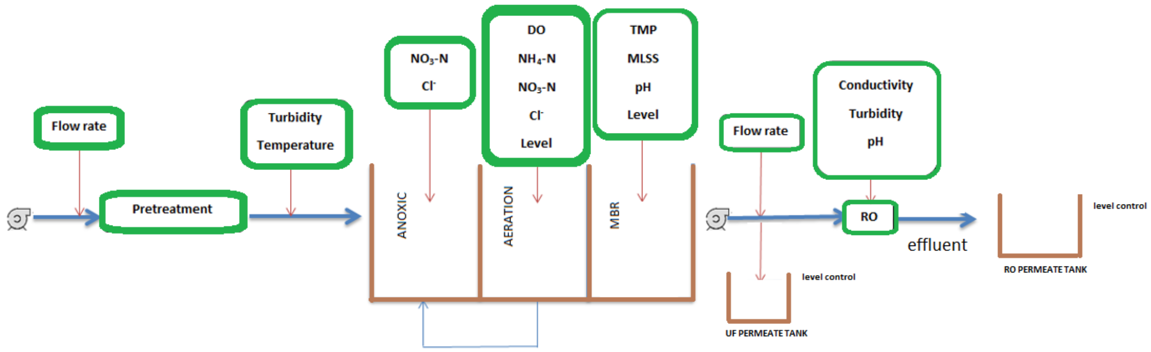

Figure 8: Sensors placed in many positions of the system

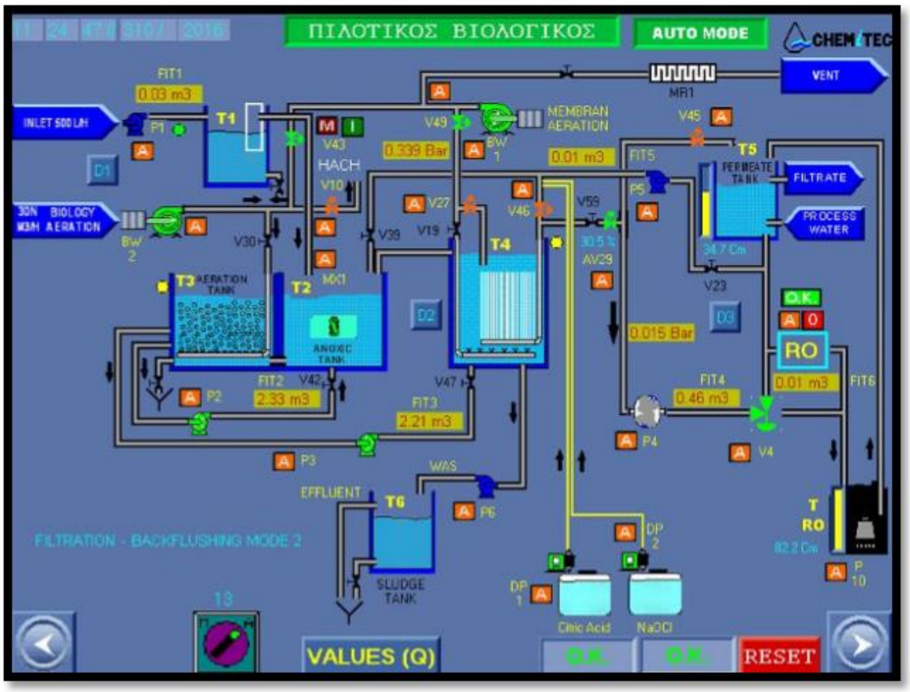

Figure 9: Control of the pilot system

4 Conclusions

The data form a platform that one can make conclusion from local and remote monitoring and also one can have control of the sensors. The data can be presented into relative graphs or excel either in real time or historical issues. Alarm can show problems during operation at real time. It is also available a site with all historical alarms for study of frequency and duration for different cases so we make upgrade of the design or they prevent maintenance of the unit accordingly. PLC, SCADA, HMI are also available for many regulations such as control of pumps, valves, blowers, pressure meters, membrane cleaning etc.

