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ENERGIE EN Grondstoffen FABRIEK

KAUMERA: ONGOING DEVELOPMENT



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KAUMERA: ONGOING DEVELOPMENT

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PREFACE

THE DEVELOPMENT OF THE KAUMERA® EXTRACTION AND PRODUCTION IS MOVING FORWARD

Resource recovery from wastewater is an important theme for water authorities. By not only removing pollutants from wastewater but also converting the byproducts into valuable resources, a circular economy is possible, leading to reduced resource depletion and lower greenhouse gas emissions.

Aerobic granular sludge contains biopolymers that can be extracted and utilized in various ways. Research conducted within the National Kaumera Research Program (in Dutch Nationaal Kaumera Onderzoeksprogramma, NKOP) shows that extracting polymers from the granular sludge of the Nereda wastewater treatment system is feasible. NKOP is a cooperation of some water authorities, Haskoning and Delf University, Since 2011, the NKOP has been studying the properties of these polymers, the extraction technique, and potential market applications. Short-term application (as a biostimulant or fertilizer coating) in the agricultural sector holds the most promise. Since 2020 the first batches from the full-scale installations Epe and Zutphen were delivered for this application. In addition to these applications, several other potential uses are on the horizon, ranging from fire-resistant insulation materials to water-repellent coatings for paper and cardboard.

Due to the complex composition, which is further influenced by the extraction method and the numerous potential applications, the NKOP has chosen the product name “Kaumera”. Kaumera means “Chameleon” in the language of the Maori people and serves as a fitting metaphor for the versatile product derived from aerobic granular sludge.

Ongoing development is vital to successfully bring Kaumera to market. Therefore, the NKOP was focusing its efforts on market and product development. The improvements to the extraction process are essential to optimize the installations further.

The water authority Rijn en IJssel and Vallei en Veluwe have demonstrated the extraction of Kaumera from industrial and municipal wastewater. Efforts are focused on bringing this product to market. Through this research program, the water sector transcends its boundaries and makes a substantial contribution to the circular economy.

Mark van der Werf
Managing director STOWA

SUMMARY

The water boards are working on a sustainable wastewater cycle, based on the production of clean effluent, minimal energy consumption and maximal energy production, and reuse of resources for a circular economy. An ambitious goal that can only be achieved by working closely together. Within the National Kaumera Research Program (NKOP) the water boards Vallei & Veluwe and Rijn & IJssel are working together with Delft University of Technology, Haskoning, and STOWA. This collaboration continues to be fruitful and is supported by four frontrunner water boards.

In recent years the standard extraction process of Kaumera has been further studied. Optimizations to the process focused on the reduction of chemical consumption, i.e. NaOH and HCl. The results are summarized in Table 1.

Table 1 **Summarised results of extraction proces optimalisations**

Optimalisation	Effect on the product or process
CO_2 stripping to lower NaOH usage	Up to 60% reduction of NaOH, no effect on product quality
Use of NH_4OH instead of NaOH	Lower ash content of product, higher chemical costs due to increased use of base
Addition of NaOCl	Slight discoloration and odor reduction of product, at a higher chemical cost

Kaumera is a biologically produced product and therefore a biodegradable product. To increase its shelf life, research was conducted on different preservation methods. The addition of food preservatives to the Kaumera was most promising and most applicable to full-scale and is currently used in practice as well.

Since 2020 two full-scale demo extraction installations have been in operation in Zutphen and Epe. Zutphen operates on dairy wastewater and Epe operates on municipal wastewater. The plants show similar yields to lab-scale tests. However, it is possible to increase the yield in full-scale as well, especially for the dairy sludge. Newly developed analytical methods show a distribution of polymer size. Roughly 25% of the polymer is as small as 3.5 kDa, whereas another fraction of 25% is larger than 5,500 kDa, as determined by size exclusion chromatography. This new analysis method also made it possible to determine the carbohydrate to protein ratio per fraction. It showed that the larger fractions in Kaumera consist of a higher ratio of carbohydrates to proteins than the smaller fractions.

With the Kaumera produced at full-scale installations, the market team has been in contact with different end users. Different sectors are of interest for the use of Kaumera. The agri- and horticultural sector could utilize Kaumera because of its variety of properties: its water-retaining properties, its biostimulant properties, and its binding properties. This last property is also of interest to the composite material market. Also in other sectors, different applications are being researched, but the first focus is on the agri- and horticultural sectors.

+

To summarize, the NKOP is moving forward with Kaumera in different directions. The focus is not only on the technical advancements, although this remains the core of the Kaumera production. The NKOP is also working on business and product development, performing legal and organizational activities, as well as staying up to date on fundamental research. This integrated approach helps ensure that Kaumera will be part of the circular economy.

SAMENVATTING

De waterschappen werken aan een duurzame afvalwaterketen, gebaseerd op de productie van schoon effluent, minimaal energieverbruik en maximale energieproductie, en hergebruik van grondstoffen voor een circulaire economie. Een ambitieus doel dat alleen kan worden bereikt door nauw samen te werken. Binnen het Nationaal Kaumera Onderzoeksprogramma (NKOP) werken de waterautoriteiten Vallei & Veluwe en Rijn & IJssel samen met de Technische Universiteit Delft, Haskoning en STOWA. Deze samenwerking blijft vruchtbaar en wordt ondersteund door vier voorloper waterautoriteiten.

In de afgelopen jaren is het standaardextractieproces van Kaumera verder bestudeerd. Optimalisaties van het proces liggen in het verminderen van het chemisch verbruik. De resultaten zijn samengevat in Tabel 2.

Tabel 2 **Samenvattende resultaten van optimalisaties van extractieprocessen**

Optimalisatie	Effect op het product of proces
CO_2 stripping om het NaOH-gebruik te verlagen	Tot 60% vermindering van NaOH, geen effect op de productkwaliteit
Gebruik van NH_4OH in plaats van NaOH	Lager asgehalte van het product, hogere chemische kosten door toegenomen gebruik van basis
Toevoeging van NaOCl	Lichte verkleuring en geurvermindering van het product, tegen hogere chemische kosten

Kaumera is een biologisch geproduceerd product en daarom een biologisch afbreekbaar product. Om de houdbaarheid te vergroten, is onderzoek gedaan naar verschillende conserveringsmethoden. De toevoeging van voedselconserveringsmiddelen aan de Kaumera was het meest veelbelovend en het meest toepasbaar op volledige schaal en wordt momenteel ook in de praktijk gebruikt.

Sinds 2020 zijn er twee full-scale extractie-installaties in gebruik in Zutphen en Epe. Zutphen werkt op zuivel afvalwater en Epe werkt op stedelijk afvalwater. De installaties laten vergelijkbare opbrengsten zien als lab-schaaltests. Echter, het is mogelijk om de opbrengst op volledige schaal ook te verhogen, vooral voor het Zutphen slib. Nieuw ontwikkelde analysemethoden tonen een verdeling van polymeren in grootte. Ongeveer 25% van het polymeer is zo klein als 3,5 kDa, terwijl een andere fractie van 25% groter is dan 5,500 kDa, zoals bepaald door grootte uitsluitende chromatografie. Deze nieuwe analysemethode maakte het ook mogelijk om de verhouding koolhydraten tot eiwitten per fractie te bepalen. Het toonde aan dat de grotere fracties in Kaumera bestaan uit een hogere verhouding koolhydraten tot eiwitten dan de kleinere fracties.

Met de Kaumera die wordt geproduceerd in full-scale installaties, is het marktteam in contact geweest met verschillende eindgebruikers. Verschillende sectoren zijn geïnteresseerd in het gebruik van Kaumera. De agrarische en tuinbouwsector zouden Kaumera kunnen gebruiken vanwege de verscheidenheid aan eigenschappen: de waterretentie-eigenschappen, de biostimulante eigenschappen en de bindende eigenschappen. Deze laatste eigenschap is ook interessant voor de composietmaterialenmarkt. Ook in andere sectoren worden verschillende toepas-

singen onderzocht, maar de eerste focus ligt op de agrarische en tuinbouwsectoren.

Samenvattend, het NKOP gaat verder met Kaumera in verschillende richtingen. De focus ligt niet alleen op de technische vooruitgangen, hoewel dit de kern blijft van de Kaumera productie. Het NKOP werkt ook aan bedrijfs- en productontwikkeling, voert juridische en organisatorische activiteiten uit, en blijft op de hoogte van fundamenteel onderzoek. Deze geïntegreerde aanpak helpt ervoor te zorgen dat Kaumera deel zal uitmaken van de circulaire economie.

ABBREVIATION LIST

STOWA	Foundation for applied water research/Stichting Toegepast Onderzoek Water
DUT	Delft University of Technology
WSVV	Waterboard Vallei & Veluwe/Waterschap Vallei & Veluwe
WRIJ	Waterboard Rijn & IJssel/Waterschap Rijn & IJssel
HDSR	Waterboard the Stichtse Rijnlanden/Hoogheemraadschap de Stichtse Rijnlanden
WBL	Waterboard company Limburg/Waterschapsbedrijf Limburg
NKOP	National Kaumera Research Program/Nationaal Kaumera Onderzoeksprogramma
EFGF	Energiefabriek Grondstoffenfabriek
EPS	extracellular polymeric substances
KEI	Kaumera extraction installation
WWTP	wastewater treatment plant
ODS	organic dry solids
TS	total solids
VS	volatile solids
COD	chemical oxygen demand
PAO	phosphate accumulating organisms
LCA	life cycle assessment
NPV	net present value
meq	miliequivalents
PAC	powder activated carbon

ABOUT STOWA

KNOWLEDGE ABOUT WATER, FOR TODAY AND TOMORROW

The Foundation for Applied Water Research – STOWA – serves as a knowledge platform for Dutch regional water managers. From our office in Amersfoort, we develop and collect, disseminate and promote the use of knowledge in water matters. Water managers need this knowledge to properly carry out the tasks and challenges they face. STOWA provides knowledge on a broad range of topics, covering subjects such as urban & rural climate adaptation, water quality and ecology, sustainable and effective wastewater treatment, safe dikes, energy transition or circular economy.

The type of knowledge we provide may be technical and scientific in nature but can also relate to governance, administrative and/or legal matters. To ensure that this knowledge can be put to practical use by water managers, our research is mostly presented in the form of reports, practical guides, tools and instruments. We also facilitate learning communities for the purpose of sharing and anchoring knowledge and we organize symposia, work sessions and webinars.

To create as much impact as possible, STOWA pays particular attention to organisational and human factors that influence the impact of our output. We believe change is realized by people, through the application of knowledge. In our quest for solutions and innovation, we look beyond our own network, at different sectors, new perspectives and other countries.

STOWA works demand-driven but also puts issues on the agenda. We gather and compile knowledge questions from water managers and assign them to the right knowledge suppliers: universities, knowledge institutes or consultancy firms. We conduct tenders and offer guidance for knowledge projects. We ensure that water managers remain connected to the projects to sustain the practical application of project results. To this end, each project is supervised by a working committee in which regional water managers are represented. The broader terms of research are determined by programme committees whose members include water managers.

STOWA is independent, impartial and transparent. The users of our knowledge output must be able to fully rely on the integrity and quality of our findings. This guarantees that our knowledge serves as a reliable source for water management and innovations that respond to the challenges of today and tomorrow. However, it is up to water managers to determine how they apply STOWA's knowledge.

STOWA is a non-profit organization (RJ-640). In addition to numerical financial statements, our annual report includes a management report on the foundation and its activities. Our annual budget is about 20 million euros. Our participants collectively contribute about 10 million euros per annum as a structural contribution. Additionally, we receive around 10 million euros per annum through contributions to specific projects.

KAUMERA: ONGOING DEVELOPMENT

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1

INTRODUCTION

BACKGROUND

The water boards are working on a sustainable wastewater chain, based on the production of clean effluent, minimal energy consumption, and reuse of resources for a circular economy. An ambitious goal that can only be achieved by working closely together.

WHAT IS KAUMERA?

EPS (extracellular polymeric substances) is produced in the aerobic granular sludge treatment process (specifically Nereda®) by bacteria cleaning the wastewater. From the sludge, this EPS can be extracted through a physical chemical process known as the Kaumera extraction process. When extracted, EPS becomes a gel-like substance, which is considered a raw material for various applications. Due to its numerous possibilities and complex composition, the product name “Kaumera” was chosen for this material. Kaumera means “Chameleon” in the language of the Maori people and serves as a metaphor for the versatile product derived from aerobic granular sludge. The application currently most researched is as a biostimulant in the agricultural sector. However, due to the properties of the biopolymers, Kaumera potentially can also be used as a coating on multiple surfaces, carrier for paint, binding material in composites, and as a fire retardant. Chapter 2 describes the extraction in further detail.

HISTORY

The partnership “Energiefabriek Grondstoffenfabriek” (EFGF), accessible at www.efgf.nl, has been established by the water boards to facilitate the extraction of energy and raw materials from wastewater. Energy production from wastewater typically involves sludge digestion, which converts organic matter in sludge into biogas. Extracting resources from wastewater treatment is more complex than energy production. Although various raw materials can be extracted from wastewater, developing successful practical applications takes a considerable amount of time. In 2017, the EFGF identified the top 5 promising resources to focus on. Different water boards support specific resources and collaborate to demonstrate the extraction and application of those resources. Kaumera® is one of these top 5 resources (formerly known as alginate or NEO alginate or ALE, alginate-like-exopolymers). If successful, Kaumera will contribute towards achieving a circular economy.

The National Kaumera research program (NKOP) was launched in 2013 by water boards Vallei & Veluwe (WSVV) and Rijn & IJssel (WRIJ), along with Delft University of Technology (DUT), Haskoning, and STOWA. Kaumera, a gel-like biopolymer extracted from aerobic granular sludge and identified as extracellular polymeric substance (EPS) by Yuemei Lin in 2010, is the program’s focus. NKOP aims to develop and demonstrate the technology for extracting and applying biopolymers from this sludge. Besides WSVV and WRIJ, five other water boards—Vechtstromen, Noorderzijlvest, Hoogheemraadschap de Stichtse Rijnlanden (HDSR), and Waterschapsbedrijf Limburg (WBL)—are involved in Kaumera’s R&D program.

