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Deliverable 4.8

Report on the operation of the demo Kaumera extraction installation plant in Faro (Portugal)

Date: 09 January 2024

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Disclaimer

The information included herein is legal and true to the best possible knowledge of the authors, as it is the product of the utilization and synthesis of the referenced sources, for which the authors cannot be held accountable.

Keywords

▪ Kaumera Extraction ▪ Case Study ▪ Transportation ▪ Optimization ▪ Operation

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Deliverable information

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History of changes

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0.1	01/12/2022	Structure report	Philipp Wilfert & Bart Verkoojen (TU Delft)
0.2	15/12/2022	Review	Maria Del Mar Mico Reche (ACCIONA), António Martins (Águas do Algarve) & Véronique Renard (RHDHV)
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1.0	31/12/2022	Final version of deliverable	Philipp Wilfert (TU Delft)
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4.0	09/01/2023	Revised based on comments from Violeta Kuzmickaite	Philipp Wilfert (TU Delft)

[1] **R**=Document, report; **DEM**=Demonstrator, pilot, prototype; **DEC**=website, patent fillings, videos, etc.; **OTHER**=other; **ETHICS**=Ethics requirement, **ORDP**=Open Research Data Pilot

[2] **PU**=Public; **CO**=Confidential, only for members of the consortium (including the Commission Services); **EU-RES** Classified Information: RESTREINT UE (Commission Decision 2005/444/EC); **EU-CON** Classified Information: CONFIDENTIEL UE (Commission Decision 2005/444/EC); **EU-SEC** Classified Information: SECRET UE (Commission Decision 2005/444/EC)

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History of Changes

Following requests for revisions to this deliverable made by the project officer on October 13, 2023, December 13, 2023 and on January 05, 2024 the following changes have been incorporated, as summarized below:

No.	Request for revision	Section	Change
Revisions requested in letter from 13/10/2023			
1	The executive summary shall be reviewed to summarize the objectives and outcomes. The executive summary stands rather as an introduction	Executive Summary	The executive summary was revised according to the suggestions
2	Headline "*Scope of Delivery*" should read "*Scope of the Deliverable*"	2	The title of respective section was changed as requested.
3	Wrong font type in bullet point list	2	Font type was uniformized.
4	Layout of the main report deviates from the standard project template (page margins, position of logo, footer, etc.	All sections	Layout of the deliverable was adapted to the project template.
5	Page size US letter should be A4	All sections	The page size of deliverable was transformed to A4.
6	List of references is missing	7	List of references was added
Revisions requested in letter from 13/12/2023			
7	At the beginning of the updated report indicate the sections where amendments have been done following requested comments.	This section	A section documenting all amendments has been added to the updated report.
8	Executive summary still does not stand as an executive summary	Executive Summary	Executive summary was revised to summarize the objectives and outcomes of the deliverable.
Revisions requested in letter from 05/01/2024			
9	Layout of the main report deviates from the standard project template (page margins, position of logo, footer, etc.)	All sections	Layout revised
10	Page size US letter should be A4	All sections	Layout revised

Executive Summary

Objective of this deliverable

This deliverable is associated with Task *4.1 Implementation and optimization of the Demonstration Kaumera Extraction Installation (KEI)*. It documents the successful achievement of subtask *4.1.3 Implementation, operation, and optimization of the Demonstration KEI in warm climate region.*

Structure of the report

In the first section, a comprehensive overview of the Water Mining project is given. This is followed by a section outlining the objectives and scope of the deliverable. In section 3, detailed information about case study 3 and the Kaumera production process are given. In section 4, details about the process units, capacity of KEI, operating conditions, process units' dimensions, and energy (and utility) requirements are provided. Visuals of the equipment are also included. In section 5, information on the implementation, optimization, and successful optimization of KEI are given. This section includes an introduction to the wastewater treatment plant Faro-Olhão, including local preparations that were required. The report concludes with final remarks and outlines the next steps.

Summary

In summary, disassembly of KEI in Utrecht, the transport to Portugal and assembly of KEI at the WWTP Faro-Olhão went well. After commissioning, and a few optimizations steps KEI was successfully operated in Portugal as an example of a warm climate region. For the first-time Kaumera was extracted beyond lab scale outside The Netherlands. The experiences of Utrecht were confirmed, the batch process was relatively simple to control and could be easily optimized. Within a few batches of operation Kaumera was produced. The quality parameters, as investigated on site ,indicated to similar quality as the Kaumera obtained in The Netherlands. Material was collected for the following in depth analyses. About 40% of all organic matter in the initial sludge was recovered as Kaumera. This yield was much higher as compared to other locations in The Netherlands (usually 20-30%).

Conclusion & Outlook

Overall, the Kaumera extraction technology and KEI proofed to be flexible, and it was confirmed that that operation is quickly adjustable to new sludge types/locations. The quality and quantity of the extracted Kaumera is very promising. The successful work documented in this deliverable underlines the wide-reaching technology replication potential of Kaumera production in warm climate regions on the Iberian Peninsula and beyond.

