Reuse, Recovery and Resource efficiency:
Innovations in urban wastewater treatment

R3water final report

June 2017

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1 Executive Summary

1.1 R3Water: Getting all the value from wastewater

The EU FP7 funded project R3Water ("Demonstration of innovative solutions for Reuse of water, Recovery of valuables and Resource efficiency in urban wastewater treatment") demonstrated solutions to support the transition **from being purely a wastewater treatment plant** using energy and chemicals, **towards a resource facility delivering different valuables**. Focus in the project was to develop, demonstrate and test solutions for upgrading existing urban wastewater treatment plants and to improve resource efficiency with the implementation of new technologies and business models.

In order to reach this target R3Water developed and demonstrated more than 10 innovative technologies **at demo sites in three countries (Belgium, Spain and Sweden)** within **3 topics:**

- **Resource efficiency** in treatment by improved aeration, better Anammox process, modelling and energy audit, better control systems, improved biogas production
- Facilitating **water reuse,** by on-line monitoring, efficient disinfection and treatment of pharmaceutical residues
- **Resource recovery,** by sludge valorisation with recycling of nutrients and other valuables

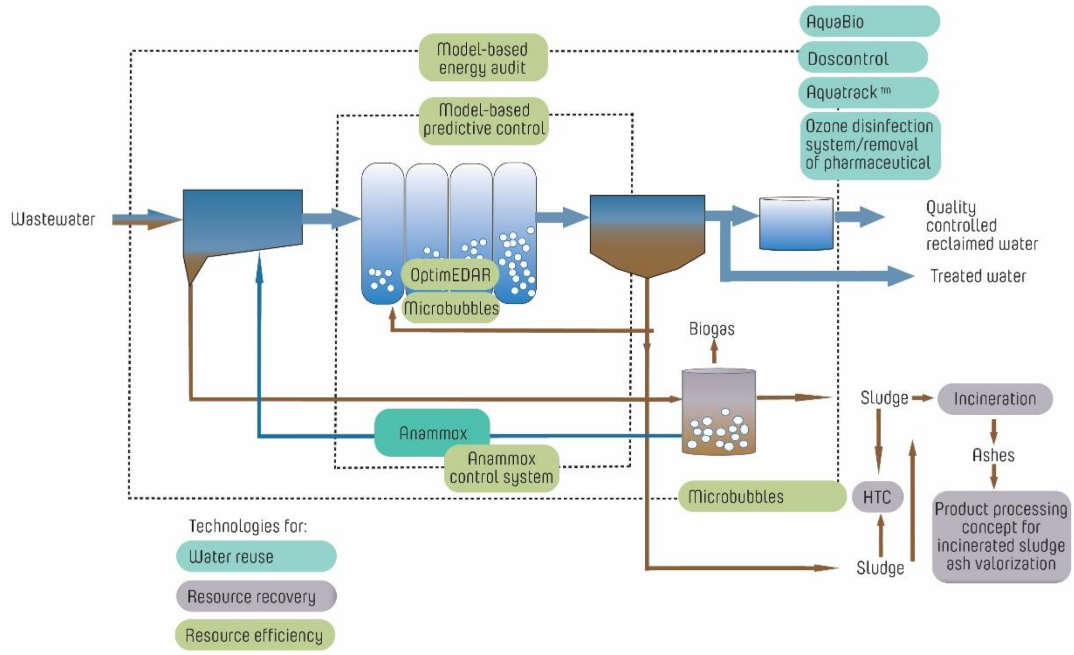


Figure 1.1: R3Water demonstrated technologies for urban wastewater treatment in three topics; Water reuse (green), Resource recovery (purple) and Resource efficiency (yellow).

Facilitating market uptake has been one of the project objectives. All of the technologies and solutions in the project made progress towards commercialization. The technologies also showed significant potential to save energy, reduce emissions and increase resource efficiency. Further, project results have been disseminated to relevant stakeholder groups via different channels like workshops, brochures, homepage, LinkedIn, demo site visits etc. The strong consortium, led by IVL Swedish Environmental Research Institute, involved 12 partners from seven European countries with a well-balanced ratio between innovative SMEs, research institutes and treatment plant representatives.

More information is available on the website www.r3water.eu

2 Summary description of the project context and the main objectives

Several parts of Europe, e.g. the Scandinavian countries, Germany and Belgium, have a strong position in terms of creating more sustainable solutions for treatment of municipal wastewater and have a good reputation globally. Europe early introduced municipal wastewater treatment and during the past ten years Sweden has become a leader in the production and use of biogas produced from municipal sludge. In Spain, and the rest of southern Europe, water scarcity is a driving force for water reuse solutions. However, those achievements have not been translated into an equal export success. Besides a few larger companies, there are mainly small companies that supply components, without real possibilities for an international commercial success.

Also needed is the development of systems that link together technologies and solutions in a more progressive manner. Such systems could produce goods in the form of energy, water that can be reused and nutrients that can be returned into circulation. This should be carried out to a lower cost than today's solutions. To get there requires cross-border development projects.

For European actors who are successful with the development of innovative systems, there is an annual market waiting in the order of 250-350 billion € and an estimated growth of 2-10% per year. This requires development of:

- improved extraction of phosphorous, nitrogen, and other materials
- removal of drug residues and other prioritized substances
- less energy consuming processes
- improved bioenergy production,
- the ability to return nutrients safely to cropland
- effective removal of silt and other inorganic substances which count for up to 60% of sewage sludge
- the ability to reuse water
- better quality control of reclaimed water to be reused

In order to be successful with the above export venture**, a well-developed cooperation with international actors such as institutes and authorities is required.** R3Water has included partners and contacts inside and outside Europe which gave access to knowledge about the needs as well as the market conditions. In addition, it gave the opportunity to influence decision makers who use these partners to bring transparency in international development.

By gathering European players in the innovation chain from experts to commercialization and export success, R3Water brought together these players' demonstration facilities for joint development of the **wastewater treatment plant of tomorrow – i.e**. the R3 **resource efficient production plants for fresh water, bio-coal and high exegetic energy.** Another benefit of conducting cooperation in common demonstration plants has been the opportunity for demonstration to potential customers and global partners. The demonstration facilities were large enough to be credible demonstrations, yet small enough to be flexible in order to sew successful systems together.

2.1 Concept

Biological treatment is the common method to treat municipal wastewater. New and interesting concepts are under development, but in many cases investments have already been done and a system change will not happen in the near future. Therefore R3Water targets the optimisation of already existing wastewater treatment plants. The concept is to see municipal wastewater treatment rather as a production facility or resource recovery facility that with efficient treatment can provide water for reuse, nutrients and usable energy. Thus, R3Water targeted three areas

(R)euse of water, (R)esource efficient treatment, and (R)esource recovery. For each of the areas, different technologies from a number of companies, including 6 SMEs, and research organisations have been demonstrated as illustrated in figure 1.1 in the summary. To cover a variety of implementations, three different geographical demonstration areas have been chosen as illustrated in figure 2.1. The demonstration sites are described further below.

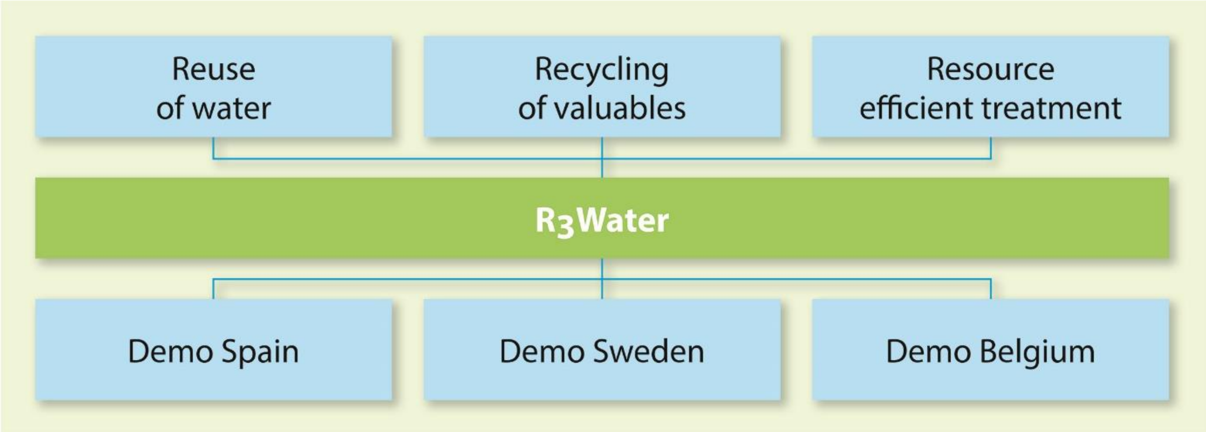


Figure 2.1: R3Water technology topics and sites

The R3Water project not only demonstrated "R3" technologies but also showed an innovative "**R3 demonstration concept":** Reviewed - Referenced – Recognized. Compared to conventional projects **this concept secures a more parallel and direct market acceptance in European countries.** The concept of Environmental Technology Verification (ETV) was directly integrated in the demonstration of the technologies in the project, reducing the need for extra testing. Besides market accepted technologies itself, the output of the project therefore also included a new concept for demonstration for increased market acceptance.

