aarhusvand

Energiteknologisk udvikling og demonstration

EUDP Final Report: Energy Generation from Waste Water Plants

October 2018

EUDP 14-II. J.nr. 64014-0565

EnviDan AARSLEFF aarhusvand

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1 Project details

Project title	Energy Generation from Waste Water Plants
Project identification (program abbrev. and file)	EUDP 14-II. J.nr. 64014-0565
Name of the programme which has funded the project	Energiteknologiske Udviklings- og Demonstrationsprogram (EUDP)
Project managing company/institution (name and address)	Aarhus Vand A/S · Gunnar Clausens Vej 34 · DK-8260 Viby J.
Project partners	Envidan A/S Per Aarsleff A/S
CVR (central business register)	32562361
Date for submission	October 31, 2018

2 Short description of project objective and results

2.1 In English

Wastewater treatment plants (WWTP) can become net energy producers, delivering electricity and heat at a competitive price. Envidan A/S and Per Aarsleff A/S aim to build such plants in Denmark and internationally. The goal of this project is to build a home market demonstration plant with demo host, Aarhus Vand, by upgrading Egaa WWTP.

Through development and combination of innovative processes in the so called ”Egaa Concept”, the project partners wish to demonstrate that Egaa WWTP can achieve 100% electricity self-sufficiency at the current load (90,000 PE) and at a future full load (120,000 PE) can generate 50% more electricity than it uses for daily operation.

Egaa WWTP was expanded in 2015 – 2017 and is now used as a reference facility with more than 30 guide tours since the beginning of the project. All the required equipment for the new processes is in place as well as the control systems. Moreover, a “Go to Market” strategy has been defined for the ”Egaa Concept”.

In the first 3 quarters of 2018, the average net energy production was 121%, with a net electricity production at 83% and a net heat production at 193%. This is lower than the expected 100% net electricity production as result of multiple challenges faced in the carbon harvesting process. Further optimization of the processes is being carried out and an increase in the net energy production is expected to be seen in a very near future.

Project partners will continue to work with development and optimization of the processes as well as on the commercial strategy.

2.2 In Danish

Spildevandsrensningsanlæg kan blive til netto energiproducerende, og levere el og varme til en konkurrencedygtig pris. Envidan A/S og Per Aarsleff A/S sigter mod at bygge sådanne anlæg både i Danmark og internationalt. Målet med dette projekt er at opbygge et demonstrationsanlæg med Aarhus Vand som vært, ved at opgradere Egaa Renseanlæg.

Gennem udvikling og kombination af innovative processer i det såkaldte "Egaa koncept" ønsker projektpartnerne at vise, at Egaa Renseanlæg kan opnå 100% netto elforsyning ved den nuværende belastning (90.000 PE) samt kan generere 50% mere elektricitet, end der bruges til den daglige drift ved fuld belastning (120.000 PE).

Egaa Renseanlæg blev udvidet i 2015 - 2017 og benyttes i dag som referenceanlæg, og har haft mere end 30 guidede ture siden projektets begyndelse. Alt det nødvendige udstyr til de nye processer er på plads. Desuden er en "Go to Market"- strategi blevet defineret for "Egaa konceptet".

I de første 3 kvartaler af 2018 var den gennemsnitlige netto energiproduktion 121%, med en netto elproduktion på 83%. Som følge af de mange udfordringer, der har været i forbindelse med kulstof høsten, er den forventede 100% netto elproduktion ikke nået endnu. Yderligere optimering af processerne vil blive gennemført, og en stigning i netto energiproduktionen forventes i den kommende tid.

Projektpartnerne vil fortsat arbejde videre med udvikling og optimering af processerne samt på den kommercielle strategi.

3 Executive summary

Danish water and wastewater utilities account for approx. 1-2% of the national energy consumption[1] and thus a corresponding part of the Danish CO_2 emissions. By transforming WWTP's into energy producing units, this EUDP project has a significant effect on the Danish independence of fossil fuels. Further, a substantial reduction of CO_2 emissions contributes to supporting the energy-policy objectives for a cleaner environment.

Through development of innovative processes, the project partners wish to demonstrate that Egaa WWTP can achieve 100% electricity self-sufficiency at the current load (90,000 PE) and that the plant at a future full load (120,000 PE) can generate 50% more electricity than it uses for daily operation.

This is achieved by incorporating several technologies in a "Egaa Concept", including a new carbon harvest and control system, a DEMON® plant, energy optimized nitrogen removal in the main process tanks and an ORC (Organic Rankine Cycle). The carbon harvest and control system is a new, innovative feature. Optimal control of the interaction between the pre-filtration, the process tanks and the DEMON®-process results in an overall reduction in energy consumption and an increase in energy production. Optimizing the distribution of the carbon source between the energy production and the energy consumption means to minimize the demand for carbon source in the main process tanks in order to maximize the carbon source available for energy production in the digester.

[1] Analyse af potentialer for ressourceudnyttelse i vand- og spildevandsforsyningen. Miljøministeriet, Naturstyrelsen 2015.

At the end of this project, Egaa WWTP has been upgraded with all the necessary equipment and control systems required to become a net energy generating plant.

The average net energy production of the plant from January to October 2018 was 121%, with 83% average net electricity production and 193% average net heat production.

The largest obstacle during the project has been to achieve a stable carbon harvest with the pre-filtration. As the pre-filtration is the first treatment-step at the WWTP, effective operation of this installation is a prerequisite for the success of the project.

The development of the net energy production at Egaa WWTP can be followed in Figure 1 together with relevant project activities.

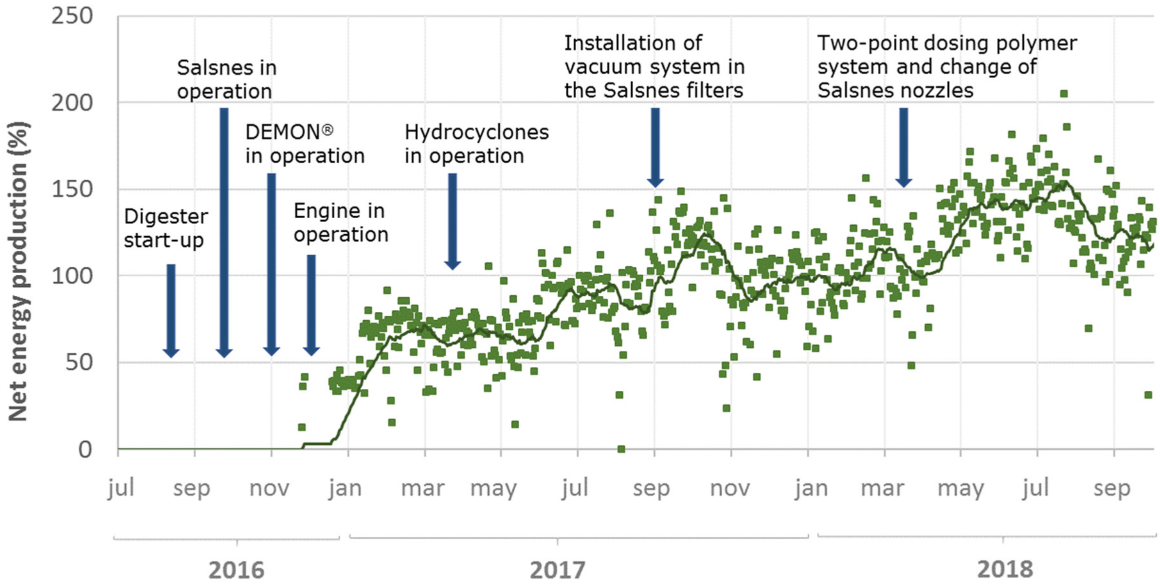


Figure 1: Evolution of the net energy production at Egaa WWTP in relation to relevant project activities (includes heat and electricity)

Continuous 100% electricity self-sufficiency has still not been reached due to multiple challenges faced with the new carbon harvesting system. Figure 1 illustrates how improvements on the pre-filtration process have had a significant effect on the increase of the net energy production.

A stable carbon harvest is expected to be achieved in the near future and consequently a 100% net electricity generation is predicted.

In Denmark alone, at least 65 WWTPs could be turned into net energy producers by using the "Egaa Concept". EnviDan and Aarsleff still see the business potential as suppliers of such systems, not only in Denmark but also internationally. The plan is to initiate three more projects based on this concept by 2021.

4 Project objectives

The project partners wish to demonstrate that through development of innovative processes Egaa WWTP can become a net energy producer. The goal is to achieve 100% electricity self-sufficiency at the current load and at future full load (120,000 PE) to generate 50% more electricity than is used for daily operation.

This is planned to be achieved by the use of the so-called "Egaa Concept", a combination of multiple technologies that includes:

- Dynamic removal of carbon from the inflow using a new carbon harvest system with micro-filtration (Salsnes filters – 350 µm) and control system, which minimize oxygen consumption in the process tanks and maximize gas production in the digester.

- Treatment of reject water with Anammox bacteria (DEMON®–process) to minimize internal nitrogen loading and reduce energy consumption.

- Nitrogen removal with a nitritation process in the main system (initially an EssDe™ process) for reduction of energy consumption.

- Further electricity generation through the use of surplus heat from biogas engine in an Organic Rankine Cycle (ORC).

The overall success criteria of the project is to develop and demonstrate that such new technologies can work individually and in interaction with each other, as well as with well proven energy technologies such as combined heat and power generation from extracted gas.

A detailed diagram of the upgraded Egaa WWTP can be seen in Annex I.

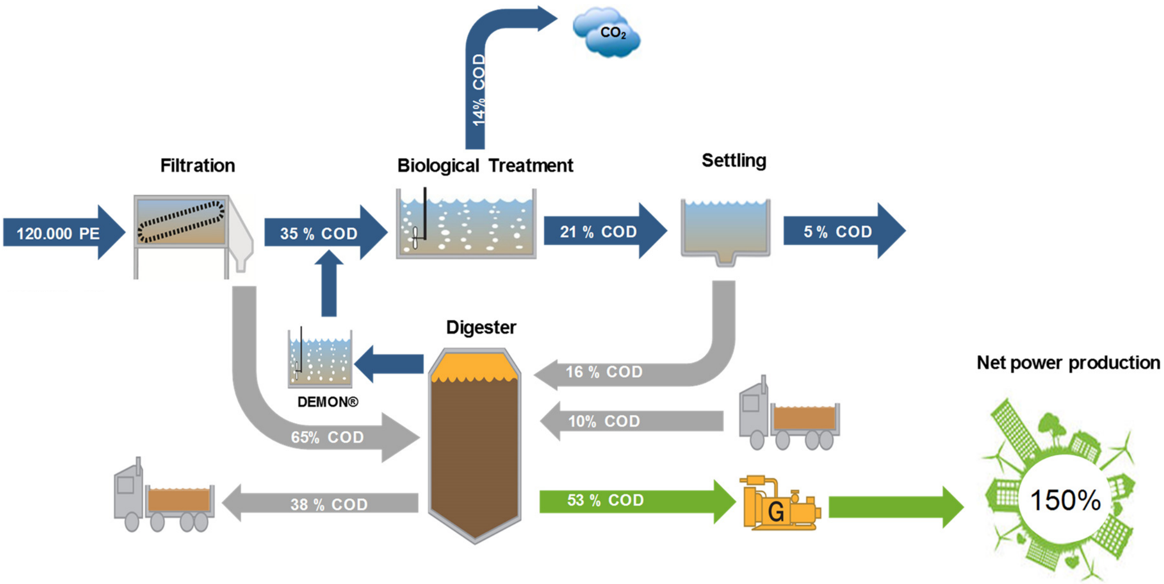


Figure 2: Energy balance of the upgraded Egaa WWTP to reach 50% electricity surplus at full loading.

The presence of anaerobic digesters on wastewater treatment plants is a prerequisite for turning these into net energy producing plants. However, the digesters alone will not be sufficient, it will also require optimization of both the energy producing process taking place in the anaerobic digester and the energy consuming process taking place in the activated sludge tanks - without jeopardizing the effluent water quality and increasing the GHG emissions. Further, the optimization cannot be seen as two independent tasks as the energy production and energy consumption are closely linked through the mutual carbon source available in the raw wastewater flowing to the treatment plant.

The upgrade of Egaa WWTP was divided into two steps. The first step includes the construction of the anaerobic digester itself and a series of activities, which are necessary to support a stable operation of not only the new digester, but also the existing biological treatment. The target of this first step is to turn Egaa WWTP into a treatment plant, which is close to being energy neutral. The activities included in this first step are based on new, but known and proven technologies, therefore are not included in this EUDP project. The second step, which is the one included in this EUDP project, consists of development and demonstration of the "Egaa Concept", which is based on new innovative technologies which combination is never seen before and opens up for further development of the processes.

The work plan for this demonstration project consists of five work packages.

Work Package 0 (WP0) was planned to ensure smooth and successful execution of the different project phases as well as effective dissemination and exploitation of the results from the project.

The objective of **Work Package 1** (WP1) was to implement a new process on the main stream biological process (initially a cold Annamox EssDe™ process), including cyclones on excess sludge, control of sludge age and implementation of new controls in the process tanks. With this implementation it was expected an energy sufficient nitrogen removal, resulting in about 30% reduction in energy consumption in the process tanks.

Work Package 2 (WP2) aims to develop and implement a control system for the COD harvest via the Salsnes filters based on the need for COD in the process tanks. With this an optimal control of the interaction between the Salsnes filters, the nitrogen removal in the process tanks and the DEMON®- process was expected to result in an overall reduction in energy consumption and an increase in energy production. As a part of WP2 was also the installation of an ORC plant for optimized electricity generation.

Work Package 3 (WP3) focuses on the demonstration site. WP3 objectives are: a) To establish a fully functional, full-scale demonstration site; b) To construct and demonstrate the integrated concept with results from WP2-WP5 that optimizes overall energy production and minimizes total energy consumption at Egaa WWTP and c) To successfully demonstrate (at a minimum of 6 months) that Egaa WWTP can generate more energy that it uses for daily operation.

The goal for **Work Package 4** (WP4) is to establish a market strategy concept.

In general lines the project has evolved as planned, although some changes have been made during its execution as result of acquiring new knowledge and experience. One of the main changes has been the decision not to implement the Annamox EssDe™ process in the main stream but instead to implement a nitrite shunt process based on the experience gained by Aarhus Vand at Marselisborg WWTP. The decision was taken after installation of the process equipment for the Annamox EssDe™ process and the installed equipment will partly be utilized during the implementation of the nitrite shunt process.

A major risk identified during the project is that a well-known technology as the Salsnes filters can be very difficult to implement when changing their use and objectives. This has had a high impact on the progress of the project as a whole. Therefore, is very important when developing a solution based on the combination of several technologies to assess this risk and carefully to evaluate the efficiency differences appearing from pilot-scale tests and full-scale demonstrations.

5 Project results and dissemination of results

5.1 WP00 – Project management and dissemination

Since the beginning, the project has received a lot of attention in the water industry and there have been a lot visits to the plant. Moreover, the project has been presented in several events/conferences and various technical and dissemination articles have been published. A list with all the dissemination activities is enclosed as Annex A. Full articles and presentations can be downloaded at the webpage for the project: https://www.aarhusvand.dk/projekter/spildevand/det-energiproducerende-ega-renseanlag/

In relation to the project management, there has been a good collaboration between the partners and with the suppliers. Nevertheless, a considerable amount of time was used at the beginning of the project to get all the contractual conditions in place between the partners of the project and the EUDP project, as not the whole upgrade of the Egaa plant is included in the EUDP grant. The need for such a comprehensive contractual basis led to significant unforeseen cost in legal services.

During the realization of the project, the following meetings were held: 26 construction meetings, 19 commissioning process meetings, 12 steering committee meetings, 8 process design meetings, various meetings with suppliers, various internal Aarhus Vand meetings and a final evaluation meeting of the project.

5.2 WP01 – Implementation of new process in the biological reactors

This work package focuses on optimizing the energy consumption. The main activities included in WP01 are:

- Reduction of the ammonium load to the process tanks through treatment of the reject water originating from the dewatering of the anaerobic treated sludge from the digester by means of a DEMON®-system.

- Reduction of the need for carbon source in the process tanks by optimizing the nitrogen removal process in the main process tanks (initially EssDe™).

- Development and implementation of an improved control system in the process tanks.

5.2.1 Reject water treatment

The DEMON®-system has been fully implemented. The start-up phase took place at the end of 2016, all relevant tests have been carried out and the plant operates as expected, with about 85% NH4 removal efficiency and an average specific energy consumption of at 1,13 kwh/kg NH4 removed.

Figure 3: Photo of the DEMON®-tank in front of the digester (left), DEMON® cyclone(middle), Installations at the top of the DEMON® tank (right).

The performance of the plant is described in the Annex B.