Table of Contents

List of Figures

List of Tables

Acronyms

AGS	Aerobic Granular Sludg
CHP	Combined Heat Power
CS	Case Study
DS	Dry Solids
EPS	Extracellular Polymeric Substances
KEI	Kaumera Extraction Installation
MWWTP	Municipal Wastewater Treatment Plant
OPEX	Operational Expenditure
VS	Volatile Solids

1. Overview of the project

WATER-MINING is a project funded by the European Commission (Horizon 2020 – Grant Agreement No 869474) with a total duration of 48 months (Start date: 01/09/2020 – 31/08/2024) and a total budget of approx € 19 million (EU Contribution: € 16,876,959.59). The project is entitled "Next generation water-smart management systems: large scale demonstrations for a circular economy and society" and it is a project granted under the call topic "CE-SC5-04-2019: Building a water-smart economy and society". Further information about all the sister projects funded under this topic can be found at the CORDIS website here. The WATER-MINING consortium comprises 38 partners from 12 countries, led by the Delft University of Technology (TU Delft). More information about the project can be found at the project website (https://watermining.eu) as well as the dedicated website at CORDIS database (https://cordis.europa.eu/project/id/869474), while an overview is provided below.

The WATER-MINING project aims to provide for real-world implementations of Water Framework Directive (and other water related legislation), as well as the Circular Economy and EU Green Deal packages by showcasing and validating innovative next generation water resource solutions at pre-commercial demonstration scale. These solutions combine WATER management services with the recovery of value-added renewable resources extracted/MINED from alternative water resources ("WATER-MINING").

The project integrates selected innovative technologies that have reached proof of concept levels under previous EU projects. The value-added end-products (water, platform chemicals, energy, nutrients, minerals) are expected to provide regional resource supplies to fuel economic developments within a growing demand for resource security. Different layouts for urban wastewater treatment and seawater desalination are proposed, to demonstrate the wider practical potential to replicate the philosophy of approach in widening circles of water and resource management schemes. Innovative service-based business models (such as chemical leasing) are being introduced to stimulate progressive forms of collaboration between public and private actors and access to private investments, as well as policy measures to make the proposed water solutions relevant and accessible for rolling out commercial projects in the future. The goal is to enable costs for the recovery of the resources to become distributed across the whole value chain in a fair way, promoting business incentives for investments from both suppliers and end-users along the value chain. The demonstration case studies are to be first implemented in five EU countries (NL, ES, CY, PT, IT) where prior successful technical and social steps have already been accomplished. The broader project consortium representation will be an enabler to transferring trans-disciplinary project know-how to the partner countries while motivating and inspiring relevant innovations throughout Europe.

2. Scope of the deliverable

Within WATER-MINING project, Work Package 4 (WP4) is focusing on the "Demonstration of extraction/valorization of Kaumera Nereda Gum".

WP4 is structured in the following five tasks:

- **Task 4.1: Implementation and optimization of Demonstration Kaumera Extraction Installation (KEI)**
- **Task 4.2:** Comparison of the properties and quality of the produced Kaumera in the warm and colder climate region
- **Task 4.3**: Investigation of the fermentability at high pH value of the residual sludge from Kaumera extraction process
- **Task 4.4:** Combined phosphate recovery with Kaumera extraction to produce a concentrated phosphate fertilizer raw material
- **Task 4.5**: Coordination of WP4 activities and interrelation with other WPs

The results from the implementation of this work package are presented through eight deliverables

- **Deliverable 4.1:** Demonstration plant KEI operation, Utrecht (connected to Task 4.1)
- **Deliverable 4.2:** Kaumera quality and properties (connected to Task 4.2)
- **Deliverable 4.3:** Fermentability of extraction residue (connected to Task 4.3)
- **Deliverable 4.4:** Phosphate recovery options (connected to Task 4.4)
- **Deliverable 4.5**: Report on the technical results from the implementation of WP4 – input for inter-related WPs (connected to Task 4.5)
- **Deliverable 4.6:** Update of D4.5 (connected to Task 4.5)
- **Deliverable 4.7:** Update of D4.6 (connected to Task 4.5)
- **Deliverable 4.8: Demonstration plant KEI operation, Faro (connected to Task 4.1)**

The current deliverable, D4.8 comprises subtasks *Implementation, operation and optimization of the Demonstration KEI in warm climate region* of Task 4.1. The work was led by TU Delft. After transport of the unit to Portugal, the installation and integration on site and the operation of KEI was completed. All works needed in Faro/Olhão Nereda MWWTP to prepare the site for the installation of the containers with the Kaumera prototype system were either subcontracted or completed autonomously by Águas do Algarve (ADA). Support came from Acciona. Águas do Algarve supplied consumables (acid, base and diesel) and provided utilities like water, sludge and electricity for the plant operation. For the utilities, several connections had been made and additional cable was purchased. For the chemicals, a fork lifter had to be hired. Additionally, a maintenance team from ADA inspected the pilot and did some repairs. The operation of the demo KEI was mainly undertaken by TU Delft with support of ADA and supported by ACCIONA.

On-site TU DELFT took care of the interconnecting piping, cabling, pneumatics, signal cables and on-site assembly. The power connections in cabinets and for equipment were done by ADA. RHDHV gave regular advice on the pilot operation.

This deliverable comprises one of the “Demonstrator” deliverables foreseen within WP4 and aims to provide information on the demo systems (and its components) and the optimization measures in form of a report.

This deliverable is also a “Public” deliverable, thus not containing any confidential information

3. Introduction CS3 – Kaumera extraction installation (KEI)

Nereda WWTPs. The pilot installation can process sludge with total solid (TS) contents between 3-5%. The production capacity is about 0.5-1 m³ Kaumera / day and 5 m³ thickened sludge / day. Below a flow scheme of the extraction process (Figure 1). An overview on CS3 plans and intentions is given in Table 1.

