Review Article

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Synapps - platform for estimating, controlling and optimizing wastewater treatment plants

Summary

Wastewater generated by the world's vast population is an important source of pollution and can accelerate the loss of biodiversity and impede the achievement of objectives set by the international community regarding the good status of water bodies.

In line with the European Union's sustainable development strategy, which foresees the adoption of increasingly demanding environmental control, energy efficiency and rational management of resources measures, a project with high potential for economic valorization is being implemented, focused on design, development and validation in real conditions, to create an innovative platform for estimating, controlling and optimizing wastewater treatment plants (WWTP), called SYNAPPS.

Based on the implementation of multiparametric measurement chains and the application of computational intelligence techniques (eg Big Data Analytics, Data Mining and Machine Learning), the SYNAPPS platform should be capable of providing integrated management of the various WWTP treatment processes, ensuring a high environmental, energy and operational performance, and also simplify and relieve the burden of operating this type of technical infrastructure.

SYNAPPS is an R&D project approved by PO Centro, through ANI, started in January 2021 and will last for a period of 30 months, with a budget of around one million euros executed under the responsibility of the consortium formed by CTGA, a company with more than 25 years of experience in the operationalization and management of WWTP and leads the consortium, and by the non-business entities of SI&I, namely, ITeCons with relevant experience in the development of automation and dynamic control systems and in the evaluation of energy and environmental performance of processes, and ISR specializes in evaluating the energy performance of complex systems and developing control algorithms based on computational intelligence.

Keywords: platform, innovative, estimation, control, optimization, SYNAPPS

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Introduction

A Wastewater Treatment Station (WWTP) is a facility composed of a set of operations and treatment processes, divided into liquid, solid and gaseous phases, with the purpose of removing pollutants and obtaining treated wastewater (effluent) with the desired and safe quality to be released into the receiving environment.[1]

Improving wastewater treatment has been one of the main objectives of international organizations, particularly the UN, as it guarantees the sustainability and safety of the receiving environment[2] constituting one of the Objectives of UN Sustainable Development by providing for the improvement of water quality, reducing by half the proportion of untreated wastewater, as well as the adoption of measures for environmental protection, energy efficiency, sustainable management and efficient use of natural resources.[3]

Since the quality of effluents is one of the most serious environmental problems today, the standards and regulations imposed through legal diplomas are increasingly strict for the operation of WWTPs, highly complex systems, where the proper functioning and control of wastewater is crucial. systems, to safeguard the quality of the final effluent and, consequently, public and environmental health.

It is in this context that the reliable and efficient operation of WWTPs has become a challenge. WWTPs are dynamic systems that are difficult to manage, which pose constant challenges to operators and require specialized knowledge and constant monitoring to ensure efficient operation.[4] The effort to optimize the wastewater treatment process is somewhat challenging, since the optimal operating conditions of WWTPs are difficult to achieve or even control, due to the biological, physical and chemical processes that occur throughout the treatment process. , be quite complex, interconnected and unpredictable. Furthermore, the dynamic behavior of WWTPs is influenced by several changes that occur simultaneously, such as environmental/meteorological conditions, strong interconnections between the parameters involved in the processes and changes in flow and concentration of influent wastewater.[5]

WWTP are processes focused on environmental and not economic benefits, since the final product is a treated effluent subsequently discharged into the receiving environment, with no type of direct economic benefit for the installation. However, the elimination of pollutants from wastewater involves energy consumption, use of chemical products (reagents), human resources and management of by-products (sludge and screens), resulting in these being some of the main operational expenses. Furthermore, WWTPs are a source of greenhouse gas (GHG) production, both through direct emissions from biological processes (H2S, CO2, CH4), and through indirect emissions resulting from the production of electrical energy necessary for the operation of the plants. installations. All these costs, with direct environmental impacts, affect the sustainability of the process. Therefore, the more efficient operation of WWTPs could significantly improve the stability of processes and the quality of the effluent obtained, reducing operational costs, particularly in energy consumption,[6] and contributing to improving the quality of environment.

