Operating Water Treatment and Recycling Systems in Isolated Environments

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Providing water for remote habitats in isolated environments is challenging due to logistics and constraints related to energy, volume and weight requirements. This is also the case for the Princess Elisabeth Antarctic Station. The building is located 200 km inland and accommodates during the summer season up to 50 scientists and crew members. The grey and black wastewater is treated in an installation combining biological and physicochemical processes. The Station is an ideal test case to evaluate the operational aspects. An effluent quality that allows discharge and reuse is achieved by these processes. Every summer season the wastewater treatment system and its performance is optimized by improving the control and automation. Due to the high load of nitrogen in the wastewaters, the removal of nitrogen components is a challenge. A control algorithm implemented in the programmable logic controller allowed to maintain nitrate concentrations in the effluent at an average concentration of 5.4 mg/l which is far below the WHO limit of 50 mg/L. The hibernation of microorganism during last winter was evaluated. Nitrifying bacteria from the previous season were successfully reactivated in the summer season of 2019-2020. During the last season, the average water use at the Station was just below 40 L per person per day and 21 % of this amount was recycled water. A total volume of 138 m³ black and grey wastewater was treated before reuse or discharge.

Nomenclature

AOB	=	Ammonium Oxidizing Bacteria
COD_t	=	Total Chemical Oxygen Demand
DO	=	Dissolved Oxygen
FA	=	Free Ammonium
FNA	=	Free Nitrous Acid
IPF	=	International Polar Foundation
LSSs	=	Life Support Systems
NOB	=	Nitrite Oxidizing Bacteria
Nt	=	Total Nitrogen
OM	=	Organic Matter
PCR	=	Polymerase Chain Reaction
PLC	=	Programmable Logic Controller
PEAS	=	Princess Elisabeth Antarctic Station
QS	=	QinetiQ Space
SCADA	=	Supervisory Control and Data Acquisition
VSS	=	Volatile Suspended Solids
WHO	=	World Health Organization
WMS	=	Water Management System
WWTS	=	Wastewater Treatment System

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I. Introduction

Long-distance manned space missions for exploration of new habitats in outer space might be reality within a few decades. These challenging activities require the development of adequate solutions for space crafts, energy supply, communication systems and Life Support Systems. Life Support Systems ensure that astronauts can live in a comfortable and safe environment proving conditioned air, oxygen, food, water and waste evacuation. Advanced Life Support Systems consider waste as a resource and aim for recycling of air and water after appropriate treatment and conditioning

The availability of water is a key element for enabling life at long-distance extra-terrestrial environments. Water is essential for consumption and hygienic use by the crew. Moreover, water is a fluid for thermal management systems, a barrier against high energy radiation, a source of hydrogen and oxygen and a solvent enabling multiple (bio)chemical reactions.

Providing water for remote habitats in isolated environments is challenging due to logistics and constraints regarding energy, volume and weight requirements. This is also the case for the Princess Elisabeth Antarctic Station. The building is located 200 km inland and accommodates during the summer season up to 50 people.

II. Princess Elisabeth Antarctic Station

In 2004, the Belgian government commissioned the International Polar Foundation IPF to design and construct a new research Station located in Antarctica. The construction of the Princess Elisabeth Antarctic Station was realized during the period 2007-2008 and the research Station is fully operational from 2009 on. The Station is located about 200 km land inward near Utsteinen Nunatak, on a small granite ridge at a height of 1382 m as presented in Figure 1. The consolidation on bedrock and the specific architecture ensure that the Station will withstand the extreme weather conditions that can occur at this location.

The Station is filling the gap of 1000 km between the nearest Japanese and Russian stations. Due to this unique location, the Station is an ideal hub for polar scientists active in the field of glaciology, earth and atmospheric sciences and biology. The Station was initially designed and constructed to accommodate a crew of maximum 18 persons. During recent years the Station occupation has increased to reach an average of 30 persons, including scientist and operational crew. With short term visitors, the total occupation can be 55 persons. This required an expansion of the Station with a garage, workshops and heated sleeping cabinets. Additional sanitary installations with ‘dry toilets’ were constructed. However, this sanitary infrastructure is stand-alone and not integrated in the existing wastewater treatment system. The Station is only inhabited during the summer season starting in early November and ending in early March. The first operational team starts up the facilities of the building before scientists and guests are arriving. End of February the shutdown procedure is initiated, and the Station is left in stand-by mode until the next season.

The design and implementation of the technical systems was challenging due to the constraints on available space, logistics and energy supply in a hostile and unpredictable environment. The ‘hibernation mode’ of the technical systems need to guarantee that the Station is preserved during winter and can be started up quickly at the start of the next summer season. The requirements are very comparable with those applicable for future extra-terrestrial habitats in space.

In accordance with the Antarctic Treaty, the “zero-emission” concept of the Station limits the impact on the environment. Renewable energy is generated by solar thermal collectors, photovoltaic panels and windmills. Wastewaters are treated, partly reused, and discharged. Waste is collected and at the end of the season taken away from the Antarctic region by the cargo.