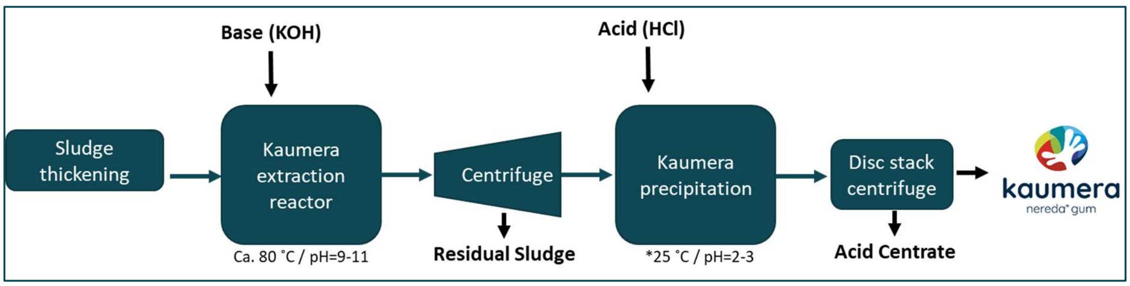

Figure 1: Flow scheme for Kaumera Nereda® Gum extraction from granular sludge.

The sludge from the gravity thickener is pumped to a skid with a 1000 L sludge buffer tank, where it is macerated and pumped from to the reaction tank. This steel reactor has a net volume of 6 m³ and is equipped with an electrical mixer. During extraction, the sludge is continuously mixed to prevent settling. The reactor is fully covered. Within the reactor the sludge is heated to 80-90 °C to extract the Kaumera and kill pathogens. A steam generator is used for steam injection to introduce heat into the reactor. The sludge in the reactor is continuously mixed while heating. Once the sludge in the reactor has reached a temperature of about 80 - 90 °C, potassium hydroxide is dosed into the reactor until a pre-set pH is reached. Hereafter the content of the reactor will continue to be mixed for some time to kill pathogens.

From the reactor the conditioned sludge is pumped to a decanter centrifuge separation unit where an alkaline sludge pellet is separated from the alkaline centrate containing solubilized Kaumera. The produced alkaline sludge pellet (~10-15% TS) is collected in the alkaline sludge pellet buffer tank. While the alkaline sludge pellet is diluted and returned to the MWWTP for further treatment in the current pilot design, the potential fermentation of this pellet to produce pure methane/green gas in future is investigated in task *D4.3: Fermentability of extraction residue*. The alkaline centrate, containing Kaumera, is collected in the alkaline centrate buffer tank. From the alkaline centrate buffer tank, the centrate is pumped to the cooling tank.

In the cooling tank, alkaline centrate is cooled overnight to a temperature of 15-30°C by cooling water in a spiral. Once it has been cooled, hydrochloric acid (HCl), or in the case of Faro/Olhão sulphuric (H_2SO_4) is dosed into the tank, until a pH below 3 is reached. During cooling of the centrate and chemical dosing, the contents of the tank are continuously mixed.

The acidified alkaline centrate is pumped to a disc centrifuge where the precipitated Kaumera is separated. The produced Kaumera is stored in an IBC and can be picked up for processing/application. The acidic centrate is collected and returned to the MWWTP for further treatments.

In addition to the process described above, the Kaumera extraction unit is equipped with a rinse system to cover the needs of flushing water of the centrifuge and of the decanter. This system includes a 1000 L water break tank and a booster pump that can is connected to the different skids/containers of the units.

All the wastewater/washwater streams are collected in the acidic centrate buffer tank, which is used to return the streams to the MWWTP for further treatments.

Similar designs are used in the demo installations in The Netherlands.[1]

Table 1: Overview on CS3 intention.

<table>
<tr><td>CS3 Names</td><td colspan="2">Urban WWTP in Utrecht – The Netherlands</td><td>Urban WWTP in Faro/Olhão - Portugal</td></tr>
<tr><td>CS3 Owners</td><td colspan="2">TU Delft (Partner No. 1)</td><td>ADA (Partner No. 26)</td></tr>
<tr><td>Scale & capacity</td><td colspan="3">Large (portable) demo – Capacity: 5 m^3/day</td></tr>
<tr><td>Key CE intervention</td><td>□ Recovery of high added value raw materials: Kaumera Nereda® Gum & Phosphate from urban wastewater</td><td rowspan="3">
Faro/Olhão, Portugal</td><td rowspan="3">
Utrecht, Netherlands</td></tr>
<tr><td>Relevant sectors</td><td>Municipal and industrial wastewater treatment /Agriculture /Construction</td></tr>
<tr><td>Special focus</td><td>Improved recovery of resources & creation of new business opportunities</td></tr>
<tr><td colspan="4">Status of the case study today:
Faro/Olhão WWTP: This plant is the first full-scale greenfield Nereda® installation treating complete flow in Southern Europe and represents the largest investment in water sanitation made in the Algarve – and one of the largest in Portugal to date. The Nereda® technology is an innovative method of treating wastewater offering significantly lower OPEX whilst able to achieve very high levels of nutrient removal in a reliable and compact plant. The Faro/Olhão plant also makes use of a Nereda® Controller which forms the heart of the plant's automatization system where data are continuously monitored and analyzed to optimize and maximize the plant's efficiency. Thanks to this emerging technology it has been possible to reduce the Faro/Olhão plant's carbon footprint by 50%, and an energy saving up to 50% is expected. The plant also has solar panels that, with an installed capacity of 50 kW, will produce energy for use by Auxiliary services. The Faro/Olhão WWTP provides a service to a population equivalent of 113,200. The plant has a maximum flow rate of 28,820 cubic metres (m^3) per day. The sludge line is designed for production of approximately 8,000 kg d.w./day.