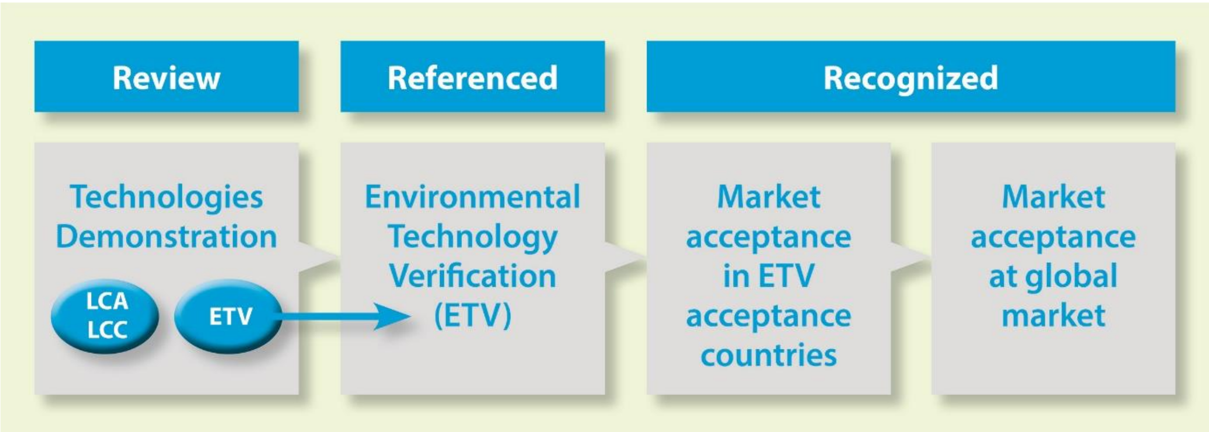


Figure 2.2: R3Water demonstration concept for better market uptake

2.2 Demonstration sites

The project included demonstration sites in 3 countries that have been selected for representative needs to enable the conversion of treatment plants into production facilities. The sites are representative for a large number of treatment plants.

The following list shows examples of the priorities in those areas.

2.2.1 IVL - Hammarby Sjöstadsverk(HSSV) (Sweden)

- Resource efficiency (often energy)
- Optimization of biogas production
- Measurement and control
- Removal of pharmaceuticals/persistent compounds/priority pollutants
- Sludge management, sludge products
- Climate change

2.2.2 Several sites of Aquafin (Belgium)

- Anammox control strategy
- Monitoring reuse facilities
- Recovery from ashes
- HTC
- Gasification
- Control strategies for plant optimization
- Aeration optimization

2.2.3 Girona Costa Brava, Consorci Costa Brava, Empuriabrava, Girona, Castell – Platja d'Arodel Mediterráneo (Spain)

Improvements needed for

- Energy efficiency
  - Aeration optimization
  - Optimization of biogas production
  - Control strategies for plant optimization
- Production of reclaimed water for reuse
  - Overcome barriers for use of reclaimed water, e.g. Remove / reduce regulatory/directive barriers for reclaimed water (e.g. Nitrate)
  - Measurement and control of pathogens in the reclaimed water

3 Results

R3Water developed and demonstrated innovative technologies at three sites (Belgium, Spain, and Sweden) within 3 areas:

• Resource efficient treatment, e.g. by efficient aeration and optimised process control

• Facilitating water reuse, e.g. by improved water quality monitoring and efficient disinfection

• Recycling of nutrients and other valuables, e.g. by valorisation of sludge

Different technologies have been developed further and demonstrated, some of them being now almost ready-to-market. In this report, results will be presented per technology giving a short overview. In addition to the technical development, obstacles and opportunities for introduction of new solutions were identified and put into policy recommendations, which are summarised here. More information about the results of R3Water is available in the final brochure of R3Water and on the website www.r3water.eu.

3.1 Policy suggestions

3.1.1 Common suggestions

• Provide incentives to overcome reluctance to make investment caused by short-time operating contracts that act as a barrier for the market uptake of innovative technologies.

• Ease the market uptake of new and innovative technologies

  – By simplifying the permission process for demonstrations at industrial sites, e.g. by using the concept of “transition periods”. For innovative technologies start with an entry level of requirement, requiring increased level of performance from the technology to prove its veracity.

  – By applying a holistic assessment: a better sustainability performance might need less strict (water) thresholds

• Use careful wording and terminology in official documents, as certain expressions create positive attitudes, while other with about the same meaning create rather negative.

3.1.2 Reuse of water

• Although the benefits of water reclamation and reuse for irrigated agriculture (and other uses) are clear, there are still doubts about the economic sustainability of reclaimed water services. Consider the reclaimed water as an additional local water resource in the scope of the integrated urban/regional water cycle, rather than an isolated service provided by the WWTP.

• Harmonize quality criteria for water re-use including methods for quality monitoring as a driver for the marketing of water reuse technologies (e.g. common standard within the EU).

• Online water quality monitoring technologies are not properly considered in EU Directives. Allow for innovation in monitoring technologies within the EU water directives review by taking the available online monitoring/detection technologies and the potential for an effective combination with water quality monitoring methods (online + conventional sampling/analysis) into consideration.

3.1.3 Resource recovery

• Support the market for recovered resources by harmonizing legislation and directives. There is a need of for such harmonized standards for recovered materials and products to make a foothold in the market dominated by virgin materials.

• Innovation partnership for the combination of research and procurement: more promotion to be enacted by member states and public authorities.

3.1.4 Resource efficiency

• Stimulate the adoption of technologies by using incentives to establish sustainability benchmarks. This will help to balance medium and long-term sustainability of increased resource efficiency and plant sustainability; with short-term economic cost disadvantages.

The whole "Report about policy and directive implementation" is available on r3water.eu.

3.2 Technologies for water reuse

3.2.1 aquaBio

3.2.1.1 Description

E. coli is a bacteria widely used as an indicator of faecal contamination. Its presence warns about a potential sanitary risk. This aspect is reflected in the Directive 2006/7/EC on the quality of bathing water. The *Escherichia coli* and total coliform parameters are also key indicators and essential for determining the potential uses of reclaimed water from the tertiary treatment of a WWTP and it is present in existing National Water Reuse Directives (ES, IT, FR, GR, CY) as well as in most of worldwide regulations.

However, traditional sampling plus laboratory method takes from 24h to 96h to obtain the results, becoming useless for early warning purposes. aquaBio can provide the results between 3h and 12h (depending on the microorganism concentration) in automatic way, and to transmit this information to a local control centre or remote on duty staff.

3.2.1.2 Addressed problems and challenges

The goals in the project were to demonstrate the operational autonomy, the reliability and robustness of the equipment running in a continuous way, and to obtain enough lab analysis to contrast with the automatic results in order to launch an ETV verification process. During the project, the maintenance requirements were decreased from the initial once a week to a final once a month.

3.2.1.3 Results

The aquaBio has been demonstrated in two different demo-sites: Castell Platja d'Aro water reclamation plant (outlet and inlet), a Spanish demo-site, and in Hammarby Sjöstadsverk (MBR outlet), the Swedish demo-site.

Different samples were compared to the IDEXX laboratory methodology using colilert- 18® concluding that there are not significant differences between aquaBio result and the laboratory result.

In order to check the independence between samples, sterile samples were interspersed during the standard operation. As a result it was demonstrated that none cross contamination exists between one sample and the following one.

During all the operational period different operation modes were tested: by time, by digital input or alarms. The Castell Platja d'Aro water reclamation plant runs on demand. The aquaBio was connected to the valve that starts the process. Since the Castell Platja d'Aro water reclamation plant runs on demand, the aquaBio was connected to the valve that starts the process, thus adapting the automated sampling to the low demand in winter and the increase of demand during spring.

Maintenance operations: Currently the maintenance operations are performed once per month (30 minutes) thanks to the improvements implemented during the project in the hydraulics and software as well in the maintenance procedures.

aquaBio

3.2.1.4 *Perspectives for the future*

One of the key priorities for the EC in the upcoming years is to increase the ratio of water reuse in the EU, while ensuring the health and environmental safety of water reuse practices and the free trade of food products. Nevertheless, this priority faces several barriers that prevent the adoption of the reclaimed water for different uses: agriculture, urban, industrial and recreational.

In order to tackle some of these barriers, the EU has launched a process for the definition of the guidelines on minimum quality requirements for water reuse for agriculture and aquifer recharge, where E. coli is the recommended bacterial indicator. In this context, the online monitoring of microorganisms with aquaBio can contribute to the efficiency of the water reclamation processes as well as on building trust on end-users.

The next goal is to demonstrate the aquaBio for drinking water use and to adapt the equipment for measuring Enterococci in bathing waters.

3.2.2 AQUATRACK®

AQUATRACK® is a real time monitoring and sampling system for pathogens in treated water for reuse and reclaimed water. The system consists of multiple conventional water quality sensors including an optical laser sensor which detects all possible forms of variations caused by contamination (natural, human error, process failure) in reclaimed and recycled water.