5.2.2 Main stream process treatment and controls

Since the application for funding of the project in 2014 more knowledge has been gained on the cold annamox process. In parallel with the Egaa project, Aarhus Vand has worked to further develop the control of the processes in the mainstream at Marselisborg WWTP, in conjunction with the establishment of a side-stream DEMON®-process. The results are quite impressive in relation to how energy efficiently a kilogram of nitrogen can be removed. Annamox bacteria were found at the mainstream at Marselisborg WWTP, but activity tests showed that their contribution is not significant (<1%) at process temperatures 10-15 °C. Different studies carried out seem to indicate that nitrogen removal at Marselisborg occurs via nitritation (Nitrite Shunt), which is being followed through another development project.

In view of these results, it was agreed that Aarhus Vand would take over the responsibility for changing the control system in the process tanks, aiming at nitritation (Nitrite Shunt) and not a cold Annamox EssDe™ process. The long-term goal is still the same, a net energy production of 150% at full organic load.

The four biological tanks of the plant are in operation, the nitrate/nitrite sensors are installed, and the control system is ready. The first biological tank is controlled according a nitrate setpoint, while the other three tanks are controlled by ammonia setpoints. In order to install the aeration equipment and to change the membranes, the 4 process tanks were emptied one after the other during May and June of 2016.

As consequence of multiple challenges offered by the pre-filtration, the COD/N ratio at Egaa has been around 7 to 9, which is too high to “cultivate” the nitritation process. When a stable reduction of the COD/N ratio is achieved to a value of about 6 to 7, as in Marselisborg, everything is in place to get the Nitrite Shunt up and running, with the subsequent associated energy savings.

Even though the expected level of COD harvest is not reached with the filters yet, the specific energy consumption in the process tanks is reduced with about 10%. Multiple activities for optimization of the main treatment process has resulted in this reduction, such as COD harvest with the filters, new control based on air flow meters, installation of a new blower, optimization of the mixers and implementation of a new process control.

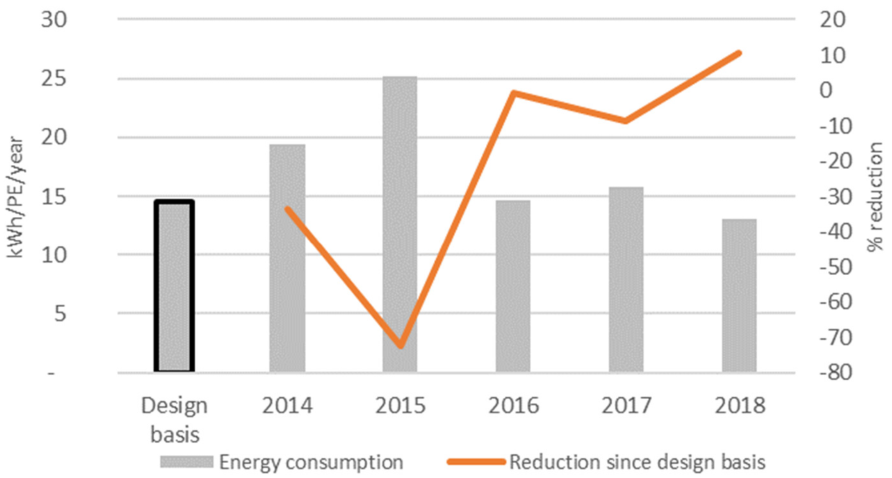


Figure 4: Specific Energy consumption in the main process tanks during the project period. Year 2015 is especially high because of a high yearly wastewater flow.

When the COD harvest is stabilized and increased, the COD/N ratio will decrease, and it is expected that the energy consumption also will decrease even further.

5.2.3 Hydrocyclone installation

The hydrocyclone installation in the mainstream process has been running since April 2017. All the surplus sludge from the secondary clarifiers passes through the cyclones. The heavy sludge is sent back to the process tanks and the light sludge is dewatered and pumped to the digester. The main objective of the cyclones at Egaa is to select the heavier sludge particles to retain the desired bacterial groups (initially Annamox) in the main process, but it should theoretically also improve the sludge sedimentation.

Figure 5: Hydrocyclone installation at Egaa WWTP

The effect of the cyclones at Egaa is still not clear.

It is well known that changing a treatment plant from a 1-step plant to a 2-step plant with carbon harvest in a pre-treatment step effects the sludge sedimentation negatively. As it is shown in the figure below the Sludge Volume Index (SVI) has generally been a little higher in 2018 compared to 2016 and 2017, which probably is connected to a higher COD harvest in 2018. Whether the SVI would have been higher, if the cyclones were not installed cannot be concluded with the existing setup.

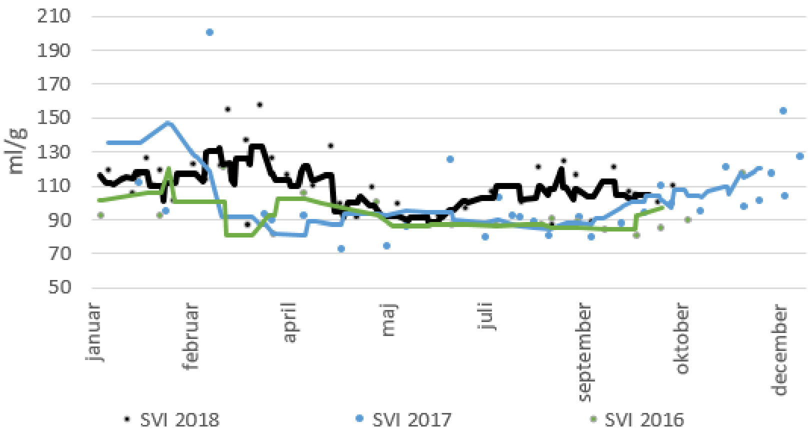


Figure 6: Sludge Volume Index (SVI) measured at Egaa WWTP in 2016, 2017 and 2018

There is almost no information about the use of hydrocyclones in the mainstream and neither positive or negative effects has been well documented. To gather more results about the practical operation of the hydrocyclones and to share experiences, Aarhus Vand has contacted the few plants using hydrocyclones worldwide and has as organized a meeting between the Scandinavian plants.

Data about full-scale experiences with hydrocyclones in the mainstream including Egaa WWTP can be found in Annex C.

In the beginning of 2018 there were problems with the sludge in the main process which did not show on the SVI results. The sludge settled as expected, but large amounts of sludge floated to the surface of the secondary clarifiers. Several theories have been considered to explain what altered the sludge properties, but no clear conclusion has been reached.

Figure 7: Left: 25-01-2018, sludge floats to the surface after 45 min. in the laboratorie
Right: 26-01-2018, the surface if the clarifiers are covered with sludge

All the way from the start of the project, there have been unusually large amounts of sludge floating on the surface of the process tanks. This is probably connected to the fact that is has been hard to keep the amount of sludge in the process tanks down to the required level at all times, see Figure 8.

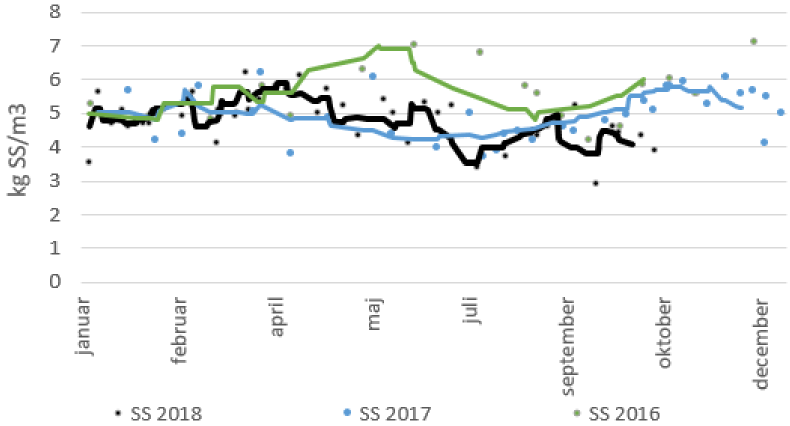


Figure 8: SS in the process tanks at Egaa WWTP in 2016, 2017 and 2018

One of the reasons why it has been hard to keep the sludge concentration at the required level, is that there is a limit to how much bio sludge there can be feed into the digester. When the ratio between primary sludge and bio sludge gets to low (or fluctuates too much), problems have experienced with foaming in the digester.

The reason why the ratio between primary sludge and bio sludge sometimes is too low,is because the amount of primary sludge is lower than expected, but also because the digester receives bio sludge from a neighbouring utility.

5.3 WP02 – Carbon harvest and control system

The main activities included in this work package are:

- Optimizing the distribution of the carbon source between the energy production and the process tanks by implementation of a dynamic primary treatment system (Salsnes filters) incl. the development of a monitoring and control system.

- Installation and commissioning of an ORC system.

5.3.1 Dynamic primary treatment (Salsnes filters)

At Egaa WWTP eight Salsnes filter SFK600 were installed during 2015-2016. The main idea behind it was that pre-filtration with fine mesh sieving poses (350 micron) high potential for harvesting of organic material. The sieves were expected to remove about 60-65% of the incoming COD.

Figure 9: Salsnes filters installed at Egaa WWTP

Salsnes filters is a well documented and used technology in Norway for the removal of SS in wastewater treatment plants with only mechanical treatment, therefore no big operational difficulties were anticipated with this technology. However, the implementation of the Salsnes filters at Egaa WWTP has been a long process, right from the first test setup to the running-in of the full-scale plant.

In autumn 2015 a 3 weeks test was conducted at a Salsnes filter pilot plant with an online COD sensor from WTW. Based on the test results, the filter mesh was selected and it was decided to buy the online COD sensor.

The Online COD measurement is based on UVVIS spectrophotometer, which measures the total spectrum from ultraviolet to visible light. The results from the test of the online COD sensor, showed a decent correlation between the online measurement and laboratory analyses, see Figure 10.

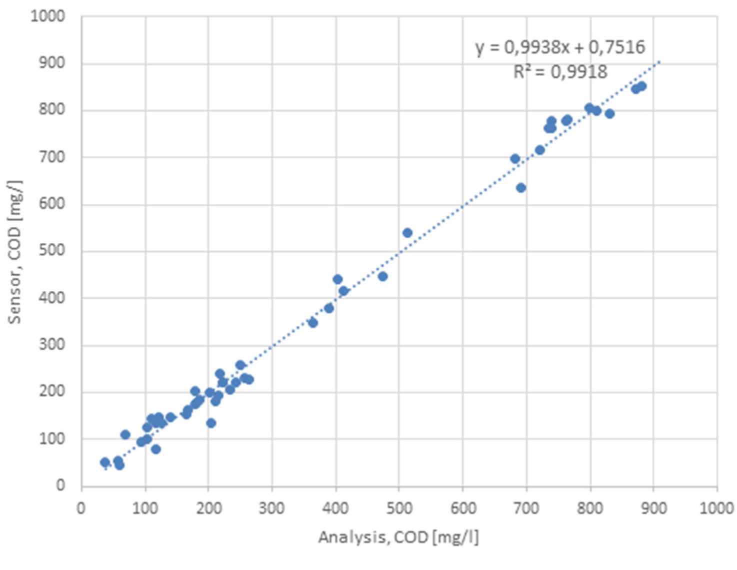


Figure 10: Correlation between online measurements and laboratory analysis during tests in 2015.

The experience from the full scale plant confirms the test results, and the conclusion is that the online COD sensor give a valuable signal for indication of the variations in the COD load to the biological plants.

The test also showed that the dosing of polymer has a very important effect on the treatment efficiency, which means that in the subsequent design of the full-scale plant there was focus on optimal mixing and maturation of polymers. It was also found that an additional SS meter was needed in the inlet to control the polymer dosage.

In April-May 2016 the most critical construction activity was completed where all the inlet wastewater was pumped past the sand trap with large diesel-powered temporary pumps, so the pipes to and from the new Salsnes filters could be established.

In the second half of 2015 and first quarter of 2016 the Salsnes filters were installed and programmed in the PLC and SRO systems. Further there were some working environmental challenges in maintaining the filter installation. This was solved by changing the crane installation, additional auxiliary equipment and some minor rebuilding of the filters.

From the second half of 2016 until the end of the project in October 2018 a lot of energy and resources were used for running-in and optimising the filters. The initial main challenge was that the filters did not deliver primary sludge with a high enough solid concentration due to poor draining of water through the filter mesh. As result, too much water was pumped into the digester and consequently less biogas than expected was produced.

Furthermore to little COD was harvested with the filters, which meant that the initiation of the new biological process could not start due to the high COD/N ratio into the activated sludge tanks.

Numerous operational conditions were changed to increase the dry matter percentage in the primary sludge:

- change of the polymer type,
- optimization of mixing the polymer in to the wastewater,
- tests with different types of filter mesh,
- change of the cleaning of the mesh by changing the soap,
- change of the cleaning of the mesh by adding hot water
- changing the nozzle type

Unfortunately, all these measures only improved the percentage of solids in the primary sludge marginally. In September 2017 a solution was finally in place, vacuum suction points were installed under each filter mesh. As a result, it is now possible to control how thick the primary sludge should be by adjusting the vacuum suction. TS concentration has increased from 3% to 6-14% depending on the suction power. By attaining high solid concentration directly on the filter, the sludge retention time at the digester is increased and more biogas is produced.

The next challenge was that the system for cleaning the filter meshes did not work properly. To ensure efficient prefiltration it is crucial that the mesh is completely clean. When the mesh clogs, the hydraulic capacity is significantly reduced and the build-up of the sludge is deteriorated. At the end of January 2018, the supplier of the filters came up with a solution that required that all 88 nozzles of the system were switched to another type. After installing the new nozzles the cleaning of the filter meshes work properly.

Figure 11: Left: New vacuum suction installation,
Mid: Filter mesh without prober build up of sludge
Right, top: Filter mesh, which a good build up of sludge
Right, bottom: Filter Mesh with stripes, as it looks when the nozzels do not work properbly

Further, it was – and still is very difficult to find the optimal type of chemical dosing to obtain a good and stable harvest of COD. Based on recommendations from the filter supplier, tests with different polymer were performed again in February/March 2018; as a result, a two-point dosing system was established in April 2018 with another type of polymer. This resulted in a COD removal efficiency of ~49 % in May 2018, which resulted in an increase in the net electricity production to about 100 %. Unfortunately, we have not managed to maintain the high COD removal during the summer.

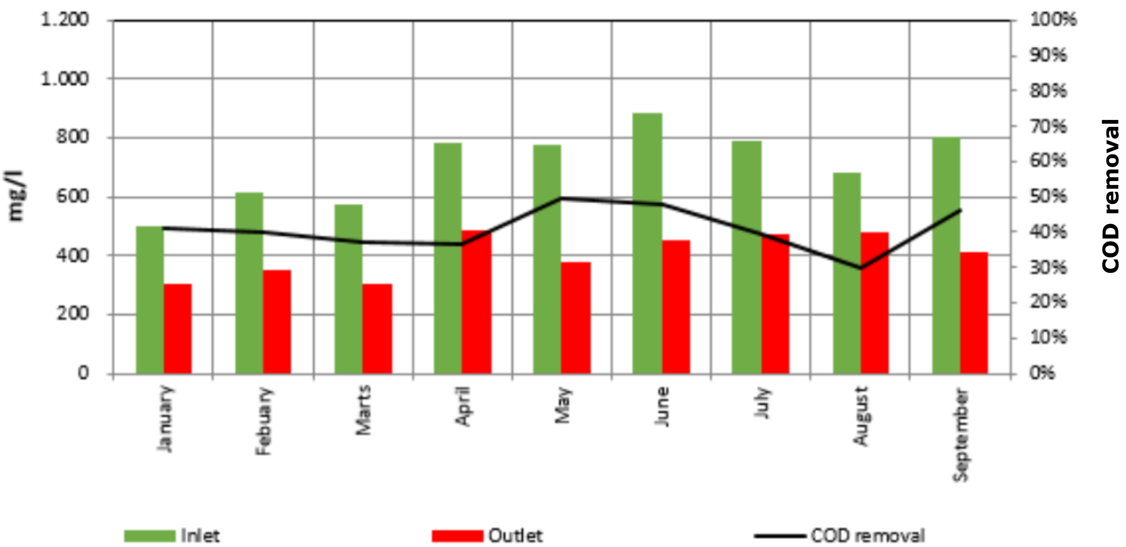


Figure 12: COD concentrations in the inlet to Egaa WWTP (inlet) and in the outlet of the pre-treatment step (after the Salsnes filters, but inclusive bypass of the filters)

In order to reach the expected 60-65% COD removal efficiency, further polymer tests are being done. Unlike pilot plants, where there are small variations in carbon and hydraulic load, completely different challenges are found in full-scale plants where the load varies greatly due to large fluctuations in flow but also suspended matter (SS) over the day. The polymer dosage at Egaa is optimized based on the carbon load of the SS, which not only reduces polymer consumption, but also increases its effect.

Additional information and results are given in Annex D.