Demonstration: The transportable demo unit will extract biopolymers from 1-3% of the wastewater treatment residuals generated.</td></tr>
</table>

Ambition at the end of the project and beyond: The Kaumera extraction initiative has been already embraced by the Dutch Foundation for Applied Water Management Research (STOWA). STOWA include water boards, provinces and the Ministry of Public Works and Water Management and supports the implementation of the Nereda/Kaumera concept for national adoption in the Netherlands (see also Letter of Support by HDSR). This project will comprise the stepping-stone to provide the necessary body of evidence that the Water Boards in the Netherlands (and abroad) would require for doing so.

4. Demo system used in CS3

4.1. Introduction to chapter 4

Deliverable 4.1: Demonstration plant KEI operation, Utrecht provided details about the capacity, the operating conditions, the dimensions and energy (and utility) requirements. In the following, these items will only be briefly outlined. The demo system from Case Study 3 comprises the following equipment– that serve as structure for this chapter (see also Figure 3).

1. Skid with Feed Buffer Tank, Macerator and Reaction Tank Feed Pump
2. Reactor Tank
3. Container with Steam Generator (10ft container)
4. Container with chemical dosing equipment (20ft container)
5. Container 1 (40ft container)
   - Buffer tanks,
   - Feed and discharge pumps,
   - Break water tank and hydro booster
   - Main control cabinet
6. Container 2 (20ft container)
   - Decanter & separator centrifuge
7. Cooling Tank

Figure 2 gives an overview over the process steps. In the following, each process unit will be briefly described.

All waste streams/discharges and gravity safety overflows are combined in one central discharge pipe which is brought back to the inflow of the MWWTP.

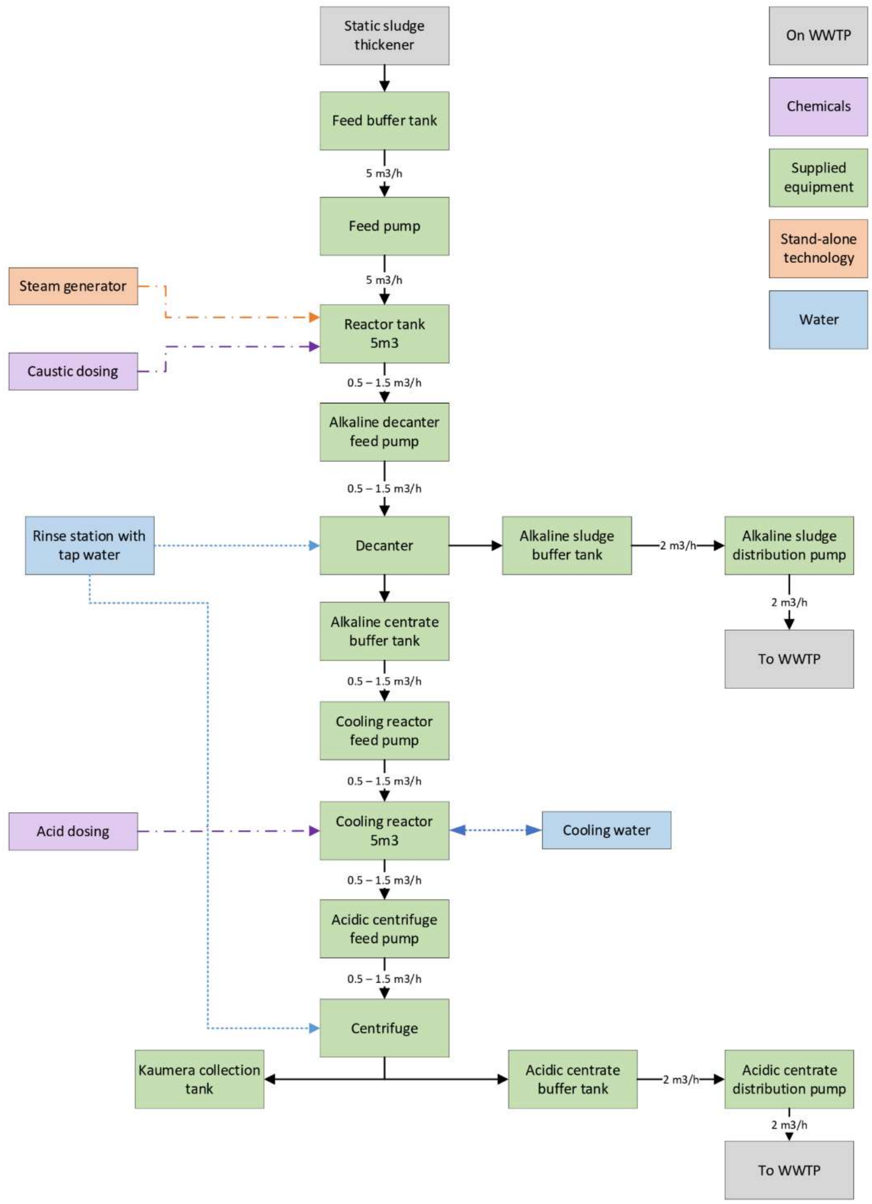

Figure 2: Simplified process diagram over the Kaumera extraction process (provided by Lenntech).