The system can communicate wireless and access data remotely. The software creates a dynamic fingerprint of effluent water based upon the micro contaminants/micro particles/micro debris in the effluent water. When the fingerprint deviates the system automatically captures a relevant water sample that can be analysed for positive identification of pathogens.

AQUATRACK® is now EU ETV certified for monitoring and sampling of drinking water, reused and reclaimed water.

3.2.2.1 Addressed problems and challenges

A main source of contamination comes from purified or insufficiently purified wastewater, both industrial and small- scale private sewage discharge. It pollutes rivers, lakes, water bodies, and coastal waters and creates a potential risk of microbial contamination in drinking water, bathing water, groundwater, etc. To eliminate the contamination and pollution there are conventional wastewater treatment processes. The treatment of wastewater is a high-energy consuming and releases green- house gases. Wastewater discharge contains contaminants like bacteria, parasites, virus and pharmaceutical residues etc. Contaminated sludge is another problem in wastewater treatment. The treated water is not fully reused in water scarcity areas today.

AQUATRACK®

To solve the above mentioned problem of contamination in the effluent water many new and modified different technologies/processes are being developed like MBR as well as tertiary treatment steps in conventional treatment plants. The effluent discharge is sometimes used for reuse or reclaimed water in agriculture and ground water recharge.

In the R3Water Project Aqua-Q developed a novel user-friendly, intelligent real time monitoring and sampling system; AQUATRACK®. AQUATRACK® is designed to monitor effluent quality 24/7. The aim is to give the management of a treatment plant early warning for sudden changes/deviations in effluent water quality. These changes are having high probability of microbiological growth due to contamination that is harmful to environment, rivers, and lakes and contains also drug residues among other organics. In R3Water, the system has been developed further to assure smooth operation. It has been demonstrated for real time quality monitoring of the effluent from a MBR process at the demosites in Sweden and now in Spain.

3.2.2.2 Results

During the R3Water project, the system has been developed further and small adaptations have been made to increase its robustness. The technology has been demonstrated at two sites in Spain and Sweden. In Sweden, the technology was verified according to the EU-ETV (Environmental Technology Verification) scheme for three different water matrices: drinking water, lake water, and water treated by an MBR (membrane bioreactor). The demonstration showed the ability of AQUATRACK ® to monitor changes in biological water effluent quality and to send alarms when thresholds are passed.

3.2.2.3 Perspectives for the future

The ETV showed that AQUATRACK ® can be used to keep continuous track of biological contaminants in drinking water, source water, and treated wastewater (MBR effluent). This performance can be considered as an important feature of an environmental monitoring technology. Information from

AQUATRACK® can be used to make intelligent decisions about the amount and kind of disinfection, hence avoiding over-disinfection and thus saving money.

AQUATRACK® gives real-time warning of possible contamination events, which can help to avert epidemics, and costs & liabilities associated with epidemics.

3.2.3 Ozone polishing system or activated carbon to eliminate pharmaceutical residues

Aqua-Q has developed a modular ozone polishing system and has successfully demonstrated that in a cost-effective way with a minimum dose of ozone both pharmaceuticals residues and pathogens can be totally removed beyond the limit of detection. This online ozone polishing pilot system is fully automatic and self-contained. Only a partial flow of effluent water from MBR process and 230 – 240 V AC electric plug is required for plug and play. Local industrial regulations have to be maintained to comply with government regulations.

In R3Water, IVL tested and demonstrated activated carbon as technology for separation of pharmaceutical residues. Effluent wastewater from the membrane bioreactor, located in an equalisation tank, was used in the demonstration to compare the effects from ozonation and activated carbon.

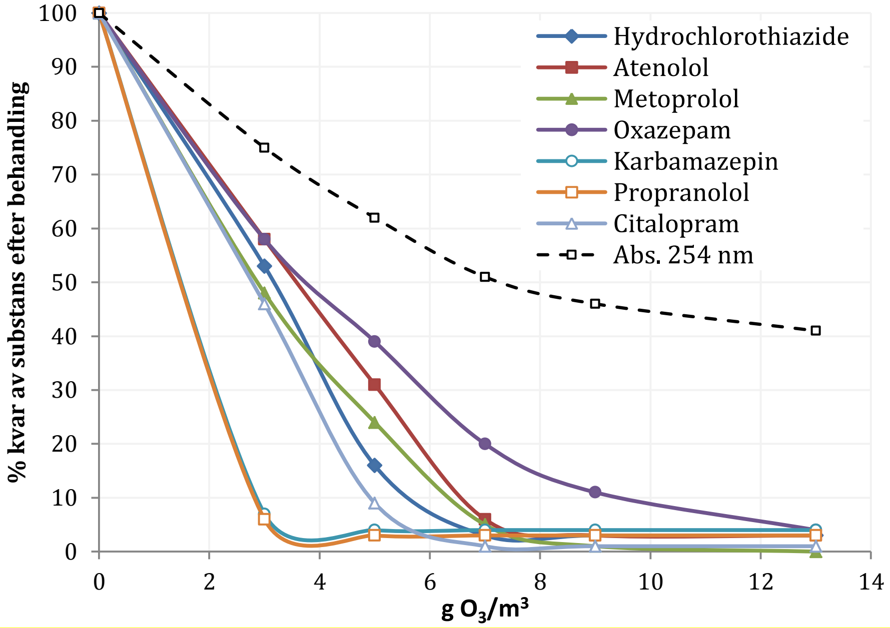
3.2.3.1 Addressed problems and challenges

Water pollution/contamination from pharmaceutical residues is a major environmental challenge in aquatic environment in many developed and emerging countries. Drug residues from human and animal use reach lakes and rivers that have become a global environmental problem. Pharmaceutical consumption in society is increasing with a significant part ending up in our water environment. Many of these drugs are found in our drinking water, source/lake water, aquatic life, bathing water, and ground water etc. Even though the concentrations of these pharmaceutical compounds are low (nanograms per litre levels the long-term exposure adverse consequences affecting human health and aquatic life are not known yet.

There is the need to develop methods to eliminate drug residues in each treatment plants before discharging the effluent water to nature or using it as reclaimed water. Stringent legislation and control is required.

3.2.3.2 Results

After ozone treatment with the lowest ozone dose; 3 g/m^3, 9 substances remained in quantifiable amounts. The detected concentrations of 7 of these substances were reduced with increased ozone dosing (the substances had a detection limit of 4 ng/L or less). At 7 g/m^3, all analysed substances present from the beginning except for Oxazepam, where small concentrations still where detectable, had been removed below detection limit. The amount of ozone needed will not be constant, specifically since the wastewater composition is constantly varying over time. For the ozone treatment, also bacteria treatment was analysed with very good results.



Percentage remaining of pharmaceutical residues in water after different ozone dosages

Also activated carbon has been tested as treatment method. Tests were performed with different retention times and after different times of operation (treatment expressed as Empty-bed-volume). This indicates that an retention time of 10 minutes already gives a high reduction, at least at an EBV of approximately 7 000. At higher EBVs, a longer time is probably needed. After 75 days a total of 2000 m^3 had passed through the filter, or close to 6 700 Empty Bed Volumes (EBV), corresponding to approximately 13 m^3/kg of carbon. Only Caffeine, Cabamazepine, Hydrochlorotiazide, Ibuprofen, Oxazepam and Sulfamethoxazole could be detected after the carbon filter. The reduction of these substances ranged from good (≥57 %) to very good (≥90 %).

3.2.3.3 Perspectives for the future

Reuse of water is essential in many parts of the world as population grows and demand for fresh clean and safe water increases. Reuse of treated wastewater with quality control provides solutions to water shortage that becomes a global problem not only in emerging countries but also in developed countries. Both ozone and activated carbon proved to be able to reduce most of the pharmaceutical residues. Ozone will also provide the possibility to treat pathogens for disinfection. The choice of technology will depend on different parameters; treatment costs exist, but are limited.

There is a need for future new EU legislation to ensure high clean and safe reuse water standard not only a minimum standard for reuse of water as discussed today.

3.2.4 doscontrol®

doscontrol® is an innovative technology developed by teqma to control the water disinfection process. Based on the optimized combination of chemical and physical disinfection, the controller is able to generate positive synergies delivering enhanced wide-spectrum microbiology load reduction and substantial operational costs reduction for a safe reclaimed water production.