Overall, it can be concluded from the experience with fine mesh sieves at Egaa WWTP, that pre-filtration is an alternative to the traditional primary clarifiers. The expected benefits of controlling the odour problems, reducing space requirements and controlling the carbon harvest are still valid. However, it is important to be aware of the challenges to operate the system and identification of where and what needs to be adjusted during the run-in period. There are more mechanical equipment that can break down in a pre-filtration system than in a primary clarifier. Furthermore, so far the carbon harvest with the pre-filtration system has been in the same level as a normal pre-clarifier and not higher as expected.

As more things can go wrong in this type of system, it should be considered where to build-in extra security. Looking back, we would have benefitted from a possibility to store the primary sludge, especially during running-in, and the operation of the system would be more robust if one primary sludge pump could pump primary sludge from all the Salsnes filters and not only 50%.

5.3.2 Installation and commissioning of ORC system

The purpose of establishing the ORC plant was to utilize the surplus heat from the gas engine to boost electricity production. Due to an extensive need for cooling, the ORC is only designed for operation during the coolest 6 months of the year. The other 6 months the excess heat is supposed to be sold to the district heating system.

Figure 13: Organic Ranking Cycle (ORC) installed at Egaa WWTP

The running-in and the final tests of the ORC were completed in January 2018. Detailed description of the results of the test can be found in Annex E.

The conclusion regarding the ORC plant can be summarized as follows:

- We have installed 1 gas engine at Egaa WWTP, which fits the current gas production well. The maximum heat output from this engine is 433 kW heat. However, as heat is used for heating the digester and the buildings, only about 150 kW surplus heat is available for the ORC plant in the winter period. The delivered ORC plant has an operating range between 272 kW and 613 kW of heat supply, which is significantly higher than the current amount of heat available for the ORC plant. The subcontractor of the plant has stated that the operating area cannot be lowered further and that there no smaller ORC is available.

- By installing one more 250 kW gas engine, more heat will be available for the ORC plant (up to approximately 450 kW) and by adjusting the ORC to operate in a narrower range, it is expected to achieve a better efficiency. However, with the current load of approx. 90,000 PE, not enough gas is produced to utilize 1 extra gas engine. In order to buy an additional gas engine, the load of Egaa WWTP should get closer to its 120,000 PE design value or more gas should be generated in other ways.

- With the current legislation the electricity produced at ORC plant is not entitled to price supplement. Moreover, a district heating network is located very close to the wastewater plant, which makes it possible to sell the excess heat.

As a result of all these factors, all surplus heat is sold to the district heating network of the city of Aarhus and the ORC is not in operation.

The overall conclusion is that it would be more appropriate to establish this type of ORC plant in a wastewater plant with a higher capacity of excess heat and with no possibility of selling to a district heating network. Furthermore, the plant should be constructed in such way that the cooling water from the condenser could be utilized to preheat incoming sludge or other processes, so that heat is not lost but instead contributes positively to reduce heat consumption. It would also be optimal if there was wastewater available for cooling.

5.4 WP03 – Demonstration

5.4.1 Energy production and savings

At the end of 2016, Egaa WWTP began to operate with Salsnes filters for primary treatment, a digester for gas production and a DEMON®-® plant for reject water treatment.

The net energy production since 2017 is shown in Figure 14.

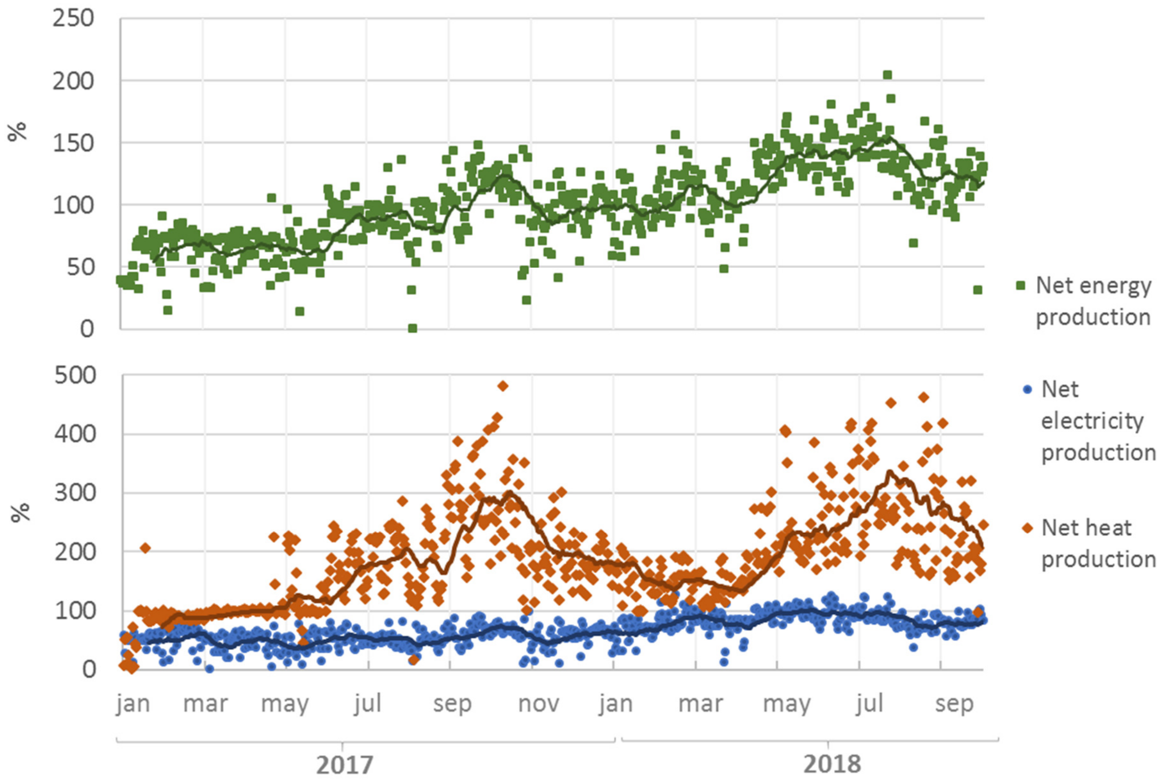


Figure 14: Net energy, electricity and heat production at Egaa WWTP 1-1-2017 till 30-9-2018.

As in can be observed in Figure 14, the net energy production has gradually increased as consequence of the optimization of the processes. The average net energy production in the first 3 quarters of 2018 was 121%. The average net heat production in that period was 193%, being the total amount of heat sold to the district heating net of Aarhus ~ 1.14 GWh.

In relation to the net electricity production, its mean value in the 9 first months of 2018 was about 83%, which is less than the expected 100%. In the months of May and June of 2018 where the average COD removal efficiency was 48-49% in the pre-treatment, the corresponding average net electricity efficiency was ~100% (see Figure 14). In fact, in periods with high and stable carbon harvest more biogas has been produced than the engine can burn off (~ 155 m^3/h) and the net energy production has been ~120% for short periods of time, which indicates that there are potential for increasing the net electricity production.

After the upgrade of Egaa, the electricity production and consumption were expected to be around 6,300 kWh/d (2.3 GWh/year). This become true for the electricity production (see Figure 15) but not for the electricity consumption, that it was ~7,500 kWh/d. This can be explained by the fact that on one hand the amount of carbon harvest at the Salsnes filters has been lower than the expected and therefore more aeration has been required in the activated sludge tanks. On the other hand, the biogas potential of the primary sludge is higher than the predicted, which means higher electricity production per ton of volatile solids. Therefore, the net electricity production can be potentially bigger than the 100% expected, once a stable operation of the Salsnes filters is achieved.

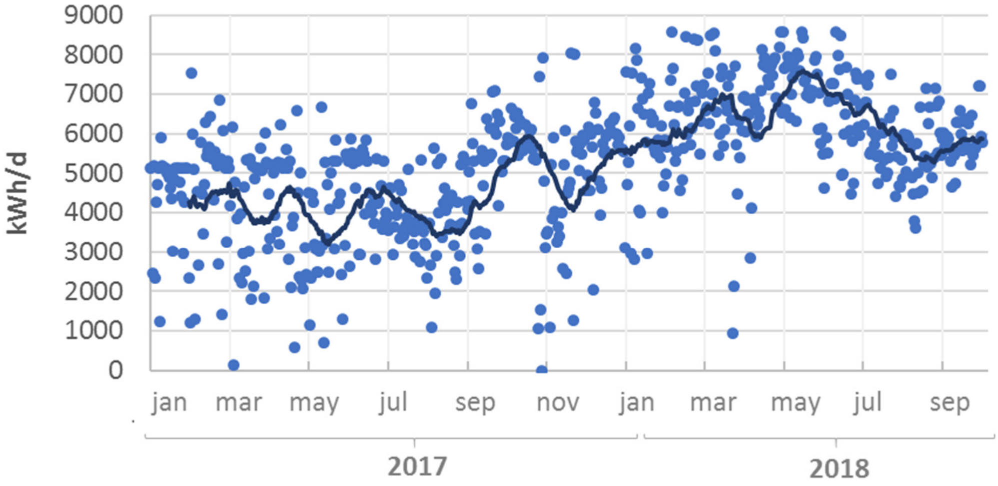


Figure 15: Electricity production from start of the digester

There is still ongoing work to reduce the energy consumption and increase the energy production, and most of all ensure a stable COD harvest. The change of the new biological process is expected to occur soon, and we hope to see a reduction of the energy consumption over the coming months/year.

Below the development in Specific Electricity Consumption at Egaa WWTP is illustrated together with the Specific Electricity Production.

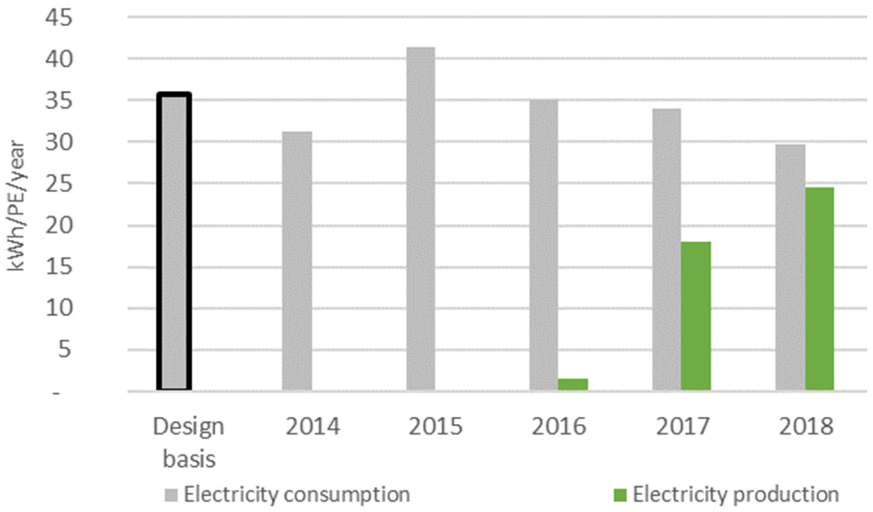


Figure 16: Specific Electricity Production at Egaa WWTP from design basis to 2018 compared with the Specific electricity production at Egaa WWTP. Data for 2018 is calculated on the basis of the average consumption fram January to September and scaled up to a whole year.

5.4.2 Fulfilment of outlet demands

All the outlet demands of the plant have been met during the whole project. Discharge limits and discharge values according to Danish Standard 2399 are given in Table 1.

Table 1: Discharge limits and discharge values according DS 2399 from January to October 2018 (17 samples)

Parameters	Discharge limits	Discharge values (according DS 2399)	Control type
pH	6.5 8.5	6.90 7.50	Minimum Maximum
SS [mg/l]	20	3.19	
SS [mg/l]	15	3.19	Guideline
BI_5 modified [mg/l]	10	1.94	
BI_5 modified [mg/l]	20	5.20	Guideline
COD [mg/l]	75	22	
NH_4-N [mg/l]	8	2.10	Maximum
NH_4-N [mg/l]	2	1.14	
Total-N [mg/l]	8	3.39	
Total-P [mg/l]	0.4	0.15	
Total-P [kg/d]	5.7	2.49	
O_2 [%]	60	86	Minimum

5.4.3 Permits and agreements

Construction permit were obtained in the first half of 2015.

Energy agreements were a bit more complicated:

- After some confusion Aarhus Vand signed an agreement with Energinet.dk in November 2016, to sell the electricity generated at the biogas engine to the grid and to get the biogas price supplement stipulated by the Danish law.

- In relation with the selling of surplus heat to the district heating company of Aarhus (AffaldVarme), the negotiations took a while because the heat distribution networks close to the plant are too small in capacity to receive the surplus heat from Egaa. Finally, Aarhus Vand got the approval for connection to a major heat transmission line, which had never been done before at AffaldVarme. Surplus heat began to be sold in May 2017.

- Regarding the sale of electricity from the ORC plant, Aarhus Vand requested an indicative opinion from Energinet.dk prior to delivery of the ORC plant to determine if the produced electricity would be entitled to a “price supplement”. The answer was yes. Nevertheless, in February 2017, there was a refusal from Energinet.dk, which means that today Aarhus Vand cannot get a supplement for the electricity generated at the ORC. As for future projects, this decision will mean a significant deterioration of the business case to increase electricity production with an ORC plant.

5.5 WP04 – ”Go to Market” strategy

This work package contains the following sub-items:

- Formalising of the "Go to Market" strategy
- Organisation of the partnership
- Egå wastewater treatment plant as a model facility
- Preparation of potential customer list
- Branding/communication plan
- Brochure about the Egå concept
- Implementation of strategy and communication plan

5.5.1 Formalising of the "Go to Market" strategy

The partners Per Aarsleff A/S and EnviDan A/S, have, in close cooperation with Aarhus Water, prepared a strategy for bringing Egaa's experiences into play at other facilities. The strategy is designed as a development plan going forward to 2021 and consists of the following elements:

- **Mission** — to produce energy-generating facilities based on concepts and forms of collaboration from Egå
- **Vision** — to create a good basis for establishing energy-generating facilities in Denmark, Sweden and Norway in a collaborative manner, as exemplified at Egaa
- **Goals —** to initiate three projects by 2021, to use Egaa as a model/reference facility and to disseminate knowledge of the concept
- **Strategies** with corresponding action plans to ensure that we reach these goals by 2021

The development plan as a whole will be used as the basis for partnership meetings, which are held 2-4 times a year. The plan has been revised several times along the way—the current version is attached in Annex F.

5.5.2 Organization of Partnership

The partnership behind the "Egaa Concept" consists of:

- Per Aarsleff A/S, Jane Dahl Larsen and Bjarne Paysen, reps.
- EnviDan A/S, Jens Albrechtsen and Morten Fjerbæk, reps.

Aarhus Water participates in the partnership's "Go to Market" meetings in the role of concept "ambassador" and assists, in part, by focusing on the Egaa project in professional contexts, articulating the concept to other utilities, and, not least, making the plant available for display to interested parties.

The partnership meets about 4 times a year at this point to follow up on the "Go to Market" strategy.

5.5.3 Egaa Wastewater Treatment Plant as a Model Facility

Egaa WWTP is already used as a reference facility and currently has more than 30 displays for delegations from Danish and international utility companies, including Norway, Sweden, Ukraine, the United States, Taiwan, Indonesia and China. A complete list of tours, presentations and articles about the project is attached as Annex A.

In agreement with Aarhus Water, the partnership can continue to bring potential customers for tours of the plant, and any involvement of Aarhus Water's personnel will be financed by the partnership.

5.5.4 Preparation of Potential Customer List

Prior to the identification of potential customers, the partnership has established a number of criteria for whom the "Egaa Concept" will be particularly relevant (and thus particularly applicable to facilities with these characteristics):

- Requirement for secondary treatment/nitrogen removal.
- "Footprint" has significance (rebuilding or bare ground where blasting is required or for other reasons a lack of space).
- Turnover of at least DKK 50 million (default DKK 50-150 million).

- Good knowledge of the customer and their preferences—the customer must be "partnership ready" (or at least willing to adapt).
- Early phase—but must be factual and current.
- Subcontractors/suppliers must be available—we must be able to assemble the right team.

Based on the above criteria, as well as the fact that both Aarsleff and EnviDan are represented with subsidiaries in the Norwegian market, it has been provisionally agreed that the initial focus will be directed toward Norway. This is also on the grounds that the wave of centralisation in wastewater treatment, which was predicted in the Danish market just a few years ago has held off, and for that reason, there are now more centralisation projects in Norway than in Denmark.

There is not yet, as of September 2018, a net list of possible leads, but EnviDan and Aarsleff are both in dialogue with their respective Norwegian subsidiaries to ensure that the Egaa concept is taken up as an opportunity for facility developers that come to their attention. When the plan is ready for roll-out (see also section 5.5.7 on Implementation), a screening of prospective facilities will be carried out and a targeted sales effort will be conducted toward the 2-3 most relevant ones.