All images and drawings are provided by Lenntech. With the exception of images from the steam generator (BKS Verkoop & Advies BV) and the drawings from the chemical dosing unit (Chemflow Doseertechniek BV.), reactor tank (PFS-Process BV) and the cooling tank (KWB Kunststoftechniek)

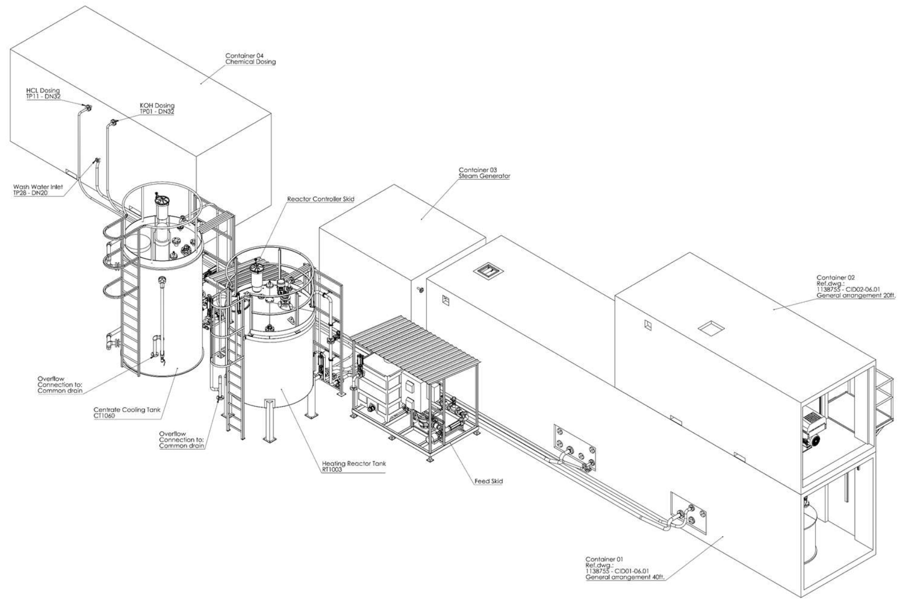

Figure 3: Engineering drawings of the pilot installation (by Lenntech).

4.2. Skid with Feed Buffer Tank, Macerator and Reaction Tank Feed Pump

All equipment of the skid is mounted on a roofed transportable steel skid (Figure 4). The 1000 L PVC feed buffer tank with level transmitter is filled automatically using a cavity pump. The sludge then passes through a macerator and is pumped by a cavity feed pump into the reactor. The whole unit has a capacity of 5 m³/h, it is mainly built of stainless steel with stainless steel piping.

Figure 4:. The feed skid with a 1000 L feed buffer tank, a macerator and cavity pump.

4.3. Reactor Tank

The macerated sludge is collected into a 6 m³ isolated steel reactor with mixer, level transmitter and pH and temperature meter, depicted in Figure 5. Within the reactor the sludge is heated with a steam generator to about 80-90 °C to extract the Kaumera and to kill pathogenic bacteria. Potassium hydroxide is dosed into the reactor until a set pH is reached.

Figure 5: The reactor tank for alkalinsation and heating up the excess sludge.

4.4. Container with Steam Generator (10ft container)

The steam generator is diesel propelled (ca. 20-50 L Diesel/batch) and connected via a silicone isolated hosing to the reactor tank. It has a steam capacity of up to 260 kg/h. All equipment is placed in a 10ft container, Figure 6. A double-walled solid 400 L safety tank for the diesel is installed directly in the boiler room. This system can even be used in water protection areas. The steam injection is automatically induced via the PLC in the 40ft container.

Figure 6: The 10ft transport container with the steam generator.

4.5. Container with chemical dosing equipment (20ft container)

The 20ft container includes two IBC drip trays (1300 L buffer). In Faro, KOH, 50% was used to adjust the pH of the heated sludge and H2SO4, 40% to adjust the pH of the alkaline centrate. The container has two opening doors on each short side and two wicket doors on the long side, see Figure 7. The acid and base section are separated with a forklift an IBC can be placed on the drip tray.

An IBC day tank system for the storage of the chemicals is implemented with a 1000 L IBC supply at a time and we have a free outlet in the day tank. The dosing units with pumps (375 L/h) are placed on a separate frame in the container – protected with PVC glass. Acid and base respectively are pumped over double-walled traced tubing in the cooling and reactor tank respectively. An emergency shower including eye shower is installed outside the container.