All these factors have contributed to major technological advances applicable to the operation of WWTPs, giving rise to new solutions and treatment technologies that make installations increasingly complex, dependent on increasingly sophisticated instrumentation, requiring the application of appropriate control strategies capable of dealing with with complex and dynamic systems. Most treatment plants have a control center that continuously receives a large number of data from installed sensors that must be interpreted to conduct the treatment process. However, during the occurrence of abnormal conditions in WWTPs, the success of establishing optimal operating conditions depends on the ability of operators to quickly identify the problem and intervene in order to prevent the emergence of more serious problems[7] such as those that result from one of the most demanding processes and most frequently used in a WWTP, the activated sludge process involving nitrification/denitrification phases[2] from the removal of organic matter and nutrients, namely phosphorus and nitrogen, where the volume of sludge (bulking) and the formation of foam (foaming) are the most frequent operational problems, caused by the excessive growth of filamentous bacteria,[8] requiring significant specialization from operators to fine-tune the process.

Faced with this constant challenge that operators face, the question arises, is it possible to design an intelligent system with the ability to monitor parameters critical to the operation of a WWTP? The development of an intelligent control system capable of continuously monitoring and optimizing processes, as well as detecting and correcting failures that occur in the initial stages of treatment, would improve the overall performance of the WWTP.

However, the operation of predicting and modeling wastewater treatment processes is not particularly easy, due to complex biological reactions and environmental conditions that constantly vary over time.[8] However, Artificial Intelligence models have demonstrated that they are capable of effectively dealing with the complexity and dynamics of these systems.[9]

It is in line with this idea that the R&D project for the design of the SYNAPPS Platform arises, focused on the development of an innovative solution for estimating, controlling and optimizing WWTP, which CTGA is implementing in a consortium with ITeCons and ISR.

CTGA – Centro Tecnológico de Gestão Ambiental, Lda. is an SME that is a company specializing in the preparation of studies and projects in the areas of Hydraulic, Sanitary and Environmental Engineering, as well as in the implementation, operation and monitoring of water treatment systems and drainage and treatment of urban and industrial wastewater, which has consolidated experience in the Water Sector as demonstrated by its activity in the Portuguese market.

Project description

Objectives

Wastewater treatment and recovery stations are complex, energy-intensive infrastructures that ensure the important function of reducing the pollutant load in urban effluents. However, the growing environmental awareness of society and the legislative pressure to which they are subject has led to the requirements to be met by WWTPs becoming increasingly demanding.

If in the past the main objective of the WWTP was limited to meeting the quality requirements of the treated effluent, nowadays the operating strategies of the WWTP also include the minimization of operating costs through the reduction of costs arising from energy consumption, waste and human resources management, and maximize the profits resulting from biogas production, water reuse, nutrient recovery, etc.. In this way, they began to ensure better energy and environmental performance, in line with the Commission's guidelines European Union regarding resource protection and adaptation to climate change.

SYNAPPS is an R&D project that aims to meet these strategies by focusing on the design, development and validation in real conditions of an innovative platform for estimating, controlling and optimizing WWTP.

The SYNAPPS project, approved by PO Centro, through ANI, which considered it to have high potential for economic recovery, was started in January 2021, with a budget of around one million euros, executed under the responsibility of the consortium led by CTGA, a company with almost 30 years of experience in the operationalization and management of WWTP, and by non-business entities from SI&I, namely ITeCons with relevant experience in the development of automation and dynamic control systems and in the assessment of energy and environmental performance processes, and ISR specializes in evaluating the energy performance of complex systems and developing control algorithms based on computational intelligence.

SYNAPPS is focused on the design, development and validation in real conditions of an innovative platform for estimating, controlling and optimizing WWTP. The project is based on the collection of data in real time, from multiparametric measurement chains, and the application of artificial intelligence techniques (eg Big Data Analytics, Data Mining and Machine Learning). The SYNAPPS platform will be made up of hardware and software modules and must be capable of providing integrated management of the various treatment processes, guaranteeing high energy performance (namely in terms of electricity consumption and biogas production), high environmental performance (particularly with regard to the quality of the final effluent, the consumption of reagents, the production of sludge and GHG emissions) and high operational performance (preventing breakdowns and reducing maintenance needs and downtime) (Figure 1).