Figure 1 View of the Princess Elisabeth Antarctic Station

III. Water Treatment and Conditioning

A. Context

The International Polar Foundation was in 2017 contracted by the Belgium Government to operate the base for the next six years. The International Polar Foundation and QinetiQ Space established a collaboration agreement with the aim to promote the Station as a reference platform for future Life Support Technology for Manned Space Exploration. Within this framework, an audit was performed by QinetiQ Space on the status and performance of the water treatment and conditioning installation situated in the technical core of the building. This was necessary since the equipment was designed based on an occupation of a maximum of 20 persons. During recent seasons, the occupation increased to a maximum of 55 people which required optimized equipment and operations

B. Water Resources and Consumption

Water is needed for human consumption, food preparation, hygienic use and maintenance of buildings and clothes. A schematic diagram of the water distribution and consumption is presented in Figure 2. At the start of the season, snow is the primary water source. A snow melter supplies the necessary drinking water to the Station's inhabitants at the start of the season. The melt water is conditioned and stored. Wastewater produced by the different activities is collected in a separate way according to its origin and composition. Wastewater containing particles from metabolic waste and food leftovers is identified as ‘black water’. Water with a lower organic load from showers, laundry and cleaning is called ‘grey water’.

The Princess Elisabeth Antarctic Station features an advanced water treatment system that allows it to treat all the grey and black wastewaters. The water is treated extensively to prevent contamination of the Antarctic environment in accordance with the Protocol on Environmental Protection to the Antarctic Treaty. The treated water is in part recycled for non-drinking applications, which allows to reduce the amount of snow to be melted to produce new water. Eventually, the treated water is discharged to a crevasse near the Station. The recycling rate of treated water depends on the available thermal energy for melting snow and was 25% during the 2019-20 season.

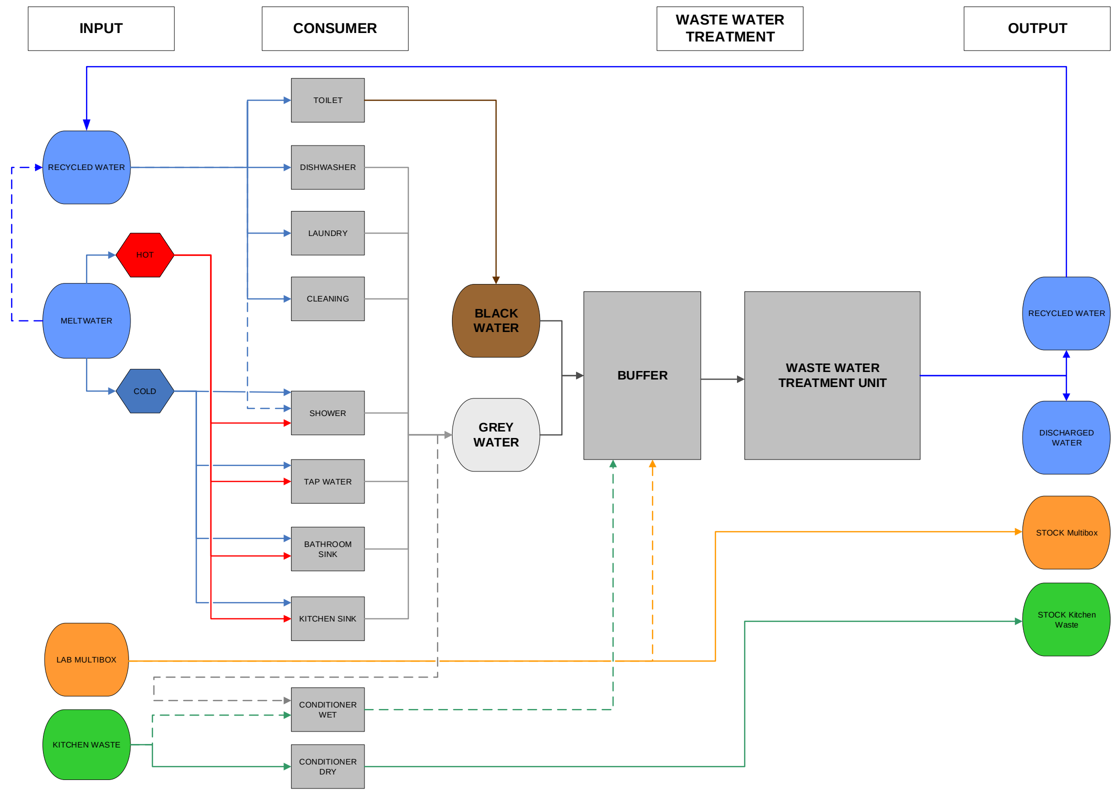

Figure 2. Schematic diagram of the water distribution and consumption at the PEAS

The amount of wastewater produced is given in Table 1. About 6 liters of black wastewater from toilet flush is produced per day per person. The water contains urine and fecal material. This value does not include the total amount of the organic waste per capita because dry toilets are also used near the workshops and the sleeping cabinets in the attached wooden building. Grey wastewater is a mixture of streams from kitchen and cleaning activities and showers. The organic contaminants in wastewater are quantified as the COD_t which is the chemical oxygen demand required to oxidize the organic material. De subscript 't' refers to the total content of COD which includes particulate and dissolved COD. About 40% of the total organic load is present in the black wastewater, 60% is present in the grey wastewater. COD can be expressed as OM or organic matter. The conversion ratio for fecal material is 1.6. This means that 15 g of fecal material per person per day is processed. A daily average of fecal material production is 29 g OM per person[1]. This means that about half of the human metabolic waste is processed in the water treatment system. Another important parameter is the N_t or total nitrogen present in the wastewater. Total nitrogen is the sum of the organic nitrogen, ammonium, nitrite and nitrate. The ratio COD/N is equal to 100/18. This is a typical ratio for municipal wastewater and indicates that there is an excess of nitrogen and an active nitrogen removal step needs to be included in the water treatment process. This is further discussed in paragraph E.