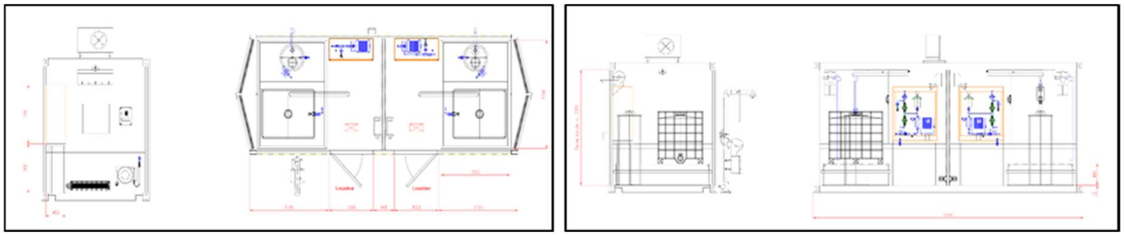

Figure 7: Schematic overview on the chemical dosing system placed in a 20ft container.

4.6. Container 1 (40ft container)

The container harbours the water break tank (1000 L) with a hydro booster pump, the main control / power supply cabinet with HDMI panels, buffer tanks for alkaline waste sludge and Kaumera (1000 L) and buffer tanks for alkaline and acid centrate (200 L). Pumps for discharging the waste steams (acid centrate / alkaline sludge pellet), pumps for feeding the disc and decanter centrifuges and for pumping Kaumera to collection IBCs are installed. A pressure generator is installed for the pneumatic system. This system is needed to automatically open / close the valves in the whole installation. The container is equipped with forced ventilation and AirCos. Figure 8 shows the internals for the 40ft container and how the stacking of the 20ft and 40ft looks like. Figure 9 depicts different views of the container.

The heated and alkalinised sludge flows through heat and base resistant hosing from the reactor tank via gravity to the 40ft container. The decanter centrifuge in the stacked 20ft container is fed with this sludge using a cavity pump (max. 1.5 m^3/h). After separation the alkaline sludge pellet from the decanter centrifuge is collected in the alkaline sludge pellet buffer tank (1000 L), diluted with water and pumped with a cavity pump (1.5 m^3/h) via pressure hoses to a discharge pit outside the container. The alkaline centrate from the decanter centrifuge (containing solubilized Kaumera) is collected in the alkaline centrate buffer (200 L) and pumped with a cavity pump (2 m^3/h) to the cooling tank.

After cooling overnight and addition of acid the acidified alkaline centrate flows via gravity through PVC hoses into the 40ft tank to a peristatic pump which is the feed pump of the disc centrifuge (1.5 m^3/h). After separation the acidic centrate is collected in the acid centrate buffer (200 L) and discharged via a peristaltic pump (2 m^3/h) to a sewer pit outside the container. The acid sludge (a.k.a. Kaumera) is collected in a 1000 L collection tank. From there it can be pumped to an IBC outside the container for collection. As alternative it can be recirculated to the influent of the MWWTP.

The power supply for the whole pilot (160 A and 80 kW) is brought from the MWWTP into the power cabinet and from there distributed to other units of CS3.

Figure 8: View inside the 40ft container (left) and an impression on the stacked on containers during loading of trucks for transport of KEI to Utrecht. The bottom container is the 40ft container.

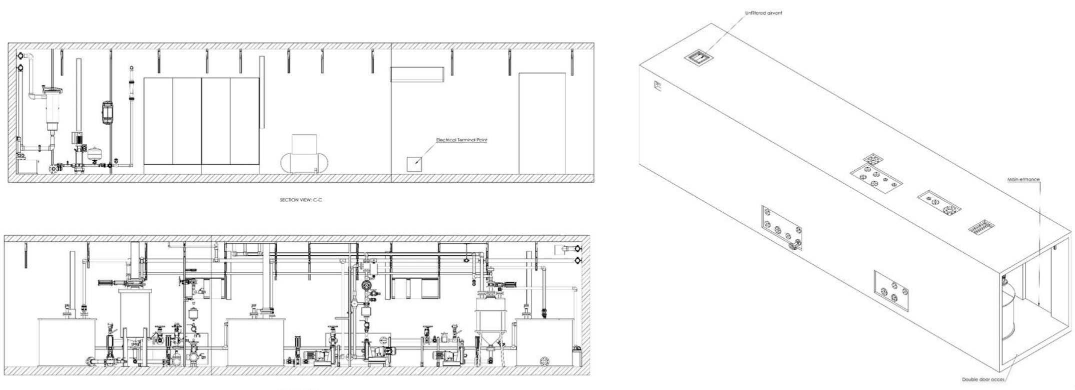

Figure 9: Section and bird view of the 40ft container.

4.7. Container 2 (20ft container)

The container is stacked on the 40ft container, Figure 8. It contains the decanter centrifuge, disc centrifuge including local control cabinets for the separation equipment and an odour filter with forced ventilation from the alkaline discharges (pellet and centrate) and a crane for maintenance work on the separation equipment, Figure 10. The capacity of the machines is indicated in Figure 2.

The decanter centrifuge is used for solid / liquid separation after the alkaline Kaumera extraction step. The disc centrifuge is separating the gelled Kaumera after acidification from the liquid phase.

Figure 10: Decanter centrifuge (left) and disc centrifuge –a.k.a. separator (right).

4.8. Cooling Tank

The alkaline centrate is collected in a 6 m³ isolated PP-H / PE-100 cooling reactor tank, section and top view are depicted in Figure 11. A mixer with frequency drive is mounted on top of the reactor tank. The reactor tank is equipped with a level transmitter, pH and temperature sensors. The centrate is cooled from about 80-90 °C down to approximately 15-30 °C within 10-12 hours using available process water with 10-25°C (10-25 m³/h).