The NKOP, with support from STOWA, has initiated several studies over the years. The highlights are shown in Figure 1. From 2013 to 2015, potential market applications were thoroughly researched. The study concluded that there was sufficient potential for Kaumera to justify continuing the research. Subsequently, in 2016, an extensive scenario study was conducted, investigating multiple extraction methods at lab scale. Concurrently, a monitoring study was performed where several sludges from different wastewater treatment plants (WWTPs) were extracted, revealing some variation in extraction yield but an average recovery rate of 25% organic dry solids (ODS) as Kaumera. In 2017, research at WWTP Apeldoorn scaled up the lab-scale extraction to pilot scale. Several extraction and separation methods were tested, leading to the design of the current installations. During 2018, while design activities were underway, further optimizations on process conditions were researched in the laboratory at Delft, where further characterization of Kaumera was also conducted. In 2019 and 2020, the Kaumera extraction installations (KEI) in Zutphen and Epe commenced operations with the assistance of Haskoning. Since then, the NKOP has focused its efforts on product and market development of Kaumera, leveraging the increased availability of the substance. Meanwhile, the two full-scale installations have been optimized, and additional enhancements in extraction technology have been pursued. In beginning of 2024 four water boards formed a cooperation. By combining their expertise and resources, the water boards can do more research and share knowledge. In this way, they accelerate the product development that the market needs. The participants in the cooperative make decisions together on production and on the strategy for Kaumera's development. The following four water boards form the cooperative: Water board de Stichtste Rijnlanden, Water board Limburg, Water board Vallei and Veluwe, Water board Rijn and Ijssel. Kaumera Sales & Services B.V. was officially launched at the beginning of November 2024. This is a joint initiative of the four Dutch water boards and engineering firm Haskoning.

GOAL OF THIS REPORT

The last report on Kaumera development in the Netherlands was published in 2019 (STOWA 2019-14). For a comprehensive overview of developments up to 2019, please refer to that previous report. It provided insights into the standard extraction and application processes of Kaumera. This current report aims to update the progress made in Kaumera as a resource. It will elucidate the optimizations implemented in the standard extraction process and serve as a guide for operating full-scale Kaumera extraction installations (KEI).

READING GUIDE

Chapter 2 details the process of converting wastewater to Kaumera, including optimizations since 2019. Chapter 3 explains the full-scale extraction process, insight into the operational aspects of running a KEI, and analysis of Kaumera quantity and composition. Chapter 4 covers NKOP's efforts to market Kaumera. Finally, Chapter 5 discusses future developments of Kaumera.

Figure 1 **Highlights of the NKOP research in chronological order**



2

KAUMERA PRODUCTION FROM GRANULAR SLUDGE

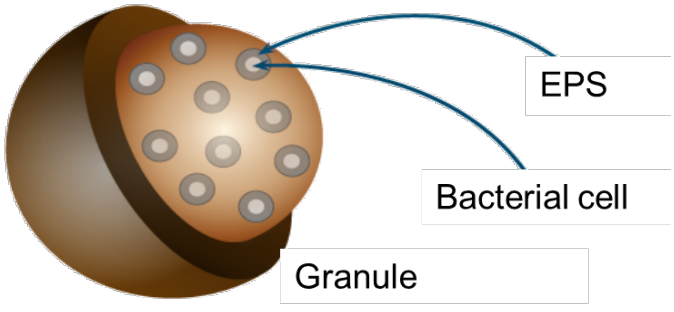
During the treatment of wastewater, bacteria produce extracellular polymeric substances (EPS). In the Nereda®[1]aerobic granular sludge process, slow-growing phosphate accumulating organisms (PAO) play a fundamental role in both phosphate removal and the granulation process due to their EPS formation (de Kreuk et al., 2005; De Kreuk et al., 2007). EPS is a complex mixture of polysaccharides, proteins, nucleic acids, (phospho) lipids, humic substances, and intercellular polymers (Felz et al., 2016). These gel-forming exopolymers can be of value in agricultural and industrial production processes (Lin et al., 2015; STOWA 2019-14, 2019; Duque et al., 2021; Kim et al., 2022). Nereda® installations can be found in multiple regions worldwide, including Europe, South America, Asia, Australia, and South Africa, illustrating the broad opportunity to extract EPS locally (see Figure 2).

Figure 2 **World map illustrating location of Nereda® installations**



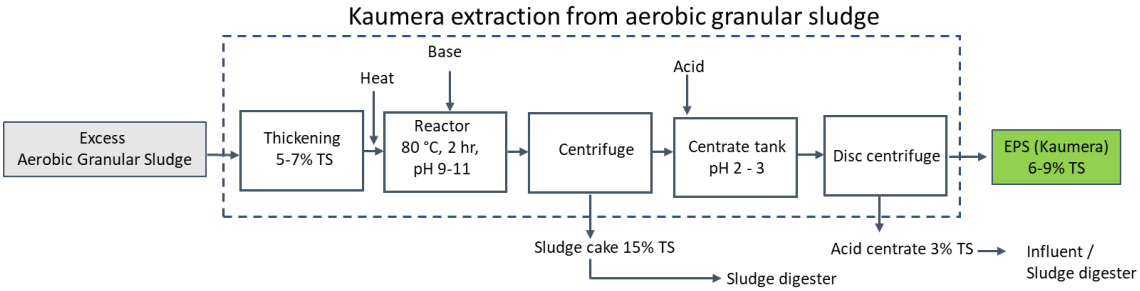
Figure 2 illustrates how EPS covers bacteria while growing in granular form.

Figure 3 **Schematic visualization of bacteria growing in granules with EPS as binding material**



While EPS is produced from wastewater in biological tanks, it needs to be extracted using physical-chemical extraction processes to utilize it. DUT developed and patented a variety of suitable extraction processes. One of these is described in detail in STOWA 2019-14. The general extraction process is displayed in Figure 3. The excess sludge is first thickened before being heated. Heat can be supplied by heat exchangers or steam injection. Afterward, the pH of the sludge mixture is increased by adding a base. The mixture is kept at this high pH for a minimum of 2 hours retention time. Afterward, the sludge cake is separated from the liquid fraction by centrifugation. Next, the polymers are precipitated by the addition of acid to pH 2 – 3. Then the formed gel is separated from the liquid by another centrifugation step. The product of this extraction process is a biodegradable gel-like substance named Kaumera.

Figure 4 **General Kaumera extraction process**



The standard extraction process for Kaumera has undergone extensive study and optimization, resulting in the development of full-scale extraction plants. The optimizations have focused on reducing chemical consumption and improving the overall yield of the extraction. The following chapter describes the full-scale extraction process.

3

FULL-SCALE EXTRACTION

Based on pilot and lab-scale research, the first two Kaumera Extraction Installations (KEIs) were designed and built at WWTP Zutphen and Epe. The extraction installation of Zutphen started up at the end of 2019 and was able to deliver batches of Kaumera as a biostimulant beginning of 2020. The Zutphen Nereda® installation is solely treating dairy wastewater. The demonstration installation of Epe was started in mid-2020 and delivered the first batch of Kaumera, also as a biostimulant, end of 2020. The Epe Nereda® installation is operated on municipal wastewater.

In this chapter, insight is given into the operational aspects of running a KEI. We end the chapter by showing some results on the Kaumera quality and show the differences between a lab-scale and full-scale extraction.

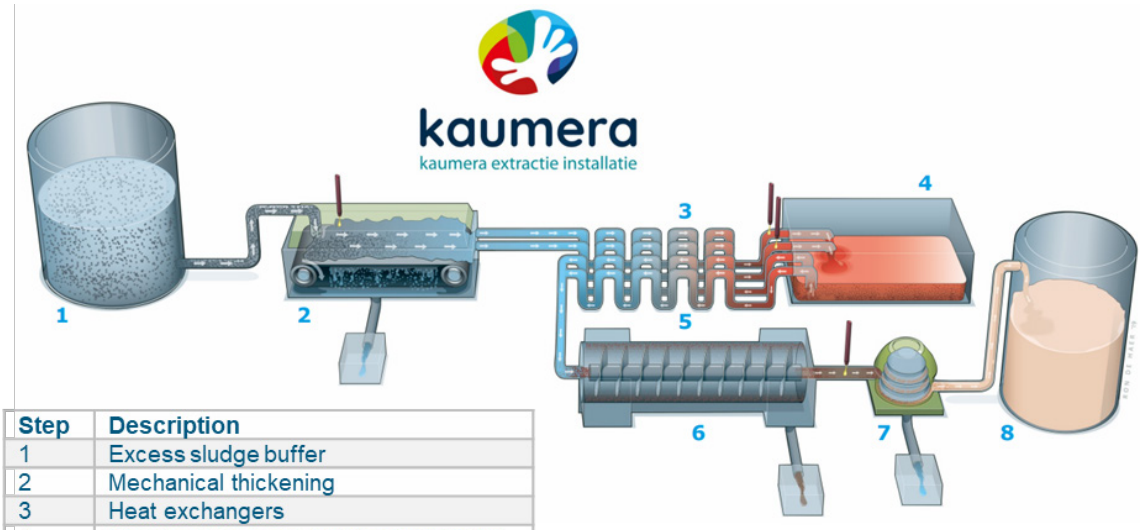
3.1 GENERAL DESCRIPTION OF FULL-SCALE EXTRACTION PLANTS

The general extraction process steps are depicted in Figure 5. In the laboratory separation of sludge and liquid is done by centrifugation. To perform this extraction on full-scale, three types of separation equipment are required:

1. Mechanical thickening which generates a sludge stream that continues in the process and a filtrate waste stream.
2. Decanter which generates a sludge cake that can be digested and a clean centrate stream which is processed further.
3. Separator which produces a gel (Kaumera) and a centrate stream that can be combined with the sludge cake and digested or processed.

In Zutphen and Epe (buffer) tanks for excess sludge, a reactor, and a storage tank for Kaumera are installed. Chemical storage for poly-electrolyte, base, and acid are also needed. A heat source is required to bring the sludge up to the requested temperature. In summary, the installation requires the input of sludge, chemicals, heat, and electricity. The output consists of Kaumera, filtrate, sludge cake, and centrate. The Kaumera is the end product. The other streams can be sent to a digester to be further processed.

Figure 5 **Schematic of the extraction installation**



Step	Description
1	Excess sludge buffer
2	Mechanical thickening
3	Heat exchangers
4	Reactor after base addition at high pH
5	Heat exchangers to recover heat
6	Decanter
7	Disc centrifuge after acid addition
8	Kaumera storage

3.2 ZUTPHEN KAUMERA EXTRACTION INSTALLATION

The Zutphen KEI is the first full-scale extraction installation ever built (Figure 6). It is designed and built for a sludge production of 600 — 2,000 tons TS/year. The installation is designed with modular capacity in mind. For the higher end of this range, some equipment needs to be added, but other parts are already designed to handle higher loads. The Nereda® operates fully on dairy wastewater. Currently, the KEI is most often operated at minimum capacity. The corresponding Kaumera production depends on operational settings, but on average results in a production of 160 tons TS/year if the installation operates year-round. The following paragraphs describe the key lessons learned during the start-up of the installation.

Figure 6 **Overview of the Zutphen treatment plant and extraction building**



SLUDGE DISCHARGE NEREDA®

The treatment of wastewater is the primary focus of a Nereda® installation. The sludge discharge functions in service of this primary purpose. When operating a Kaumera installation, that focus needs to be balanced with another purpose: Kaumera production. The wastewater still needs to be cleaned, but the sludge discharge becomes increasingly important. The NKOP research showed that the way sludge is discharged influences the EPS quality. The installation in Zutphen has operated under different recipes to find the sweet spot for operation of both the Nereda® and the KEI. This is a topic of further research within the NKOP. We found out that an average granule size of > 2 mm is not beneficial for the sludge production. Due to the high volatile fatty acid content of the dairy wastewater, this size is easily reached. However, the excess sludge production lowered consequently. In contrast, a maximisation of sludge production by lowering granule size can have a negative impact on the effluent quality.

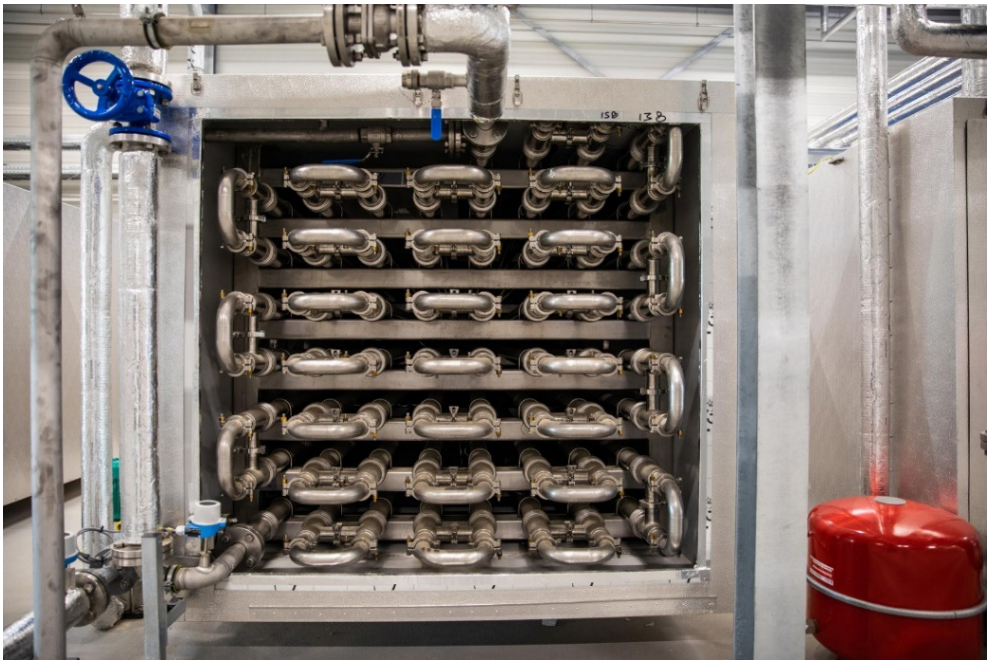
CONTINUOUS OPERATION

When the decision was made to build the first KEI, the NKOP was at a crossroads. We could either continue in lab-scale to produce small amounts of Kaumera and try small testing with market parties for a long time. Or we could invest in a bigger scale installation and produce more Kaumera, speeding up the time to market. The installation is built for continuous operation. As there was no continuous demand of Kaumera product at the start of the installation, this resulted in an installation that proved to be less efficient during start/stop operation, with prolonged startup times.

HEAT SUPPLY

The heat necessary for the extraction of EPS from sludge is supplied by a combination of heat pump and heat exchangers (Figure 7). Notably, both the heat pump and heat exchangers performed as expected, without encountering any scaling issues. The heat is partially recovered and reused by cooling down the extracted sludge before centrifugation.

Figure 7 **Image of one of the heat exchangers in Zutphen**



CENTRIFUGE OPERATION

The operation of the centrifuges is another important parameter in the extraction process. The decanters need to be operated with a different purpose than for conventional dewatering. Where a dry sludge cake is the main goal of the latter, the centrate quality is the main goal of the first. During start-up this required a mindset change of the operation and maintenance personnel. Moreover, we recognized that the interplay between the decanter and separator operations is indispensable for maintaining a steady extraction process. Because the extraction process benefits from low buffering times, the operation of the decanter directly influences the quality of the influent of the separator. Therefore, if the separation of solids in the decanter is insufficient, the separator will have to increase its number of ejections to still be able to treat the same flow. Together with the supplier (GEA), several optimizations have taken place to optimize both machines. Further investigations into the final separation step are in progress to improve separation efficiency.