5.5.5 Branding/Communication

An actual branding plan for the “Egaa Concept” has not been prepared, as it awaits the outstanding circumstances described in section 5.5.7. However, the partnership has drawn up a number of USPs (Unique Selling Points) that should be central to branding of the concept, including:

- The consortium has extensive experience with advanced wastewater treatment facilities in Denmark.
- The concept includes first-class technology and construction techniques, but at very competitive prices.
- The consortium possesses the core competencies "in-house" and can, therefore, make a comprehensive solution tailored to current needs without many interfaces.
- The partnership’s collaborative method has documented efficiency gains.
- The project form puts the project at the centre and adjusts the environment—not vice versa.
- Operations and users are involved from day one.
- The concept has solid examples of technology, process and collaboration.

Independent of plans for the Norwegian market, the partnership is in full swing with branding the Egaa concept via exposure in professional journals and presentations at professional conferences. The August issue of the magazine “Spildevandsteknik” contains an article about some of the experiences that has been gained at the Egaa plant (see Annex G). The plan is that the article will be supplemented by an additional article grounded in the experience and happening in conjunction with a scheduled workshop on November 26, 2018, where the particular work processes and the roles of the parties along the way are on the agenda.

The expansion of the Egaa treatment plant has, furthermore, been the centrepiece for a number of lectures at professional conferences and courses, including the Danish Water Conference, a day course at the Wastewater Association, Nordiwa and others, and the facility concept has been featured in several international reports, for example, Norwegian Water’s "Examples of Implementation of Sustainability in the Water Industry" from 2016.

5.5.6 Brochure about the "Egaa Concept"

It is the partnership's intention to develop informative material in both Danish and Norwegian, describing the Egaa concept. For the time being, a draft of a concept sheet that broadly describes the plant has been prepared—see Annex H.

Further development of brochure materials will contain the USPs previously described in this Annex and target the 2-3 plants selected in the next phase.

5.5.7 Implementation of Strategy and Communication Plan

As described in the article in "Spildevandsteknisk" (see Annex G), there is one unfinished item in particular that must be finalised before the partnership is ready to turbocharge the marketing of the Egaa concept. This relates to the Egaa plant's experience with degraded sludge properties after establishing carbon harvesting, and there may be a correlation between the installation of the Salsnes filters and the impaired settling properties. This is currently being investigated, and final conclusions are yet to be drawn.

BIOFOS (which owns the largest wastewater treatment facility in the capital) has planned to carry out a parallel test that will reveal whether the connection exists and how it can be handled. In parallel there are reports from other plants with pre-filtration, as well as continuous interpretation of the results obtained from the Egaa treatment plant.

It is expected that there will be a conclusion during the first half of 2019 as to whether this problem is present to an extent that could put an end to scaling up of the solution, as it appears at the moment.

Hopefully, it will be revealed that there is no connection, or that the negative influence on settling properties can be handled with other measures. In that case, the partnership is ready to move on and has already had some thoughts about the overall constellation of the partnership to be brought into play for the introduction of the Egaa concept in the Norwegian market:

- Construction and engineering: Aarsleff, with a local contractor as subcontractor.
- Process design, management concepts and design: EnviDan.
- Machine and forging supplies: A Danish supplier, e.g. Holsted Forge and Machine Workshop or Aquagain (already represented in Norway).
- Electrical installations: Local installer.
- Architect: Local architect, dependent on geography, etc.

In order to make things as clear as possible for customers, it is being considered that one party should be allowed to be the lead party and act as tenderer. For the first projects, it may be advantageous to let Aarsleff take the lead with the remaining parties as subcontractors/advisors. It will simplify the partnership agreement and possibly make it easier to persuade a builder to try out this form of collaboration.

Remaining Procedural Methodology:

- Uncover potential collaborators and make non-binding agreements.
- Screen the market and designate 2-3 potential facilities/projects.
- Identify opportunities for PR promotions in general.
- Individual promotions to specific customers (1:1 meetings and invitations to visit Egaa).
- Possible preparation of feasibility studies and other preparatory work ad hoc.
- Work offers ad hoc.

The timetable for activities mentioned is to be established once results of the studies regarding the current negative effect on sludge properties are presented.

6 Utilization of project results

The learning's in the project have had high value for the future activities of all the partners.

As explained at the "Go to Market" strategy the results of the project are expected to be utilized by Per Aarsleff A/S and EnviDan A/S to initiate three more projects based on the Egaa Concept by 2021, with focus on Norway. To that end:

- A list of criteria to identify potential customers has been established and a potential customer list is being developed.
- Egaa WWTP is and can continue being used as a reference facility.
- It is planned to prepare a branding plan for the "Egaa Concept" based on seven Unique Selling Points already drew up by the partnership. Including the elaboration of informative material. A draft of a concept sheet can be seen in Annex H.
- Overall distribution of tasks in the partnership has been discussed to the introduction of the Egaa Concept in the Norwegian market.

Aarhus Vand has acquired extensive knowledge and experience in innovative process' and their interaction, which is going to be highly relevant in the design and construction of the five times larger Marselisborg ReWater plant. Furthermore, Aarhus Vand will continue to develop and optimise the different processes at Egaa WWTP.

As a net energy producing wastewater treatment plant Egaa WWTP contributes to the strategic energy goals of Aarhus Vand. Aarhus Vand goals are to be 55% energy self-sufficient for electricity and heat in 2020 and net energy producing in 2030.

So far, the project at Egaa WWTP has increased the energy self-sufficient for electricity and heat with about 10 %-points, and with the expected results at Egaa WWTP, Aarhus Vand expects to achieve the goal to be 55% energy self-sufficient for electricity and heat in 2020.

Egå WWTP represents a new generation of net energy producing plants. It shows that this kind of plants is a reality and opens the way for the transformation of other plants with the same or other new innovative technologies. In Denmark alone, at least 65 WWTPs could be turned into net energy producers, which means a reduction of approximately 2% of the national electricity consumption.

The results of the project have been disseminated to other companies in the water sector as well as universities, technological institutes and the public in general by the active participation of the partners in conferences and events, the publication of articles, as well as guide tours at the plant (see Annex A). These transference activities are planned to continue after the finalization of the EUDP project.

7 Project conclusion and perspective

The overall purpose of the project was to develop and demonstrate the "Egaa Concept", in which innovative technologies are set to work individually and in interaction with each other, as well as with well-proven technologies in order to bring a model of energy-generating wastewater treatment plants to the market.

Overall, the project has demonstrated that it is possible to build a net energy producing wastewater treatment plant, with an average net energy production in the last 9 months of operation of 121%. In the same period of time the average net electricity production was 83% and the an average net heat production was 193%

It is relevant to highlight that when combining new technologies, it is very important to evaluate carefully what can go wrong and how to build-in extra security. In this case the numerous unexpected challenges faced when using a well-known technology as the Salsnes filters, in another context and with other objectives, has been very critical for the execution of the project. The other processes at Egaa WWTP are highly dependent of the outcome of the pre-filtration system. Therefore, the difficulties with the pre-filtration has prevented the full implementation of the full process.

Highly valuable knowledge and experience have been gained during the project which is going to be used to further optimization of the "Egaa Concept" by the partners.

It can be concluded that:

- **Harvest of COD with filters**
  Dynamic harvesting of carbon in the primary step using filters has been more challenging than anticipated. Despite being a mature technology for removal of total suspended solids (TSS) in wastewater treatment plants without anaerobic digestion, a long list of operational difficulties has been faced. As result, the average reduction of the incoming COD in the first 3 quarters of 2018 has been 40 %, which is significantly lower than the expected 60-65%. Several control and mechanical improvements have been made based on the gained expertise and it is expected to reach a stable and higher carbon removal in the time to come.

  Overall, it can be concluded from the experience with Salsnes filters at Egaa WWTP, that pre-filtration is an alternative to the traditional primary clarifiers. The expected benefits of controlling the odour problems, reducing space requirements and controlling the carbon harvest are still valid.

- **Sludge properties when using pre-filtration**
  There should be focus on pumping and mixing the primary sludge and the surplus sludge into the digester when using pre-filtration. Much higher viscosity of the sieved material and the digestate has been found compared to sludge and digestate from other plants operated by Aarhus Vand with traditional primary treatment. Besides, test with electroporation shows an ~15% increase in methane production of the sludge from Salsnes filters. Therefore, Aarhus Vand plans to work with pre-treatment methods to enhance biogas production from sludge from the sieves.

- **Reject water treatment in a DEMON® plant**
  Reduction of the ammonium load to the main process has been successfully reached by implementing a DEMON®-system to treat reject water coming from the dewatering of the anaerobic treated sludge from the digester. The DEMON®-process have been proved to be very robust and it operates as expected with 85% NH4 removal efficiency. An average of ~129 kg Tot-N/d has been removed at the DEMON®-plant in 2018, which correspond to ~15% of the total nitrogen inlet concentration into the wastewater treatment plant.

- **Energy optimized nitrogen removal in the main process tanks**
  Energy optimized nitrogen removal in the main process tanks has still not been fully accomplished. It was initially planned to stablish a cold Annamox EssDE™ process from

Sweco. In view of the knowledge acquired since the application for funding and the experience gained by Aarhus Vand developing a new control of the mainstream processes at Marselisborg WWPT, it was agreed to implement the same process existing at Marselisborg, most probably a Nitrite Shunt process.

So far, this has not been possible to see the effects of the new control as consequence of the high COD/N ratio at the biological process due to the lower COD harvest with the filters. However, a reduction of specific energy consumption of ~10% has been achieved in the process tanks thanks to multiple activities for optimization.

As soon as the carbon harvesting system is stabilized, and the right COD/N ratio is achieved, everything is ready to get the Nitrite Shunt up and running with the consequent reduction of energy consumption. During the project the control system was developed and nitrate/nitrite sensors as well as hydrocyclones were installed. At the moment, the effect of the cyclones at Egaa is still not clear. Further studies will be performed to try to clarify in which way they influence the process.

- **Organic ranking cycle (ORC) for optimized electricity production**
  The installed ORC has a heat supply operating range significantly higher than the current amount of heat available from the installed engine, and with the current load of 90,000 PE, not enough gas is produced to utilize an extra gas engine.

  With the current legislation the electricity produced at ORC plant is not entitled to price supplement and a district heating network is located very close to Egaa WWTP. So it is a better business case to sell all the heat produced at the biogas engine to the net.

  The overall conclusion is that it would be more appropriate to establish this type of ORC plant in a wastewater plant with a higher capacity of excess heat and with no possibility of selling to a district heating network.

  We are going to explore whether the ORC plant can be sold to another facility, where it can be more profitable than at Egaa WWTP.

- **Fulfilment of the effluent discharge limits**
  The effluent discharge limits have been met during the whole project, which shows that it is possible to upgrade existing WWTP with the "Egaa Concept" fulfilling the plant outlet demands.

- **Energy self-sufficiency at Egaa WWTP**
  The goal of achieving 100% electricity self-sufficiency at the current load (90,000 PE) has been partially achieved during shorter periods of time, in which the carbon harvesting at the filters has been relatively high and stable. Nevertheless, the average net electricity production in the first 3 quarters of 2018 has been 83%. Further optimization of the processes is being carried out and an increase in the net energy production is expected to be seen in a very near future.

- **Utilization of project results**
  There has been a big interest in the sector for the project. More than 30 relevant delegations from Danish and international utilities companies have visited Egaa WWTP, several articles have been published and the project has been presented in various events/conferences.

  The partners have conceptualised a "Go to Market" strategy to further commercialise the "Egaa Concept".

Annex A
Liste over formidlingsaktiviteter (List of dissemination activities)

Artikler

21-05-15 ”Aarsleff og Envidan bygger energiproducerende renseanlæg”. Building Supply, Aarsleff.

Jan/Feb 16 ”US water infrastructure needs US$271 billion investment”. World Water.

Dec. 2016 Aarhus Vand blev interviewet til det svenske blad Cirkulation. Interview med Lise K. Hughes.

June 2016 ” Aarhus prepares to push the energy from wastewater limit”. Aqua Strategy, s13. Interview med Per O. Pedersen (AaV).

Febr. 2017 ”Højteknologisk renseanlæg bliver fjernvarmeleverandør i Aarhus”. Artikel i bladet Fjernvarmen.

April 2017 ”Great Danes: Making Wastewater Treatment Energy Positive”. Water Online.

April 2017 Aqua Strategy review: Water utilities – what is your energy strategy? Aqua Strategy

Aug. 2018 Per O. Pedersen (AaV), Lise K. Hugher (AaV), Rasmus Johansen (Envidan) og Jens Albrechtsen (Envidan).”Enfaringer fra Danmarks første forfiltreringsanlæg på Egaa Renseanlæg”. Spildevandsteknisk Tidsskrift, s18.

Præsentationer

06-11-15 Louis Landgren (Aarhus Vand) og Lise Hughes (Aarhus Vand). "Ressource udnyttelse, kulstofudnyttelse og gasproduktion på det nye Egaa Renseanlæg". Døgnkursus i Spildevandsteknisk Forening.

17-11-15 Bjarne H. Petersen (EnviDan) og Lise Hughes (Aarhus Vand). "Fremtidens energiproducerende renseanlæg i Egaa" . Dansk Vand Konference.

30-11-15 Lise Hughes (Aarhus Vand). "Egaa Renseanlæg - vejen til et 150 % energiproducerende anlæg". Workshop: "Frem mod det energineutrale vandselskab", arrangeret af Dansk Miljøteknologi, DANVA og DI.

08-11-16 Lise K. Hughes (Aarhus Vand) og Bjarne Hjorth Petersen (EnviDan). ”Driftsresultater fra fremtidens energiproducerende renseanlæg i Egaa”. Dansk Vand Konference.

01-11-17 Per Overgaard Pedersen (Aarhus Vand). ”Egaa WWTP-New Energy Production Plant”. Worshop mellen Aarhus og Udaipur (Indien)

Begivenhed

20-01-16: Rejsegilde på Egaa Renseanlæg, med deltagelse af daværende miljø- og fødevareminister Eva Kjær Hansen.

I forbindelse med rejsegildet fremlagde Povl Frich (EUDP) og Per O. Pedersen (AaV) en kort præsentation med titlen ”Fremtidens energiproducerende renseanlæg i Egaa”.

Artikler relateret til arrangementet:

18-01-16 ” Rejsegilde på strømproducerende renseanlæg”. Energy-supply.dk.

20-01-16 ”Dansk renseanlæg sætter nye internationale standarder”. Dr.dk

20-01-16 ” Epokegørende teknologi får strømmen til at Flyde”. Jyllands-posten.dk.

20-01-16 ” Minister til fest på Envidan-projekt”. Midtjyllands Avis’ nyhedssite (mja.dk).

20-01-16 ”Rejsegilde på renseanlæg, der laver strøm”. Bygtek.dk.

20-01-16 ” Miljø- og Fødevareministeriet - Verdenshistorie i Aarhus”. Altomteknik.dk.

21-01-16 ”Epokegørende teknologi får strømmen til at flyde”. Aarhusportalen.dk.

21-01-16 ”I fremtiden skal vores rensningsanlæg være energileverandører og ikke energislugere, som i dag. Nyt anlæg i Egaa kommer til at producere strøm og levere varme til over 100 parcelhuse”. Stiften.dk.

Rundvisninger

29-03-16 Rundvisning for Hørsholm Vand. Rundviser: Aarhus Vand, Per O. Pedersen.

06-04-16 Rundvisning for IØR/AHSA IKS (Norge). Rundviser: AaV, Per O. Pedersen.

04-05-16 Rundvisning for Nokian Water. Rundviser: Aarhus Vand, Per O. Pedersen.

19-05-16 Rundvisning for IEA. Rundviser: Aarhus Vand, Per O. Pedersen.

24-05-16 Besøg på Egaa Renseanlæg af en delegation af forsyningsselskaber, rådgivere og myndigheder fra Chicago området, der var på ”Fact-finding Tour”. Lise K. Hughes (Aarhus Vand) fremlage præsentationen ” Energy Production and new processes at Egaa WWTP” og viste rundt på anlægget.

31-05-16 Rundvisning for Argentinske ambassade. Rundviser: AaV, Per O. Pedersen.

10-08-16 Rundvisning for Norconsult – fokus Salsnes filtre. Rundviser: Aarhus Vand, Lise K. Hughes.

15-08-16 Rundvisning for Grundfos – fokus på energioptimering. Rundviser: Aarhus Vand, Lise K. Hughes.

16-08-16 Rundvisning for Frederikshavn Forsyning og Niras – Rundviser: Aarhus Vand, Lise K. Hughes.

22-08-16 Rundvisning for bestyrelserne for Forsyningen Allerød Rudersdal, Fredensborg Forsyning og Hørsholm Vand. Rundviser: AaV, Lise K. Hughes.

21-09-16 Rundvisning for norks forsyningsselskab, IVAR. Rundviser: Aarhus Vand, Lise K. Hughes.

07-10-16 Rundvisning for CNN (India). Rundviser: Aarhus Vand, Per O. Pedersen.