3.2.4.1 Addressed problems and challenges

Reclaimed water is obtained from treated wastewater, a challenging effluent strongly influenced by upstream wastewater treatment processes with a highly variable concentration and composition in time of the physical chemical and microbiological quality directly affecting the effectiveness and reliability of disinfection processes. Disinfection agents and techniques used in water reclamation have been commonly adopted from drinking water treatment (i.e. Chlorine dioxide, Sodium Hypochlorite, UV radiation, Ozonation). Combined disinfection (e.g. synergetic use of UV radiation and chemical oxidation) is a solution for effective disinfection in drinking water and reclaimed water and its being used in several full scale sites. Although the combination of complementary disinfectant agents generates synergies broadening the disinfection spectrum, affecting pathogens that are not inactivated by conventional chemical oxidizers as chlorine at the normal concentrations (i.e. spore forming bacteria, viruses and protozoa) while ensuring a residual concentration of disinfectant in the distribution network, these processes lack an effective and optimal control system in order to ensure:

•Reliable operation, flexible against variable conditions

•Maximum synergies, cost optimization delivering the mini- mum dosage to achieve the required disinfection level

•Continuous safe water production

doscontrol® is an automatic controller specifically designed to ensure effective disinfection in drinking water treatment and water reclamation delivering the needed amount of each disinfectant agent to continuously produce safe water while optimizing the amount of UV dose and chlorine dosage reducing costs and environmental footprint.

doscontrol®

3.2.4.2 Results

Thanks to doscontrol® 100% of the analysed water samples achieved the most strict disinfection level at the Spanish demo site in Castell-Platja d’Aro (0 cfu E.coli/100ml) allowing the use of reclaimed water for raw edible crops irrigation under changing influent conditions

Additionally, results show a significant reduction of disinfectant used:

•30% to 45% less sodium hypochlorite consumption at the same disinfection level (dosage optimization) avoiding overdose and the undesired disinfection by-products formation

•15% to 50% (according to the operational conditions) less power consumption by UV systems by optimizing the nº of units in service and the power level

As a totally automated process, with doscontrol® less man- power is needed and maintenance is properly managed allowing appropriate service scheduling and easy equipment fault diagnosis.

3.2.4.3 Perspectives for the future

As water reclamation specialized company, teqma is proposing doscontrol® system to water reclamation managers and water re-users in the Spanish and European market to promote the positive experiences and results obtained in the R3Water project demonstration in the Spanish and Swedish demo sites helping to improve the reliability, efficiency and effectiveness of water disinfection processes.

3.3 Technologies for resource recovery

3.3.1 Hydrothermal carbonisation (HTC)

AVA Green Chemistry Development (AVA) offers advanced technologies for the treatment of biomasses and waste streams, based on the hydrothermal treatment technology (HTC). This technology allows the recovery of the most important ingredients such as potassium, calcium, magnesium, nitrogen, sulphate and the limited resource phosphate as fertilizer (fertilizer production) while simultaneously producing high quality biocarbon or activated carbon e.g. as soil improvement. This integrated approach is called "HTCycle", showing hydrothermal carbonisation as a platform technology for the circular economy with a zero waste approach.

3.3.1.1 Addressed problems and challenges

The ongoing process in the EU to collect and treat the wastewater in more and more European municipalities produces vast and growing amounts of sewage sludge. The last collected data show a yearly production of 9,637 thousands of tons in the EU28 countries. Sludge treatment and reuse issues are getting more important for most European municipalities and industries (such as sewage sludge disposal companies, waste water treatment plants) due to changing legislation and increasing costs. At present, there is no energy efficient, environmentally and economically viable process implemented for sludge disposal and the reuse of valuable resources as phosphorus. The most common disposal methods for sludge are spreading on agricultural soil, composting and incineration. Spreading on soil entails on average the lowest cost (around 15 €/ton), but it is not an available option in every EU28 countries, due to the different legislations in force, and its being banned due to safety concerns. Incineration entails the highest costs, but is also considered the safest disposal method at the moment. Therefore, it is fast growing and widely adopted. However, it presents also technical difficulties, such as the low overall efficiency of the process (sludge can contain up to 85% water, which renders the process very inefficient), the huge logistic efforts required to transport the sludge to the incineration plants, or the disposal of the ashes after the sludge has been incinerated. In the project different kinds of sewage sludge from different plants of Aquafin were tested extensively. The major challenges were to find optimal and easily reproducible reaction conditions for a variety of sludges and to develop recovery technologies for valuables.

3.3.1.2 Results

HTC treated sludge has significantly better mechanical dewatering properties than the raw sludge.

Costs of treating wastewater treatment sludge with HTC and AVA cleanphos technologies were assessed and compared with current sludge treating practices. HTC technology carbonizes the sludge and improves its dewaterability. This lowers energy usage in thermal drying, since there is significantly less water to evaporate. AVA cleanphos technology recovers phosphorus from carbonized sludge. Here carbonized sludge was considered to be used as fuel for the cement industry. Possible higher-value end-uses for the sludge were not assessed.

The highest uncertainty on the costs of HTC and AVA cleanphos treatments comes from the need of nitrogen retreatment at the wastewater treatment plant. During HTC reaction, around 60% of nitrogen content of the sludge dissolves. The fraction of this dissolved nitrogen eventually returned to the waste water treatment and it is one of the highest uncertainties in HTC process and has high impact on total treatment costs. AVA developed a technical solution to extract nitrogen from the filtrates, to recover nitrogen as nutrient ammonium sulphate. Therefore, costs for nitrogen treatment in WWTP are reduced substantially.

Plant concept with 12 vessels in 2 rows

All these improvements are additional benefits to the existing advantages of AVA's HTC as a technology for an integrated sewage sludge treatment. Economic analysis shows, that for a full featured HTC plant (50,000t/a), running 24/7 total treatment costs for 1t of sewage sludge (dry matter) are around 150 €, whereas for a simple dewatering or drying technology are in the range of 250 €/t.

3.3.1.3 Perspectives for the future

There is also an increasing pressure coming from the legislation that requires phosphorus recovery from sludge prior incineration. AVA cleanphos technology extracts phosphorus as phosphoric acid from HTC treated sludge. In comparison with thermal drying, HTC and AVA cleanphos processing introduces added CAPEX but the total sludge treatment costs are at the same or lower level. Thus it can be concluded that AVA cleanphos technology provides a promising solution for phosphorus recovery that is also economically competitive.

With the technology of HTC at its heart, AVA not only is able treat the sewage sludge, but also to transform it into high value products such as fuel, activated carbons for water treatment, recovery of phosphorus, soil remediation material, carbon sequestration schemes and other applications (on the base of the circular economy approach). The HTCycle process will turn the present sewage sludge disposal from a costly process into an income-generating activity.

3.3.2 Sludge ash valorisation

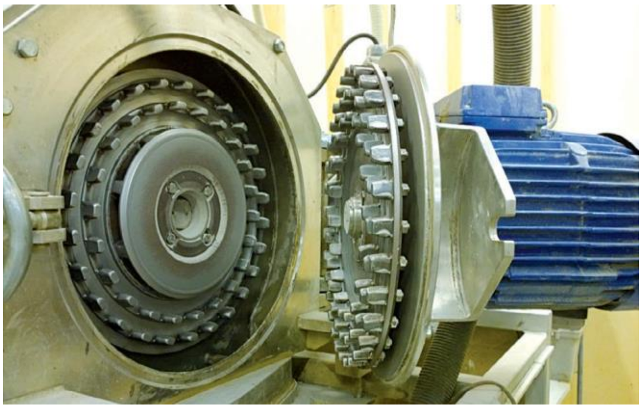
Treatment of municipal wastewater sludge by incineration is a common method in some European countries, with a growing trend. The remaining ash contains valuables as phosphorous, which could be reused. Renotech has investigated possible treatment routes for ash from municipal wastewater treatment sludge combustion.

3.3.2.1 Addressed problems and challenges

The main problem with the ash as a raw material is the small particle size. In fertilizer applications this can lead to dusting, and therefore the ash has to be granulated in some way before use. Sludge ash does not have hydraulic properties in itself, which necessitates for the use of a hardening agent. Potentially other ashes could be used as binders in this application, further improving the recycling of the process.

3.3.2.2 Results

Traditional methods for leaching ash are enhanced with high impact milling (mechanic-chemical activation).By producing new surfaces through activation the leaching process can be accelerated significantly. The ash may be used in processes where it contributes beneficial properties based on its chemistry. Even though the ash is not viable as an agricultural fertilizer it can potentially be used as forest fertilizer. Leaching results for the ash were typical for the field. About 80 % of the phosphates were extractable with traditional heap leaching processes. Grinding of the ash increased the rate of the leaching and this is a viable pre-treatment of the ashes in a leaching process. The ash had a high content of iron (Fe) and aluminium (Al) which are known to be difficult to remove.



Milling equipment for the treatment of ashes

By pre-treating the ash effectively an enhanced leaching can be obtained. The main challenge with leaching is that about 75% of the material still remains and must be disposed of in some way. Furthermore, the residue of a leaching process is acidic or alkaline depending on the process used, which can change the classification of the waste material. This can have an impact on the deposition costs. The leaching solution needs significant processing to produce a clean product, but since it recovers valuable phosphorus this is a viable route for recycling nutrients in the future.

A benefit in fertilizer application is the form of the phosphates in the ash. Iron and aluminium phosphates are more sparingly soluble than the calcium phosphates traditionally used in fertilizers. Since the release of phosphates in forests is taken care of by fungi the leaching is slower, and phosphate uptake better. Therefore less eutrophication by run-off is observed. If the granulation process is further optimized by making light weight aggregate the particles will hold moisture better and provide better growth substrate for the microbiota.