Figure 8 **Setup of the two centrifuges in Zutphen. Left the decanter centrifuge and front right the disc centrifuge**



3.3 EPE KAUMERA EXTRACTION INSTALLATION

The Epe KEI has a smaller capacity and is built as a demonstration installation of Kaumera production on municipal sludge. Therefore, the installation is only in operation during weekdays, with an average production time of 90 hours per week. The average sludge treatment capacity is 90 tons TS/year, with a corresponding Kaumera production capacity of 15 tons TS/year (15% of Zutphen capacity).

HEAT SUPPLY

Because the Epe installation is of a smaller scale, the use of a heat pump and heat exchangers was not viable. Therefore, the heat supply in Epe is generated with a steam vessel. This ensures an installation that can start up faster, but the recovered heat can't be re-utilized in the extraction installation.

CENTRIFUGE OPERATION

Epe is the second Kaumera installation that is started up, meaning several of the lessons learned in Zutphen were implemented in the Epe design. An example of this was the decanter and disc centrifuge configuration. These machines are more effectively aligned in this second extraction installation.

STORAGE CAPACITY

The Kaumera storage capacity is relatively big in Epe. Initially, this presented certain operational challenges due to the comparatively low production capacity and the biodegradable nature of Kaumera. As can be seen in Figure 9, the Kaumera is therefore stored in IBCs and transported when the requested amount of Kaumera is produced.

Figure 9 **Outside look at the extraction installation in Epe, with IBCs filled with Kaumera**



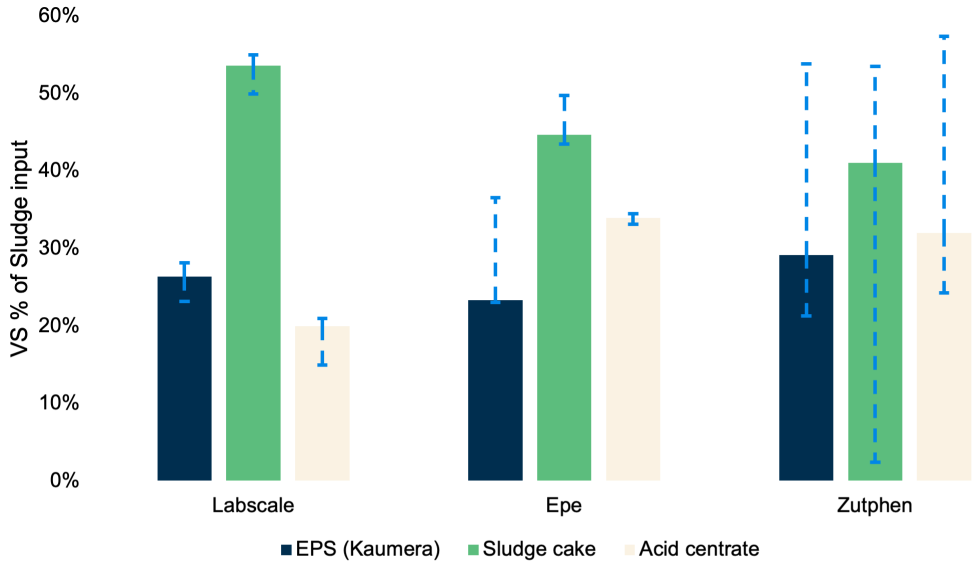
3.4 KAUMERA QUANTITY AND COMPOSITION – COMPARISON OF LAB AND FULL-SCALE INSTALLATIONS

KAUMERA QUANTITY – EFFICIENCY OF THE EXTRACTION PROCESS

As stated in the STOWA 2019-14 report, the average yield of Kaumera on sludge from the lab-scale and the pilot-scale extractions was between 25% - 35% of VS. In Figure 10, the VS distribution over Kaumera, centrate, and sludge cake for three situations are shown. An example lab-scale extraction with a yield of 25% is shown as a reference.

The average, optimized yield from Epe after several optimization weeks is 23%, whereas Zutphen can reach a yield of 29% with good product quality. Although the overall VS amount which ends up in the Kaumera in the full-scale plants is similar to lab-scale extractions, the distribution of VS over the other output streams (centrate and cake) is different from lab-scale extractions.

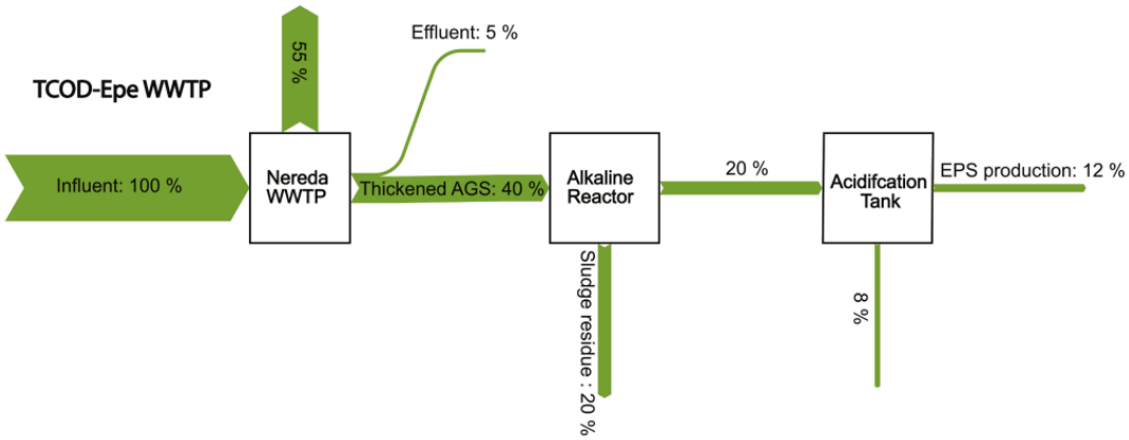
Figure 10 **Volatile solids distribution of Kaumera, sludge cake and centrate for lab-scale, Epe (three sampling days) and Zutphen Kaumera (seven sampling days)**



A change in operational conditions, for example, decanter settings, will result in a different distribution of VS. In Zutphen it was shown that the yield of the extraction process could be increased to 50%. This yield was achieved by focusing on a dry sludge cake from the decanter. As a result, more dissolved biopolymers end up in the centrate. However, more impurities are also likely to end up in the centrate, thus impacting Kaumera product quality.

Baghat et al (2023) have shown in their research that the lab-scale extraction can be modified to fit the full-scale extraction process better. Therefore, making it possible to investigate the product quality on lab-scale as well. They have also demonstrated the mass balances of the Epe plant for COD, phosphorus, and nitrogen. During those tests, the Epe installation was able to reach a 30% yield on COD, see Figure 11. The same COD yield was reached in the lab-scale tests performed.

Figure 11 **Total COD balance of Epe WWTP and extraction installation, source: Baghat et al, 2023**



To summarize, the operational settings influence the Kaumera yield, but a similar yield to the lab-scale is achievable. More research is needed on the difference, if any, in Kaumera quality if lower or higher yields are obtained.

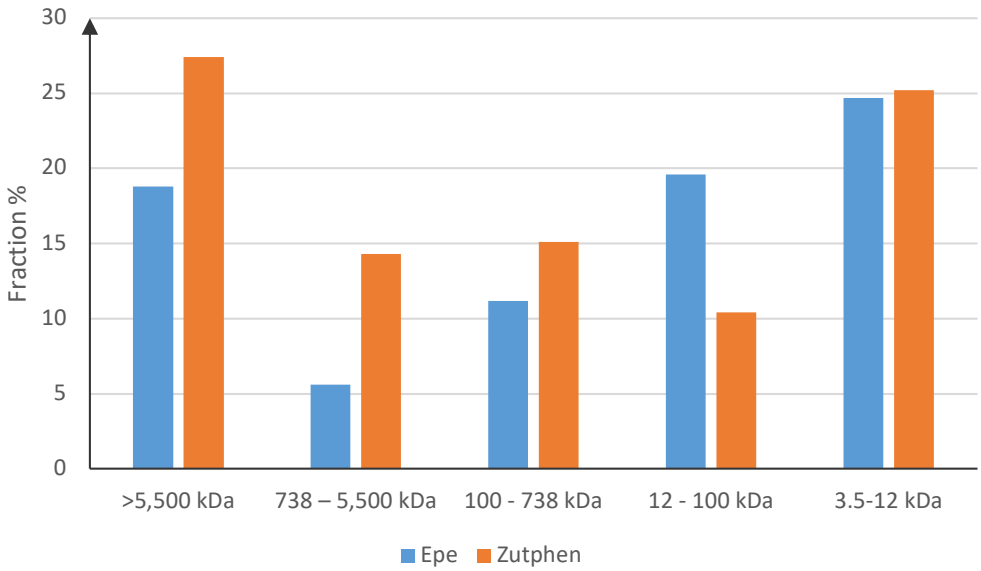
COMPOSITION OF KAUMERA

The composition of Kaumera was previously described in STOWA 2019-14. Since then, new analytical methods have been developed by DUT, providing updated insights into the Kaumera composition.

MOLECULAR WEIGHT

The NKOP research aims to understand the impact of molecular size on the properties of Kaumera and how to control it. Previous analyses on lab-scale and pilot-scale Kaumera indicated an average molecular weight variance between 20 and 120 kDa based on viscosity measurements. It was hypothesized that this substantial range was due to variations in the extraction protocol and sludge origin. However, recent analyses using size exclusion chromatography have revealed that a single Kaumera sample contains biopolymers with a range of molecular weights. Figure 12 illustrates the distribution of fractions within different molecular weight ranges for samples from Epe and Zutphen. One sample was used from each location. Due to the insolubility of certain polymer fractions, these percentages do not sum up to 100%, but they indicate the size distribution.

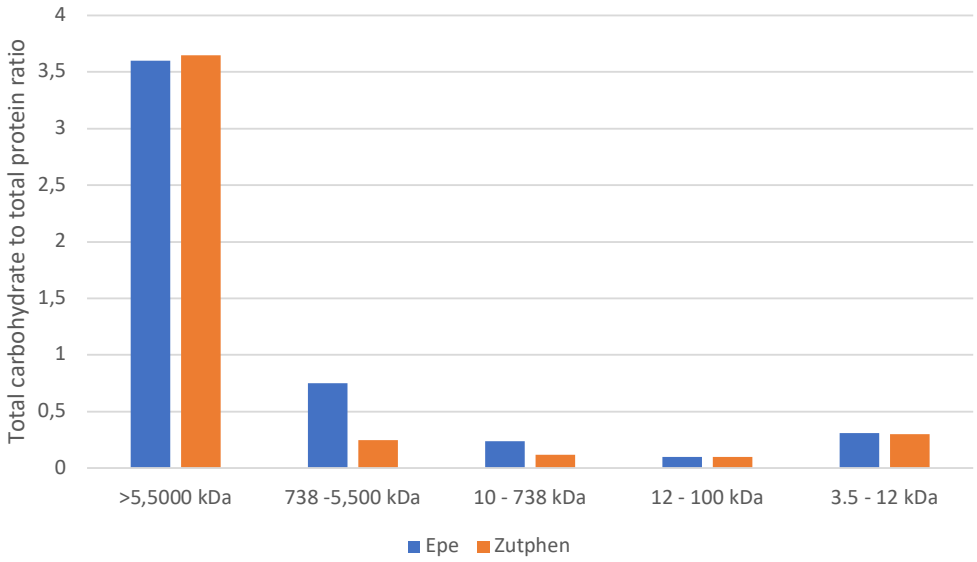
Figure 12 **Molecular weight distribution for Epe and Zutphen Kaumera**



ORGANIC COMPOSITION

Previously, the carbohydrate and protein content of Kaumera was reported (STOWA 2019-14). Approximately 50 – 70% of the Kaumera composition was identified as proteins, while around 25% consisted of carbohydrates. Through fractionation, DUT analysed the carbohydrate to protein ratio in these fractions. The analysis revealed that the ratio decreases with a reduction in molecular weight (Figure 13). This trend was observed in both dairy sludge (Zutphen) and municipal sludge (Epe). The distribution of proteins and carbohydrates is hypothesized to have an influence on the viscosity of Kaumera, thus influencing its application. More carbohydrates normally results in higher viscosity, since protein is more dense and carbohydrate chain is more flexible and easily interact with each other to increase the viscosity.

Figure 13 **Total carbohydrates (phenol sulphuric assay) to total proteins (BCA assay) ratio of Kaumera from Epe and Zutphen per size fraction (2022)**



3.5 SUMMARY

The two full-scale extraction installations are currently in operation and continue to perform successfully following their scale-up from laboratory to full-scale. The main challenge in the operation is the alignment of the two centrifuges which requires much attention of the operator.

Detailed analysis indicates that the obtained yield at the full scale installations is comparable to the yield at lab-scale. It is possible to produce a product similar to lab-scale in these full-scale installations. Furthermore, the development of new analytical methods provides deeper insights into the composition of Kaumera. It is now understood that Kaumera consists of polymers of varying sizes, from small (less than 12 kDa) to large (more than 5,500 kDa), and that the carbohydrate to protein ratio varies across these different fractions. These analyses reveal a high degree of similarity between the Kaumera produced in Epe and Zutphen. Further research aims to determine whether the size distribution and carbohydrate to protein ratio can be influenced.

4

OPTIMIZATION OF KAUMERA PRODUCTION

With the advancements made in the extraction and analysis of Kaumera, it is important to continue refining the procedures to enhance efficiency and sustainability. Chapter 4 delves into the ongoing efforts to improve the Kaumera extraction process, focusing on reducing the environmental impact and operational costs. The chapter begins by examining key factors that influence the footprint of the Kaumera production, followed by an analysis of potential improvements.

4.1 IMPROVEMENT OF THE EXTRACTION PROCESS

In the report "LCA of 8 resources from sewage (Dutch), STOWA 2023-08," it is noted by authors CE-Delft, that the Kaumera extraction process exhibits a lower environmental impact compared to its alternatives. Specifically, the net carbon footprint is calculated to be 0.22 kg CO_2-eq per kg of Kaumera, whereas alginate derived from seaweed has a footprint of 2.7 kg CO_2-eq per kg of alginate[1]. These calculations predominantly reference the Zutphen extraction facility, which utilizes fewer chemicals due to its lower buffer capacity. Therefore, the chemical usage of the Epe installation was used in the calculations. This comparison provides an insight into the CO_2 footprint of Kaumera relative to alginate. Additionally, various applications are being explored using different materials for footprint comparison.

The primary contributor to the Kaumera production footprint is electricity consumption, accounting for 61% of the total footprint. The LCA study utilized the average Dutch electricity mix as the basis for this calculation. The study notes that the results depend on the choice of base, the electricity mix used, and the overall amount of chemicals employed.