Table 1. Average wastewater production and characteristics

		Black Wastewater	Grey Wastewater	Total
Volume	L/d.person	6	30	36
COD_t	g/d.person	24	36	60
OM	g/d.person	15	-	-
N_t	g/d.person	9	1.8	10.8

C. Configuration of the Water Management System

The configuration of the Water Management System is schematically presented in Figure 3. The WMS include the production system of drinking water, the water distribution system and the wastewater evacuation and treatment system. The production system for drinking water includes the snow melter, the active chlorine disinfection system and the melting water storage buffer from which water is distributed to points of consumption as shown in Figure 2.

The Wastewater treatment system combines biological and physicochemical treatment technology. Black water is collected in a buffer system in which all particles are macerated to a size of 4 mm by means of a submerged macerator pump. The water is transferred by the same pump to an anaerobic bioreactor in which fermenting bacteria are degrading the particles into smaller soluble molecules in the absence of oxygen and at temperature of 55°C. The thermophilic process ensures also elimination of pathogenic microorganisms. The reactor content is filtered over ceramic membranes and the filtrate is forwarded to the aerobic treatment system and further processed together with the grey water. In the aerobic system, soluble organics are biodegraded and converted to CO_2 and N_2. The water is separated from the bacteria by a flat sheet membrane nanofiltration unit. The effluent is finally polished in an activated carbon column to remove traces of organics substances. In case that the effluent is stored in the recycled water tank, the pH is adjusted and the water disinfected with an automated dosage of active chlorine at a concentration of 0.2 ppm. No further disinfection is performed when discharged in the crevasse. Note that it was decided not to include a final treatment by means of reverse osmosis to save energy necessary for pumping. The rational of the use of membrane bioreactors is further described in next paragraph D.

The WWTS is mounted on four mobile stainless steel frames on wheels or ‘skids’. The integrated skids were transported overseas to the PEAS. The skids contain the reactors, the associated sensors and actuators and maintenance utilities. The system is integrated in a technical room located at the central core of the building. The water treatment room is located between the battery room and the electrical power distribution system. This required that all off-gassing needed to be minimized and evacuated. Stringent requirements were respected during the design phase. The skids are positioned in a space with a small footprint size of 3.2 m x 3 m. The total weight needed to be below 500 kg to allow lifting with a mechanical pulley. The total installed power of devices needed to be below 5 kW.