Another application that has been identified in the project and where ashes are beneficial is the manufacture of mineral wool. The melting properties of the ash are good for this application, and phosphate that is in the ashes improves the properties in the process and the biocompatibility of the product. Other application fields for sludge ash are refractory materials where it functions as a flux and can contribute a desirable size fraction for better density of the material. Often sludge ashes have been used in construction materials as filler.

In mineral wool manufacture powder raw materials can also be problematic, and therefore the ash may need to be made into briquettes or granulated before use. This can raise the costs for use of the material. Since the main benefit of the material is its low cost this can be a significant burden. However, systems exist for the addition of powder raw materials into the system which may allow for the addition of ash directly into the process.

Investigations also showed that with these types of application for the ash the process must be located fairly close to the facility. If the ash must be transported long distances the margins of profit are quickly lost.

3.3.2.3 Perspectives for the future

In the future as costs for deposition of waste materials rise the incentive to recycle ash will rise. Ashes and slags have many desirable properties, and an increased use of this type of materials is both desirable and probable. In the future manufacture processes will be planned with local raw materials from wastes in mind, and a more circular economy will be implemented. Some of the investigated routes for use of ashes will become more attractive.

3.4 Technologies for resource efficiency

3.4.1 Anammox

The anoxic ammonia oxidation (Anammox) process is a unique biological process for nitrogen removal, which allows significant savings (up to 60%) in aeration demand compared to the classical nitrification/denitrification process. The Anammox process has proven to be successful in ammonium-rich wastewaters at temperatures above 25°C. Reject water from anaerobic digestion of sludge is an excellent stream to be treated by the Anammox process. Many WWTPs already have an Anammox reactor to treat reject water from anaerobic digestion, but there is a need for advanced control strategies to increase process robustness.

3.4.1.1 Addressed problems and challenges

Although there is a significant number of implemented Anammox process for reject water treatment, the potential is estimated to be much higher. A possible way of optimising the process would be improved process control. The main objective within R3water was developing new algorithms for dynamic Anammox control that are applicable in all side stream Anammox reactors (such as reject water treatment). These control strategies have been tested and demonstrated at two pilot-scale Anammox reactors in Sweden and Belgium, and the results are being compared.

This study is specifically targeted for the following one-step Anammox treatment reactors operated with suspended active sludge. The introduction of a more advanced control strategy requires:

•A thorough follow-up of sensor conditions and adequate maintenance

•An acceptable water quality, facilitated by a process that is more robust and/or achieves better removal efficiencies compared to simpler control strategies

3.4.1.2 Results

3.4.1.2.1 Results – Belgian demonstration

For the Belgian demonstration, 5 control strategies were tested and at last integrated:

1. Feed control based on ammonia, as baseline control strategy. Ammonia was first determined by a proxy measurement (conductivity), and subsequently by direct measurement.

2. Feed control based on ammonia with ‘free ammonia (FA) inhibition’ determination and mitigation.
3. Aeration control based on nitrite measurements. This control strategy was implemented on top of the continued feed control. The aeration time was increased or de- creased, to limit the build-up of NO2-N at the end of the aeration phase, which would favour growth of NOB.
4. Aeration time was extended by alkalinity dosage.
5. Process control targeting the NOB washout based on free ammonia shocks.

The Anammox pilot was at first located in Leuven WWTP. The Leuven centrate waters had a rather high COD/N ratio, resulting in a poor Anammox performance. In July 2015, the pilot was moved to Antwerp-Zuid, resulting into feasible Anammox operations. Process performances were boosted by bicarbonate dosing as a source of alkalinity. The process stability was impacted by sensor failure, which could only be countered by intensive maintenance and manual follow-up of the process. The process stability was as well impacted by fluctuating influent nitrogen loads.

During the baseline period (ammonia-based feed control), the pilot operated relatively stable with a total nitrogen (TN) removal of 75-80%. However, frequent NO_2-N accumulations were observed, which can be detrimental to Anammox activity. During aeration control phase, TN removal was stable at satisfying removal percentages between 77-87%.

Feed control was optimized with more stable effluent ammonia in the reactor. Free ammonia inhibition was also prevented, targeting the accumulation of NH4-N due to load variation of the centrifuges. The application of ammonia shocks was also investigated with determination of optimal FA exposure levels and con- tact time. Results were tested in lab scale and implemented in pilot scale. The purpose of this feature is the reduction of temporary nitrite oxidising bacteria residual activity.

3.4.1.2.2 Results – Swedish demonstration

The aim of the Swedish demonstration was to evaluate the efficacy of redox potential combined with pH for controlling the partial nitritation/Anammox process. The testing was centred on three key variables (pH, ORP, and nitrogen load). In addition to verification of the control scheme working to an acceptable level, the study also sought to determine the optimal set point for each of the three variables. The optimal point was assessed from a variety of different response variables such as nitrogen removal efficiency and cost of nitrogen removed.

Using a standard full-factorial design of experiments, with two levels for each variable, eight different periods were deemed necessary. In addition, two middle points were included as a reference point for the other tests, which brought the total number of periods to ten.

Stable operation and acceptable levels of nitrogen removal (>80%) were achieved for three periods where the common factor was an ORP value of 70 mV. The highest nitrogen removal rate (83.7%) was found when the test conditions were pH 8, nitrogen load 1 gN/m2/d, and ORP 70 mV. The economic performance of each period was also evaluated and it was found that the optimal point, in terms of aeration and of the three periods with sufficient removal efficiencies, was the same as the optimal removal conditions except with a pH of 7.

A secondary test was performed in order to directly compare the performance of ORP with dissolved oxygen (DO) as a control parameter. It was found that DO significantly outperformed ORP under identical test conditions, yielding a higher nitrogen removal rate (78.2% vs. 65.3%) as well as significantly less aeration energy.

3.4.1.3 Perspectives for the future

A marketable control algorithm should rely on robust sensors with a low risk of failure. In the Belgian demonstration case, the control strategies relied on sensors that required auto- mated sample filtration and determination of N-compounds, required intensive maintenance and were prone to failure. Additionally, an ideal Anammox control process should not only be based on energy savings and N-removal. As societal awareness towards environmental themes increases, a process control must also be able to incorporate environmental considerations in its system, such as greenhouse gas (N2O) emissions.

3.4.2 OptimEDAR

OptimEDAR is a low-cost aeration control system for WWTP, based on virtual sensing techniques that adapt the use of the blowers to the organic load in the bioreactor, allowing energy savings (20% on average), longer denitrification cycles, and improving the quality of the effluent.

3.4.2.1 Addressed problems and challenges

Between 45 and 75 % of the energy costs in a WWTP are spent in the aeration of the biological reactor. The optimization of this process is fundamental to decrease the operational costs of the whole plant. Additionally, the optimization has to be done without affecting the quality of the treated water that has to accomplish with the UWWTD regulations.

OptimEDAR uses DO and Redox measures to determine the status of the biological reactor calculating the Equivalent Organic Charge (EOC), a ‘virtual sensor’ that estimates the organic matter load in the bioreactor. By adjusting the timing and operating conditions of the blowers according to the stringent reactor’s oxygen requirements, the energy consumption is optimised while allowing longer denitrification cycles.

3.4.2.2 Results

Within the R3Water project, the OptimEDAR demonstration was held in Wijer (Belgium) (1,440 P.E., design flow max. 2470 m3 /day) and in Empuriabrava (Spain) (70.000 P.E., 16.000 m3 /day), as case studies for a small plant in different climatic conditions and a big plant with highly seasonality.

Empuriabrava WWTP belongs to Consorci Costa Brava (CCB) facilities, a water agency in Spain that is in charge of 18 municipal wastewater treatment plants, operated by the Empresa Mixta d’Aigües Costa Brava (EMACBSA). Empuriabrava WWTP operators have been testing different control strategies for the aeration process during the lasts years. Thanks to this situation, it has been possible to compare the OptimEDAR results with 3 other methods in terms of energy consumption as well as the quality of the effluent. The results obtained shows 20% less use of the blowers related to the previous year.

After comparing the use of blowers related to flow and the quality of the effluent we can conclude that the OptimEDAR control is more efficient than the control by redox or time and similar to ammonium control in terms of the quality of the effluent. Nevertheless the operational costs of OptimEDAR are much lower and robustness much higher compared to ammonium control.

Wijer WWTP belongs to Aquafin NV that operates in Flanders and collects & treats the municipal wastewater of around 5.5 million people equivalents in 289 plants. Wijer WWTP is characterized by its diluted charge, and the OptimEDAR was optimized to run under these conditions. After this optimization, the results showed a strong improvement of the energy balance of the aerators, with a reduction of energy consumption about 10% compared to the previous O2-control method.

3.4.2.3 Perspectives for the future

OptimEDAR in Wijer and Empuriabrava will be transferred to the regional agencies to continue with the operation. These 2 experiences will be used as success cases for the future commercialisation strategy.