The following chapters describe three possible improvements that were previously studied by the NKOP.

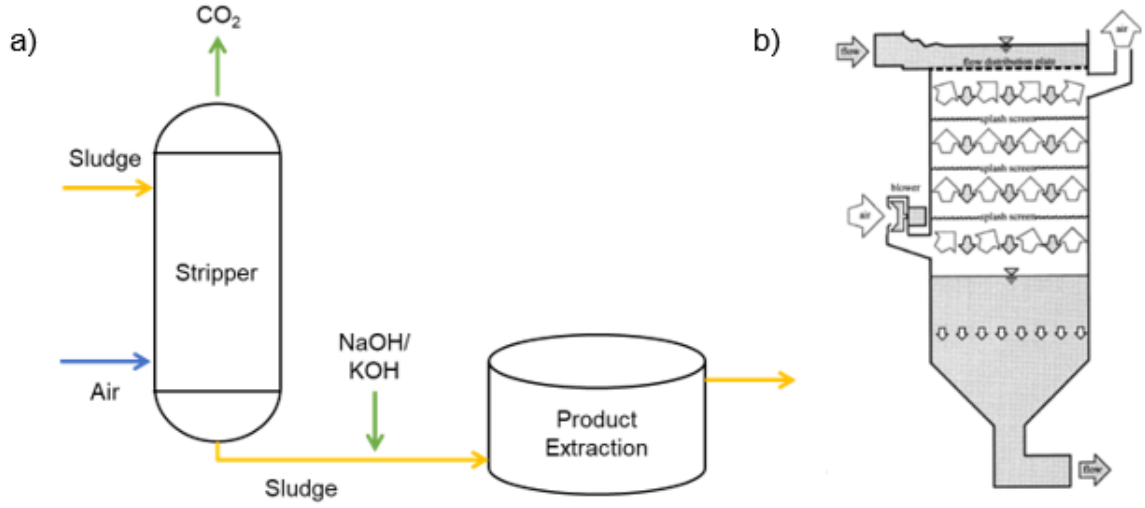
4.1.1 POSITIVE EFFECT OF CO_2 STRIPPING ON CHEMICAL CONSUMPTION

INTRODUCTION

Base and acid use in Kaumera extraction affects costs and add to the carbon footprint. Reducing chemical consumption can make the process more cost-effective and sustainable. Reducing the buffer capacity of feed sludge decreases chemical consumption during extraction by allowing pH to rise with less base. This can be done by stripping CO_2 from the sludge before extraction, as shown in Figure 14a. Figure 14b illustrates a full-scale cascade stripper column with perforated plates.

1 Alginate was deemed the closest material to Kaumera to compare the CO2 footprint to. However, it entirely depends on the application which material Kaumera would be replacing. Therefore, alginate serves as a model material to compare Kaumera to.

Figure 14. **a) Schematic representation of the process with CO_2 stripper and b) schematic of a cascade (perforated plates) stripper column (Source: Summerfelt et al. (2000)**



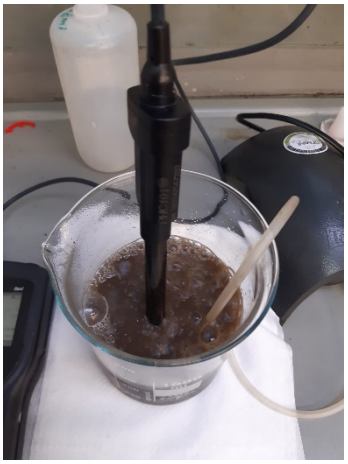
The impact of CO_2 stripping on buffer capacity and base consumption during extraction was evaluated through alkalinity modelling and experiments. The economic viability of a CO_2 stripper was then assessed based on these findings.

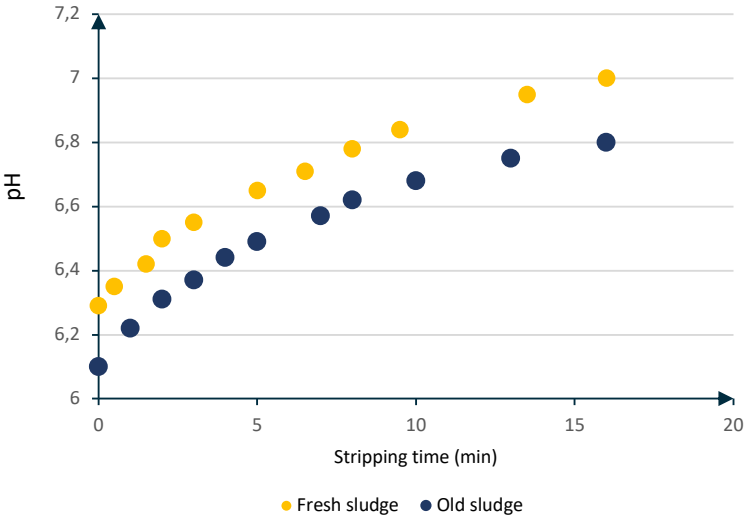
METHODOLOGY

To estimate the decrease in base consumption by stripping, different lab-scale tests were carried out. These tests aimed to determine the alkalinity, free CO_2 content, and the effect of stripping on the buffer capacity of the sludge. Both alkalinity and free CO_2 were calculated based on a titration methodology and theoretical calculations based on Lahav & Birnhack, 2019.

The CO_2 stripping test was done on a thickened fresh sludge sample and a thickened old sludge sample (1 week old in the refrigerator). The buffer capacity of sludge changes as it ages. The samples were diluted to have a DS concentration of 20 gr/l approximately since the lab-scale aeration setup was not able to strip the CO_2 with a higher TS concentration of the sludge (Figure 15). The change in pH was monitored during the stripping and is shown in Figure 15. The starting pH of the old sludge is lower due to acidification which occurred while the sludge was stored in the fridge. The pH of both sludges increased after stripping.

Figure 15 **Laboratory scale stripping of sludge (left) and its effect on sludge pH (right)**





In Table 3, the assumptions for the economic feasibility calculations are given. Prices date from 2022/2023 and might differ from the current pricing. Furthermore, an incoming flow of 1.2-2.0 m^3/h of thickened sludge (scale KEI Zutphen), an electricity consumption of 5 kWh/m^3 in the CO_2 stripper, and 0.25 FTE to operate the stripper were assumed.

Table 3 **Assumptions for economic feasibility study**

Parameter	Unit	Value
NaOH (30%)	€/ton	700*
KOH (50%)	€/ton	1.610**
Electricity	€/kWh	0,30
Personnel costs	€/fte	50.000
CO_2 stripper	€	600.000***
Removal efficiency of the CO_2 stripper	% of free CO_2	90

* Price level of January 2023

** Bases on the price ratio of NaOH/KOH in 2022

*** Based on the received estimation for an ammonia stripper from Byosis, realisation costs not included

A comparison was made between stripping or no stripping, the use of fresh or old sludge and the use of KOH or NaOH as base. A total of eight scenarios were compared based on their Net Present Value (NPV) over 15 years.

RESULTS

Based on the lab-scale stripping experiments and the theoretical calculation, the base consumption to reach a pH of 10 at a temperature of 80°C for scenarios with and without stripping is given in Table 4 along with sludge characteristics. Since the lab-scale experiments were done on diluted sludge with a lower DS concentration (2%), all the calculated values were corrected for the original sludge DS concentration of 4.7%.

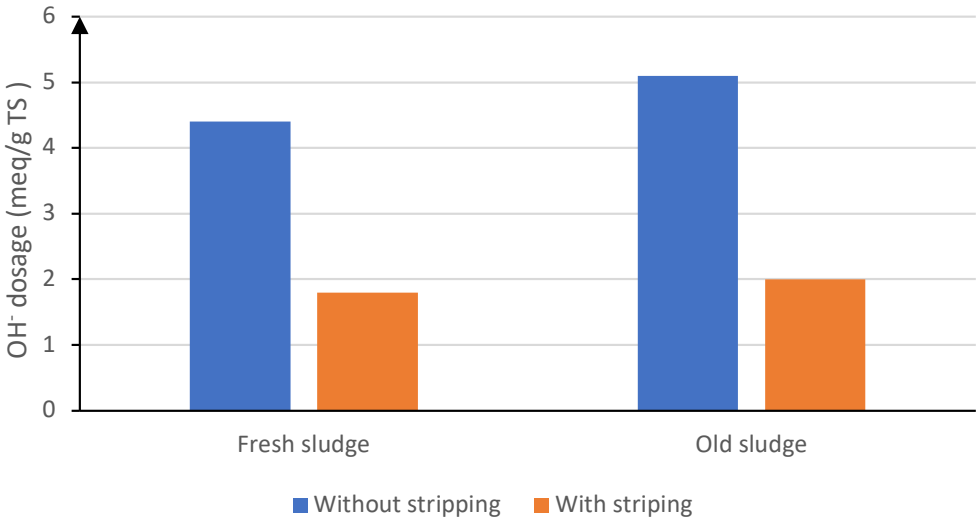
Table 4 shows that the old sludge has a lower alkalinity (HCO^-_3) compared to the fresh sludge. In addition, the old sludge was characterized by a lower pH and higher free CO_2 content. This indicates acidification during the storage of the sludge which has led to the consumption of the bicarbonate alkalinity of the old sludge.

Figure 16 shows the effect of stripping on OH^- consumption in milliequivalents[2] (meq) per g DS. After stripping, both fresh and old sludge needed a significantly lower amount of OH^- dosage to reach pH 10 at a temperature of 80°C. These reduced OH^- consumption of 1.8 meq/g DS for fresh sludge and 2 meq/g DS for old sludge were the basis of the economic feasibility study.

Table 4 **Characteristics of fresh and old (1 week old kept in fridge) sludge**

Parameter	Unit	Fresh sludge	Old sludge (1 week)
DS	%	4.68	4.68
VS	% of DS	81.4	81.5
pH (20°C)	-	6.54	6.32
HCO_3^-	mg/l	4,995	3,619
CO_2 (H_2CO_3)	mM	53.4	62.3

Figure 16 **The effect of stripping on base (OH^-) consumption to reach the pH value of 10 at the temperature of 80°C**

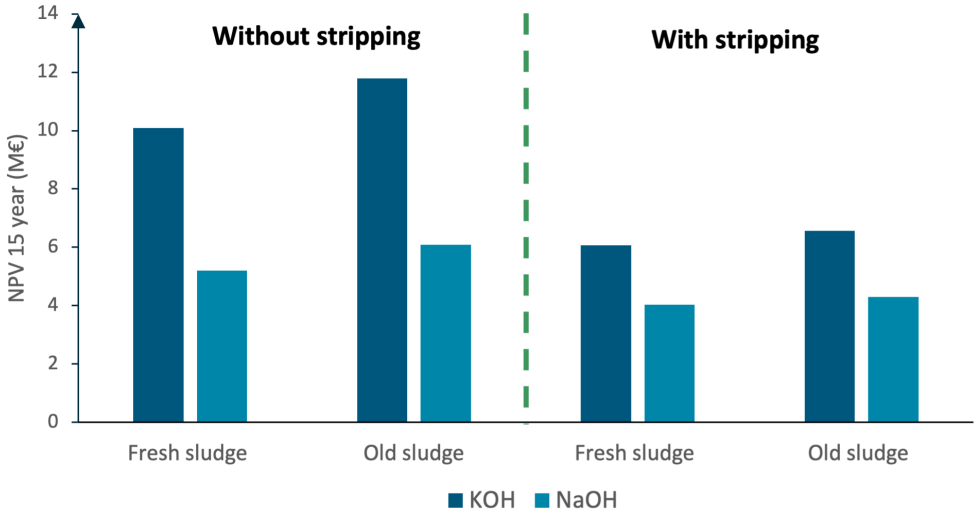


ECONOMIC FEASIBILITY

A total of eight scenarios were compared based on their Net Present Value (NPV) over 15 years. The results of the analysis are shown in Figure 17. The analysis shows that implementing a CO_2 stripper is economically more favourable (lower NPV) than a process without a stripper, for both fresh and old sludge. Therefore, it can be concluded that the costs of having a CO_2 stripper (investment and operational costs) outweigh the savings on base consumption. The economic benefit achieved by a CO_2 stripper is strongly influenced by the price of the base. When using KOH as base, the absolute decrease in NPV when purchasing a CO_2 stripper is considerably greater than when using the cheaper NaOH (Figure 17). Therefore, implementing a CO_2 stripper can be more economically favourable in the case of using a more expensive base. Figure 17 shows that old sludge is more costly than fresh sludge due to its lower pH and higher free CO_2, which increases base consumption. Stripping the free CO_2 reduces the cost difference between fresh and old sludge.

2 * meq = milliequivalents. This is related to the number (mmol) and electric charge of ions in solution. Monovalent ions (K^+, Na^+, Cl^-) have the same amount of moles as equivalents in solution.

Figure 17 **Net Present Value (NPV) over 15 years of the scenario's with KOH/NaOH dosage and with or without CO_2 stripping. A CO_2 removal of 90% has been assumed in the CO_2 stripper.**



CONCLUSION

The following conclusions can be drawn:

- The analyses in this study showed that the implementation of a CO_2 stripper for both fresh and old sludge results in a lower NPV than the reference scenario without a stripper. Since KOH is twice as expensive as NaOH a CO_2 stripper is more feasible when KOH is needed in the extraction process.
- The economic feasibility depends on the investment cost of the stripper, the alkalinity of the thickened sludge, and the CO_2 removal efficiency. Therefore, the specific sludge characteristics and the intended scale must be evaluated on a case-by-case basis to determine whether implementing a CO_2 stripper is justified.

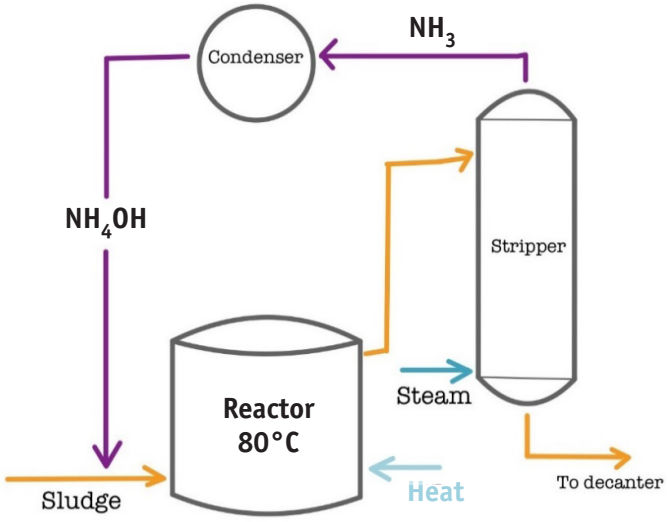
4.1.2 NH_4OH AS RECOVERABLE BASE

INTRODUCTION

To extract Kaumera, a combination of heat and base is used. It is currently common practice to use either NaOH or KOH, however, these bases contain salts which can reduce the organic content (VS) of Kaumera. Therefore, one of the extraction processes developed by DUT is based on using NH_4OH. This will not add salts to the extraction and enable the recovery of NH_3 through steam stripping and recycling it as NH_4OH after the extraction (Figure 18), thus improving the sustainability of the process. A preliminary business case suggested NH_4OH as a base with recovery had high potential. Lab-scale experiments and theoretical calculations were conducted to further investigate.