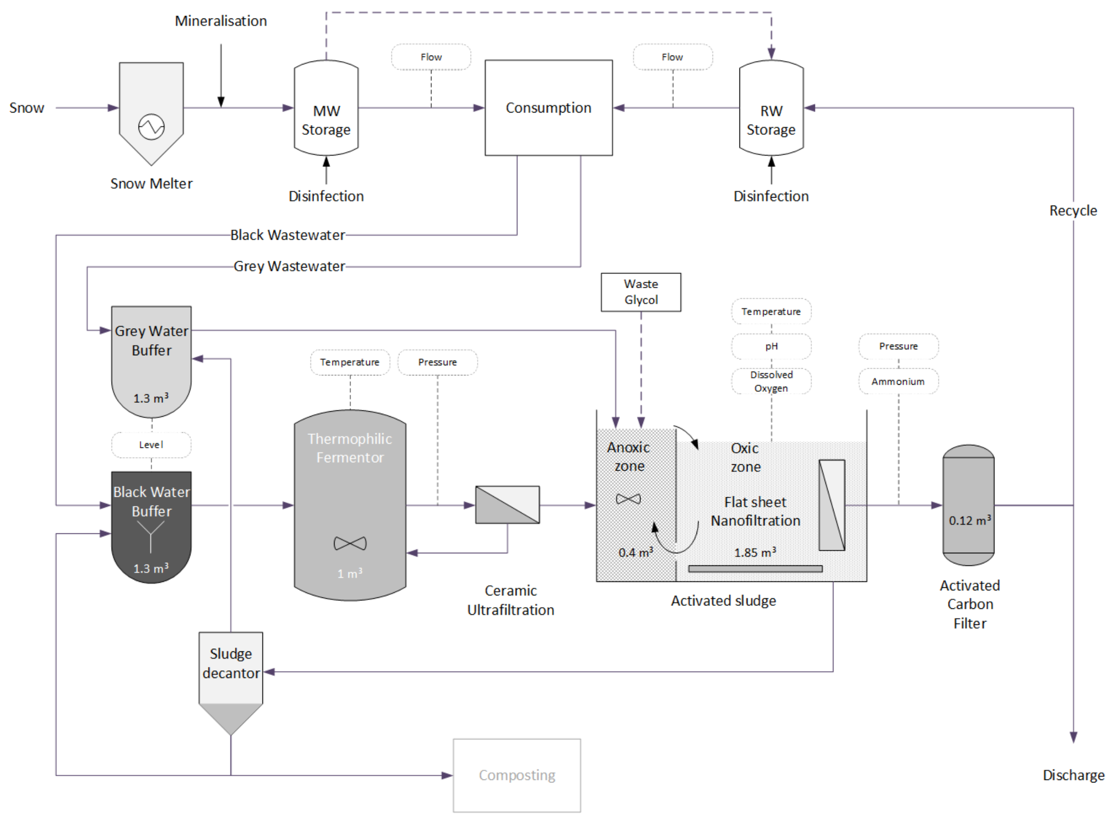

Figure 3. Water Management System at the PEAS

D. Membrane Bioreactors

Organic material present in wastewater is efficiently biodegraded by microorganisms. Biodegradation can occur in aerobic or anaerobic conditions. The choice of the optimal process depends on the characteristics of the wastewater. Anaerobic biodegradation is traditionally used for water with a high load of organics and suspended particles. The pathway of the process is presented in Figure 4. The first step in anaerobic degradation is the hydrolysis of solid particles into soluble components by bacterial enzymes. The produced long-chained carbohydrates, fatty acids and amino acids are in the acidogenesis step fermented resulting in the production of volatile fatty acid, alcohols and ammonia. In the subsequent acetogenesis and methanogenesis step, these products are further fermented with CO_2 and CH_4 as final products. Several genera of bacteria are involved in the anaerobic biodegradation process. Since the fermentation products themselves might be inhibitive in a certain concentration for the involved bacteria, the process must be in balance to prevent autoinhibition. The anaerobic process at the PEAS is operated in such a way that the process stops at the acetogenesis phase. The produced fermentation products are not further converted to biogas but separated by means of ultrafiltration and fed to the anoxic stage of the aerobic activated sludge. In this way, readily biodegradable COD is available for the denitrification process described in paragraph E. The ceramic ultrafiltration membranes are Atech Al_2O_3/TiO_2 ceramic 19 channels membrane elements with 8 mm width each and a pore size of 0,05 µm. A centrifugal pump recycles the fermenter content through the membranes resulting in a tangential flow in the membranes of 2 m/s. A peristaltic pump is collecting the filtrate containing the fermentation products. The undigested particles are recycled to the reactor. In that way the hydraulic residence time is uncoupled from the solid residence time. A long solid residence time can be achieved which is favorable to digest the slowly biodegradable fraction such as fibers.

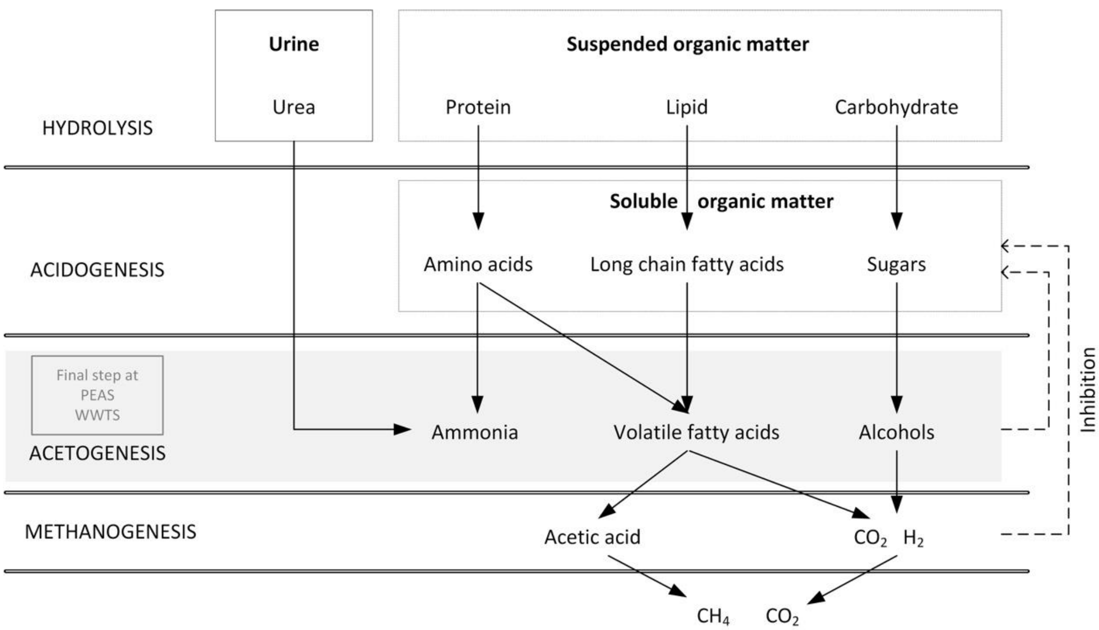

Figure 4 Anaerobic digestion pathway

The aerobic activated sludge system has an anoxic zone of 0.4 m³ and an aerated zone of 1.45 m³. The aeration is provided by a blower with a capacity of 90 m³/h at 200 mbar counter-pressure that distributes the air through membrane aeration disks. A polyethersulfone flat sheet nanofiltration membrane rack is inserted in the aerated zone of the activated sludge. The Microdyn Bio-Cel membrane has a nominal pore size of 0.04 µm which allows to collect an effluent free of bacteria through the suction of a peristaltic pump.

The membrane bioreactor systems allow also to operate the system at higher sludge concentration up to 12 g volatile suspended solids (VSS) per liter. The VSS is a measure of the total sludge biomass. This allows to increase the sludge COD load. However, the aeration capacity is the limiting factor in this situation.

The activated sludge system is treating the grey water and the filtrate of the digester which contains readily biodegradable COD. The feed enters in the anoxic zone where the COD is used for denitrification. The activated sludge is continuously recycled between the aerated and anoxic compartment for nitrogen removal. There is a possibility to add glycol to the denitrification compartment in case no sufficient COD is available. Details on the process are described in paragraph E and H.

E. Nitrogen removal

The wastewaters contain a high load of nitrogen because of the presence of urine and proteins from food leftovers. In order to meet the requirements for discharge and the reuse of the water it is necessary to remove the nitrogen, including organic nitrogen, ammonium, nitrate and nitrite. The Drinking Water Directive (98/83/EC) sets a maximum allowable concentration for nitrate of 50 mg/L or 11 mg/L expressed as nitrate nitrogen and 0.5 mg/L of ammonium in water for consumption. These values are also recommended by the WHO in their latest Guidelines for Drinking-water Quality[2].