3.4.3 Model based predictive control

Model predictive control (MPC) has its roots in optimal control and has become the most popular advanced control technology in the chemical processing industries. There are many variants of MPC controllers, both in academia and in industry, but they all share a basic concept which is to use a dynamic model to forecast system behaviour, and optimize the forecast to produce the best decision - the control move at the current time. Models are therefore central to every form of MPC. Because the optimal control move depends on the present state of the dynamic system, a second basic concept in MPC is to use the past record of measurements to determine the most likely present state of the system. Thirdly, most MPC controllers are able to account for constraints both in manipulated variables and states/controlled variables through the formulation of the optimization problem. The foundation of MPC relies on the computation of the sequence of future control moves, performed by solving the optimization problem. Only the first computed control move is implemented. The model based predictions are corrected using feedback information at each sampling instant, before a new optimal sequence of the future control moves is computed, according to the receding horizon principle.

3.4.3.1 Addressed problems and challenges

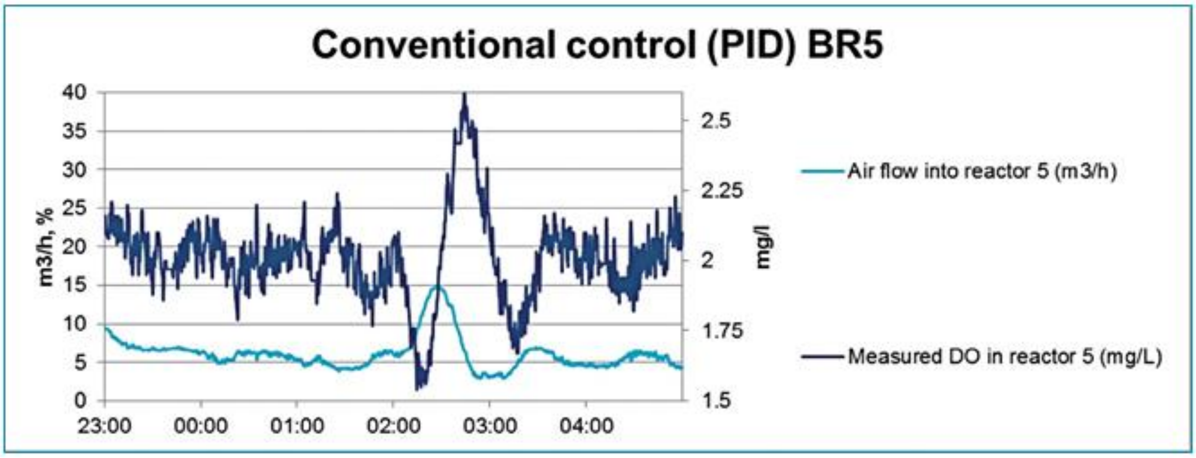
Although being successfully implemented in other industries the potential of Model Predictive Control (MPC) for process optimisation is not yet exploited in control of urban wastewater treatment. The overall aim of the project is to design, implement and validate a control structure for efficient WWT plant operation based upon a Model Predictive Control (MPC) technology where a simplified process model together with estimation techniques is used to minimize a cost function. This cost function is represented by a prediction of defined quality parameters related to a desired set-point.

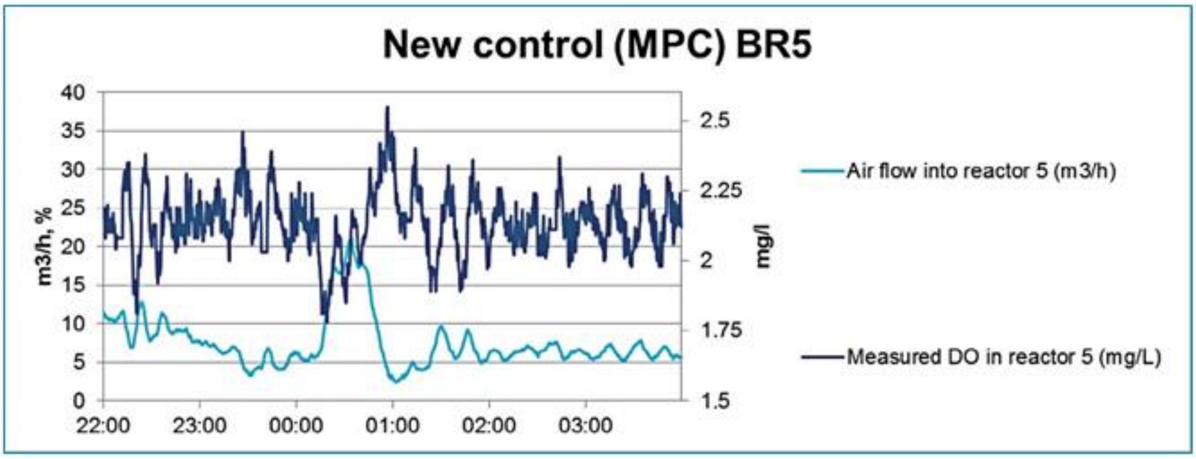
3.4.3.2 Results

Plant Simulator: A lot of time has been spent on understanding the complex dynamics and relations within the wastewater treatment (WWT) and evaluation of the existing research results and publications regarding the control issues in WWT. A few available (both commercial and freeware) simulators such as STOAT and Dynamo have been considered as an aid for design of controller structure. However, these provided unsatisfactory results due to challenging and complex configurations and data requirements. Thus, the aim of the project changed towards using in-house software for implementation of a simulator that could describe the Swedish pilot plant. This has been accomplished through application of the well-known Activated Sludge Model 1 (ASM1).

Estimator: During evaluation of the simulator at site in Stockholm, it became clear that fitting the simulator to the plant can be a time-consuming task due to the large number of parameters and states. With much support from the IVL group, the simulator was validated through application of Extended Kalman filtering (EKF) which is a state and parameter estimation technique. The EKF uses a reduced-order ASM1 model as its internal model in addition to the available on- line measurements. The reason for this model reduction has been the lack of observability of the complete ASM1 model, which is an essential pre-requisite for estimation capability of the system. Finally, a platform now exists for online real-time dynamic simulations of the pilot plant, that is a simulation running in parallel with the plant, and using the same inputs and outputs. One additional benefit of this is the possibility to try out new strategies and changes in the way the pilot plant is operated such as changing the number of reactors, where and how the recirculation is done, and other interesting ideas. Furthermore, this platform is the base for applying advanced control systems with much less effort than before.

Controller design: Several approaches and strategies have been considered and even partially implemented. These approaches have mainly focused on finding a proper model for the model-based controller (MPC). After gaining valuable process insight through the simulations, a simplified model was designed to be used in the MPC with the aim of controlling the dissolved oxygen level in a single bioreactor. This has been successfully implemented and tested in closed-loop at Swedish pilot plant.





Comparison of results for dissolved oxygen (DO) with different control strategies

That means the MPC has replaced the PID-controller for one reactor using both data from the simulator (states and parameters) as well as the estimated dissolved oxygen in the same reactor. The MPC shows better performance in terms of set-point tracking (keeping the level of dissolved oxygen close to 2 mg/L) and disturbance rejection (the same disturbance occurs for both the PID and the MPC structure).

Future enhancements: Further enhancements of the MPC have been considered. Examples include control of the oxygen content of bioreactor 4 (BR4), amount of sludge recycled in the system, and economic optimization of the air blower volume flow to the aerators in the bioreactors. All these enhancements can be implemented within the current framework.

3.4.3.3 Perspectives for the future

Simulation and experimental results obtained during this projectindicate that using an advanced control strategy (such as combining nonlinear state and parameter estimation technique and nonlinear model predictive control) can be economically beneficial. That means, keeping the different material concentrations (such as O2) at appropriate levels while using the energy resources more efficiently. Considering the developed platform by Prediktor during the R3water project, the commercial potential of such product is considerably high, in addition to increased interest from academic institutes (such as universities) for possible research studies. Thus, it opens up the possibility for numerous research and commercial activities within WWT, specially focusing on modelling and controller aspects of the process.

3.4.4 Model-based energy audits in wastewater treatment plants

The total operation costs of a wastewater treatment plant (WWTP) are, for a large part, determined by its electricity consumption. Energy audits can identify opportunities to reduce energy use in WWTPs, but they cannot pinpoint ways to optimize energy use. Only a model based approach with robust multi-variate data analysis can deal with such complexity. Aquafin has developed a model-based energy audit tool that integrates water and sludge dynamic models with a detailed modelling of all single process units and a correct model parametrization. By means of a detailed data analysis, the model output can be used to determine: a robust parameter set, critical operations of blowers and other unit processes, total costs and single cost components, life cycle analysis, and detailed cost- and energy-saving strategies. This whole-plant modelling tool of Aquafin is demonstrated through the R3 Water project at the full-scale WWTP of Girona (Spain).

3.4.4.1 Addressed problems and challenges

Aquafin faced some challenges at the Girona WWTP:

•A complex blower algorithm needed to be upgraded with a new parametrization as to increase lifetime.
•The primary settling tank was modelled in function of different parameters, validated in full scale and its malfunctioning integrated in the model.
•Air distribution through the 4 aerated basins did not seem to follow the diffusers surface distribution. The data collected in full scale did not alleviate the uncertainty on this aspect.
•Eventually, high saving opportunities were identified due to the actual continuous aeration in the biological tanks.
•A malfunctioning of the sludge thickeners was identified by establishing a detailed sludge mass balance, and was later solved by the plant operators.