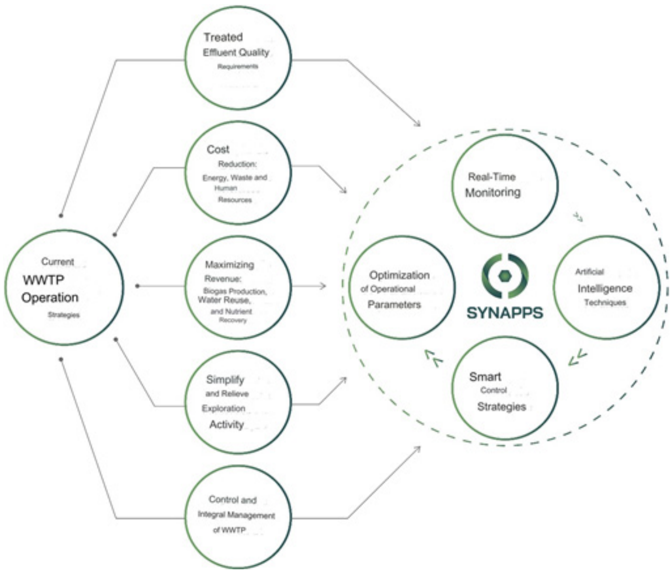

Figure 1 Current WWTP operation strategies.

With the adoption of the SYNAPPS platform, it will be possible to simultaneously achieve all of the previous objectives and also

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optimize and maximize the performance of the entire installation. In other words, in addition to maintenance, operability, compliance with quality requirements and minimization of operating costs, the integral control system, composed of multiple sensors, status indicators, actuators, etc., aims at coordinated management of all treatment units in real time, using a wide range of information that makes it possible to know at each moment the quality of the effluent, stage by stage, the degree of readiness of the installation (organs, equipment, etc.), the degree of use of the installation, etc., demonstrating being "intelligent" and "learning" from past events and being able to respond promptly to disturbances in inflow conditions, particularly variations in flow rates and pollutant loads.[10]

SYNAPPS is an integrative platform, composed of hardware and software modules, with the aim of being installed in most medium and large WWTPs, with the hardware module composed of sensors existing on the market and the software module, developed in this R&D project, designed for each treatment phase, namely liquid, solid and gaseous phases. It will be a flexible and adjustable platform for each WWTP.

Once the R&D project has been completed, the next step for SYNAPPS will be commercialization as a platform adjustable to the different objectives/scenarios of each WWTP and respective client, with various solutions for the different challenges faced at each WWTP.

Methodology

The methodology involved, in a first phase, the acquisition of in-depth technological and scientific knowledge regarding advances in the functional, energetic and environmental performance of WWTP, namely through the collection of bibliographic information.

At the same time, data was collected from a WWTP in normal operation, aimed at establishing an operational, energy and environmental performance benchmark, as well as identifying the critical parameters for the optimization and valorization of the various treatment processes. These initial studies made it possible to support the definition of functional requirements for the new control and optimization system, taking into account the possibility of integrating it into different types of WWTP and its responsiveness in different application scenarios.

The technological development of the project was based on the definition of a functional structure capable of providing integrated management of the various treatment processes, including the identification of the best sensing, data communication and real-time optimization techniques.

Based on this definition, kits of components (hardware modules) necessary for the instrumentation of the various processing processes and respective data transfer were designed, based on which optimization models (software modules) are simultaneously being implemented that They will allow you to adjust treatment processes in real time, based on continuously collected data, ensuring high operational, energy and environmental efficiency.

These models are being developed taking into account the critical parameters of the operation of a WWTP previously identified, as well as the knowledge consolidated in the initial phase of the project, particularly with regard to soft sensors (estimation), intelligent, adaptive and tolerance control. failures, with an emphasis on methodologies based on artificial intelligence and machine learning. Technological development will also include the establishment of rules for implementing and operating the new system in different application scenarios.

After evaluating the performance of components and functional modules through numerical and experimental studies, the platform will be installed at the WWTP, which served to establish the operational performance reference, operational, energy and environmental performance, in order to validate the concept in all aspects relevant to its commercialization and subsequent use. The operational, energy and environmental performance of this WWTP was also monitored over the course of a full year, which could, in the meantime, be controlled using the new estimation, control and optimization platform.