METHODOLOGY AND RESULTS

Figure 18 **The process schematic of extraction with NH4OH and its recovery with stripping**



The first step in lab-scale experiments was to determine how much NH_4OH is needed to increase the sludge pH to 10 at 80°C. pH 10 was used in these experiments as a standard setpoint. This was tested on a sludge sample with a 4.4% DS concentration.

Figure 19 **The dosage of NH_4OH in mmol per gram of volatile solids (VS) of sludge**

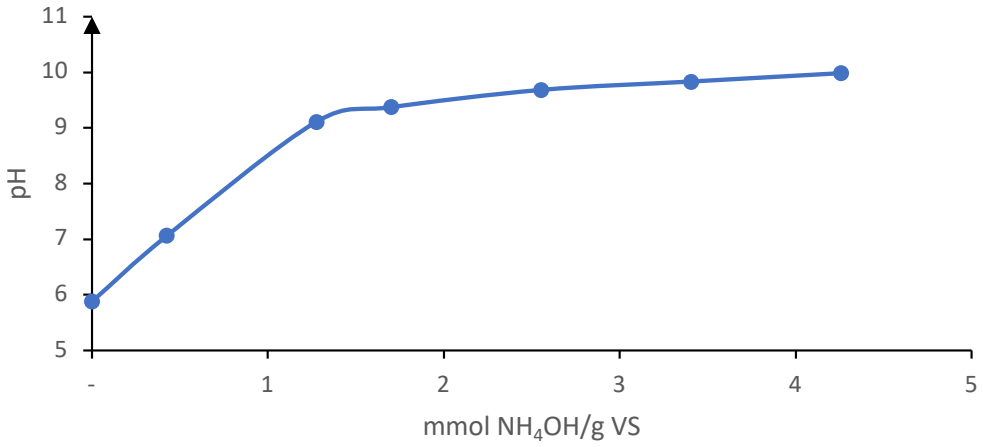


Figure 19 shows that a significant amount of NH_4OH is needed to increase the pH to 10 and that the pH increase is not linear due to the pKa of NH_4. NH_4 is in chemical equilibrium with NH_3. The pKa for this equilibrium is 9.24. The ammonium equilibrium is illustrated in below equation. Therefore, to reach pH 10, a relatively high dose of NH_4OH is needed.

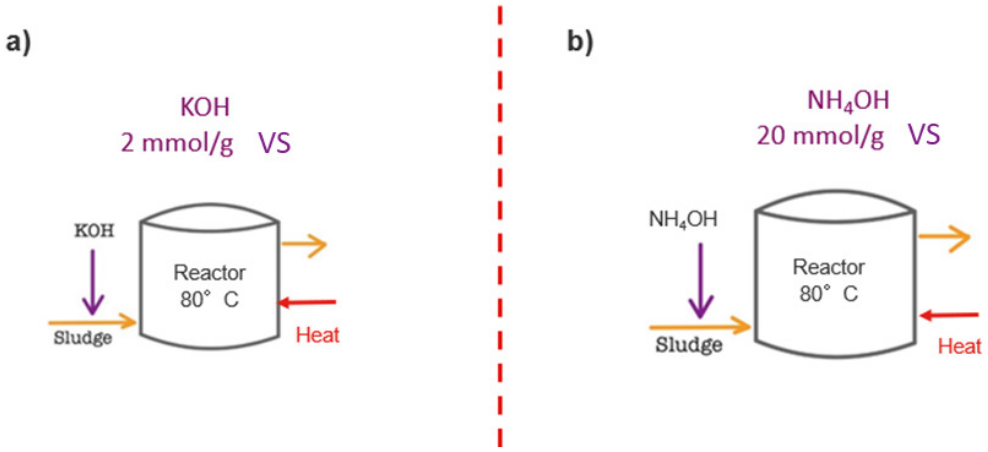
$$NH_3 + H_2O \Leftrightarrow NH_4^+ + OH^-$$

The high amount of NH_4OH dosage comes at an increased extraction cost, removing one of the advantages of wanting to use NH_4OH. Although, in different lab-scale experiments by DUT, it was observed that using NH_4OH can cause colour alteration of the Kaumera from darker shades to lighter shades of brown.

To further investigate the feasibility of using NH_4OH in practice, different scenarios were simulated and calculated with the CHEMCAD simulation tool. Water was considered as the inlet stream instead of sludge for simplification of simulation. In this simulation, the effect on buffer capacity from the presence of VFAs, CO_2 production, release of extra ammonia, and salt precipitation were not considered. Therefore, the numbers given below can only be considered as an indication to compare different scenarios.

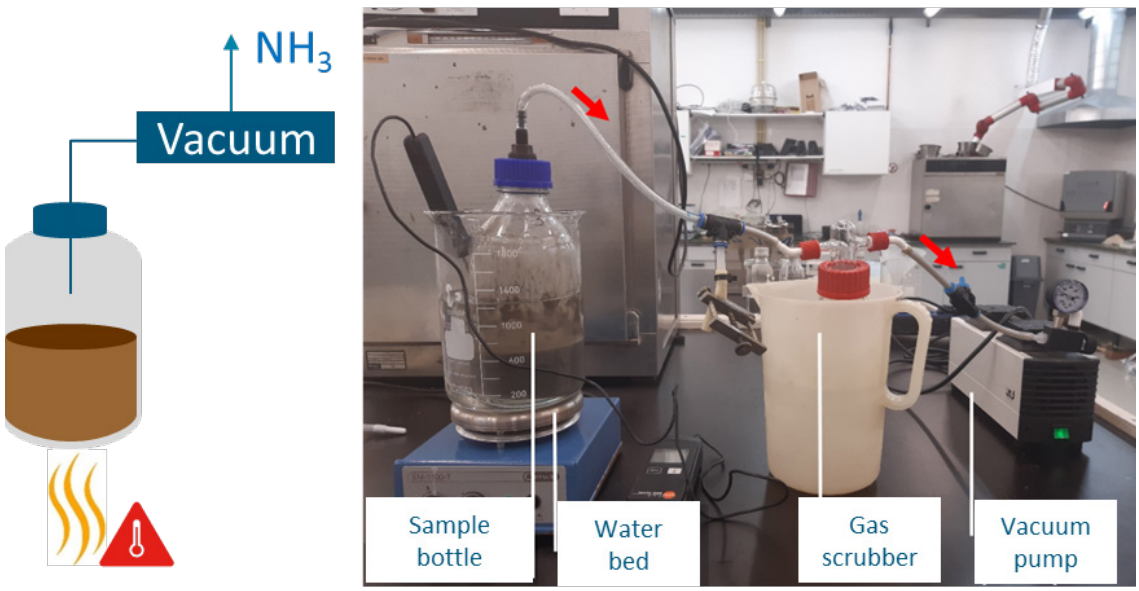
In the simulation conducted using CHEMCAD, it was determined that to raise the pH to 10 at a temperature of 80°C, an addition of 20 mmol/g VS of NH4OH is required without any recovery. In contrast, for KOH, this value is 2 mmol/g VS (Figure 20).

Figure 20 **Kaumera extraction at 80°C with a) KOH consumption and b) NH_4OH consumption without recovery**



To calculate NH_4OH recovery, maximum possible recovery (%) was tested in the lab. Various stripping setups were evaluated for this purpose. Thermal vacuum stripping showed high potential, with nitrogen recovery ranging from 50 to 70%, depending on the temperature (30 to 60°C). Higher temperatures led to higher recovery percentages. Figure 21 depicts the lab-scale setup for thermal vacuum stripping.

Figure 21 **The lab-scale setup for thermal vacuum stripping to recover nitrogen.**



Considering the possible maximum recovery percentage of 70%, the NH_4OH consumption was recalculated for a scenario with a stripper for recovery of NH_4OH. The NH_4OH consumption in this case is 12.4 mmol/g VS which is still significantly higher than 2 mmol/g VS of KOH.

CONCLUSION

This chapter explored the feasibility and efficiency of using NH_4OH as a base in comparison to KOH for Kaumera extraction. The simulations and laboratory experiments revealed that NH_4OH consumption is significantly higher than KOH, even when considering the possible recovery methods for NH_4OH.

The need for the extraction to be performed at pH 10 or higher comes from a preservation and yield standpoint. If alternative preservation methods are found which guarantee product longevity, the use of NH_4OH can be investigated further.

From a cost perspective, the high consumption rate of NH_4OH makes it a less favourable option. However, the potential advantage of NH_4OH regarding product quality remains application-dependent and warrants further investigation to understand its impact on the desired extraction yield. Consequently, while NH_4OH may not be economically viable as a base under current conditions, its role in enhancing product characteristics could justify its use in specific scenarios, meriting additional research and evaluation.

4.1.3 NAOCL ADDITION

INTRODUCTION

The ongoing research into improving Kaumera quality and minimizing chemical consumption during the extraction process has made significant strides. In 2022, a particular focus was placed on studying the effects of sodium hypochlorite (NaOCl) addition. The chemical was hypothesized to have a positive effect on pathogen removal, base consumption, and the overall quality of Kaumera. Pathogen removal is important when extracting Kaumera from municipal activated granular sludge (AGS) to broaden its potential applications. To address this, one of the extraction processes developed by DUT incorporates the use of hypochlorite to enhance pathogen removal and improve Kaumera properties. The research questions were defined as below:

1. How does NaOCl concentration (1%, 3%, 5% v/v) affect pathogen removal?
2. How does NaOCl concentration (1%, 3%, 5% v/v) impact discoloration?
3. How does NaOCl concentration influence base consumption in the first extraction step to reach pH 10?

METHODOLOGY

Three different concentrations (1%, 3%, and 5% *v/v*) of NaOCl along with a sample with no NaOCl addition (Reference) were tested for comparison. Thickened AGS samples (DS: 4.7%, VS/DS: 74.5%) were taken from Epe WWTP. After sludge samples reached a temperature of 80°C, the NaOCl was added for all samples except the reference. The set pH in all samples was adjusted to 10 with the addition of KOH 33% *v/v*. All the analyses were done in duplicate.

RESULTS

The DS and VS content of the extracted Kaumera with the addition of three different NaOCl

concentrations and the reference sample (0% *v/v* NaOCl) is shown in Figure 23. The deviations between duplicates were not significant and are not shown in the figure. As seen in Figure 23, the increase in NaOCl addition does not affect the absolute VS concentration (g/l) of Kaumera. However, with higher NaOCl addition, the relative VS content over DS (g VS/g DS) of the Kaumera decreases. This observation aligns with previous tests conducted in 2016, which indicated that the ash content of Kaumera increased with the addition of NaOCl. In Figure 24, the effect of NaOCl addition on Kaumera yield is depicted. The Kaumera yield decreases with increasing NaOCl addition. Adding 5% *v/v* NaOCl led to a significant yield decrease (22% vs. 30.5% from the reference extraction). This may be due to radicals from NaOCl disrupting EPS. No significant change in KOH and HCl consumption was observed across samples with NaOCl ranging from 0% to 5% *v/v*.

Figure 22 **The dry solids (DS) and volatile solids (VS) content of Kaumera with different NaOCl addition amount**

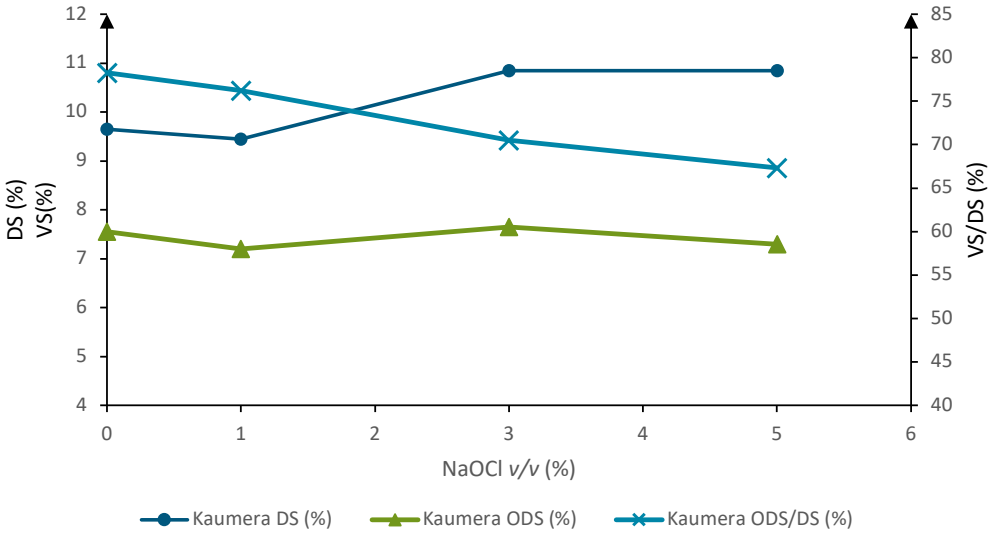
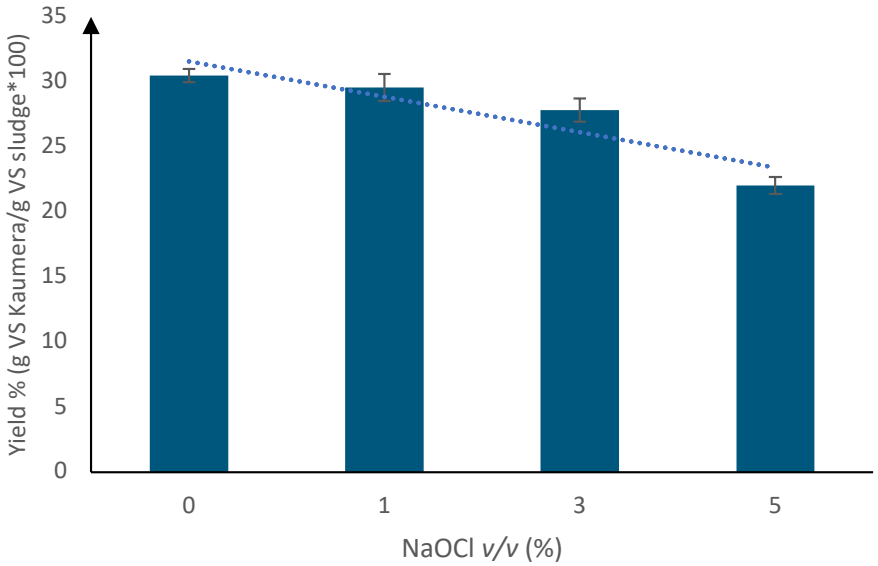


Figure 23 **The effect of NaOCl addition amount on the Kaumera yield**

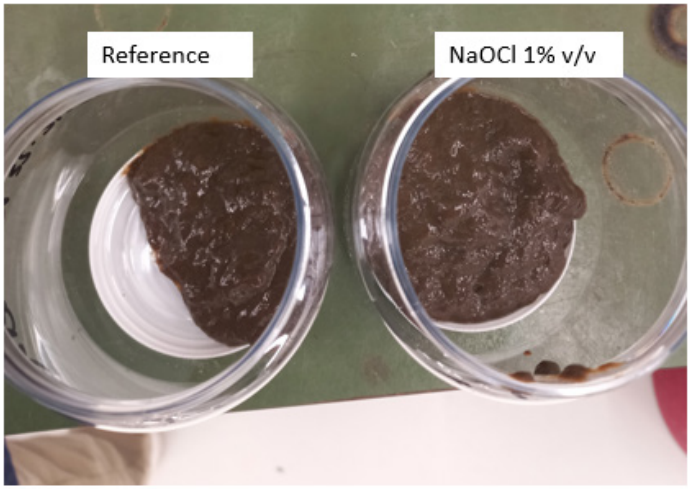


The extracted Kaumera samples were sent to an external laboratory (Nutrilab BV) for pathogen analysis shortly after extraction. The analysis indicates that no pathogens were detected in any of the samples, including the reference sample. Therefore, no conclusion can be drawn about the effect of NaOCl addition on pathogen removal from this experiment. It

can be concluded that the conventional extraction method results in complete pathogen hygienisation.