3.4.4.2 Results

To model the Girona WWTP, Aquafin used data from the year 2013 (January-October). The yearly dynamic data were fitted with regards to: effluent quality, primary settling tank effluent concentrations, removal performances, sludge produced, and power consumption of each different compartment. Data are evaluated considering an overall 'yearly cost', because energy savings can be counterbalanced by, for ex- ample, increased sludge production or reagents costs.

The evaluated scenarios include actions that are: (I) operations based, such as solving the thickener malfunctioning, or reducing the mixed liquid suspended solids (MLSS) concentration; (II) control-based, such as optimizing the blowers algorithm, DO sensor position, external recycle control; (III) based on on-line nitrogen control; or (IV) a combination of these. With the baseline scenario having operational cost (over 300 days) of € 507,000 Euro and total nitrogen (TN) removal of 90.2%, changes in TN removal for different scenarios were not dramatically, but between -3.5 and +2%. Cost savings between 5,000 and 125,000 Euro were estimated.

3.4.4.3 Perspectives for the future

The outcomes of the modelling exercise will be communicated to the operators of the respective WWTPs, to allow them to make informed decisions to improve the energy and cost balance of their plant.

Aquafin is bringing their modelling and support service to the market. Factors that influence the marketability include the practical applicability of the outcome to the specific situation, the risk of failure of the proposed improvements, the impact of the proposed improvements on effluent water quality, and the achieved economic benefit.

3.4.5 InnoWatt

Wastewater treatment plants (WWTP) are a significant consumer of electricity. Within a WWTP, electricity consumption accounts for between 25 and 45% of the facility's total operating costs. WWTPs are therefore important targets for reducing energy demand. Energy audits, which identify opportunities to reduce energy use and greenhouse gases in WWTPs, are typically based on the average energy consumption of a facility; they include benchmarking with similar plants or comparison against some standard performance indicators. However, current energy audits could potentially be improved through the use of energy and cost monitoring tools together with dynamic models that integrate water and sludge lines. Because this potential had not been explored in the European market, ICRA developed InnoWatt, a novel energy audit tool was demonstrated through R3Water. The main goal of ICRA's technology is to minimize energy consumption while maintaining good process performance.

3.4.5.1 Addressed problems and challenges

Wastewater treatment plants spend up to 45% of their operating costs on electricity. Plants generate a lot of data, but usually don't have the tools to answer important questions such as "How much energy do we consume?", "How could we save money on electricity?"

3.4.5.2 Results

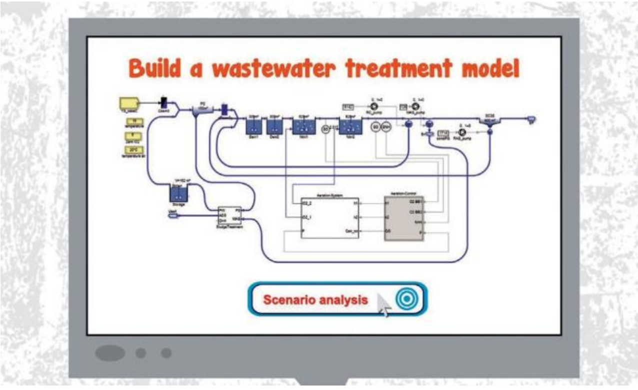
Within the project, ICRA has developed InnoWatt, a tool that gives clear and reliable information needed to reduce energy costs. The process starts simple by installing InnoWatt in the electricity counter of the facility. Using four modules, InnoWatt tells how much energy is used and how you to save it well as saving money.

•Module 1: The first module gives access to real-time energy consumption. It allows for access to historical data and visualisation of the consumption patterns

•Module 2: The second module calculates the energy costs in real-time

•Module 3: The third module provides the optimal contracted power for the plant, which can allow saving money without changing any infrastructure. Most plants have contracted more power than they need, so by lowering the contracted power, money is saved.

•Module 4: Whole plant modelling. In the last module ICRA will simulate the wastewater treatment plant and run scenario analyses for energy and cost reduction. ICRA shows how to operate the plant with less energy without sacrificing the quality of treatment.



Module 4: plant modelling

Girona WWTP: The focus of the study was on the aeration system, which rep- resents 63% of the plant's energy consumption. A dynamic model consisting of a process, a realistic controller, and a very detailed air supply model, was developed and calibrated to be used as the baseline for testing various scenarios. Results show that the implementation of an ammonia-based controller and a redistribution of the diffusers led to energy savings between 12 and 21 %, depending on wastewater temperature. In addition, the model demonstrated that the current blower is too large, which causes an intermittent behaviour, endangering the equipment and shortening its life-time, plus limiting the minimum air-supply. The applied aeration system models enable engineers to identify bottlenecks by modelling equipment constraints (e.g. blower turn- down). Ignoring the air supply side in an assessment could result in an overestimation of energy savings or treatment performance and consequently in non-optimal control solutions or equipment selection. The carbon footprint assessment showed that direct N2O and CH4 emissions from the biological reactor are of the same magnitude as indirect CO2 emissions from electricity use. Hence, efforts should not be only allocated to reduce electricity consumption but also direct emissions.

Harelbeke WWTP: ICRA developed an integrated model of the Harelbeke WWTP. The model was used to find strategies to enhance Biological Phosphorus Removal in order for the plant to reduce resource consumption. Currently phosphorus is removed chemically and thus 400 tons per year of $FeCl_3$ are used. The evaluated scenarios included decreasing the flow-rate of return activated sludge, adding an internal recycle from the aerobic zone to the anaerobic zone and adding an external source of volatile fatty acids. Based on the simulation results we recommend that the

Harelbeke plant implements the reduction of the return activated sludge flowrate to 50 % of the influent flowrate. Without any capital investment or other direct costs to the plant, this modification could reduce the energy consumption of blowers by about 7 % and the consumption of $FeCl_3$ solution by about 40%, while maintaining an effluent quality that meets Belgium's current regulations.

3.4.5.3 Perspectives for the future

The outcomes of the modelling exercise have been communicated to the respective WWTPs, to enable more informed decisions to improve the energy and cost balance of their plant. Innowatt showed its potential and can be used further as a service for treatment plants

3.4.6 Fluidic oscillation

By using fluidic oscillation microbubbles can be generated, which significantly improve gas transfer to liquids. This can be used to improve oxygen transfer which is an important process in aerobic biological wastewater treatment. There is also a potential to improve gas transfer in anaerobic digestion.

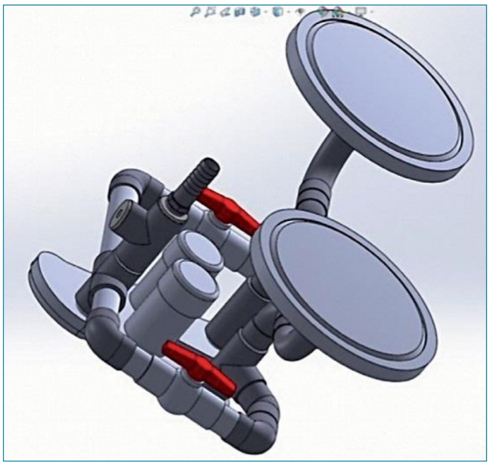
3.4.6.1 Addressed problems and challenges

Many industrial processes can be improved if the method of transfer from gas to liquid was more efficient. Wastewater treatment and Anaerobic Digestion are such processes. Perlemax has developed a microbubble technology which has low power requirements allowing increased gas transfer with no energy penalty. The R3Water project gave the company the opportunity to build upon its experience of scaling up from laboratory and pilot level operations. This was to confirm that microbubble technology could allow a significant reduction in energy consumption whilst maintaining the required performance in wastewater treatment plants. The justification for the experiments was that power requirements for wastewater treatment across Europe are considerable and have been estimated at € 750 m per annum.

Anaerobic Digestion was also investigated to see if performance could be improved whereby more methane gas is produced and the sludge is more stable. These experiments were conducted with CO_2 instead of Oxygen.

3.4.6.2 Results

First experiments were carried out by "above water oscillation" with the fluidic oscillator positioned outside the waste water tank. The results showed little difference in efficiency using this technique and was considered to be due to a difference in pipe design between already tested sites in the UK and Aquafin's facility specifically a design that equalizes air flow. Above water oscillation was originally pursed because it would allow retrofit in any wastewater treatment plant.



Oscillator design

To overcome the design for air flow equalization an oscillator design that is not positioned above water but within the wastewater tank was investigated. The device has been nick-named the TOAD. It featured all the requirements of a fluidic oscillator but on a much smaller scale and included 2 diffusers as part of the device. This has been tested at the Swedish site and produced a significant improvement in oxygen transfer in some tests.