01-11-16 Rundvisning for GWC. Rundviser: Aarhus Vand, Per O. Pedersen.

25-11-16 Rundvisning for italiensk delegation fra Torino og den Danske Ambassade i Rom. Rundviser: Aarhus Vand, Lise K. Hughes.

06-12-16 Rundvisning for Mariagerfjord Forsyning, fokus Salsnes filtre. Rundviser: EnviDan Jens Albrechtsen og Aarhus Vand, Lise K. Hughes.

21-12-16 Rundvisning for medarbejderne i Syddjurs Spildevand. Rundviser: Aarhus Vand, Lise K. Hughes.

23-01-17 Rundvisning for Beijing Enterprise Water Group-Nissen energiteknik. Rundviser: Aarhus Vand, Per O. Pedersen.

25-01-17 Rundvisning for NCC. Rundviser: Aarhus Vand, Per O. Pedersen.

13-03-17	Rundvisning for Kemira. Rundviser: Aarhus Vand, Lise K. Hughes.
15-03-17	Rundvisning for ukrainsk delegation fra Zaporozhie City Administration og repræsentant fra Aarsleffs ukrainske selskab. Rundviser: Aarhus Vand, Lise K. Hughes, Envi-Dan, Bjarne Hjorth.
27-03-17	Rundvisning for indonesisk delegation fra City of Jambi. Rundviser: Aarhus Vand, Lise K. Hughes.
22-05-17	Rundvisning for bestyrelserne i SHARED. Rundviser: AaV, Lise K. Hughes.
29-09-17	Rundvisning for Norge – Fylkes Kommune (2 administrative og 3 politikere). Fokus: energioptimering, ressourceudnyttelse og fremtiden indenfor vores renseanlæg. Rundviser: Aarhus Vand, Lise K. Hughes.
04-10-17	Rundvisning for Kinesisk delegation ledet at AVK. Fokus: Energi. Rundviser: Aarhus Vand, Lise K. Hughes.
01-11-17	Rundvisning for Amerikansk WTA delegation. Fokus: Energi. Rundviser: Aarhus Vand, Flemming B. Møller.
10-11-17	Rundvisning for Svensk pojektgruppe ved Tekniska Verken i Linköping AB (publ). Fokus: Energi, Salsnes, Demon. Rundviser: AaV, Lise K. Hughes.
07-12-17	Rundvisning for 2 pHd studerende ved DTU. Fokus: Energi og Forfiltrering. Rundviser: Aarhus Vand, Lise K. Hughes.
27-02-18	Rundvisning for Nedre Romerike Avløpsselskap. Rundviser: Aarhus Vand, Per O. Pedersen.
28-02-18	Rundvisning for 2 personer fra Roslagsvatten. Fokus: Energi og strategiarbejde. Rundviser: Aarhus Vand, Lise K. Hughes.
06-04-18	Rundvisning for Norsk delegation fra Østfold. Fokus: Energi og udvidelsesmuligheder. Rundviser: Aarhus Vand, Per Overgaard Pedersen.
03-05-18	Rundvisning for Ukrainsk delegation ledet af Aarsleff. Fokus: Energi. Rundviser: Aarhus Vand, Lise K. Hughes.
18-05-18	Fremvisning af energianlæg for delegation fra Taiwan. Fokus: Gasmotoranlæg. Rundviser: Michael B. Nissen fra Nissen Energi Teknik.
14-06-18	Rundvisning for Amerikansk WTA delegation. Fokus: Energi. Rundviser: Aarhus Vand, Flemming B. Møller.

Annex B
DEMON®-system for reject water treatment

In the DEMON®-plant the nitrogen from the anaerobically digested sludge reject water is removed by ammonia oxidizers and Anammox bacteria without the use of carbon and with a lower energy consumption than the conventional nitrification/denitrification process (40 – 50% lower).

The new DEMON treatment plant at Egaa WWTP has a volume of 435 m^3 and an average capacity of 200 kg NH_4/d. The technology is based on activated sludge and it is designed for a daily flow of 150 m^3/d. The sludge is discharged thorough a cyclone (with a capacity of 10 m^3/h) and the treated reject water is returned to the mainstream process. The DEMON®-process is controlled by oxygen and pH. The aeration is intermittent, and the oxygen level is kept low at around 0.3 mg/l. pH setpoint is 6.975.

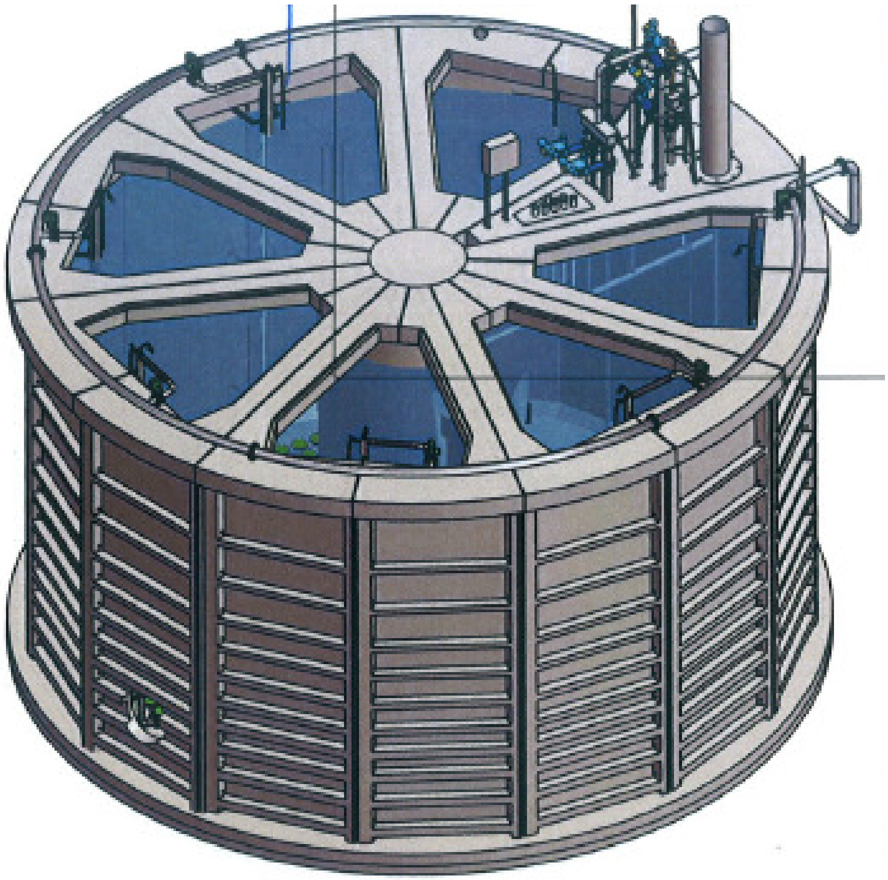


Figure B - 1: DEMON ® tank drawing

The start-up phase took place at the end of 2016 and the DEMON®-plant was inoculated with 60 m^3 of feed sludge from Marselisborg.

Key design process parameter and average results are showed in Table B - 1.

Table B - 1: Key design process parameter and results from the first three quarters of 2018

Process data		Design (average)	Results (average)	Design (max)	Results (max)
Parameter	Unit		Internal data		Internal data
Key performance indicators					
NH_4-N removal	%	85	**84.5**		**96.1**
Tot-N removal	%		**78.3**		**91.6**
NH_4-N load	kg NH_4-N/m^3	0.7	**0.5**		**1.1**
Specific energy consumption	kWh/kg Tot-N removed		**1.15**		**1.91**
Specific energy consumption	kWh/kg NH_4-N removed	1.16	**1.21**		**2.34**
Inlet					
Daily flow	m3/d	150	**130**	250	**284**
NH_4-N	kg/d	200	**146**	250	**250**
	mg/l	1333	**1082**	1667	**1458**
Tot-N	kg/d	200	**164**	250	**268**
	mg/l		**1210**		**1520**
SS	mg/l	300	**186***	1000	**364***
COD	mg/l	1233	**887***		**3175***
Alkalinitet / NH_4-N		1.0	**1.1***		**1.3***
Outlet					
NH_4-N	mg/l	200	**171**		**878**
Tot-N	mg/l	370	**265**		**474**

* Data from 2017

The operating results have shown that the process is generally stable and very robust. The ammonium removal efficiency in the first three quarters of 2018 is illustrated in Figure B - 2. The average ammonium removal efficiency has been 84.5%, which fits well with the design criteria (85%). Moreover, the ammonium reduction rate is generally high despite a very variable inlet load, fluctuating between the 10 - 150% of the capacity of the plant (see Figure B - 3).

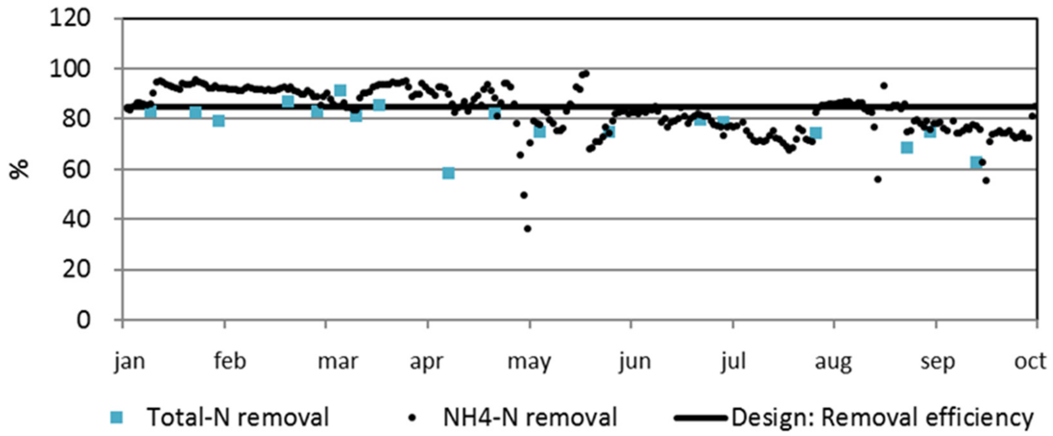


Figure B - 2: Total nitrogen and ammonium removal efficiency of the DEMON plant in 2018

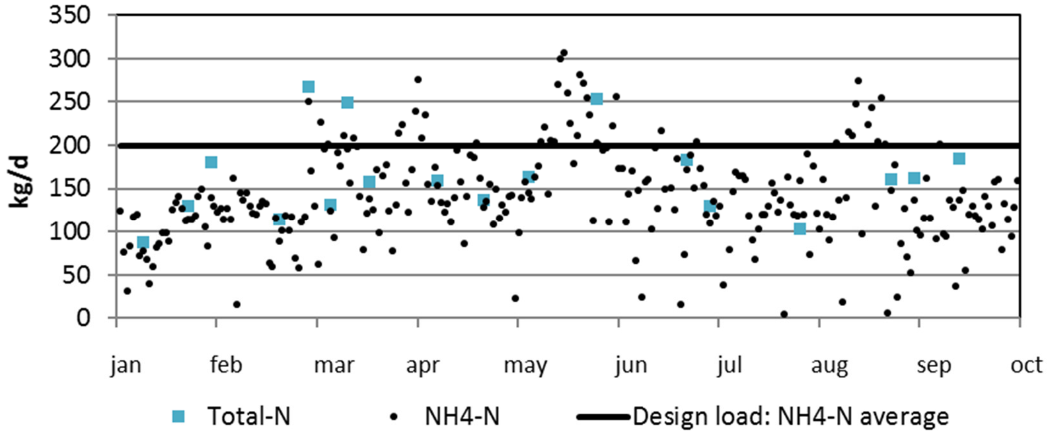


Figure B - 3: Total nitrogen and ammonium inlet load in 2018

The nitrogen content in the treated water, after the DEMON®-plant, is also in the expected level, being kept mostly under the design criteria (Figure B - 4).

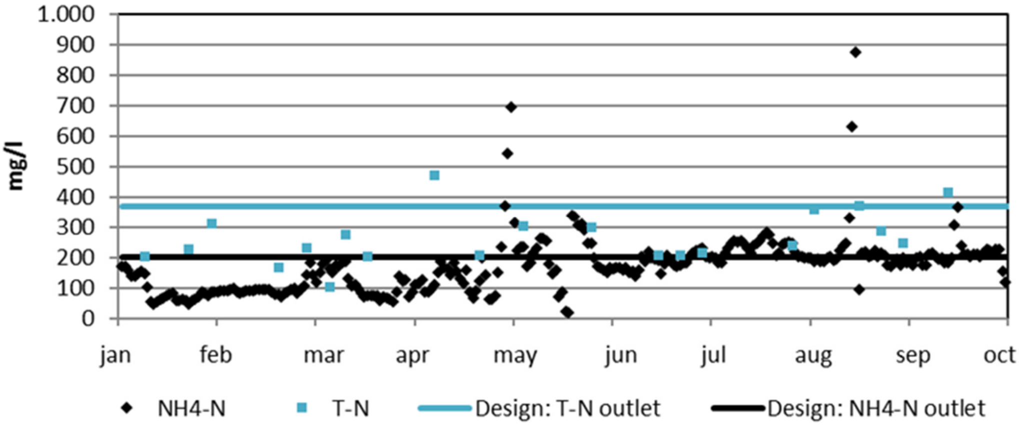


Figure B - 4: Nitrogen content of the DEMON plant effluent in 2018

Regarding to the temperature, the optimal temperature range for the Anammox process is between 30 and 34 °C. The process temperature in the DEMON®-tank is showed in Figure B - 5. It has been observed that when the temperature in the process tank drops below 27 °C, it becomes critical to the biological process as efficiency decreases. On the other hand, when the temperature rises to above 34-35 °C there foaming occurs.

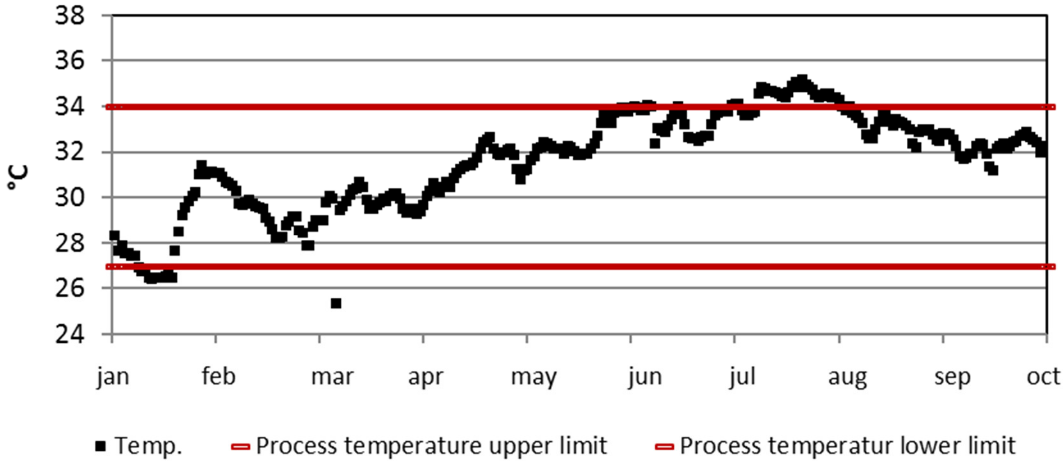


Figure B - 5: Temperature in the DEMON®-process tank in 2018

In relation to the specific energy consumption (see Figure B - 6) , the average consumption per kg of NH_4-N removed in the first three quarters of 2018 was 1.21 kWh/kg NH_4-N removed, which is very close to the expected 1.16 kWh/kg NH_4-N removed.

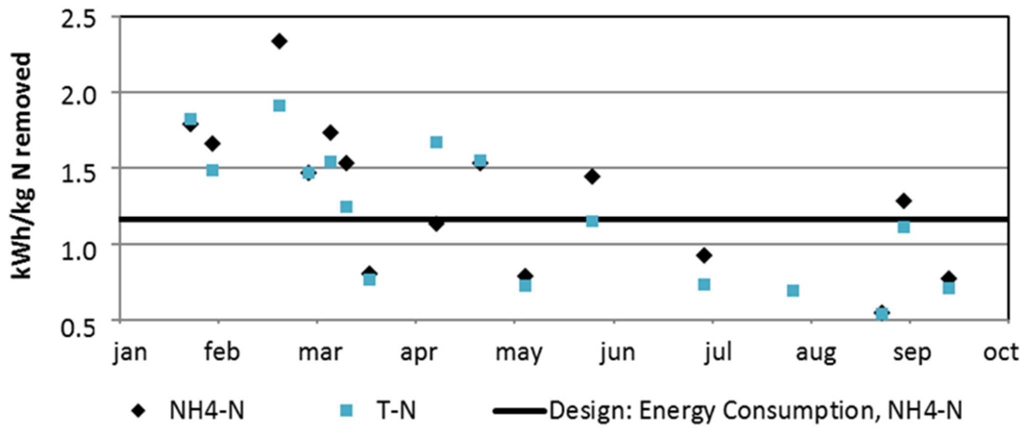


Figure B - 6: Specific energy consumption per kilogram of ammonium and total nitrogen removed

It can be concluded that the DEMON®-plant after almost 2 years of continuous operation performs as expected, being a stable and very robust process. During some periods struvite precipitation has been problematic when PO_4-P is high (>150 mg/l). In order to avoid the clogging of the pumps/air system a formic acid dosing system has been installed.