All these details make the proposed system robust and innovative. Evaluation of the results obtained in the demonstration and guidelines and recommendations for transfer to other Water Scarcity sites will be submitted and extensively discussed in the subsequent deliverable D34.3 – "*Evaluation of the results obtained in the demonstration and guidelines and recommendations for transfer to other Water Scarcity site*". Furthermore, a showcase of Athens pilot can be found in D41.4.

Figure 10: Athens pilot – Outer view

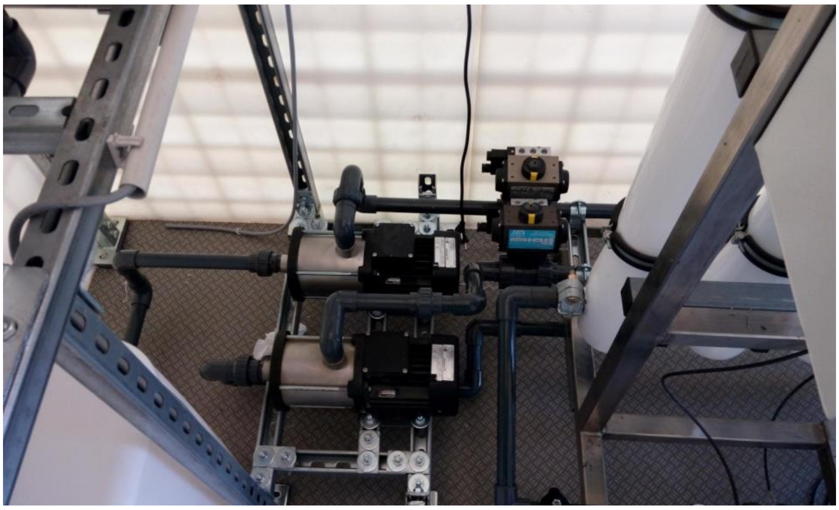