In an anaerobic digestion laboratory experiments, when a reactor was dosed with CO_2 microbubbles the methane production increase by over 100% and the stability of the sludge was improved. The over 100% improvement level was not replicated in the test facility at Aarteselaar, NL, but an improvement was shown. One of the major differences between laboratory and the first test was direct dosing of the CO_2 directly into the reactor achieved in the laboratory but not in the test tanks. This is a major consideration in any retrofit programme as it is likely to change the design of the AD tanks substantially. Tests in Sweden lasted only for a short time and did not give sufficient results for a clear evaluation.

3.4.6.3 Perspectives for the future

The potential for this technology is significant but further larger scale tests are required. These tests are in planning and will take place later in 2017. Further development is to be funded by Innovate UK after the R3Water project is complete.

4 Description of the potential impact

The ***R3Water*** *project showed impacts contributing* ***to integrated, innovative, technological, urban and industrial relevant solutions on Reuse of water, Recovery of value added substances and Resource efficiency*** in urban wastewater treatment supporting the conversion of a treatment plant for urban wastewater to a production unit of different valuable substances. Below is a summary showing how R3Water addressed the expected impacts from the call.

Within the project, also the need and opportunity for policy improvements was obvious. A number of policy recommendations has been worked out and is presented also in the final brochure of the project.

4.1.1.1 Europe2020 innovation union initiative:

•Used the innovative R3Water demonstration & market access approach to facilitate the market uptake of innovative UWWT technologies in a medium to long term perspective and demonstration activities demonstrates a strategic approach to innovation.

•Made an overview of the most relevant financing instruments that are available in Europe and the countries that are partners in R3Water

•Demonstrated new technologies and solutions for increased resource efficiency in existing UWWTP performance through innovative monitoring, advanced control strategies and management measures

•Demonstrated innovative wastewater technologies that enable reuse of water and recovery of valuable substances such as nutrients.

•Addressed the major societal challenge of water scarcity.

•Resource and climate efficient treatment with online water quality monitoring, innovative process control, and increased energy efficiency, including bioenergy production.

4.1.1.2 Smart Cities and Communities (SCC)

•One main objective of the project was to market solutions that support the conversion of a treatment plant for urban wastewater to a production unit of different valuable substances. Energy technologies and ICT technologies were used to reduce emissions of green-house gases and increase the energy efficiency.

•The project developed solutions to facilitate water reuse in different purposes

•The R3Water solutions allow increasing the resource efficiency in waste water treatment and reducing the pollution in the effluents, reduce the waste volumes, and support green infrastructures by producing a valuable product and support climate policies by reducing energy consumption and increasing energy production (biogas).

4.1.1.3 European Innovation Partnership on Water

R3Water contributes to the aims of the proposed European Innovation Partnership (EIP) on Water

The innovative R3Water demonstration & market access approach is directly addressing the overarching aims and vision of the EIP on Water.

4.1.1.3.1 Water reuse and recycling;

R3Water demonstrated efficient treatment technologies that produce fit for purpose water qualities that meet environmental and sanitary criteria.

R3Water demonstrated technologies that (I) are optimized in efficiency to produce reclaimed water and (II) to monitor at real-time the quality of water to be reused for urban and agricultural uses to preserve ecosystems.

The R3Water monitoring systems are capable to determine e.g. the quality of recycled and reclaimed water to improve management and public acceptance according to health requirements.

4.1.1.3.2 Water and wastewater treatment, including recovery of resources:

R3Water demonstrated innovative concepts for wastewater treatment and recovery of resources.

4.1.1.3.3 Water-energy nexus:

R3Water demonstration approaches contributed to reducing energy consumption related to wastewater treatment and reuse.

4.1.1.3.4 Decision support systems and monitoring:

Well targeted monitoring and modelling of wastewater treatment processes are demonstrated in R3Water to enhance decision making for more efficient treatment concepts.

4.1.1.4 Partnership

R3Water demonstrated solutions that support the conversion of a treatment plant for urban wastewater to a production unit of different valuable substances. Therefore, a strong partnership between public authorities, regulators, water utilities and companies, the research community and the public was realized in the project e.g. via the cross cutting issue workshop concept in WP8 and the fact that water utilities (Aquafin) were partners in R3Water.

4.1.1.5 Pool resources, market opportunities and uptake

R3Water pooled Environmental Technology Verification (ETV), Life Cycle Assessment and Life Cycle Costing together with in the R3Water demonstration & market access approach.

R3Water linked its demonstration concept and technology demonstration on local/regional level with European exploitation concepts that also have a global outreach (e.g. global ETV activities).

R3Water combined resources to realize and facilitate market opportunities on different economic scales (regional – global) to clearly strengthen the global leadership for the European wastewater technology.

R3Water involved participation from the developing countries in the advisory board. This avoided developing an isolated European solution.

4.1.1.6 Objectives of water-related policy

The R3Water Project contributed to Water Framework Directive (WFD both directives and Groundwater Directive (GWD) by:

- setting demonstration targets and verification claims in a way that they directly help to fulfil discharge limit values clearly, thus directly contributing to the achievement of a good quality status of water and groundwater bodies, thus preventing and reducing pollution

- By demonstrating improved water reuse sustainable water use is supported directly

Together both approaches directly improved environmental protection and support the improvement of aquatic ecosystems

4.2 Technological Impact

R3Water demonstrated a number of different technologies in the three main areas of water reuse, resource efficiency and resource recovery. All technologies made technical progress, some of them are even near to or ready to market. Thus, these technologies can contribute to technological progress in urban wastewater treatment. The technologies facilitated the following improvements:

- Minimise energy consumption by better control mechanism, optimised aeration and the Anammox process with the technologies:
    - OptimEdar (ADASA)
    - Model based predictive control (Prediktor)
    - Model-based energy audit InnoWatt (ICRA)
    - Microbubbles by fluidic oscillation (Perlemax)
    - Anammox control system (Aquafin and IVL)
- Sludge valorisation including the option for phosphorous recovery with the technologies:
    - HTC (AVA Green Chemistry Development)
    - Ash treatment system (Renotech)
- Water re-use to minimise water scarcity and treatment to secure water quality with technologies for monitoring, disinfection and treatment of micropollutants:
    - AQUATRACK and ozone treatment (Aqua-Q)
    - AquaBio (ADASA)
    - doscontrol (Teqma)
    - Activated carbon and ozone treatment (IVL)

4.3 Socio-economic impact and wider societal implications

The support to policy implementation and compliance is integrated via the verification approach (EU ETV Pilot Programme). **Verification claims and demonstration targets for technologies were defined in such a way that the technologies contribute to the achievement of policy requirements and support status improvement of rivers and water bodies**. Thus policy implementation and compliance in the demonstration concept ensured that the R3Water developments were in conformity with, and contributed to the compliance with European policies. **Demonstrating the contribution to policy compliance increased the market acceptance of new solutions to be applied in practice**.

R3Water has strengthened the participating companies, of which 6 are SMEs. They have increased their knowledge, developed their technologies further and improved their business models. All this together helps to secure the jobs involved as well as it strengthens competitiveness of European water technology suppliers.

A number of technologies were developed and demonstrated for the treatment of water for water reuse and reclamation. These technologies contribute to improved water quality as well as to secured access to clean water which are important wider societal impacts.

4.4 Dissemination activities

R3Water followed **a tailored made multi stage dissemination and exploitation strategy**. This strategy started already with the proposal setup and consortium building, and resulted in impact focused project design, containing complementary dissemination and exploitation measures within the project and integrated mechanisms that ensure a continuing impact beyond the project duration.

Dissemination of results has been an important part for R3Water to reach out to relevant stakeholders. Important means of dissemination have been:

- The website: www.r3water.eu with regular updates
- A project flyer and a brochure with first results of the technologies
- Final brochure (available on the website for download)
- 3 workshops (Brussels, Leeuwarden, Barcelona) with 93 participants in total
- One final conference to present the results with over 50 participants
- 3 newsletters
- press releases
- Site visits at all demonstration sites
- Updates on LinkedIn
- Participation in fairs and conferences, with presentations and stands, e.g. at IWA Leading Edge Conference, WssTP, WWTmod2016, ICA2017, Sludge treatment days, SMAGUA, iWater Barcelona etc.

Interaction with the thematic EIP on Water action groups and WSSTP groups has taken place (e.g. on water monitoring and resource recovery).

4.5 Exploitation of results

The basis for implementation of results for R3Water partners was the **strong demonstration focus** of the project. **A significant part of the total budget was dedicated to demonstration**. Combined with the assessment and verification tools this **provided the knowledge base for informed decisions by high level decision makers of the end user partners**.

The demonstration site partners operated multiple treatment plants, where the R3Water demonstrated technologies can be implemented. The technology providers could approach existing and potential new clients with the R3Water results. To support the exploitation of results, market studies have been performed for each of the three areas. In addition a small outlook to further markets in other countries has been collected. Environmental Technology Verification has been started for 3 technologies and was completed successfully for one technology; the AQUATRACK from Aqua-Q. The other two were still ongoing at the end of the project as such.

An external consultant provided additional support financed by an initiative from EU where R3Water applied for. The consultant performed an exploitation booster seminar, where exploitation strategies for 10 different exploitable results were discussed and developed further.