Annex C
Full-scale experiences with the use of hydrocyclones

Just few full-scale wastewater treatment plants have published experiences with hydrocyclones used in the mainstream in scientific papers or at conferences. Even a broader search at other public sources such as thesis projects, project reports, brochures or at homepages from suppliers has only resulted in substantial publications from four plants:

- Ejbymølle Wastewater Treatment Plant in Odense (VCS), Denmark.
- Käppalaverket in Stockholm, Sweden.
- Strass Wastewater Treatment Plant, in Austria.
- James River Wastewater Treatment Plant, Virginia, US.

Käppalaverket and James River WWTP have been operated with hydrocyclones since 2015, and Ejbymølle since 2014.

Damhusåen WWTP operated by Biofos in Copenhagen, Denmark plan to have a full-scale installation. The plant will operate one out of four lines with hydrocyclones in order to evaluate the impact on settling properties. However, as the installation is not finished yet it is not included below.

None of the plants has until now published more operational data about the hydrocyclones such as clogging problems, cleaning procedures, effect on downstream processes for instance dewatering of the overflow etc. Only from James River Wastewater Treatment Plant, optimisation of operation has been described.

Aarhus Vand has consequently contacted the plants in order to gather more results about the practical operation of the hydrocyclones as a supplement to the more process related experiences presented in the literature. Below results are presented (if available) from the four plants together with the present results from Egaa WWTP operated by Aarhus Vand.

Table C - 1: Data on full-scale hydrocyclone installations

	Ejbymølle	Käppalla	James River	Strass	Egaa
Hydrocyclone installations					
Trademark	Not identified	Not identified	World Water Works	Not identified	Not identified
Number, Capacity	4 each 10 $m^3 h^{-1}$	2	8 each 20 $m^3 h^{-1}$		5 each 10 $m^3 h^{-1}$
Installation	Whole plant	Test line 1, of 11 lines	Whole plant	Whole plant	Whole plant
Main reason for installation	Nitritation and Anammox	Improved settling	Nitritation and Anammox	Nitritation and Anammox	Nitritation. Originally anammox
Secondary goals	Improved settling	Improved processes	Improved settling and Bio-P		

	Ejbymølle	Käppalla	James River	Strass	Egaa
Typical operation of cyclones					
Pressure, incoming (bar)	1.1	1.1	1.6		Set point 1.8, however operational pressure is in the range 0.7-0.9[1].
Share under/overflow (%)	20:80 – 10:90	5:95	5:95[2]		35:65
General strategy	Fixed setting	Working with change of pressure and share	Many tests of Share and pressure		Fixed setting
SS incoming to cyclones ($g\ L^{-1}$)	10-20		3-5 (return sludge)		12-20 (return sludge)
Exchange rate of sludge[3] (d)	15		3		17
Typical operation of the plant					
Type	Traditional BNR (phase isolated with anaerobic selectors and CEPT)	Bardenpho/CEPT with addition of methanol	Bardenpho, IFAS for nitrification	Nitritation (aimed at anammox)	Traditional BNR (aimed at nitritation)
Flow through cyclones ($m^3\ h^{-1}$)	20		45-68		14.5
Sensors	TS inlet and outlet from cyclones				SS sensors inlet and underflow (Hach Lange Solitax)
Control programme	None	SS and P mass balance each week	Many operational strategies have been tested		None
Downstream processes for overflow					
Concentration	Centrifuged	Centrifuged with other surplus sludge	Band filter		Band filter
Use of polymers	Yes				Yes
Final handling	Digestion	Digestion	Digestion		Digestion

[1] The plant currently uses all 5 cyclones at the same time and not 3 as originally planned

[2] Many settings of exchange rate have been tested.

[3] Volume aeration tank divided by flow through the cyclones, or mass of sludge in the aeration tank divided by mass through the cyclones, in case of flow from return sludge line.

The table clearly demonstrate that hydrocyclones are operated in a wide spectrum of ways for different purposes and at different plants with very different activated sludge systems. Only at James River Wastewater Treatment Plant, examination that is more substantial has taken place.

Central operational parameters such as pressure, share over- and underflow vary substantially. In addition, the frequency where the sludge passes the cyclones vary in a broad span. The literature contains many examples of testing of the efficiency of the cyclones.

It is well established that the cyclones separate more heavy sludge from lighter fractions. However, solid documentation of effects on the processes in the plants are scarcer.

It seems that some plants have experienced better settling measured as improved SVI or better settling velocity but not all evaluations have shown that. Documentation on selection of relevant properties of the sludge to an extent where it is documented to have significant effect on the operation of the plant are almost non-existing. Although some effects on Bio-P and nitritation has been claimed, the effects are not clearly demonstrated and, in several cases, not detected at all.

References:
More information about the different plants can be found in the following publications:

Ejby Mølle:

- Protocols for Researching the Impact of Sludge Granulation on BNR Processes. Willoughby, Adrienne; Houweling, Dwight; Constantine, Tim; et al. Proceedings of the Water Environment Federation, WEFTEC 2016: Session 400 through Session 409, pp. 5865-5877(13). Water Environment Federation. DOI: https://doi.org/10.2175/193864716819713231

- Improved Settleability in a BNR Process From Hydrocyclone-induced Biomass Granulation. (2016). Sandino, Julian; Willoughby, Adrienne; Houweling, Dwight; et al. Proceedings of the Water Environment Federation, WEFTEC 2016: Session 300 through Session 309, pp. 4688-4696(9). Water Environment Federation. DOI: https://doi.org/10.2175/193864716819706743.

- Modelling the Selective Retention of PAOs and Nitrospira (Comammox?) in a Full-Scale Implementation of WAS Hydrocyclones at the Ejby Mølle WWTP. Uri, Nerea; Nielsen, Per Henrik; Willoughby, Adrienne; et al. Proceedings of the Water Environment Federation, WEFTEC 2017: Session 500 through Session 508, pp. 4079-4084(6). Publisher: Water Environment Federation. DOI: https://doi.org/10.2175/193864717822155939

- Microbial Community Analysis Revealed the Selective Retention of Functionally Important Microorganism by Hydrocyclone in Biological Nutrient Removal (BNR) Processes. (2017) Bagchi, Samik; Hiripitiyage, Yasawantha; Willoughby, Adrienne; et al. Proceedings of the Water Environment Federation, WEFTEC 2017: Session 500 through Session 508, pp. 4013-4022(10). Water Environment Federation. DOI: https://doi.org/10.2175/193864717822156217

- Long-Term Effect of Hydrocyclones as External Selectors for Granular Biomass at a Full-Scale WWTP. Yasawantha D. Hiripitiyage, Samik Bagchi, Adrienne Willoughby, et al. The 2nd International Ressource Recovery Conference Aug 5-9 2017, New York.

- Induced Sludge Granulation by a Full-Scale Implementation of WAS Hydrocyclones at the Ejby Mølle WWTP. Adrienne Willoughby, Nerea Uri, Lise Havsteen, et al. IWA Biofilms: Granular Sludge Conference Delft March 18-21, 2018.

- Inducér Biomass Granulation Through Hydrocyclones to Archive BNR Performance Improvements. P. H. Nielsen; J. Sandino; D. Houweling, Dwight; et al.

Käppalaverket:

- Nya processlösningar för skärpta villkor. Michael Nielsen, Sari Vienola, Andreas Thunberg. Nationella konferensen Avlopp & Miljö Växjö 24-25 januari 2017.

- Hydrocyklonpilot i fullskala på Käppala ARV – Resultat - Fortsatta studier. Sari Vienola. Bio-P netverksträff 24-25 oktober 2017 i Lund.

- Improving the capacity of the Käppala WWTP by using hydrocyclones. Sari Vienola. World Water Congress & Exhibition 2018. 16 – 21 SEPTEMBER 2018 / TOKYO / JAPAN

- Improving the capacity of the Käppala WWTP by using hydro-cyclones. (Udateret)S Vienola, A Thunberg. NordIWA 2015.

- Vienola. 2017. Förbättra kapaciteten på Käppala reningsverk med hydrocykloner. Käppalarapport. Lidingö, Sverige.

James River WWTP:

- Improving Settleability and Enhancing Biological Phosphorus Removal through the Implementation of Hydrocyclones. Welling, Claire; Kennedy, Amanda; Wett, Bernhard; et al. Proceedings of the Water Environment Federation, WEFTEC 2015: Session 221

- Implementing Hydrocyclones in Mainstream Process for Enhancing Biological Phosphorus Removal and Increasing Settleability through Aerobic Granulation. (2017). Amanda Ford, Bob Rutherford, Bernhard Wett, Charles Bott. Proceedings of the Water Environment Federation, Nutrient Symposium 2017, pp. 468-479(12). Water Environment Federation. DOI: https://doi.org/10.2175/193864717821494510.

- Microbial Community Analysis Revealed the Selective Retention of Functionally Important Microorganism by Hydrocyclone in Biological Nutrient Removal (BNR) Processes. (2017) Bagchi, Samik; Hiripitiyage, Yasawantha; Willoughby, Adrienne; et al. Proceedings of the Water Environment Federation, WEFTEC 2017: Session 500 through Session 508, pp. 4013-4022(10). Water Environment Federation. DOI: https://doi.org/10.2175/193864717822156217

- Enhancing Biological Phosphorus Removal and Improving Settleability Using Mainstream Hydrocycklones for External and Metabolic Selection. Amanda Ford, Bob Rutherford, Berhard Wett, Charles Bott. Proceedings of the Water Environment Federation, WEFTEC 2017: Session 400 through Session 409, pp. 2521-2532(12). Water Environment Federation. DOI: https://doi.org/10.2175/193864717822153049

- Microbial Community Analysis Revealed the Selective Retension of Functionally Important Microorganisms by Hydrocyclones in Biological Nutrient Removal (BNR) processes. Samik Bagchi, Yasawantha Hiripitiyage, Adrienne Willoughby, et al. WEFtec 2017, Chicago.

- Improving Settleability and Enhancing Biological Phosphorus Removal through the Implementation of Hydrocyclones. Claire M. Welling. Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science.

Annex D
Pre-filtration at Egaa WWTP

In 2016, eight Salsnes filters SFK600 were installed at Egaa WWTP. The Salsnes filters have a capacity of 250 m^3/h each, utilizing a mesh cloth and gravity in order to separate the water and solids. The 350-micron filter mesh develops a layer of sludge, which acts as an even finer and more effective filter being able to trap smaller and smaller particles

Figure D - 1 shows the configuration of the eight Salsnes filters and the pump room underground.

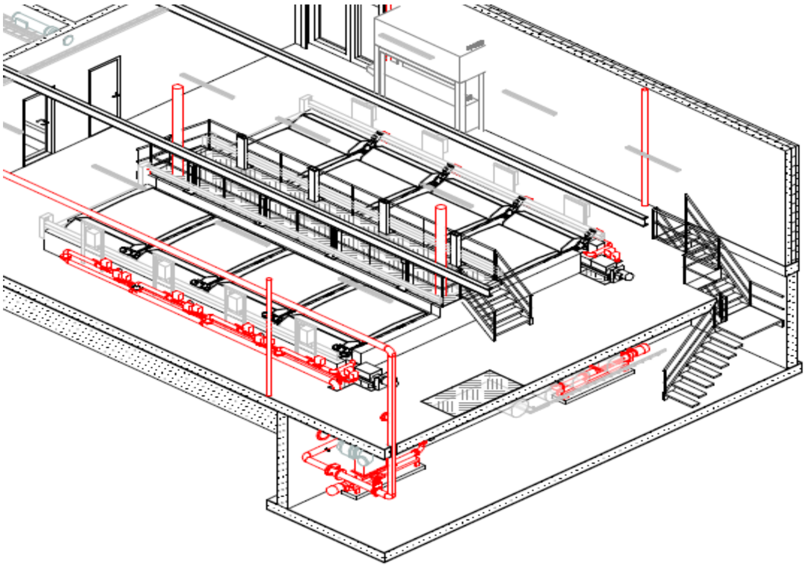


Figure D - 1: Salsnes filter configuration

When the water level reaches a set point, the motor will start to rotate the filter cloth like a conveyor belt and transports the sludge out of the water. When the level of the water rises, it is an indication that the filters are ready for cleaning. A stream of air is used to loosen the sludge so that it falls into the collection area where a screw transports it to the pumps. Figure D - 2 shows the filter mesh cloth

Ideally, 60-65% of the incoming carbon can be harvested by the filters and sent to the digesters. For cleaning purpose water is sprayed over the top of the filter cloth to provide cleaning (unlike the conventional Salsnes filters that spray water up through the cloth).

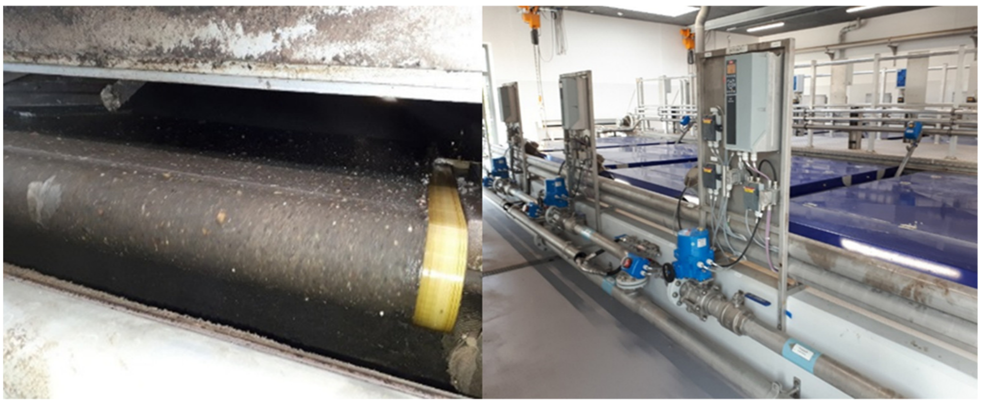


Figure D - 2: Photos of the Salsnes filter installation of Egaa WWTP

1. Primary sludge

It is important to be able to pump enough sludge to the digesters with the right percentage of solids. A total solids content of 6-12% is desired because it does not require pre-dewatering before being pumped to the digesters. The average %TS pumped to the digesters from January to October 2018 was 8% with an average flow of 35 m3/d. In 2017, due to low TS percentage a vacuum system was installed, which makes possible to control the solids content in the desired interval. Before the vacuum system the average %TS was only 3.6% and the average flow to the digesters was 65 m3/d. A picture of the vacuum system is showed in Figure D - 3.

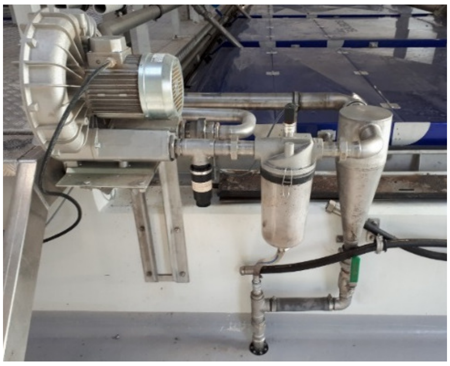


Figure D - 3: Photo of vacuum system

2. Polymer dosing

Polymer is dosed to the wastewater before the Salsnes filters. The purpose of dosing polymer is to create larger flocs that will be more effectively filtered out. Polymer can be used in combination with iron chloride. The idea behind is that iron chloride will produce small flocs and which the polymer will gather to larger flocs, which will be filtered out easily.

Polymer dosing and type has been a critical operational parameter for the Salsnes filter.

In autumn 2015 a Salsnes filter pilot plant was installed at Egaa WWTP. Different tests were performed with polymer addition, without polymer addition and with polymer plus iron chloride. Two different polymers from Dansk Aquakemi A/S were tested. One of them, Aquaflok 03LF (Flopam EM145CT) was recommended by Salsnes. The other Aquaflok P 6268 R was the polymer used at that time at the final sludge dewatering process. The best results were obtained when using the Aquaflok 03LF without iron chloride addition. Therefore, it was decided to use this polymer without iron chloride at the full-scale plant.

From August to December 2016 two engineering students carried out further laboratory tests with Aquaflok 03LF and with a bio polymer, Praestol™ K750BIO, as part of their bachelor project. They concluded that it was necessary to use 5-6 times more Praestol™ K750BIO to achieve the same results as with Aquaflok 03LF.