With regard to environmental performance, a life cycle assessment study will be carried out to highlight the main advantages of using the new product. For this purpose, data on the operation and performance of the WWTP will be used in the pre- and post-application period of the control and optimization platform.

Using methods for determining performance indicators, which allow comparison between equivalent systems, an energy performance assessment will also be carried out with equivalent WWTPs. It is therefore believed that the complete sensing of a WWTP and the application of computational intelligence techniques will allow the development of optimization strategies that will lead to an overall increase in the efficiency of the treatment facility.

Target infrastructure of the project

The infrastructure selected for the development of the SYNAPPS Platform and which served to establish the benchmark for operational, energy and environmental performance was the Olhalvas WWTP, located in the city of Leiria, owned by the company Águas do Centro Litoral, SA and whose treatment line, nominal flow rate and equivalent population are described in the following Figure 2.

Population (HP 2035) - 60 000
HE Inflow flow-8 600 m3 / day

Liquid phase:

- Harrowing and sieving;
- Elevation,
- Degreasing/degreasing;
- Primary treatment;
- Secondary treatment:
  - Activated slats (2 anoxic Tanks + 2 Aerobic tanks, which promote the nitrification and denitrification processes)
  - Secondary decantation.

SOLID PHASE:

- Thickening;
- Anaerobic digestion;
- Mechanical dehydration.

GAS PHASE:

- Cogeneration.

Figure 2 Project target infrastructure.

The following Figure 3 shows an aerial view of the Olhalvas WWTP.

The choice of this installation was due to the fact that it complies with all the necessary requirements for the project, particularly in terms of location and because it covers the different phases and processes that may be involved in the treatment of wastewater, such as liquid, solid and gaseous, which encompass the processes of pre-treatment, primary treatment (primary decantation), biological treatment (which incorporates aeration and anoxic tanks, which promote the nitrification and denitrification processes, and secondary settlers), sludge treatment (thickening, anaerobic digestion and dehydration) and energy cogeneration.

Figure 3 Aerial view of the Olhalvas WWTP.

The Figure 4 shows the WWTP treatment scheme.

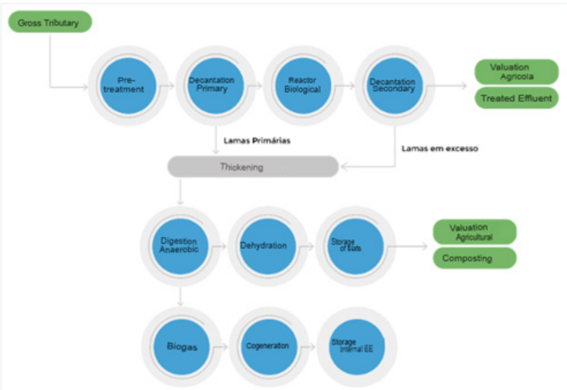

Figure 4 WWTP treatment scheme.

Project development status

In the initial studies, some of the most important aspects in the development of estimation, control and optimization systems, related to the selection of variables and models, were considered. Thus, with regard to wastewater treatment, an exhaustive survey was carried out of the variables that participate in the various treatment stages, as exemplified by a diagram of the treatment process of a WWTP composed of primary, secondary and tertiary treatment modules, implementing on These are the main parameters that determine the quality of effluents and sludge (Figure 5).

Thus, with a view to implementing a sensor network that serves the purpose of the new estimation, control and optimization platform, a survey and subsequent analysis of sensors available on the market was carried out, in order to allow the selection of instrumentation that can be applied in the acquisition of data on effluent quality by treatment stage and by analytical parameter. Once the equipment was selected, a first project was prepared for the network of sensors and controllers to be installed in the selected WWTP to establish the reference for operational, energetic and environmental performance, so that through the sensing of the various treatment stages and consequent data collection in time The development of the SYNAPPS platform will be continued, thus completing the system materialization phase, followed by fine-tuning the functioning of the data generating infrastructure to which computational intelligence techniques, studied in the meantime, will be applied, testing their suitability operation with real data, followed by a period of 14 months of monitoring that allowed the concept to be validated in all relevant aspects for its commercialization and subsequent use (Figures 6–11).