Nitrogen is mainly present as urea in urine. Hydrolyses of urea results in the formation of ammonium and bicarbonates. The urine is present in the black wastewater and enzymatic urea hydrolysis by urease takes place in the fermenter according equation 1. Note that the reaction is causing an increase in pH.

$$CO(NH_2)_2 + 2\ H_2O + H^+ \rightarrow 2\ NH_4^+ + HCO_3^- \qquad (1)$$

Ammonium can be further converted by bacterial oxidation into nitrate. Finally, nitrate can be reduced to nitrogen gas and released in the atmosphere. The nitrification-denitrification cycle is a natural process in which several genera of bacteria are involved.

The first step is performed by Ammonium Oxidizing Bacteria (AOB) that oxidize ammonium to nitrite This reaction is referred to as nitritation and is usually the rate limiting step of the nitrification. The genus *Nitrosomonas* is a typical AOB besides *Nitrospira* and *Nitrococcus*. The reaction is acidifying the activated sludge.

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O \qquad (2)$$

Nitrite oxidizing bacteria (NOB) are responsible for the oxidation of nitrite to nitrate. This reaction is referred to as nitratation. A typical NOB genus is *Nitrobacter*.

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \qquad (3)$$

In anoxic conditions where no dissolved oxygen is present, the nitrate can be the terminal electron acceptor for the oxidation of dissolved organic substances. Denitrifying bacteria are facultative aerobic heterotrophs and can switch from aerobic respiration to denitrification in anoxic conditions. The reaction is presented in equation 4. Denitrification requires the availability of readily biodegradable COD such as alcohols are volatile fatty acids that are produced in the fermentation reactor.

$$5CH_3OH + 6NO_3^- \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^- \qquad (4)$$

In practice, a good understanding of the described principles is required in order to create and maintain the optimal process conditions for the bacteria. Nitrifying microorganisms are sensitive to multiple compounds which can affect their growth and activity rates or even completely inhibit the nitrification. Inhibition and toxicity are species dependent. The most important inhibitory compounds are free ammonium (FA) and free nitrous acid (FNA), which are also the feed and intermediate products. The multiple step nitrification-denitrification process requires a careful operation of the water treatment system which is supported by advanced instrumentation and automation at the PEAS as described in paragraph H.

F. Biomass Inoculation and Growth

The WWTP at PEAS is fully depending on microbial processes. Since the treatment system is only in operation during the summer season the challenge is to inoculate and start-up the system in a reliable and fast way. At the start of the season about 80 liter of start-up inoculum with nitrifying bacteria is transported each season to the PEAS to start up the activated sludge system. In order to increase the start-up speed, biomass was stored at the end of season 2018-2019 in hibernation conditions (around 4°C and no aeration) and used to start-up the season 2019-2020. The start-up of the activated sludge was successful and discussed in paragraph J. The stored inoculum together with the imported inoculum allowed a direct startup and treatment of the produced grey wastewater. Samples of the 2019-2020 will be characterized using PCR analysis techniques to identify the bacterial community and to evaluate the stability during time.

The start-up of the anaerobic system relies on the autochtonous bacterial community present in the black wastewater. Anaerobic sludge can hibernate for several months as long it does not freeze.

The anaerobic bacteria and nitrifying bacteria are slow growers and their production of bacterial sludge is minimal. Heterothrophic aerobic bacteria have a high sludge yield. During season 2019-2020, detailed data were collected to optimize the sludge handling in the upcoming seasons.

G. Control System and Automation

An overview of the architecture of the control system is given in Figure 5. The WMS is connected to the central control system of the PEAS. This control system exists of two redundant Quantum processors. The processors retrieve data from sensors and command actuators. Control algorithms are programmed at PLC process level and a SCADA system allows the user to interact with the process via a synoptic display. A view of the interface of the WWTP is presented in Figure **6**. The SCADA can be accessed via satellite and VPN connection from virtually any place. The high level of automation and remote access allows to support the onsite operator in an interactive and remote way.

The WWTP was during season 2019-2020 equipped with an online AMTAX® ammonium analyzer from Hach. The analyzer communicates via a Hach SC1000 transmitter using the MODBUS protocol with the Quantum PLC. A control algorithm described in Paragraph H was implemented in order to automate the transfer of filtrate from the digester to the activated sludge reactor. The ammonium concentration in the sludge needs to be maintained as low as possible to prevent autoinhibition of the nitrification process.