The odour of Kaumera significantly changed to a 'cleaner' odour due to the presence of chlorine, as reported by the lab technician. Slight discoloration in extracted Kaumera was observed when NaOCl was used in the extraction (Figure 25). The extracted Kaumera changed from dark brown colour for the reference to lighter brown shades as NaOCl concentration increased and confirmed the expected discoloration effect of hypochlorite.

Figure 24 **The effect of NaOCl on discoloration of Kaumera**



CONCLUSION

Based on the information provided above, the following conclusions were drawn:

- How does NaOCl concentration (1%, 3%, 5% v/v) affect pathogen removal?
  Since no pathogen was found in the reference sample, we cannot determine NaOCl's effect on pathogen removal. The tests were conducted under similar temperature, residence time, and pH conditions as the reference.
- How does NaOCl concentration (1%, 3%, 5% v/v) impact discoloration?
  Some discoloration was achieved. Further research is needed for specific applications to benefit from this. Additionally, NaOCl addition significantly affected Kaumera's odour towards a more 'cleaner' odour due to the presence of chloride. This was observed for all tested concentrations (1%, 3%, 5% *v/v*).
- How does NaOCl concentration influence base consumption in the first extraction step to reach pH 10?
  No significant change in KOH and HCl consumption was observed across samples with NaOCl ranging from 0% to 5% v/v.

Additionally, a higher addition of hypochlorite led to a decrease in VS yield. Hypochlorite may facilitate milder extraction conditions; it is necessary to pursue further investigation in this area to draw this conclusion. The observations from this test indicate that additional research into the use of NaOCl for Kaumera extraction is inadvisable.

4.2 IMPROVEMENT OF KAUMERA PRESERVATION

INTRODUCTION

Kaumera is a biobased raw material extracted from sludge granules that are formed in the Nereda® treatment process. As Kaumera is a biodegradable product, the NKOP wanted to gain knowledge on the shelf life and potential preservation methods of Kaumera. The goal of the study performed in 2022/2023 was to create a preservation method that is applicable in the field, cost-effective, and retains Kaumera's physical and chemical characteristics for as long as possible. Aside from the visual quality of the Kaumera, we also aimed to analyse the quantity and viscosity of the Kaumera over time. A slight degradation of the Kaumera quantity is not necessarily a problem if accounted for. However, users should be made aware of quality degradation over time

METHODOLOGY

The investigated preservation methods are (1) the addition of food preservatives (sodium benzoate, potassium sorbate and calcium propionate), (2) nitrogen headspace, (3) an oil layer on the Kaumera surface, Two controls were tested as well: (4) a negative control without preservation, and (5) a positive control with the addition of a biocide. Two types of tests were performed:

A. Method 1 and control 4, and 5 were tested at an increased temperature of 30 ˚C for a duration of 17 days under anaerobic circumstances on Zutphen Kaumera. Analysis was done on:
   a. Visual fungal or bacterial colony growth
   b. pH change
B. Methods 1, 2, 3, and control 4 were tested at room temperature (21.5 ˚C) for a duration of 17 weeks on Epe Kaumera. Analysis was done on:
   a. Visual fungal or bacterial colony growth
   b. pH change
   c. Dynamic viscosity

The samples were categorized based on the test (A or B) and the preservation method employed (1 — 5) and summarized in Table 5.

Table 5 **Test setup Kaumera degradability**

Test	Preservation Method	Temperature	Duration	Analysis	Kaumera Type
A	1 = Food preservatives	30 ˚C	17 days	Visual fungal or bacterial colony growth, pH change	Zutphen
A	4 = negative control	30 ˚C	17 days	Visual fungal or bacterial colony growth, pH change	Zutphen
A	5 = positive control	30 ˚C	17 days	Visual fungal or bacterial colony growth, pH change	Zutphen
B	1 = Food preservatives	21.5 ˚C	17 weeks	Visual fungal or bacterial colony growth, pH change, Dynamic viscosity	Epe
B	2 = nitrogen headspace	21.5 ˚C	17 weeks	Visual fungal or bacterial colony growth, pH change, Dynamic viscosity	Epe
B	3 = oil layer blanket	21.5 ˚C	17 weeks	Visual fungal or bacterial colony growth, pH change, Dynamic viscosity	Epe
B	4 = negative control	21.5 ˚C	17 weeks	Visual fungal or bacterial colony growth, pH change, Dynamic viscosity	Epe

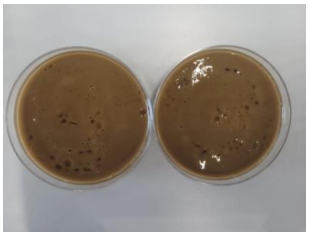
RESULTS

Visual changes

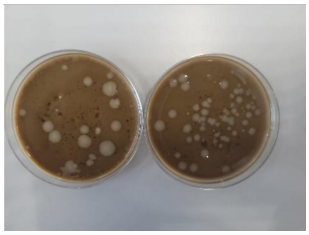
As seen in Figure 26, in both tests A and B the negative control displayed the growth of fungal or bacterial colonies on the surface of the Kaumera. The positive control of test A (A5) did not show these colonies, as did both tests with food preservatives (A1 and B1). The nitrogen blanket (B2) and oil layer (B3) methods did lead to colony growth, indicating that these methods are less effective. It is interesting to note that the fungal colonies grew on top of the oil layer and not on the Kaumera itself.

Figure 25 **Observational results of different methods**

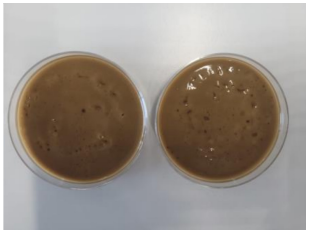
Tests A: 17 days, 30 ˚C



Food preservatives (A1)

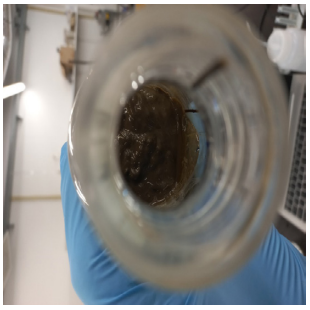


Negative control (A4)

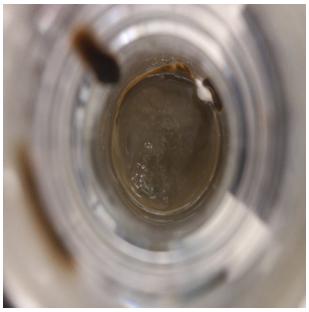


Positive control (A5)

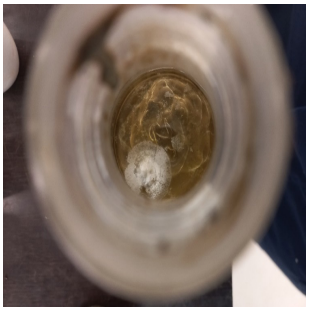
Tests B: 17 weeks, 21.5 ˚C



Food preservatives (B1)



Nitrogen headspace (B2)



Oil layer (B3)

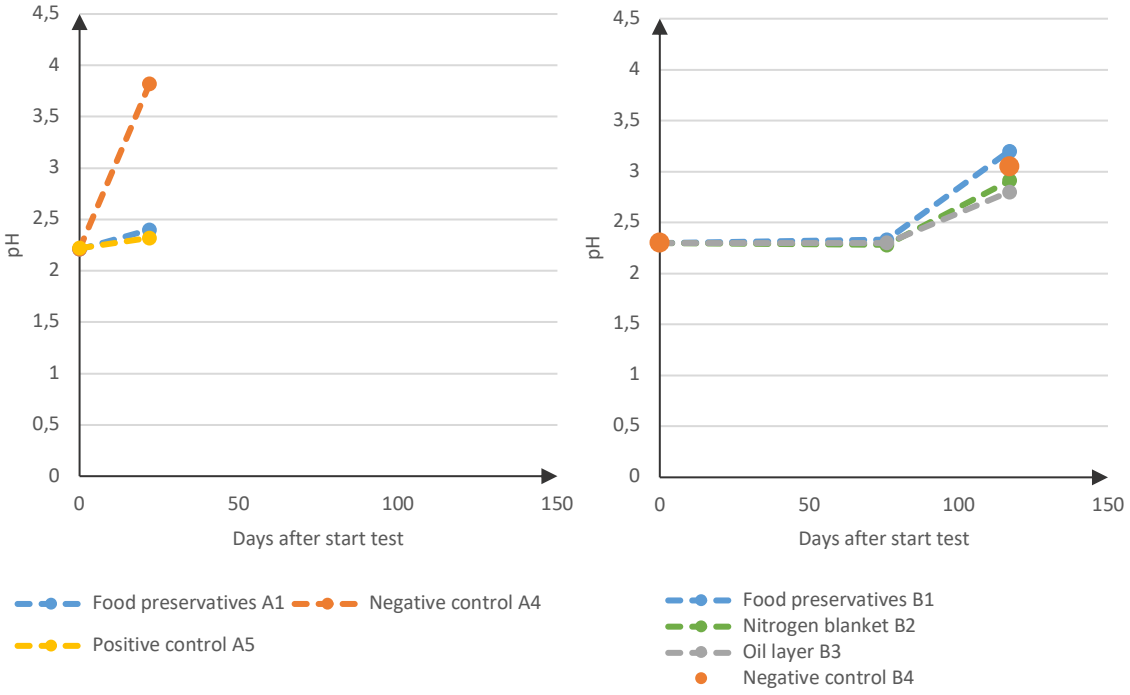


Negative control (B4)

Property changes of Kaumera

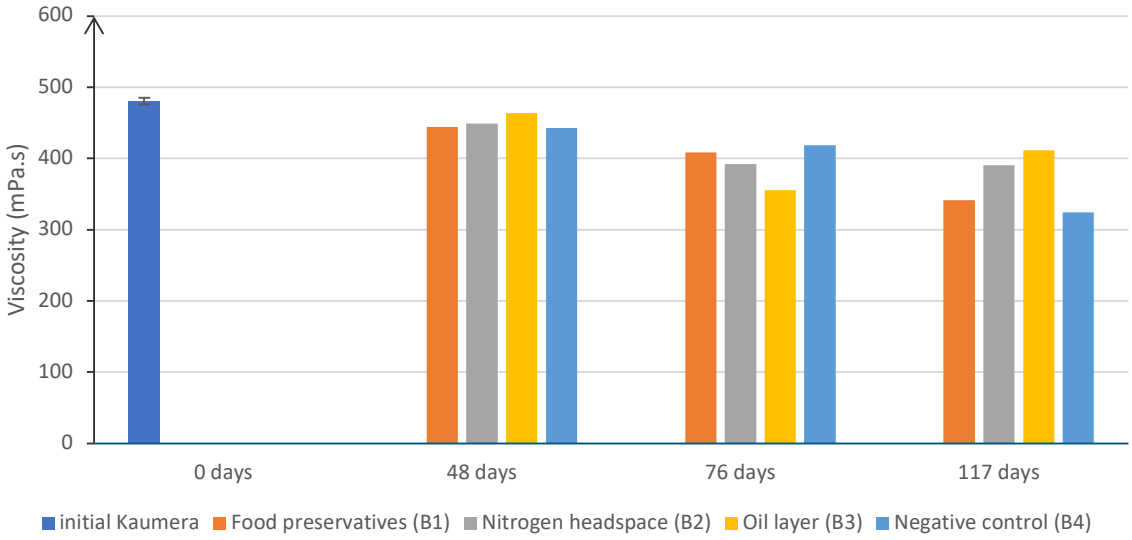
To measure if the properties of the Kaumera changed over time, pH and viscosity were measured. In Figure 27, the negative control shows an increase in pH for both test A and B. During the brief testing period of test A, no increase in pH levels was detected for the food preservatives. The food preservative method, nitrogen headspace, and oil layer did show an increase in pH after 117 days in test B. This indicates that some changes in the Kaumera occur after almost 4 months. After 2,5 months no pH increase was observed yet.

Figure 26 **pH changes of test A (left) and B (right) over time.**



The same trend can be seen from the viscosity measurements of test B which is shown in Figure 28. A decrease in viscosity was observed after 2,5 months (76 days) for the food preservative method. The oil layer test results are unreliable because some of the oil was included in the sample during analysis. Further research with end users is needed to identify which decrease in viscosity is still acceptable.

Figure 27 **Viscosity analysis results of Test B, shown as bar graphs for shear rate 200 s^{-1}**



CONCLUSION

The test with food preservatives showed no visual fungal or bacterial growth. The findings from the viscosity and pH measurements indicate that Kaumera's properties do change over time. When Kaumera is stored at room temperature, the pH increases after about four months, and viscosity decreases after roughly two and a half months. These changes were

observed in the food preservative method, nitrogen headspace, and oil layer tests, emphasizing the need for further research to understand their implications. Future studies should focus on establishing precise parameters for maintaining Kaumera's quality and usability over time.

Since the food preservatives demonstrated no fungal or bacterial growth, this method is now being used in full-scale plants.