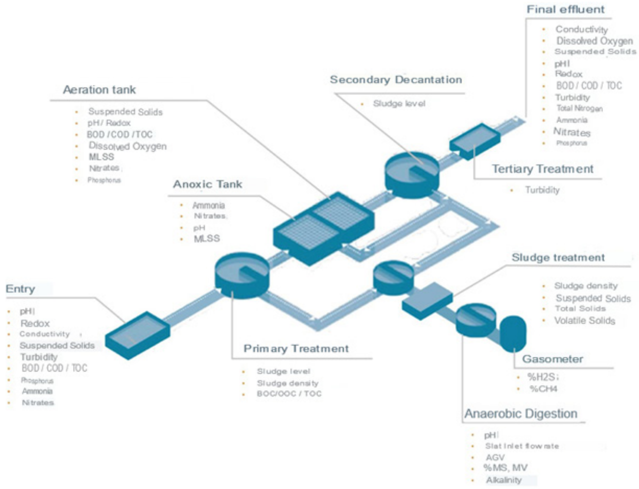

Figure 5 Scheme of the treatment process of a composite WWTP.

Figure 6 Entrance work.

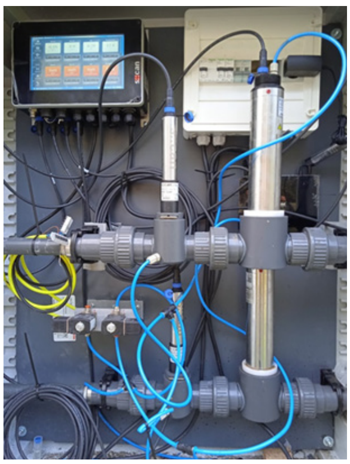

Figure 7 Primary treatment (liquid line).

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Figure 8 Primary treatment (solid line).

Figure 9 Anoxic tank.

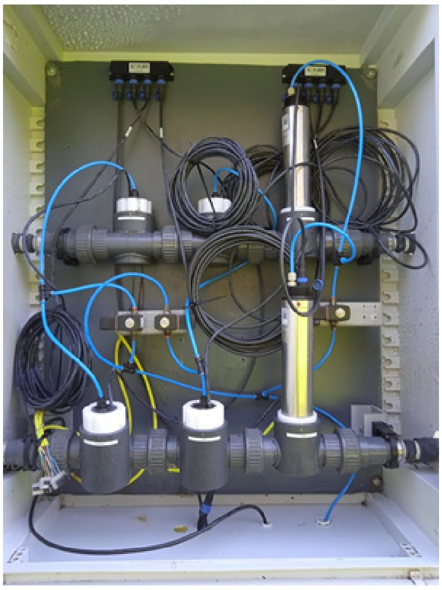

Figure 10 Aerobic tank.

Figure 11 Treated effluent.

The implementation of the sensor network was completed with the development of data acquisition and processing software, programmed in Labview and installed on a dedicated server (Figure 12) (Figure 13).

Figure 12 Data acquisition and processing software – Biological reactor – Aeration tank.

Figure 13 Data acquisition and processing software – Input work.

Supporting the information and data worked on in the meantime, a functional structure of the new estimation, control and optimization platform was outlined, dividing it into treatment modules, including treatment modules framed in the reality of the selected WWTP to establish the operational performance reference, nergy and environmental, but which project the replication of project results to different types of WWTP (Figure 14).

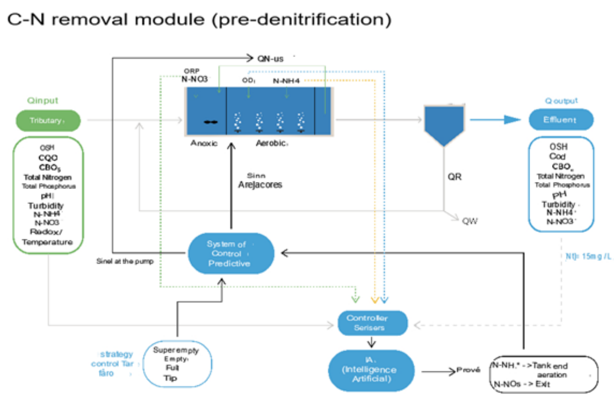

Figure 14 CN removal module (Pre-denitrification).