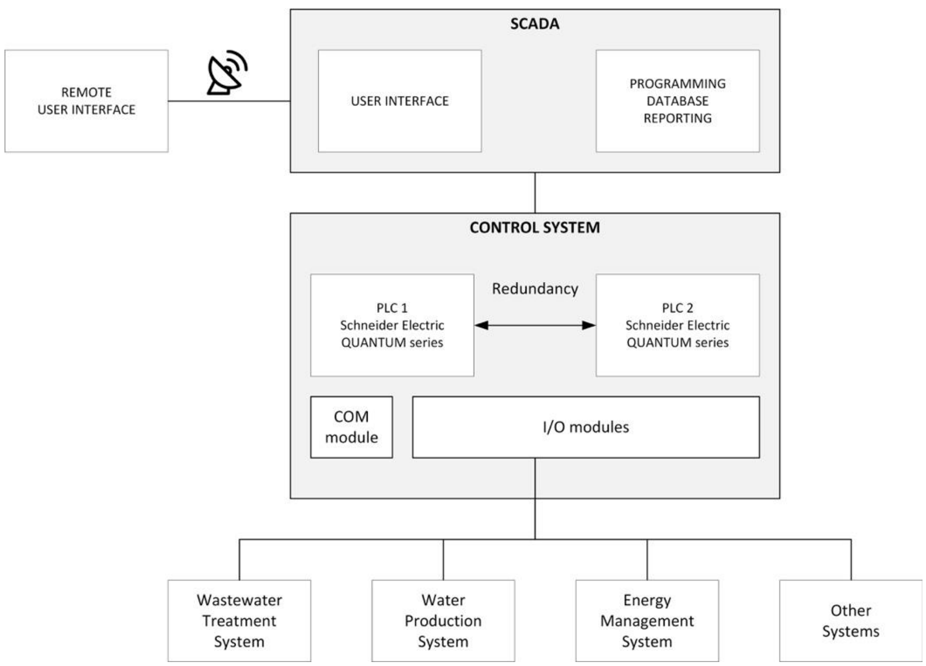

Figure 5 Architecture of the control system at PEAS

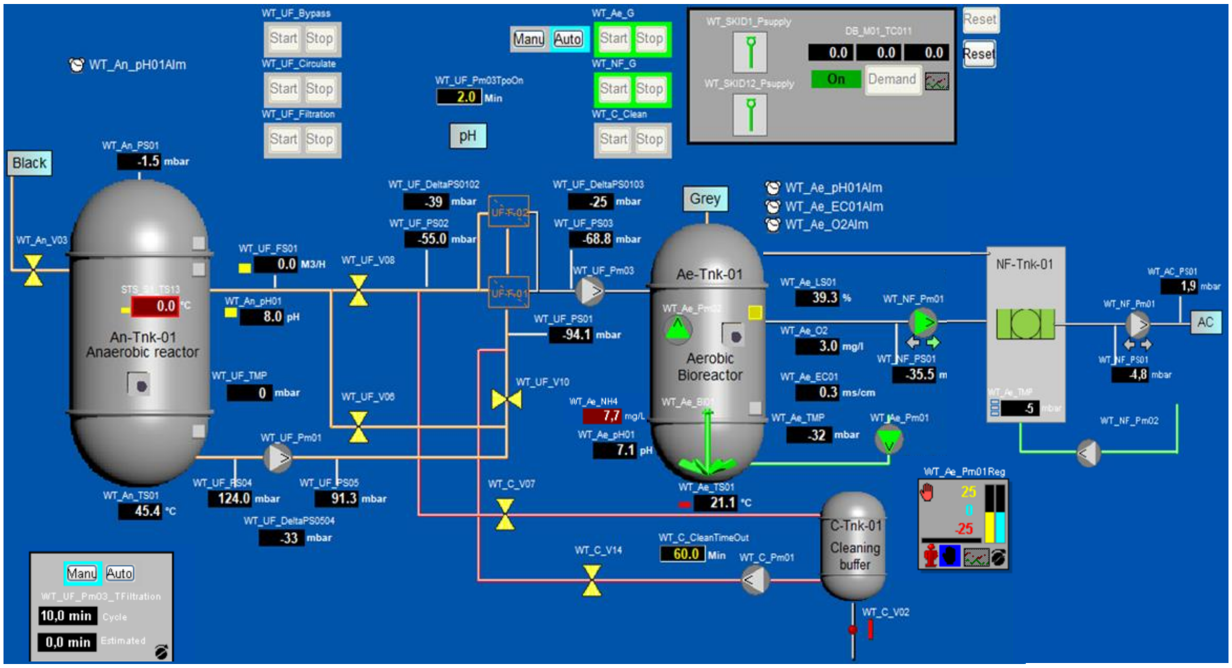

Figure 6. **Water treatment screen of the SCADA interface, allowing to supervise the operation of the anaerobic and aerobic reactors.**

H. Optimization of nitrogen removal

Effective control of the nitrogen load to the bioreactors is paramount to reaching nitrogen removal targets and to maximize process performance. While ammonium ions are a source of energy for bacteria, these can also induce toxicity and decrease biological activity if building up in the bioreactor. Ammonium is in chemical equilibrium with ammonia, which has an inhibitory effect on AOB, decreasing their activity by 50% at a concentration of 0.7 mg NH_3-N/L[3].

To address this challenge, the inflow of the filtrate of the digester to the aerobic bioreactor is controlled based on the ammonium and dissolved oxygen concentrations inside the bioreactor, according equation 5:

$$T_{filtration\ ,max} = MAX\left\{\frac{[NH_4^+]^* - C_{NH_4^+,o}}{F_i\ C_{NH_4^+,i}} V_{Ae}\ , 0\right\} \quad (5)$$

$T_{filtration,max}$ is the maximal time that filtration of black water can be active (with an influent flowrate F_i and influent ammonium concentration $C_{NH4+,i}$) before reaching the inhibitory ammonium concentration, $[NH_4^+]^*$, at which performance of the reactor will start to decrease. V_{Ae} is the volume of the reactor, and $C_{NH4+,o}$ the concentration of ammonium in the effluent water, which is assumed to be identical to the concentration inside the reactor (continuously stirred-tank reactor). Note the use of the *MAX* (maximum) function to forbid computation of negative times of filtration.