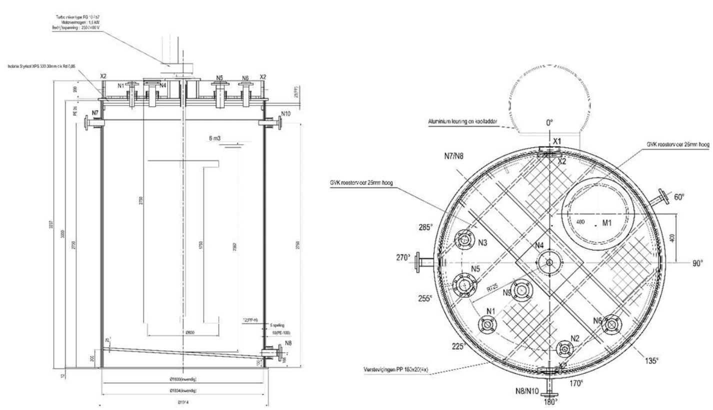

Figure 11: Section and top view on the cooling reactor.

5. Implementation and Optimization KEI

5.1. Introduction to the MWWTP Faro/Olhão

The MWWTP in Faro/Olhão treats the wastewaters of Faro and Olhão (Figure 12)[2]. The plant is owned and operated by Águas do Algarve. It started operation in 2018 and was the first full-scale greenfield Nereda® installation in Southern Europe and represents the largest investment in water sanitation made in the Algarve – and one of the largest in Portugal to date. The plant uses an automatization system where data is continuously monitored and analysed to optimize and maximize the efficiency. Thanks to the Nereda® technology, which makes use of the aerobic granular sludge, it was possible to reduce the Faro/Olhão MMWTP carbon footprint by 50%, and energy saving up to 50%. The plant also has solar panels with an installed capacity of 50 kW.

Figure 12: Overview on the main CS3 equipment and the location of CS3 in Faro, Portugal

The plant was designed for a capacity of 113.200 p.e. with a maximum daily flowrate of about 28.000 m³ sewage. The sewage comprises mainly municipal wastewater with little industrial contributions (<5%). The sewage is collected via a drainage system comprising 57 km piping and 14 pumping stations. The treated effluent is released into a lagoon system connected to the Ria Formosa. For this reason, 75% of the plant effluent receives an UV treatment. Influent and effluent qualities are shown in Table 2.

Table 2: Average influent and effluent qualities for 2020.

Parameter	Raw water	Treated effluent
BOD_5 mg/l O_2	383	16
COD mg/l O_2	723	68
Nt mg/l N	68	11
Pt mg/l P	8	5

The reusability of the effluent is limited by seawater intrusions into the sewer system. The extent of intrusions is influenced by the tides. Because of this the influent conductivity during the pilot operation period varied between 3 and 18 dS/m.

The excess sludge in Faro/Olhão is gravity thickened from about 0.5-1 % DS to about 3-4% DS and dewatered with decanter centrifuges to about 20% DS. The sludge is then stored in two silos, before it is transported to composting facilities. Eventually, the sludge is used in agriculture. In 2020, about 90 m^3/d of excess sludge with an average DS of 3.2 % DS was produced in the MWWTP Faro/Olhão. It is excess sludge which is used in the Kaumera extraction installation.

We assume that the main difference between excess sludge used in the demo installations in The Netherlands and the excess sludge from Faro/Olhão that could have an impact on the Kaumera extraction and Kaumera properties are related to seawater intrusions in the sewer system and the elevated ambient and sewage temperatures.

5.2. Preparations at the MWWTP Faro for installing CS3

Based on the footprint of the installation a spot with lose ground close to the gravity settler was chosen for pilot. Access to utilities like cooling water (effluent), fresh water (rinsing, operation), to waste discharge and to the excess sludge was available in a radius of 30 m. For the main power supply an additional cable with a length of 30 m had to be purchased.

Águas do Algarve made connections and installed adapters and valves for water and excess sludge during the summer 2022. As well, connections for power were made in the electrical cabinet including the installation of a circuit breaker.

Figure 13: Spot for the Kaumera extraction pilot installation in Faro/Olhão.

In spring 2022, Águas do Algarve subcontracted work related to the building of a concrete slab (30 x 10 m) for the pilot installation. The slab is accessible via a gravel ramp. Access is needed for loading the IBCs with chemicals in the dosing container.

Figure 14: Concrete Slab for the pilot installation on site of the MWWTP Faro Olhão.

5.3. Disassembly Utrecht, Transport to Faro and assembly

In Utrecht, it took three people about 8 days to dismantle the pilot installation and prepare it for the transport.

Special care had to be taken for the disc centrifuge. Together with GEA the 400 kg bowl of the centrifuge had to be removed and placed and fixed in the 20 ft. container. For the transport to Faro, the reactors / tanks had to be transported horizontally to save costs and reduce the height of the trucks. For this reason, the tanks had to be dismantled completely and the agitators had to be stabilized to prevent swinging of the steel rod and the mixer during the transport which would damage the machines. Additionally, two cranes were required for bringing the cranes in horizontal position (Figure 15). Overall, the loading took about 5 hours.

Most of the equipment was placed inside the containers. In total 4 trucks were needed for the transport:

- Truck 1: 2 x 20 ft. High cube containers (approx. 4 & 7.5 t)
- Truck 2: 1 x 10 ft container approx. 2 t + loose material (+/-10 m: frames, ladders and skids)
- Truck 3: 1 x 40 ft. High cube container (approx. 7.5 t)
- Truck 4: 2 reactors

Figure 15: Loading the tanks on trucks.