Synapps architecture

Taking into account that the management platform under development must simultaneously ensure the estimation, control and optimization of the treatment stages of a WWTP, identify the best computational intelligence techniques, as well as test their suitability in the presence of real data constitute essential next steps for the training and validation of algorithms, the SYNAPPS platform presents the possibility of different architectures, one according to an informative/classical aspect and another that will present itself as more interactive/intelligent/predictive.

The first then appears from an informative perspective to aid in the monitoring of WWTPs, in order to facilitate decision-making and make adjustments that allow improving the performance of WWTPs, both at an environmental, operational and/or energy level. It consists of different informative modules for each stage of treatment, which can be selected/aggregated based on what you want to improve/optimize. Each module will consist of hardware capable of continuously measuring critical control parameters and applying artificial intelligence techniques to estimate parameters in advance, providing alerts, as well as indicating to the operator the action(s) necessary to implement so that adjustments to processes are made prior to the development of problems.

The second comes from a perspective of greater interactivity with the aim of making WWTPs self-sufficient, without the need for constant intervention by operators to correct actions necessary for the normal functioning of WWTPs. It will be designed to optimize the WWTP, reducing environmental, operational and energy costs, act at the process level, automatically correcting the system, as soon as it deviates from what is desired or even before that happens, or even if it is not possible, automatically switch to a optional method that does not use the failed equipment, notify operators and automatically return to normal operation when the problem is rectified. This architecture is based on the application of artificial intelligence techniques to estimate parameters in advance so that adjustments to processes are made prior to the development of problems. This second option can act as a complement to the first when system automation is desired.

The following table presents the standardized modules developed within the scope of the SYNAPPS project.

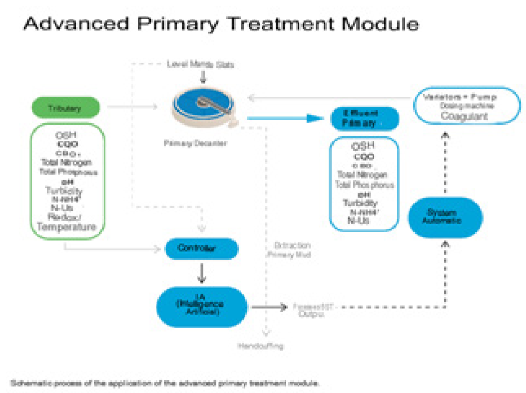

Figure 15 Advanced primary treatment module.

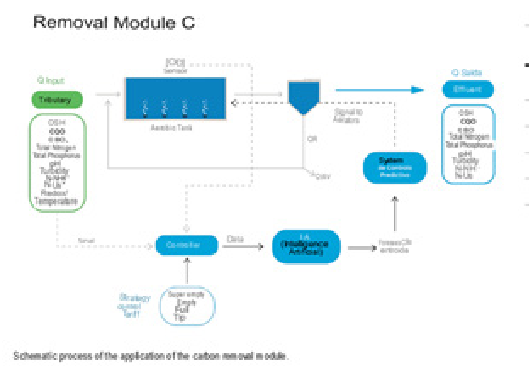

Figure 16 C removal module.

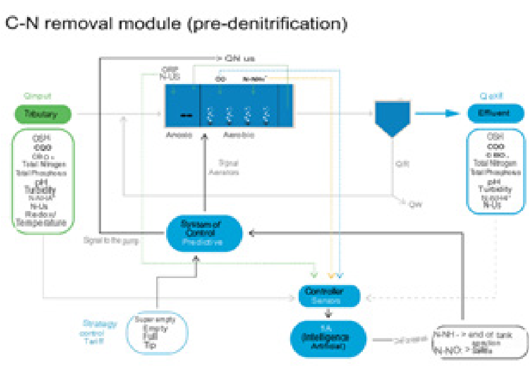

Figure 17 CN Removal module(Pre-denitrification).