The inhibitory ammonium concentration is calculated according to equation of Anthonisen *et al.*[4], based on real-time values of *pH*, temperature (*T*), and the inhibitory ammonia concentration, C^*_{NH3}:

$$[NH_4^+]^* = \frac{18}{17}\ C^*_{NH_3}\left(\frac{e^{\frac{6334}{273.15+T}} + 10^{pH}}{10^{pH}}\right) \quad (6)$$

Finally, the actual time of filtration required for continuous oxidation of ammonium is estimated based on the bacterial activity, biomass concentration and dissolved-oxygen concentration, and expressed as a function of the maximal time of filtration:

$$T_{filtration\ ,est} = \left(\frac{F_o\, C_{NH_4^+,o} - k_N \dfrac{[DO]}{[DO] + K_{DO}} [X]\, V_{Ae}}{F_i\, C_{NH_4^+,i}} \right) T_{filtration\ ,max} \qquad (7)$$

Where F_0 is the effluent flow rate, k_N the bacterial oxidation rate constant, [*DO*] the concentration in dissolved oxygen , K_{DO} the half-saturation constant for oxygen utilization, and [*X*] is the sludge concentration. As the above equation shows, the rate of ammonium oxidation is assumed to depend on dissolved-oxygen concentration following the Michaelis-Menten behavior with a half-saturation constant K_{DO}[3] equivalent to 1 mg DO/L.

Computed in real time during process operation, the two time variables $T_{filtration,est}$ and $T_{filtration,max}$ are used to control cycles of operation of the pump that introduces black water digestate into the aerobic reactor. In a period of time equivalent to $T_{filtration,max}$ black water filtration will be active for a variable amount of time between 0 and $T_{filtration,max}$ and set as $T_{filtration,est}$.

IV. Operational results

I. Optimization of Nitrogen Removal

Figure **7** shows the results of the control strategy described in paragraph H. When the ammonium concentration in the bioreactor rises or the oxygen becomes scarce, the filtration time that is instructed to the influent pump decreases. This automatic control strategy ensures an appropriate load onto the reactor, which prevents accumulation of NH_4^+ and subsequent inhibition of bacterial activity.

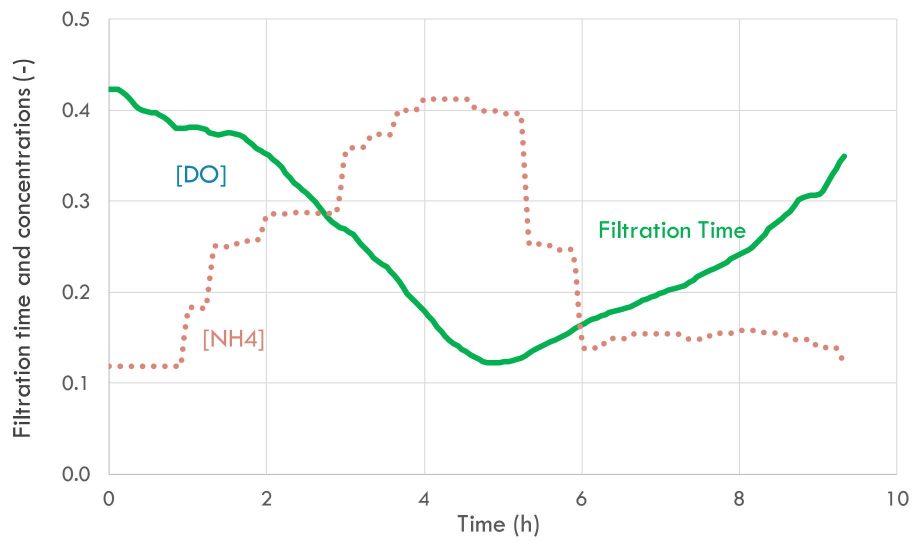

Figure 7**. Results of the control strategy for the ammonium concentration in bioreactor. When the concentration in ammonium inside the reactor rises (dotted curved labelled [NH4]) and / or dissolved oxygen drops (dashed curved labeled [DO]), the calculated filtration time decreases (solid curve), such that less black water is fed to the bioreactor, and vice-versa.**

J. Sludge Production

During the start-up of the system, it is important to stimulate the growth of activated sludge in order to be ready to process an increased load of COD and nitrogen. The growth of sludge is presented in Figure 8. After a lag phase of about 14 days, an exponential growth was observed. The sludge was regularly drained to maintain a sludge

[3] K_{DO} is defined as the concentration at which half of the maximal reaction speed is achieved.

concentration between 8 and 10 mg VSS/L. During the season about 255 kg of COD was processed and 55 kg of sludge organic dry weight produced resulting in a sludge yield of 0.21 kg sludge organic matter per kg COD processed. The possibility of processing of the sludge by co-composting with other organic waste will be investigated for the next season.