The transport itself went smooth without any significant damage of the installation. The equipment arrived in Faro/Olhão in the first week of September.

The unloading of the equipment was concluded in about 4 hours. Then it took three people about 10 working days until the assembly was completed (Figure 16). Some minor items that needed repairs during the assembly were fixed by the maintenance team of Águas do Algarve. The assembly was mainly done by TU Delft with significant support by Águas do Algarve, e.g. by providing an electrician to connect the power supplies, giving support with a crane, doing an initial maintenance check for the equipment and by providing tools and spare parts.

Águas do Algarve organized the chemicals (including fork truck and driver to load IBCs into the chemical container) and Diesel for the steam generator.

The commissioning was completed at the end of September and was followed by the optimization of the operation – Kaumera extraction.

Figure 16: Assembly of the pilot installation in Faro/Olhão in progress.

5.4. Optimization, Operation & Differences to The Netherlands

Similarly, to the experiences in Utrecht it turned out that the batch process was relatively simple to control and optimize. Within a few weeks Kaumera was produced with identical gelling properties (visually observed), total solid and volatile solid contents as in Utrecht, Epe and Zutphen. The pilot operation proofed to be flexible, and operation was quickly adjustable to the new sludge type/location.

In trial laboratory extraction experiments the main process parameters, like KOH and H_2SO_4 dosing required for an optimal extraction, were established by TUD and RHDHV. These optimal parameters were re-evaluated on site and further optimized within a few batches within a few weeks. The pH for the Kaumera extraction from excess sludge from Faro/Olhão and Utrecht and for acid Kaumera precipitation are in the same range.

After the optimal pH was found, the separation equipment was optimized one after the other starting with the decanter centrifuge settings. However, from the beginning of the operation on, the separation turned out to be very efficient and only little modifications were made. Different settings for the disc centrifuge were tested during optimization, e.g. varying separation time. Several batches were needed to optimize the disc centrifuge. At the end, a similar configuration was chosen as in Utrecht.

The dosing of chemicals expressed in OH and H+ per kg VS was in Faro about the same as in Utrecht.

On the 28th of October 2022 the pilot was officially opened with about 40 guests from industry, academia, authorities and NGOs. A press released was published. On the same day the community of practice meeting took place.[3] All activities were organized by Águas do Algarve and Acciona. Employees of TU Delft and RHDHV joined the meeting / opening as well. During this meeting, the installation was fully operational. Thus, the visitors could see the world's first Kaumera produced beyond lab scale outside The Netherlands.

After the successful start-up and optimizations, several batches with constant operational conditions were made. During these batches, multiple samples were taken from different streams to complete mass balances (energy, chemicals, TS/VS and thus Kaumera yield). Águas do Algarve did the analyses of TS and VS in their laboratories. The fate of volatile and total solids are crucial information to understand the extraction process and to determine the Kaumera yield. During these batches about 100 L Kaumera was collected and sent to TU Delft for the work described in *Task 4.2 Comparison of the properties and quality of the produced Kaumera in the warm and colder climate region*.

The mass balances are currently completed. It seems the yield of Kaumera is at least as good as in The Netherlands. Furthermore, a visual inspection indicated that the Kaumera quality is in the range of Dutch Kaumera, Figure 17.

In Faro/Olhão, sulphuric acid instead of hydrochloric acid was used to adjust the pH of the alkaline centrate. The Kaumera from Faro/Olhão should be used for agricultural trials but high Cl-concentration may limit the applications of Kaumera for agricultural purposes in the Algarve. Sulphate from the sulphuric acid can be added to the soils without any restrictions.

The mass balances including the Kaumera quality will give Águas do Algarve an impression an idea on the feasibility to realize a full-scale installation for Kaumera extraction in Faro/Olhão. The collected numbers are i.a. an essential ingredient for further upscaling considerations as they influence the business case significantly. Furthermore, Águas do Algarve employees were introduced to the technology / extraction process and occasionally joint the operation to familiarize with the process.

Figure 17: Kaumera extracted from excess sewage sludge from the MWWTP Faro Olhão.

6. Concluding remarks

The objectives of subtask *4.1.3: Implementation, operation and optimization of the Demonstration KEI in warm climate region* has been successfully achieved.

The components from the demo systems, as described in this report have been successfully commissioned and optimization steps completed at the MWWTP Faro/Olhão. Mass balances are currently established over the process for further Water Mining activities (for LCAs, business cases/models, social impact studies) and to address further upscaling considerations for Kaumera extractions in Portugal.

The optimizations were successfully completed, and main setting screws were used. Once Kaumera is produced in Faro/Olhão for a specific application with specific demands on quality and characteristics, the operation can be further optimized. From an operational point of view, the settings of the pilot installation with sludge from Utrecht and Faro/Olhão are comparable. The coming quantitative (mass balances) and qualitative (Kaumera application/composition) measurements will reveal how Kaumera from Faro/Olhão compares to Kaumera from the Netherlands.

Kaumera was collected for these further analyses and material tests described in task *4.2 Comparison of the properties and quality of the produced Kaumera in the warm and colder climate region.*

At the end of 2022, CS3 operation in Faro-Olhão is concluded.

7. List of references

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