4.3 EFFECT OF POWDERED ACTIVATED CARBON DOSING IN NEREDA® ON KAUMERA

INTRODUCTION

In recent years, awareness about micropollutant removal has increased. Soon, effluent requirements will become more stringent and water boards are acting on the removal of micropollutants from wastewater. One of the solutions for removing micropollutants from wastewater is dosing of powdered activated carbon (PAC). In 2017, a collaboration was started between Haskoning and the water board "Waterschapsbedrijf Limburg" (WBL) to investigate the dosing of PAC in the aerobic granular sludge (AGS) -Nereda® installation of Simpelveld. The full results of the STOWA study can be found in STOWA report 2020-20 "Feasiblity study powder activated carbon dosing in Nereda for removal of micropollutants at WWTP Simpelveld". Additional to the study, initial tests were performed to study the effect of powdered activated carbon on Kaumera.

METHODOLOGY

A study was conducted on two Nereda® reactors: one without PAC dosing (reference reactor) and one with PAC dosing. The impact of PAC dosing on Kaumera production was also examined. To assess this, sludge samples from both reactors were compared. A research setup was defined to answer the below questions:

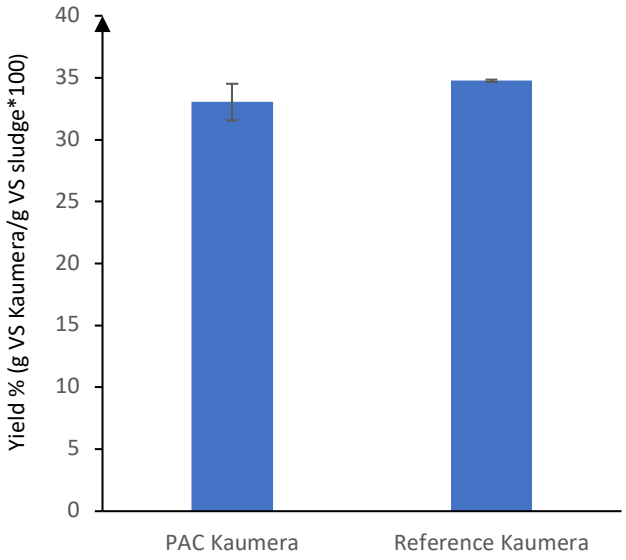
- Does dosing PAC in a Nereda® reactor affect the quantity, colour, and/or smell of the Kaumera extracted from the granular sludge of this Nereda® reactor?
- Are there other observable differences between the Kaumera produced from granular sludge from a Nereda® reactor with and without PAC dosing?

During the full-scale practical trial at the Nereda® in Simpelveld, the dosage of PAC was increased in four steps. These four dosages of PAC were 5,10, 15, and 20 gr per 1 m^3 of influent which were implemented over 14 months. The samples for Kaumera extraction were taken from the period of the test with 15 $g/m^3_{influent}$ PAC dosing. The extractions were done in the laboratory of Haskoning. The VS distribution was monitored over the extraction processes.

RESULTS

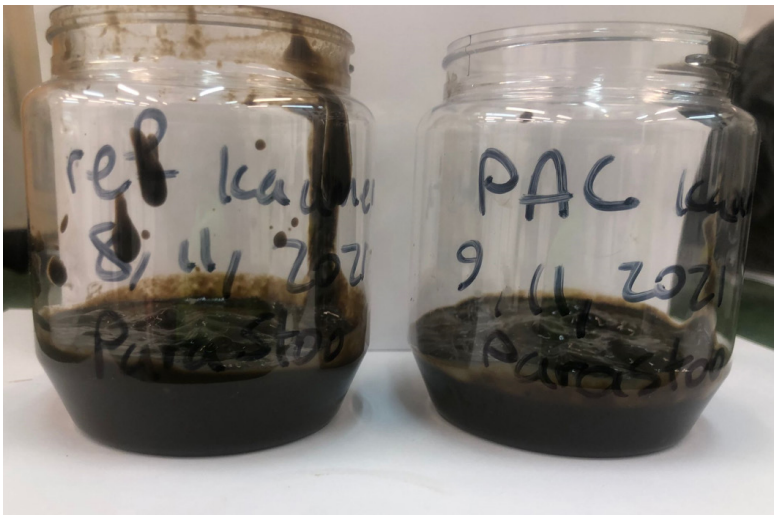
The results of Kaumera extraction yields in g VS Kaumera/g VS initial sludge are given in Figure 29. The Kaumera extracted from the Nereda® reactor sample with PAC dosage is referred to as PAC Kaumera, whereas the Kaumera extracted without PAC dosage is referred to as Reference Kaumera. Figure 29 shows that there is no significant difference between the VS yield of the two types of Kaumera samples. The TS yield (g VS Kaumera/g TS sludge) for the PAC Kaumera is 21.1% and for the reference Kaumera 21.6%. Because the exact amount of PAC ending up in the Kaumera was not measured, the TS yield only indicates whether additional solids may have affected the EPS extracted from the sludge.

Figure 28 **Yield comparison of PAC Kaumera and reference Kaumera on duplicate tests**



There is no significant difference between PAC Kaumera extraction and Reference Kaumera extraction in terms of VS or TS distribution. Moreover, there was no distinctive difference in colour (Figure 30), smell, or other observable differences between PAC Kaumera and Reference Kaumera.

Figure 29 **The reference Kaumera (left) and PAC Kaumera (right) with no observable difference**



CONCLUSION

The dosing of PAC into the Nereda® reactor did not significantly affect the observed parameters. Future studies should investigate the effect of PAC dosing on the micropollutant content of Kaumera, as this research did not include measurements in the sludge matrix.

4.4 SUMMARY

The CO_2 stripping research has focused on reducing the chemical consumption in the extraction process. One potential improvement is the installation of a CO_2 stripper in front of the extraction installation. This stripper lowers the buffer capacity of the sludge, meaning less base and acid are needed to achieve pH setpoints.

Use of NH_4OH and NaOCl: Tests with NH_4OH and NaOCl as substitutes or additions to the base have shown some potential, if a higher extraction cost outweighs the benefits. NH_4OH has the potential to increase the organic content of Kaumera but leads to lower yields and higher chemical consumption. On the other hand, NaOCl offers benefits in terms of discoloration and odor reduction of Kaumera but does not reduce the use of base, thus increasing operational costs.

Preservation Methods: Research on different preservation methods to increase the shelf life of Kaumera has been conducted. The addition of food preservatives has proven to be the most promising and applicable on a full scale.

5

APPLICATION OF KAUMERA

Kaumera is a sustainable raw material with several unique physical/chemical properties and can be used in many applications. For example, it can retain water but also repel water and it has fire-retardant properties and is an excellent binder for composite materials. This makes many different applications interesting, for example in agri- and horticulture, or the paper and construction industries. For example, it could be used as a biostimulant, adhesive, binder or coating. At the same time, this versatility can be a challenge when trying to focus on specific markets for the product. To provide guidance for this focus, the possible applications have been ranked by the market team to select the most promising markets. Then the product is further tailored to said market group to the specific wishes. This creates an interplay between product development and market development. The following chapters will describe several opportunities that the Kaumera Sales & Service B.V. team is pursuing. More information can be found on the Kaumera website: https://kaumera.com/en

Figure 30 **Most promising markets for Kaumera use as identified by the Kaumera Sales & Service B.V.**



5.1 AGRI- AND HORTICULTURAL APPLICATIONS

ECOLOGICAL ENHANCEMENT FOR SOIL AND CROP

As abiotic stresses such as drought and soil depletion become more prevalent, and with rising limitations on pesticides, the demand for natural products that support soil health or enhance plant processes—including root development, photosynthetic efficiency, and crop yields—is steadily increasing. Kaumera helps improve soil and plant stress tolerance. Kaumera has the capacity to adsorb (metal) cations, among other dissolved substances. It has the capacity to adhere and facilitate the attachment of nitrogen-fixing bacteria to plant roots and soil particles, which mediates a symbiotic relationship. Kaumera promotes the aggregation of soil particles, leading to the formation of stable soil aggregates. This enhances porosity and aeration, enabling better root penetration. The capacity to bind water, helping soils retain moisture for longer periods which enhances plant growth and yield.

Figure 31 **Exemplary pictures of possible use locations of Kaumera**



WATER RETENTION IN SOIL

When new trees are planted, they require intensive watering to make sure they will survive the three years. As summers are seeing increased periods without rain, this can be an intensive activity. Together with Hoefakker and Flexyz B.V. the NKOP has started a test where Kaumera was mixed in several different concentrations in the soil surrounding the young trees. As Kaumera has water-retaining properties, the hypothesis was that the trees that had soil around their roots that contained Kaumera would require less watering. To check if this was indeed the case, several soil moisture sensors were installed (Figure 33).

Figure 32 **a) Tree planting and b) soil moisture sensors**



(a)

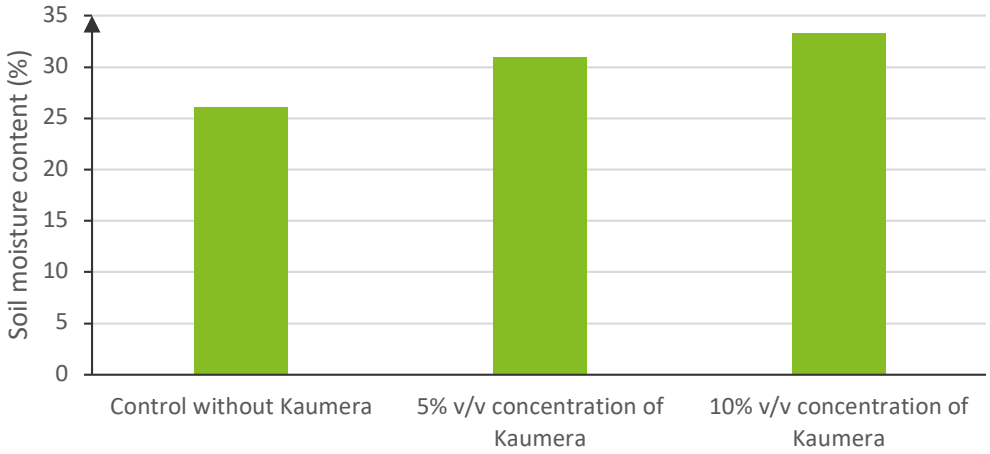


(b)

After the first summer season, the results are promising. The soil containing Kaumera showed higher moisture content than the reference case (Figure 34). The process is still being monitored, as trees need to survive the first three years before they are more resilient towards different climates.

The experiment was conducted on elevated sandy terrains. The sensors yielded robust indications of Kaumera retaining moisture. Additionally, ancillary indicators related to growth, such as shoot length, root formation, and leaf setting, can only be reliably ascertained over an extended timeframe. The advantages resulting in enhanced moisture regulation become most pronounced during periods of stress, as exemplified by the preceding arid summers. In instances of ample precipitation, these effects exhibit limitations.

Figure 33 **Average soil moisture content over 8 months since trees were planted in the control soil, the soil which contained a low concentration of Kaumera and the soil with a higher Kaumera concentration.**



EXAMPLE USE CASE – DIKES TEST

16 April 2025 we started a test for improving the grass root structures on dikes.
Location: Bevermeer Dike, Hoog Keppel
Duration: 2025 – 2029
Partners: Rijn and IJssel Water board, Bureau Waardenburg Ecology, Lumbricus Consultancy.
Support: Kaumera Sales & Services B.V.

The objective of this field trail investigates how Kaumera can enhance the resilience of grass cover on sandy dikes during periods of extreme drought. Strengthening the grass root system is essential for dike stability — particularly in locations where grass struggles to establish naturally.

Approach:	Field Setup: Test plots with varying dosages of Kaumera, alongside compost and a control plot with no additives (see Figure 35).
Monitoring:	Sensors continuously measure soil moisture, root depth, and grass growth. A local weather station records climate condition.
Duration:	Five years, to observe effects across multiple seasons and weather conditions.
Expected Impact:	Soil Improvement: Enhanced water retention and soil structure. Stronger Grass Cover: Better root establishment on vulnerable sandy dikes.
Circular Application:	High-value use of residual materials from the water cycle.

Relevance: This trial represents a significant step in exploring new applications of Kaumera at the intersection of climate adaptation, circular economy, and infrastructure management. Successful outcomes may lead to broader adoption of Kaumera in Dutch water safety strategies.

Figure 34 **Field setup of dike testing with Kaumera**



BIOSTIMULANT

The application of Kaumera as a biostimulant is one of the most promising. The field tests of recent years gave good results, and the time-to-market is favorable because of the interest from the market to replace fertilizers and because legal barriers have been overcome by having obtained end-of-waste status for Kaumera for this application. Treated plants exhibited significantly higher shoot biomass, larger stem thickness, while soil plant analysis development (SPAD) values suggest improved nutrient availability and photosynthetic efficiency.

Kaumera consists largely of proteins and sugars. Proteins, among other functions, play a crucial role in numerous processes within plant cells. For example proteins are found in the cell wall, contributing to its strength and flexibility. Proteins act as enzymes, catalyzing biochemical reactions such as photosynthesis, respiration, and nutrient metabolism. They regulate the movement of water, ions, and nutrients into and out of the cell.

Many of the sugars and nitrogen produced and consumed by the plant are utilized for protein synthesis. This synthesis consumes a substantial amount of energy. When a crop undergoes a stressful period, such as drought, cold, herbicide, or fungicide treatments, it responds with a stress reaction. This reaction demands the production of many new proteins, along with a significant quantity of amino acids and energy. There are indications that when a stressed crop is provided with amino acids through foliar spraying or soil application, it can directly utilize these amino acids for protein synthesis. Consequently, the crop requires less energy for the stress response, potentially preventing growth retardation and yield loss. Based on its constituents, this mechanism could underlie the functionality of a biostimulant. Proteins

are currently employed in various forms of biostimulant applications within the agricultural sector.

WHAT COMES NEXT

In addition to identifying specific applications, it is expected that Kaumera can ultimately serve as a soil conditioner. Kaumera contains all the elements commonly found in the agricultural sector, such as proteins, sugars, nutrients, and trace elements. Kaumera could also function as a sustainable alternative for replacing ingredients in existing products. Due to its origin, Kaumera offers several environmental benefits, including being sourced locally, having a favorable carbon footprint, and being obtained through wastewater treatment processes. It could be a very suitable replacement for peat, thereby helping to reduce the GHG emissions as well.

Within the market, the focus lies on achieving the highest value with the best-added value, while also ensuring a sufficient demand of product. However, achieving the highest value also means making significant investments in terms of time, thus taking a substantial risk. This is why various alternative paths are explored.

Field tests require attention and time; however, there is reason to believe that based on the composition of Kaumera, this approach could lead to the quickest time to market. The product has been tested in practice by Koppert Biological Systems in recent years. The promising results led to a contract with Koppert for selling Kaumera as a biostimulant. Crops grow faster and retain more nutrients and water. The product is sprayed over the crops in liquid form, a foliar application. To use Kaumera as a biostimulant in other countries, some legal hurdles need to be taken. In all European member states different regulations and interpretations of regulations mean that a separate effort needs to be undertaken in separate markets, not only within the EU but also in other international markets.