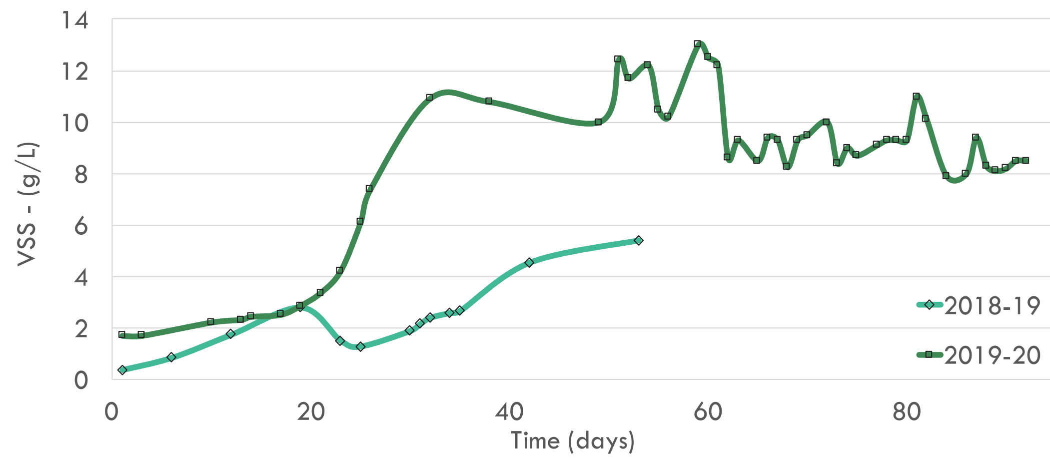

Figure 8. Evolution of the sludge concentration in the activated sludge system

K. Water balance

Despite fluctuations in the occupation and the energy status of the PE Station, the Snow Melter Unit (SMU) has produced enough water to satisfy daily needs of all PEA occupants (30 persons on average, with 3300 man-days over the 16 weeks). Table 2 shows water production data during the 16 weeks of operation, as meltwater and recycled water. The operation of the WWTS allows to obtain reusable-grade water out of wastewater, and to recycle this water for non-drinking applications. Table 2, shows that the average water use at PEA was just below 40 L per person per day. Recycled water was used for cleaning and washing activities, Meltwater was used for consumption and personal hygiene. As a comparison, the daily average water use in Belgium is close to 100 L per person per day, 130 L in the European Union[5] and 200 L in the United States[6].

Table 2. Water production data, for Melt Water and Recycled Water.

	Meltwater	Recycled water	Total
Total volume (L)	108 520	27 260	135 800
Average use (L.person^{-1}day^{-1})	34.4	8.6	39.5

Table 3. Station occupation (mandays) and produced and treated grey and black wastewater (m³) per month.

	Occupation	Grey wastewater	Black wastewater	Total wastewater
November	629	24,3	2.4	26.7
December	1064	36	6	42
January	1121	33,1	9.6	42.7
February	602	24,6	2.9	27.5
Total		118	20.9	138.9

L. Energy balance

Figure 9 gives the average and maximal power consumption of the water treatment unit, over the 16 weeks of operation. A power factor (cos ϕ) of 0.9 is assumed. The average power consumption over the 16 weeks period is 2.0 kW. The main power consumers are the aeration blower, the electrical heating of the reactors and the circulation pump of the ceramic filtration modules of the fermenter.

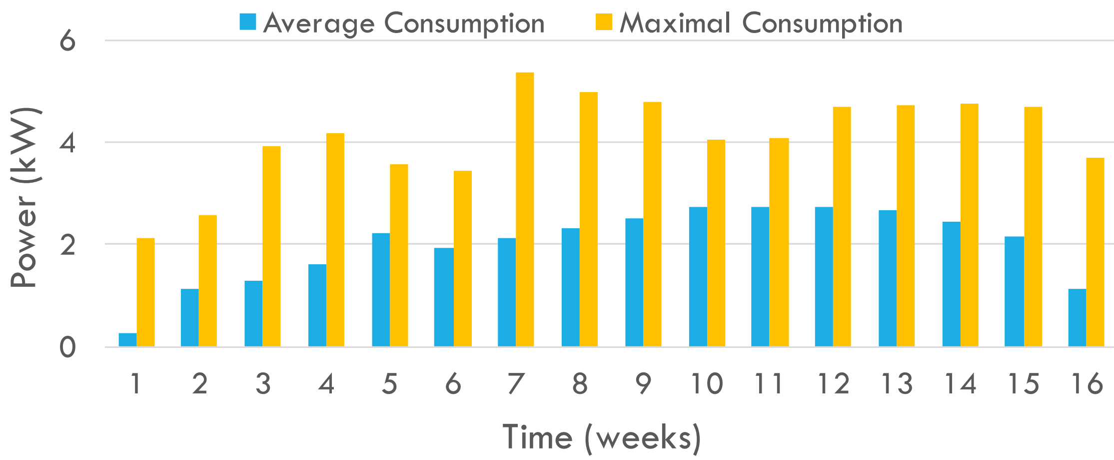

Figure 9. Average and maximal power consumption of the Water Treatment Unit, over a period of 16 weeks of operation.

V. Conclusion and Future Work

The experience at the Princess Elisabeth Antarctic Station learns that it is possible to use wastewater treatment systems based on a combination of biological and physicochemical processes. The underlying microbial processes might seem complex but with adequate instrumentation that deliver online analytical data it is possible to program control algorithms that allow to manage the processes in an automated way.

An efficient N-removal was achieved based on a new developed algorithm. The remaining fraction in the final effluent was nitrate at an average concentration of 5.4 mg/L which is far below the limit of 50 mg/L for drinking water.

The start-up at the beginning of the season by using bacterial inoculum that hibernated at PEAS was successful. The bacterial strains will be determined and followed up in the future by means of PCR analysis.

The high activated sludge concentration allowed to process high load of COD but resulted also in a relative high sludge production and energy consumption for aeration. Improvements in oxygen transfer to reduce energy consumption will be studied for the next seasons.

The information and results obtained are valuable since they support to a deeper insight in the design but also to practical operations of wastewater treatments that need to function in a reliable way in remote and hostile conditions. The knowledge can be valorized in evaluating concepts for water management systems on future manned space stations.

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