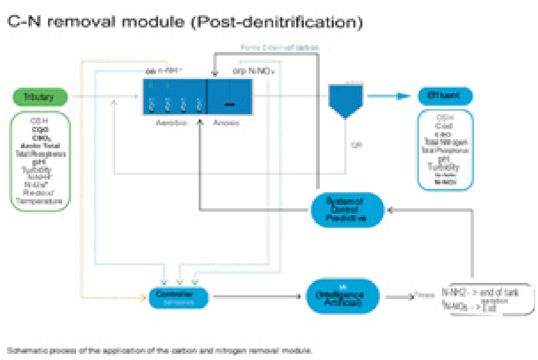

Figure 18 CN Removal module(Post-denitrification).

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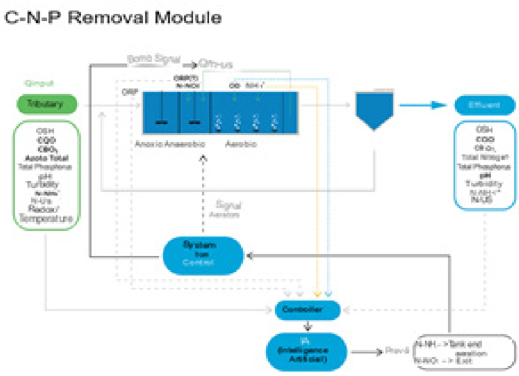

Figure 19 CNP removal module.

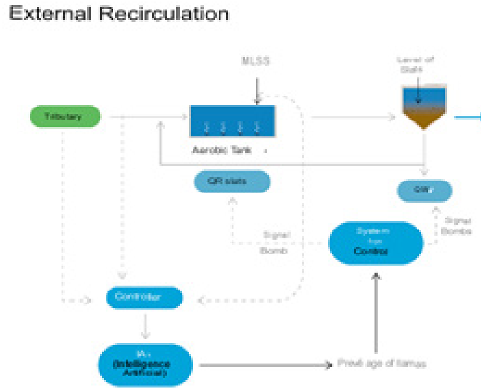

Figure 20 External recirculation.

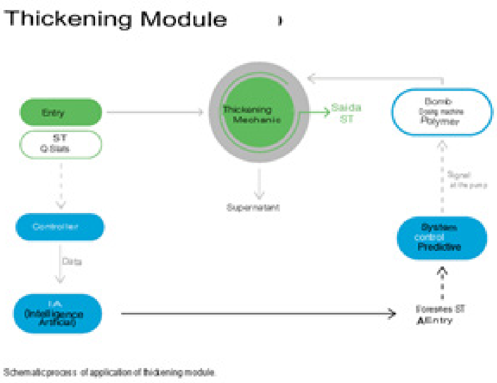

Figure 21 Thickening module.

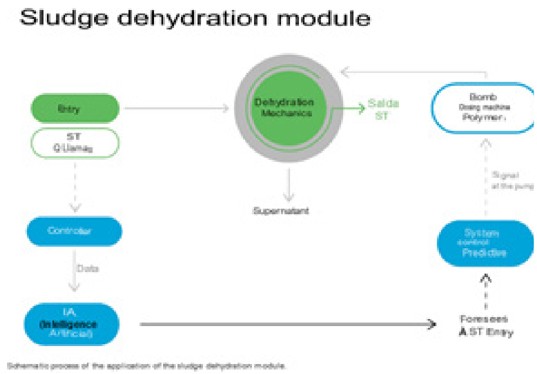

Figure 22 Sludge dewatering module.

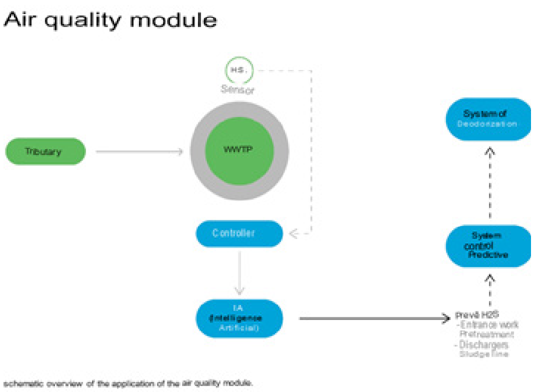

Figure 23 Air quality module.

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Conflicts of interest

The authors declare that there is no conflict interest.

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