The typical Aquaflok 03LF dose was of 1.5 g/kg SS from the start-up phase of the Salsnes filter system to the beginning of 2017. The polymer was dosed in the outlet of the sand and grease trap before entering the Salsnes filter.

As a result of the difficulties to obtain a primary sludge with a high enough solid concentration due to poor draining of water through the filter mesh, it was decided in the first quarter of 2017 to change the polymer type to Aquaflok P 6268 R. Aquaflok P 6268 R has a higher percentage of active component than the Aquaflok 03LF, it is cheaper and at that moment it was used at the dewatering process of the surplus sludge. No significant differences were observed in the performance of the filters after this polymer change, dosage of 1.5 g/kg SS was maintained.

In the autumn 2017 the desired content of solids in the primary sludge was finally achieved thanks to the installation of a vacuum system. Nevertheless, difficulties to attain a high and stable COD removal remained. Therefore, based on recommendations from Salsnes, new laboratory and full-scale tests with different polymers with and without iron chloride were performed in February/March 2018. The tested polymer were: Aquaflok P6268 R, Aquaflok 03LF, Aquaflok K 6268 M, Aquaflok 415 C and Amin C-577.

As result Aquaflok 415 C was selected as new polymer type at a dosing rate of 1.5 g/kg SS without iron chloride. Moreover, a two-point dosing system was established and polymer is now dosed in the outlet of the sand and grease trap before entering the Salsnes filters, as previously, and just before the filters in the center channel. There is also the option to dose iron chloride, which enters the channel right before the sand and grease trap.

A challenge is that the polymer dosing pipes sometimes clog. However, a high-pressure hose can be used to clean the pipes if necessary. Another issue is that the iron chloride dosing pump needs to be programmed to be able to dose specific measurements as it currently only has one setting.

3. Controlling/programming

Aarhus Vand has developed a control system for the Salsnes filters. Sensors that measure the water level in front of the filters are the primary control for the Salsnes filters.

In short, the water level in front of the filters control the speed of the filter motors and speed controls the amount of filters in operation.

When the level of water in front of the filters increase, the motor starts to rotate the filter cloth and the filters begin to operate. When the filters move too slow (set point 30% of min. speed) one filter is taken out of operation. When the filters move too fast (set point 80% of max. speed), another filter will start. Besides, there is a set point for minimum of filters in operation. Currently a minimum of 3 filters must be running simultaneously.

As an extra surveillance, the SS sensors is used to calculate the load of SS to the filters. The load (kg/h) is divided by the area of filter surface in operation to get the kilograms SS per m^2 of filter surface. This allows the controllers to adjust not only for the amount of water but also for solids load.

The goal of using the least filters necessary to achieve the best SS and COD removal can be optimized by using the right dose of polymer and/or iron chloride and achieving the right flow through the filters.

4. Results and Conclusions

The sieves were expected to remove about 60-65% of the incoming COD. However only few days have reached this level, the average reduction is much lower, about 40%. The highest average monthly reduction ~ 48-49% was obtained in the months of May and June after a period of optimization of the operational conditions of the filters. COD reduction fell during the summer to an average of 39 % and 30% in July and August, respectively. This was due to a high SS concentration in the inlet wastewater because of a very dry summer season. A new optimized control for dry periods is under consideration.

As an average of the first three quarters of 2018, VS/TS in the primary sludge has been 86% with a maximum of 92%. At another WWTP in Aarhus, Marselisborg WWTP, which has traditional primary settling, the average was 74% with a maximum of 88%. VS/TS in the digestate at Egaa WWTP is significant higher than at Marselisborg WWTP, which effects the dewatering negatively. It is difficult to compare the production of methane from the primary sludge in both plants as it is mixed with bio-sludge before entering into the reactor. At Egaa WWTP the production of methane was 205 ml CH_4/g SS with a percentage of primary sludge of 41 % (kg SS). At Marcelisborg

WWTP the production of methane was 226 ml CH_4/g SS with a percentage of primary slam of 66 % (kg SS).

In order to evaluate the potential for further degradation of VS, tests with electroporation and subsequent BMP tests have been made. Table D - 1 shows the resulting BMP potential of the raw material compared to material after electroporation. An increase in potential of about 15% has been found.

Table D - 1: BMP after 30 days incubation with and without electroporation of the sludge from fine mesh sieves.

Sample	Methane potential Nm^3/kg VS
Untreated	**312.4**
Treated with electroporation	**359.4**

5. Challenges

The fine mesh sieves offered several challenges during start-up and optimization caused by many technical and mechanical problems such as failure to drain enough water through the filter mesh, poor cleaning of the mesh, needed replacement of destroyed band and defect spray nozzles. Further, it was – and is still very difficult to find the optimal dose of chemicals to obtain a good and stable harvest of COD. Very high and low SS has been experienced. Too low concentration reduces the retention time in the digester and too high make problems for the transportation into the digester. Furthermore, the high SS concentration and very sticky sludge have caused problems for the mixers. Now SS concentration can be controlled thanks to the installation of a vacuum system to suck out water.

The challenge at the moment is that two high concentrated sludge streams with varying SS content is pumped into the digester, which makes it difficult to keep the TS in the digester under 4.5%.

It also seems to be hard to mix the two types of sludge together efficiently. When sludge with a high concentration of SS is pumped into the digester, it seems to bypass straight down to the recirculation pump, which have difficulties to draw in the highly concentrated sludge.

In order to solve this mixing problem the pumping system is going to be changed, so the primary sludge and surplus sludge are going to be mixed in the recirculation stream. Much higher viscosity of the sieved material and the digestate was found compared to sludge and digestate from other plants operated by Aarhus Vand.

6. International outlook

Salsnes fine mesh sieves used at Egaa WWTP is developed in Norway for mechanical treatment of municipal wastewater in order to meet the EU criteria for primary treatment, i.e. at least 20% removal of organic matter (measured as BOD5) and 50% removal of total suspended solids (TSS). Many installations exist and the process is widespread presented in the literature. The process has later been utilized in The Netherlands for harvesting of cellulose fibers from the wastewater in order to be able to recycle the fibers. In Norway, the goal was to secure high and stable removal of TSS and good dewaterability of the material for further handling. Polymers are widespread used and test with coagulants like iron chloride has been made in order to further improve the operation. In The Netherlands, the focus was on the fiber harvesting and typical no coagulants or polymers are used as this favors entrapment of other particles than cellulose fibers. The work has resulted in several reports and presentations often mediated by the network Werkgroep Cellulose Zijn (Working group on Cellulose). From these two starting points, the process has been spread to other countries.

At Egaa WWTP the goal has been to use the filters for harvest of as much organic material as possible for digestion and in order to reduce the COD load at the activated sludge stage. As the filters from the beginning not lived up to the expectations with respect to harvest of the of the COD or dry matter content of the material, a search started to identify applications similar to Egaa WWTP but no full-scale has been found neither through contact to the supplier or in the international literature.

Although the basic examination in Norway included measurement of the BioMethanePotential of the material from the filters, the number of plants that digest the material are few and no reports or international presentation of digestion in full-scale has been found. Further, it has not been possible to get operational experiences from the few plants that digest the material. In The Netherlands, the material is not digested, as the intension is to recycle cellulose fibers not to produce biogas.

A screening of the literature databases and public sources such as EU-databases, university databases with publications of Master's Thesis and the homepage of Salsnes has shown that only few international publications from Norway and the Netherlands exists on digestion of primary sludge from Salsnes filters. No publications or references has been identified where the digestion is combined with treatment of the filtered water in an activated sludge treatment plant as at Egaa WWTP.

In Norway, the most detailed examination is presented in a master's thesis from Stavanger University where materials from the filters are digested in laboratory scale in parallel with traditional primary sludge from Nordre Follo WWTP.

In the Netherlands the publications mainly consist of papers presented in a PhD thesis from Delft University where sludge from a full-scale installation at Blaricum WWTP is digested mesophilic and thermophilic in laboratory scale.

In both cases the material is characterized as sticky and difficult to handle. In the experiments from The Netherlands, the viscosity of the mesophilic digestion has been found extremely high compared to digestate from thermophilic digestion.

The observations on high viscosity comply very well with the experiences gained at Egaa WWTP as indicated above.

Annex E
Opsamling af resultater fra ORC-anlæg ("Results from the ORC-plant")

I forbindelse med ombygningen af Egå Renseanlæg er der etableret et ORC-anlæg.

Nærværende notat har til formål at samle op på erfaringerne fra test af ORC-anlægget og sammenstille resultaterne med de forventninger der var til anlægget.

1. Baggrund for valg af ORC-anlæg

Formålet med etablering af ORC-anlægget har været at udnytte overskudsvarmen fra gasmotoren til at booste el-produktionen.

Da projektet gik i gang var det ikke muligt for Aarhus Vand at sælge overskydende varme til fjernvarmenettet, hvilket var baggrunden for, at man i første omgang valgte at etablere et ORC-anlæg.

Inden ORC-anlægget blev udviklet og designet færdigt, blev der alligevel mulighed for at sælge overskudsvarmen til fjernvarmenettet, hvilket Aarhus Vand valgte at udnytte, så der kunne leveres overskudsenergi til både el- og varmeforsyningsnettet.

ORC-anlægget blev følgelig designet til kun at køre om vinteren (når udetemperaturen er under 10 °C), da en Business Case viste, at Aarhus Vand kunne få den bedste pris ved salg til fjernvarmenettet om sommeren, samtidig med at og kølingen af ORC-anlægget i vinterperioden periode er mere effektiv.

Forventningerne til ORC-anlægget var, at der kunne opnås en netto-elvirkningsgrad på omkring 7-8%, hvilket ved en varmetilførsel på omkring 0,7 GWh/år svarede til en forventet ekstra elproduktion på omkring 52.000 kWh/år.

Den forventede tilbagebetalingstid for etablering af ORC-anlæg samt tilslutning til fjernvarmenet lå samlet set omkring 13 år.

Det skal bemærkes, at det i Business Casen var forudsat, at vi kunne opnå pristillæg fra Energinet.dk efter VE-lovens §44, stk. 2 på salg af el fra ORC-anlægget svarende til omkring 0,79 kr./kWh eller 41.000 kr./år. Aarhus Vand havde på daværende tidspunkt et forhåndstilsagn om pristillæg på el produceret fra ORC-anlægget. Da det endelige tilsagn skulle gives, viste det sig desværre, at vi ikke fik tillægget, hvilket har betydning for den pris vi kan få ved salg af el fra ORC-anlægget og dermed også tilbagebetalingstiden. At vi ikke får pristillæg lægger omkring 3 år på tilbagebetalingstiden.

2. Resultater fra testen i 2018

Tests gennemført i januar 2018 viste en netto-elvirkningsgrad på 1,6% ved maksimal indføring og en negativ netto-elproduktion ved det laveste driftspunkt, hvilket vil sige at ORC-anlægget i dette driftspunkt forbruger energi (se nærmere i vedlagte notat). Disse tal er er betragteligt under de forventede tal.

En af årsagerne til at tallene er under det forventede er, at der bruges en stor mængde el på at holde nødkølerne for kondenseren kørende. En anden form for køling ville forbedre netto-elvirkningsgraden betragteligt. Yderligere så er minimumsydelsen skruet så langt ned, at det generelt påvirker effektiviteten af ORC-anlægget.

I nedenstående tabel er de vigtigste tal opsamlet og sidestillet.

Tabel E - 1: Resultater fra testen i 2018

Scenarie	**Business Case** (2016)**	**Maks ydelse (Test 1)**	**Minimumsydelse (Test 2)**
Varmetilførsel	159 kW	613 kW	272 kw
Køling	4 kW	11 kW	9 kW
El produktion	16 kW	21 kW	1 kW
Brutto-elproduktion*	10%	3,4%	0,2%
Netto-elproduktion	7,5%	1,6%	-1,3%

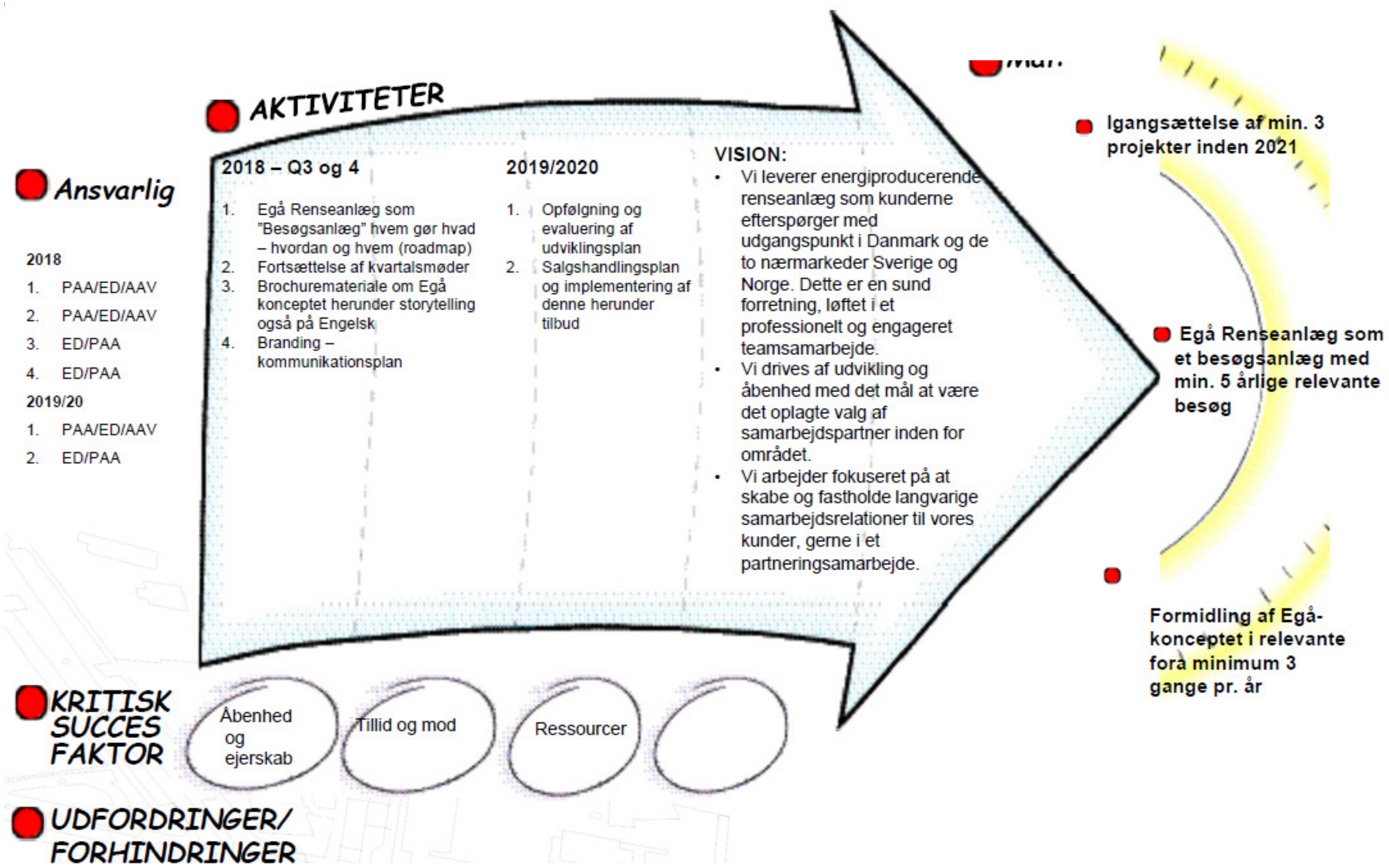
* Ved at reducere driftsintervallet vil man kunne udnytte anlægget mere optimalt, dog vil det være på kompromis af drift i det lave område.
** Udarbejdet i forbindelse med design af ORC-anlægget.

Leverandøren oplyser, at det vil være muligt at optimere på anlægget så brutto-elvirkningsgraden generelt øges, det kræver dog at driftsområdet begrænses, hvilket kan være relevant ved etablering af en ekstra gasmotor.

Såfremt netto-elvirkningsgraden skal øges yderligere, skal der findes en kølemetode med væsentligt lavere elforbrug.

Det giver dog ikke meget mening at optimere på anlægget så længe, at vores overskudsvarme er lavere end driftsområdet på ORC-anlægget.

Annex F
"Go to Market" strategy



MISSION: Samarbejdspartnerne Aarsleff/EnviDan anlægger energiproducerende renseanlæg, med udgangspunkt i koncept og samarbejdsformer i forbindelse med etablering af Egå Renseanlæg, i tæt samarbejde med Aarhus Vand.