Table 6 **Summary functions of Kaumera to soils and crops**

SOILS	PLANTS
Improvement in Soil Structure	Promotes Root Development
Water Retention and Management	Increases Stress Tolerance
Enhanced Nutrient Availability	Enhances Plant Growth and Yield
Support for Beneficial Microbial Communities	Disease Suppression
Soil Pollution Mitigation	Better Seed Germination and Establishment

BINDER AND COATING

The horticultural and agricultural sectors are also seeking sustainable alternatives for various products like binders and coatings in fertilizers. Currently, petrochemical and/or synthetic products are often used for these purposes. In the near future, the use of these substances will be prohibited in the EU. Initial research has shown promising results in testing the application of Kaumera as a binder in substrate plugs for young plant cultivation. Further investigations are still required to achieve further optimization. The binding of substrates is the main focus. However, other factors also come into play, such as drying speed (linked to inventory management), physicochemical conditions within the plug for growth, shelf life, and odor. Additionally, various tests have been conducted with fertilizer manufacturers regarding the coating application. The challenge is to ensure that a Kaumera coating can act as a slow-release fertilizer, thus requiring the coating to have the right properties to release water when needed.

5.2 KAUMERA AS BUILDING MATERIAL/ FIRE RESISTANT

Traditional composite materials consist of fibres and resins. They have excellent material properties like strength, stiffness, and low weight. However, the resins are usually fossil-based, and the fibres require energy-intensive processes. Therefore, the industry is looking for biobased alternatives. We have found that Kaumera can be used as a binder but also gives a better fire resistant. Tests on the university of Eindhoven have showed that were Kaumera was applied to wooden façade panels and tested for fire behaviour using two methods: prolonged heat exposure (radiant heat exposure) and direct exposure to open flame (direct flame exposure). The results showed that all tested coatings improved the fire behaviour compared to untreated wood. In some Kaumera tests, a self-extinguishing effect was observed, where flames did not spread further and gradually died out. Although Kaumera's performance was positive, the coating in its current form did not yet meet the requirements for fire class B — the standard for many construction applications. Further product modification is therefore necessary.

Figure 35 **Testing of fire-resistant properties at Eindhoven University**



5.3 OTHER PROMISING APPLICATIONS AND PROPERTIES

TEXTILE DYES

Aside from these larger projects, the market team is also pursuing other opportunities. One such example is the recent project where Kaumera is used as a carrier material for textile dyes. The ability to form a hydrogel is the important property that the dye industry is looking for. The first proof of principle tests have been undertaken and seem to indicate positive results. Together with the customer we have developed more Kaumera types such as bleached Kaumera. Kaumera is tested in the laboratory and approved. Now we are working on the proof of concept to scale up the development.

FLOCCULANTS

Another example of a promising application is Kaumera as a flocculant. Obvious application would be to use it in the water treatment process itself, as a replacement of chemical flocculants, but due to the negative charge of the Kaumera, the ability to serve as a flocculant for wastewater treatment plants is less promising. First tests on paper sludges however showed the ability of Kaumera to form flocs. Therefore, this application could be promising for different types of positively charged sludges such as clay.

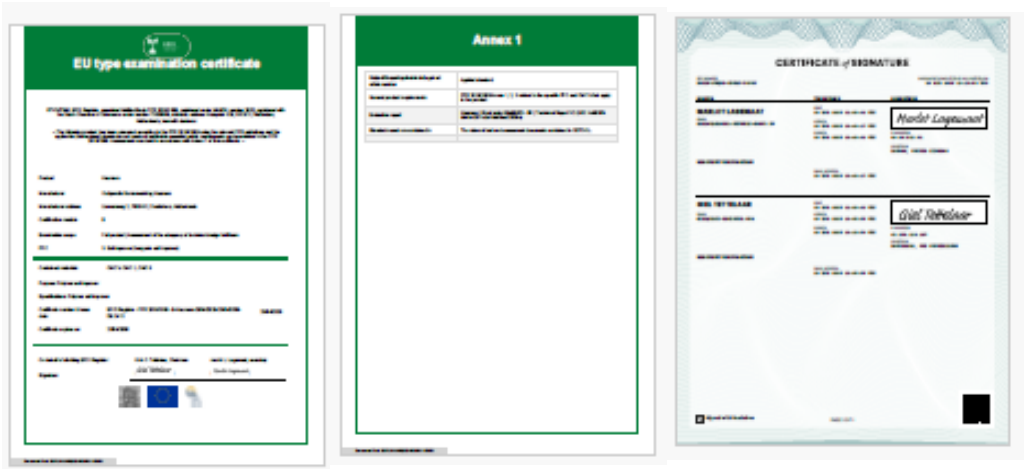
KAUMERA WASTE SLUDGE VALORISATION

The two main waste streams of the Kaumera extraction process are the acidified centrate and waste sludge. The Kaumera Sales & Service B.V. team is looking into possible valorisation of this waste sludge as well. Further improving upon the business case of Kaumera extraction.

5.4 PROOF OVER PROMISE

Data from internal, customer, and knowledge institute trials and pilots is essential to build confidence among target audiences, particularly in agriculture and industry, where new inputs or materials are often met with scepticism. To highlight the benefits of Kaumera, certification plays a key role. From the initial development to the present, we have achieved the following recognitions:

- FPR 2019/1009: Certified as a soil improver under CMC 1/CMC 9, classified as PFC3.
- Module B: Quality control certification for the production process.
- Compliance: Meets regulatory standards for heavy metal limits, seed and worm toxicity, and pathogen safety.
- End-of-Waste Status: Automatically granted through the CE label under the FPR regulation.
- PFC6 (Biostimulant): Currently under development



kaumera soil improver

www.kaumera.com

General Information
Kaumera® soil improver is an acidic bio-based gel containing peptides (amino acids), polysaccharides and fatty acids. Kaumera® soil improver is designed to maintain and improve the physical properties and increases the water retention capacity of EU fertilising products when applied to soil. Kaumera® soil improver can also be used in nutrient mixes as a functional ingredient.

Product specific labelling requirements

Dry matter	7.5	% m/m
Nitrogen (N)	0.6	% m/m

Ingredients
Extracellular polymer — CMC 9: Polymers other than nutrient polymers

Intended use
Applied to soil to maintain and improve the physical properties and the biological activity of the soil.

Application rates, timing and frequency

- **Irrigation (spraying)**

Dose 20 to 200 litres product/hectare through the irrigation spraying system with an interval of at least 3 months. The product can be diluted in tap water for field applications and optionally solubilised if needed. Avoid spraying on edible crops within 5 weeks prior to harvest.

- **Pouring into the soil**

Use the product with an interval of at least 3 months, applying between 1000 and 5000 litres of product/hectare in the soil. The product can be diluted in tap water for field applications and optionally solubilised if needed.

- **Creating a soluble formulation (optional)**

When the product (pH 2.2) is diluted in water it forms a gel suspension that will settle without agitation (e.g. mixing or shaking). In case a soluble liquid formulation is needed, the product can be neutralised. Instructions can be found on the product website.

- **General recommendation**

When mixing with other products, compatibility has to be tested by a jar test prior to mixing. No adverse effects are known when the acidic product is diluted and comes in contact with the soil, root, plant or leaves.

Functionality period
Re-application during the functionality period of 3 months is not allowed.

Storage recommendations
Store in tightly closed original packaging. Store in a well-ventilated place. An overpressure relieve opening is recommendable for bulk storage. Keep away from direct sunlight, frost or extreme temperatures. Store preferably cold.

Health & safety
To our knowledge this product does not present any particular risk, provided it is handled in accordance with good occupational hygiene and safety practice. Pressure buildup can be caused by organic decomposition (risk of over pressure). Persistence and degradability: readily biodegradable.

Please wear recommended personal protective equipment. Ventilate spillage area. Do not breathe vapors. Avoid contact with skin, eyes and clothing. Do not eat, drink or smoke when using this product. Always wash hands after handling the product. Keep out of reach of children. Read label before use.

First-aid measures:
- general: no hazards which require special first aid measures.
- after inhalation: remove person to fresh air and keep comfortable for breathing.
- after skin contact: take off contaminated clothing. Wash hands with water and soap.
- after eye contact: rinse eyes with water as a precaution.
- after ingestion: call a poison center or a doctor if you feel unwell.

Warranty
Registrant warrants that this product conforms to its description and is reasonably fit for the purpose stated on the label when used in accordance with the stated directions under normal conditions of use. Buyer assumes the risk of any use contrary to such directions.

Product function category
PFC 3 (B) Inorganic soil improver

Manufacturer
Cooperative Kaumera | Liemersweg 2 | 7006 GG |
PO Box 148 | 7000 AC Doetinchem The Netherlands |+31314 369 369
Website: www.kaumera.com e-mail: info@kaumera.com

Quantity

Production date

Batch Number

CE

Waterschap Rijn en IJssel | Liemersweg 2 | 7006 GG | Postbus 148 | 7000 AC Doetinchem
SWIFTadres NWABNL2G | IBAN NL68NWAB063675331 | BTW NL 805432759B01 | KvK 0921548

6 OUTLOOK

The development of the Kaumera extraction and production is moving forward. This report shows the research and efforts that have been done in recent years. This chapter will highlight some initiatives to bring Kaumera even further. For most up to date information, please visit the Kaumera website: www.Kaumera.com

GOVERNANCE STRUCTURE

Since 2013, the National Kaumera Development Programme (NKOP) has been working together between STOWA, DUT, Haskoning and water boards on the development of the concept for the production and application of Kaumera. To stimulate the production of raw materials as a water sector, frontrunner groups of water boards were set up in 2017 that are committed to the realisation of specific raw material chains. For Kaumera, this has resulted in the establishment of a cooperative to produce Kaumera. In anticipation of this, the demo installation at WWTP Epe was already realized from the frontrunner cooperation.

Product and business development of raw materials and products has traditionally not been a task of the water boards or the other members of the NKOP. For this reason, the water boards set up a BV for this purpose from the cooperative in collaboration with Haskoning at the end of 2024: Kaumera Sales and Services BV. The cooperative and Haskoning are both 50% shareholders of this BV and also invest in proportion to the shareholding. The aim of this BV is to realise cooperation chains for the production and sale of Kaumera, resulting in stable production and sales of Kaumera from the Epe and Zutphen locations in preparation for additional production capacity at new locations.

COOPERATION WITH END-USERS OF KAUMERA

For further development, it is important to work together with end users. The collaboration partners are focussing on parties who are willing to cooperate and customize Kaumera to their applications' needs. This will ensure a feedback loop from the end-user back to the extraction process. Which settings or processes can be changed to ensure the best quality for that application?

INVESTIGATION OF HIGHER PRODUCTION CAPACITY

Aside from the technical aspects of Kaumera extraction, the NKOP is also looking into the best organization to bring Kaumera forward. Two production locations are in operation, Epe and Zutphen. When market demand increases, the maximum production capacity will quickly be reached. The cooperative partners aim to realize new production locations in the future.

Due to the CE status, Kaumera can be more easily marketed in the EU. This is significant, as international interest has begun to increase. For instance, a pilot study has been initiated in the UK to explore the potential of Kaumera, among other objectives. To be able to produce and use Kaumera locally is part of the reason why resources should be part of the circular economy.

FUNDAMENTAL RESEARCH ON EPS PRODUCTION IN NEREDA® AND CAS SYSTEMS

The research on the extraction process is also ongoing. The collaboration partners are searching to understand on a more fundamental level how the sludge production in the Nereda® influences gelation in the product. Are there ways to stimulate gelation at the start of the process? Could we increase the protein content to enhance biostimulant properties? Moreover, to improve the operation of the extraction installation, a quest for the improvement of the separation process is ongoing.

Aside from the studies on Kaumera which is EPS produced from aerobic granular sludge, further fundamental research has started up on the production of EPS in general. The REThiNk[3] project is a collaboration between DUT, Aalborg University, and Aarhus University. This study is taking a look at activated sludge and identify the microbial community responsible for EPS production. The expectation is that this knowledge can be transferred to Kaumera production. Therefore, the Kaumera partners follow this research with great interest.

MOVING FORWARD

To summarize, Kaumera is moving forward in different directions. The focus is not only on the technical advancements, although this remains the core of the Kaumera production. The collaboration partners are also working on business and product development, performing legal and organizational activities, as well as stay up to date on fundamental research. It is expected that the above-mentioned initiatives will help to establish Kaumera as a resource from wastewater with a positive environmental impact.

3 Project title: Recovery of extracellular polymers from wastewater treatment residuals as a new circular biopolymer https://www.bio.aau.dk/forskning/projekter/rethink

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REFERENCE LIST

Bahgat, N. T.; Wilfert, P.; Korving, L.; van Loosdrecht, M. (2023). Integrated Resource Recovery from Aerobic Granular Sludge Plants. Water Res. 2023, 234, 119819.

De Kreuk, M. K. et al. (2007) 'Kinetic Model of a Granular Sludge SBR: Influences on Nutrient Removal', Biot, 97(4), pp. 801—815.

De Kreuk, M. K., Pronk, M. and van Loosdrecht, M. C. M. (2005) 'Formation of aerobic granules and conversion processes in an aerobic granular sludge reactor at moderate and low temperatures', Water Research, 39(18), pp. 4476—4484.

Duque, A. F., Campo, R. and Val, A. (2021) 'Wastewater Valorization: Practice around the World at Pilot- and Full-Scale', International journal of environmental Research and public health, 18, p. 9466

Felz, S. et al. (2016) 'Extraction of Structural Extracellular Polymeric Substances from Aerobic Granular Sludge', J. Vis. Exp., (September)

Kim, N. K. et al. (2022) 'Insight on how biopolymers recovered from aerobic granular wastewater sludge can reduce the flammability of synthetic polymers', Science of the Total Environment, 805, p. 150434

Lahav, O., & Birnhack, L. (2019), *Aquatic Chemistry*, De Gruyter

Lin, Y. M. et al. (2015) 'Sustainable Materials and Technologies Sustainable polysaccharide-based biomaterial recovered from waste aerobic granular sludge as a surface coating material', SUSMAT, 4, pp. 24—29.

STOWA 2019-14 (2019) Kaumera Nereda gum: summary of NAOP research 2013-2018 (In Dutch). Amersfoort. Available at: https://www.stowa.nl/

STOWA 2023-08 (2023) LCA of 8 resources from sewage (In Dutch). Amersfoort. Available at: https://www.stowa.nl/

Summerfelt, S., Vinci, B., & Piedrahita, R. (2000). Oxygenation and carbon dioxide control in water reuse systems. *Aquacultural Engineering*, 87-10