Figure 11: Feed RO pump and CIP RO pump

Figure 12: MBR –RO instrument controllers

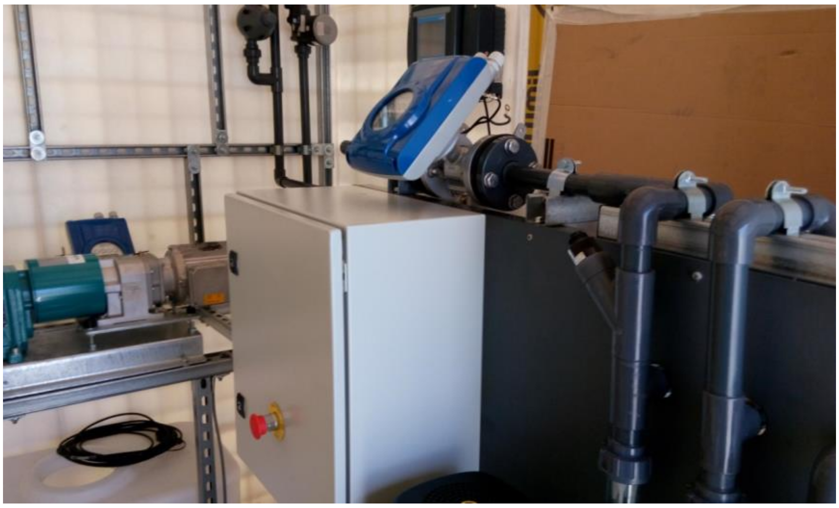

Figure 13: RO MCC panel

Figure 14: MBR MCC panel

Figure 15: MBR Layout

Figure 16: NO3 /NH4 and DO instruments

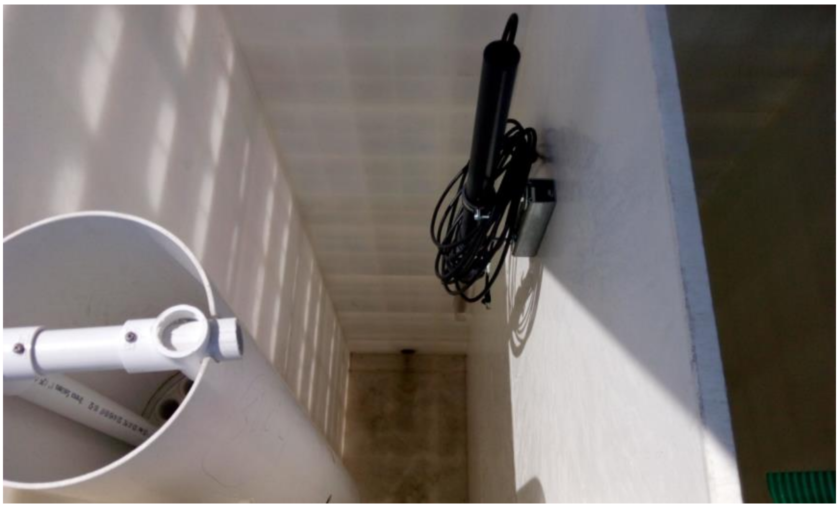

Figure 17: Waste conductivity meter

Figure 18: NH4 measurement instrument – mixer

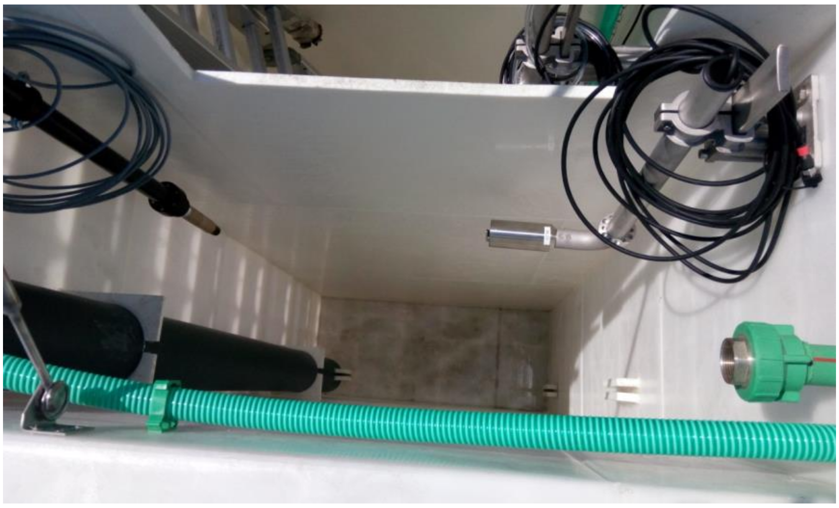

Figure 19: MLSS /pH measurement

Figure 20: Aeration Tank

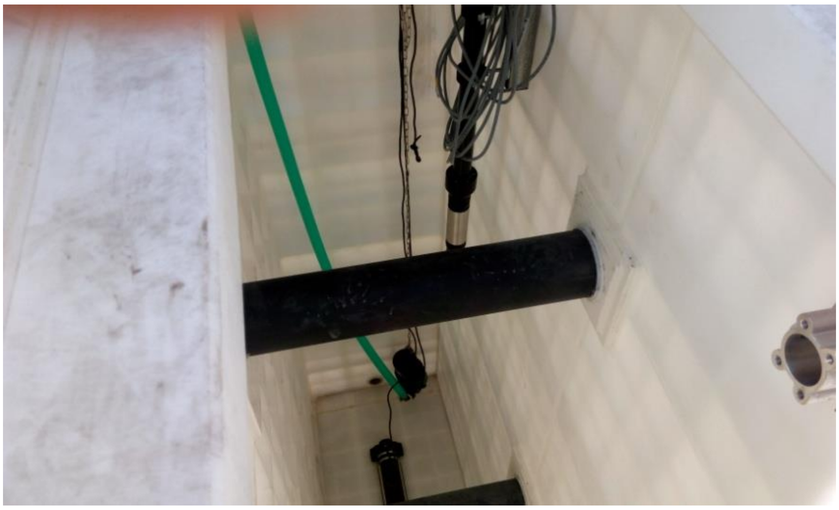

Figure 21: Aeration Tank

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