Annex G

Erfaringer fra Danmarks første forfiltreringsanlæg på Egå Renseanlæg ("Experiences Denmarks first pre-filtration plant at Egaa WWTP")

Erfaringer fra Danmarks første forfiltreringsanlæg på Egå Renseanlæg:

Testanlæg til forfiltrering fortæller langt fra hele sandheden

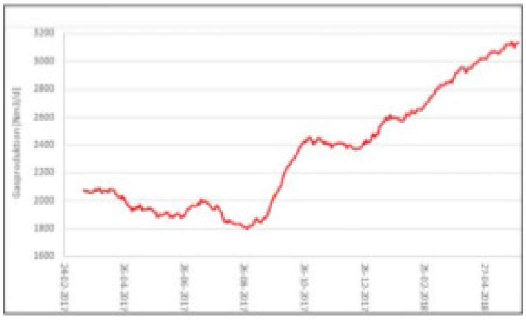
Der er ingen tvivl om, at forsøg med nye teknologier i testanlæg er en effektiv metode til at afprøve og verificere hvilke løsninger, der skaber den største værdi. Men det er i opskalerings- og implementeringsfasen, at vi for alvor høster de mest værdiskabende erfaringer. Det har vi lært i etableringen af det nye forfiltreringsanlæg på Egå Renseanlæg, som nu leverer flotte resultater, og samtidig har givet os en unik viden omkring implementering af denne type anlæg.

Tekst: Per Overgaard Pedersen og Lise Karstenskov Hughes, Aarhus Vand, Rasmus Johansen og Jens Albrechtsen, EnviDan A/S

Ved Aarhus Vands idékonkurrence om bygning af fremtidens energiproducerende anlæg, vandt Norske Salsnes prisen i kategorien "Hvordan ser fremtidens kulstofhøst ud?" med en teknologi til forfiltrering på renseanlæg. Teknologien var efterfølgende en del af den løsning, som blev valgt, og er nu implementeret på Egå Renseanlæg.

Implementeringen af filtrene på Egå Renseanlæg har været en lang proces. Lige fra de første testopstillinger til indkøring af fuldskala-anlægget. Implementering af innovative teknologier er kendetegnet ved, at effekten af de enkelte optimeringstiltag skal registreres, før det næste tiltag iværksættes. I modsat fald opnår man ikke sikkerhed for, hvad det er, der virker, og hvad der ikke virker.

De tiltag, der er i dag er en del af forfiltreringen på Egå Renseanlæg, har givet en positiv udvikling i både funktion og energiproduktion. Udviklingen i gasproduktion er direkte afledt af filtrenes funktion, og fremgår af nedenstående figur.



Renholdelse af filterdug, type og mængde af polymer, doseringspunkt og indblandingsenergier er væsentlige faktorer ifm. forrensning, og det har det også været på Egå Renseanlæg. I modsætning til testanlæg, hvor der er små variationer i stof og hydraulisk belastning, er der helt anderledes store udfordringer i fuldskala anlæg, hvor fluxen varierer meget på grund af store variationer i flow, men også suspenderet stof (SS) over døgnet. Polymerdoseringen er optimeret ud fra stofbelastningen af SS, hvilket ikke bare reducerer polymerforbruget, men også øger effekten.

Det er en afgørende parameter for at sikre en effektiv forfiltrering, at dugen er fuldstændig ren. I det øjeblik, der sker blot en mindre tilklokning af dugen, nedsættes den hydrauliske kapacitet væsentligt, og måtteopbygningen forringes. Det er derfor afgørende, at filtreringsinstallationerne udstyres med særligt renholdelsesudstyr, da almindelige spuledyser erfaringsmæssigt ikke kan renholde dugen.

Under indkøringen er filtrene desuden blevet udstyret med vacuumsug, der har øget afvandingen fra omkring 3% TS til 5-14% afhængigt af sugestyrken. Muligheden for at opnå høj TS direkte på båndet resulterer i, at der ikke er behov for efterfølgende forafvanding samtidig med, at slamopholdstiden i rådnetanken øges og energiforbruget til opvarmning af slam til rådnetanken reduceres.

En god løsning – når man udnytter erfaringerne
De opnåede resultater er en konsekvens af en målrettet indsats fra alle projektets parter, Aarhus Vand, EnviDan og Salsnes.

En meget vigtig læring er, at man skal være forsigtig med at overføre renseresultaterne fra et testanlæg til et fuldskalaanlæg. Præmissen for et testanlæg er jo netop, at der er en stor grad af kontrol med og eftersyn af anlægget, som i sagens natur kun belastes med en meget lille delstrøm, der ofte udtages under "gunstige" betingelser, hvor polymerdoseringen bedre kan tilpasses i forhold til mængde og indblandingsenergi. Det betyder, at de virkelige udfordringer ofte ikke når at opstå i testperioden, men først i fuldskala, hvor indløbsvariationerne rigtig kommer til udtryk. Arbejdet er med andre ord ikke slut, når det fulde anlæg sættes i gang – tværtimod.

At finde de løsninger, der giver en god stabil effekt kombineret med et fornuftigt energi- og tidsforbrug, er en lang og sej proces, der kræver en stor indsats af alle parter. Aarhus Vand, EnviDan og Salsnes har nu med installationen på Egå Renseanlæg vist vejen for, at mekanisk forfiltrering er et alternativ til traditionelle forklaringstanke, og vi viser gerne installation frem samt fortæller om udfordringer og muligheder.

Når man lægger skinnerne, mens man kører på dem...
I forbindelse med udbygningen af Egå Renseanlæg har innovationsflyvehøjden været stor, og ønsket om at skabe fremtidens energiproducerende renseanlæg har givet en unik viden og erfaring, som kan lette indkøringen af nye danske renseanlæg i fremtiden. I den forbindelse er det vigtigt at huske, at det koster tid og penge at tænke nyt, og at innovation ikke handler om at vinde priser eller mødes på workshops. Innovation er mod, hårdt arbejde, overbærenhed og tålmodighed, og det er, hvad der kræves af alle projektets parter, hvis man skal lykkes.

Til gengæld er der også noget at hente i den anden ende, og en vigtig erfaring fra projektet i Egå er, at forfiltrering ER en god idé. De oprindelige fordele med styr på lugtgenerne og reduceret pladsbehov er stadig gældende. Det handler bare om at være opmærksom på, hvor og hvad der skal justeres i indkøringsperioden, og vi er nu meget klogere på, hvad vi skal være opmærksomme på, når innovationen møder driften, og anlægget kører, mens vi innoverer.

Udbygning af Egå Renseanlæg

Aarhus Vands udskrev i 2013 en åben idékonkurrence om fremtidens energiproducerende anlæg med det formål at høste de bedste idéer i branchen. Resultatet blev en lang række spændende og innovative forslag, og der var tre vindere, hvoraf Salsnes filtre til forfiltrering var den ene. Aarhus Vand udbød herefter i 2013 udbygningen af Egå Renseanlæg som partneringopgave. En opgave, som blev vundet af Per Aarsleff A/S og EnviDan A/S i samarbejde med Salsnes Filter. Projektet er desuden delvist finansieret med midler fra EUDP.

De bærende teknologier i udbygningen af Egå Renseanlæg var:

- Dynamisk udtag af kulstof på Salnes® filtre, for maksimering af kulstoftilførsel til ny rådnetank.
- Rejektvandsbehandling med Anammox-bakterier (DEMON®), som minimerer den interne kvælstofbelastning.
- Kvælstoffjernelse med Anammox-bakterier i hovedanlægget (EssDe).
- Højeffektivt gasgeneratoranlæg, for strøm- og varmeproduktion baseret på den producerede biogas.
- Yderligere el- produktion på en ORC, Organic Rankine Cycle.

Målsætninger, resultater og udestående punkter:

- Målsætning for nettoelproduktion var ved projektets opstart 150% ved fuld belastning på 120.000 PE.
- Ny viden erhvervet i løbet af projektfasen har medført, at delprojekt med Anammox i hovedstrømmen er foreløbigt skrinlagt.
- Med nuværende belastning på omkring 90.000 PE, samt med eksisterende procesopbygning og maskinel bestykning, er grænsen for nettoelproduktion i størrelsesordenen 110-120%.
- Den aktuelle nettoelproduktion er ca. 100% og fortsat stigende.
- COD-høsten på Salsnes-filtrene er aktuelt på ca. 45-55% og SS-reduktionen er ca. 50-60%.
- ORC er testet og ikke fundet energieffektivt ved den nuværende varmeproduktion. Overskudsvarme leveres i stedet til varmeforsyningsnettet i Aarhus.
- I perioden efter ombygning af Egå Renseanlæg, har der været forringede slamegenskaber. Der har været mange forskellige teorier om, hvad disse ændrede slamegenskaber skyldes. Der er blevet lavet DNA analyser af slammet, der er søgt efter erfaringer fra udenlandske anlæg med forfiltrering, der er talt cellulose fibre vha. mikroskopering og meget mere. Der foreligger dog stadig ikke en entydig konklusion. Slamegenskaberne på Egå Renseanlæg er dog forbedret i løbet af foråret.

Annex H

Brochure om Egå-konceptet ("Brochure about the Egaa Concept")

ENERGIPRODUCERENDE RENSEANLÆG

Case: Egå Renseanlæg

Baggrund

I 2013 vandt Per Aarsleff A/S og EnviDan A/S opgaven med at udbygge Egå Renseanlæg til energiproducerende anlæg. Et projekt, som Aarhus Vand havde udbudt som en partneringopgave. Aarsleffs og EnviDans løsning blev udarbejdet på baggrund af Aarhus Vands idékonkurrence om fremtidens energiproducerende anlæg, hvor resultatet blev en lang række spændende og innovative forslag, blandt andet anvendelse af Salsnes-filtre til forfiltrering. Projektet er delvist finansieret med midler fra EUDP.

Bærende teknologier

- Dynamisk udtag af kulstof på Salsnes filtre, for maksimering af kulstoftilførsel til ny rådnetank.
- Rejektvandsbehandling med Annamox-bakterier (DEMON), som minimerer den interne kvælstofbelastning.
- Højeffektivt gasgeneratoranlæg, for strøm- og varmeproduktion baseret på den producerede biogas.
- Grundig gennemgang af alle renseanlæggets installationer med henblik på energioptimering.

EnviDan AARSLEFF aarhusvand

ENERGIPRODUCERENDE RENSEANLÆG

Case: Egå Renseanlæg

Belastning og resultater medio 2018

- Belastning ca. 90.000 PE
- Nettoelproduktion >100%
- Energiproduktion >200%
- Rensegrader:

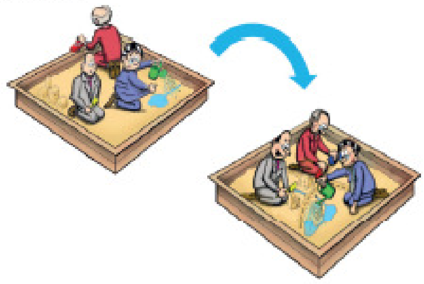
Rensegrader:	Krav:	Aktuel udledning:
COD	<75 mg/l	21,86 mg/l
TN	<6 mg/l	4,13 mg/l
TP	<0,4 mg/l	0,15 mg/l

Proces og samarbejde

Projektet er udført som en partneringopgave, hvor Per Aarsleff A/S og EnviDan A/S i et konsortium har indgået aftale med Aarhus Vand om udbygning af Egå Renseanlæg. Denne samarbejdsform er valgt, fordi Aarhus Vand har gode erfaringer med de elementer der ligger i partnering, herunder tidlig involvering af entreprenøren, åbne kalkulationer, risikostyring, fælles målsætninger og et samarbejde baseret på tillid og åbenhed.

Processen har helt fra den indledende idekonkurrence til anlægget stod færdigt været præget af, at parterne arbejder tættere sammen end i "almindelige" totalentrepriser, hvilket blandt andet har medført, at projektet ganske smertefrit er blevet justeret som følge af den læring og viden, er frembragt undervejs i forløbet.

Projektparterne kalder det at lægge skinnerne mens man kører på dem – hvilket ikke alene kræver hårdt arbejde og mod, men netop også åbenhed, omstillingsparathed og ikke mindst, at alle arbejder mod samme mål!



Vil du vide mere?

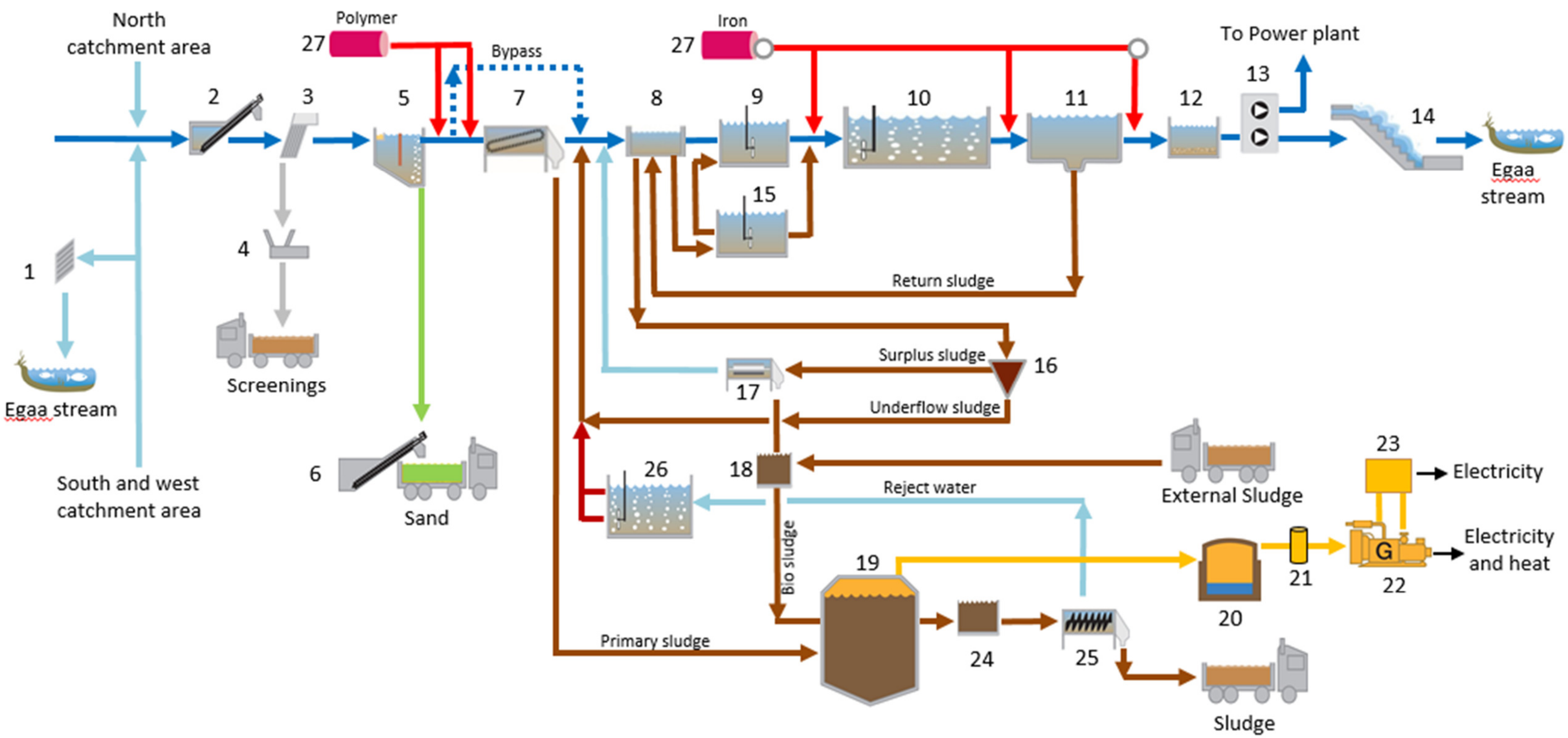
Hvis du er interesseret i at høre, hvad vi kan gøre for, at dit renseanlæg bliver energiproducerende, eller vil du gerne have en fremvisning
på Egå Renseanlæg, så kontakt:

EnviDan A/S:
Jens Albrechtsen på T: 40 53 28 06/M:jal@envidan.dk

Per Aarsleff A/S:
Bjarne Paysen på T: 40 44 23 15/M:bpa@aarsleff.com

EnviDan AARSLEFF aarhusvand

Annex I
Diagram of the upgraded Egaa WWTP



Primary water flow	Blue
Secondary water flow	Light blue
Sludge	Brown
Chemicals	Red
Biogas	Yellow
Sand and grease	Green
Screenings	Grey

1: Coarse screen
2: Inlet pumping station
3: Inlet screen
4: Screening press
5: Grit chamber
6: Sand washer plant
7: Salsnes filters
8: Selector tanks
9: Anoxic tank (bio-P removal tank)
10: Process tanks
11: Secondary clarifiers
12: Sand filters
13: Effluent pumping station
14: Aeration trap
15: Side-stream Hydrolysis tank
16: Hydrocyclone
17: Sludge pre-dewatering
18: Buffer tank
19: Anaerobic digester
20: Gas storage tank
21: Gas treatment (activated carbon)
22: Gas motor
23: Organic Rankine cycle (ORC)
24: Buffer tank
25: Final sludge dewatering
26: DEMON® tank
27: Chemical tanks