"AquaSPICE – Advancing Sustainability of Process Industries through Digital and Circular Water Use Innovations"

George ARAMPATZIS[1]

[1]1School of Production Engineering and Management, Technical University of Crete, Chania, Crete, 73100, Greece

*corresponding author: George Arampatzis
e-mail: garampatzis@tuc.gr

Abstract Either we rethink how we use water or we threaten the availability. Even though there is overall enough water to meet the world's growing needs, it is necessary to make changes in how water is used, managed and shared. The EU-funded AquaSPICE project will increase awareness in resource efficiency. It will also deliver compact solutions for industrial applications, including water treatment and reuse technologies, and closed-loop recycling practices. The project will also develop a cyber-physical-system controller including a system for real-time monitoring, assessment and optimization of water use and reuse at different interconnected levels. The overall approach is based on the adaptation of technologies and practices – from a single industrial process to an entire industry..

Keywords: wastewater treatment, process industry, modelling, circular economy, cyber-physical systems, digital twins

1. Introduction – Challenges

More and more industries strive to become water supply independent by incorporating water recycling and re-use practices via new construction, upgrades, or retrofits of existing treatment processes, to be able to recover water and utilize it. The availability of advanced wastewater treatment technologies allows for extremely high purification levels and opens the possibility for many forms of re-use and recycling. **Zero-liquid discharge** (ZLD) is a principle and an engineering approach to water treatment where closed-loops are used so that all water is recovered while contaminants are reduced to solid waste. Although ZLD systems are capable of minimizing freshwater consumption, their industrial-scale applications are restricted due to their high cost and intensive energy consumption.

An important aspect to be considered, when adopting closed-loop water re-use options, is that there is no 'one size fits all' solution. The reality is that, across any industrial facility, water is required, at very different levels of quality and quantity. In (or around) the plant there are also different sources of (waste) water with different quality characteristics. The production of water at a higher quality than required can result in overtreatment, leading to unnecessary cost and overuse of resources such as energy. Water recycling and re-use engineered with a **fit-for-purpose** (FfP) approach can result in much more cost-effective solutions.

The **digital transformation** of the process industry is one of the biggest shifts we see moving forward. Production processes are in the throes of Industry 4.0 and related Water 4.0 transformation. By providing insights into water and energy consumption, and implementing proactive and more targeted maintenance, digital technologies may enable operators to optimise water re-use practices and offer valuable tools to address water sustainability challenges. More importantly, it is the suitable combination of digital solutions with novel water recycle and re-use technologies that offers much greater potential, due to synergies that allow for extensive optimisation. In contrast to prior innovations that were primarily bound to physical devices/technologies, new products are increasingly embedded into systems that span the physical and digital world. These synergies can be pursued beyond the boundaries of a single industry by making it more aware of its external environment. There is much potential left unexploited in the application of smart digital technologies for supporting holistic water management schemes.

Considering that future process industries must be more and more agile and adaptable, industrial water efficiency systems should also be adaptable to changes (e.g. new product versions/types, changes in production lines and technologies). Currently, the huge potential of the Cyber-Physical Systems (CPS) technology is reflected in the better design of an asset, based on extensive simulations under various conditions by applying mathematical models to simulate the behaviour of complex systems and providing a snapshot of the real world. However, in an era where real-time data is quickly becoming a commodity, the role of data becomes critical in effectively modelling real-world assets. Built on the foundations of the IIoT and utilising big data analytics combined with AI, deep learning and cognitive capabilities to find patterns in structured and unstructured data from industrial systems, the emerging field of **Cognitive Manufacturing** is characterised by the vision and capacity to perceive changes in the production process and know how to respond to dynamic variations.

2. Project Outline and Objectives

AquaSPICE aims at materializing circular water use in the European Process Industries, fostering awareness in resource-efficiency and delivering compact solutions for industrial applications. That challenging aim necessitates (i) multiple state-of-the-art water treatment and re-use technologies, (ii) diverse closer-loop practices regarding water, energy and substances, (iii) a cyber-physical-system controller in the form of a system for real-time monitoring, assessment and optimization of water (re-) use at different interconnected levels and (iv) an effective methodological, regulatory and business framework. AquaSPICE not only offers these but claims their sufficiency, as also supported by the breadth of European process industries who are here to evaluate (i)-(iv).

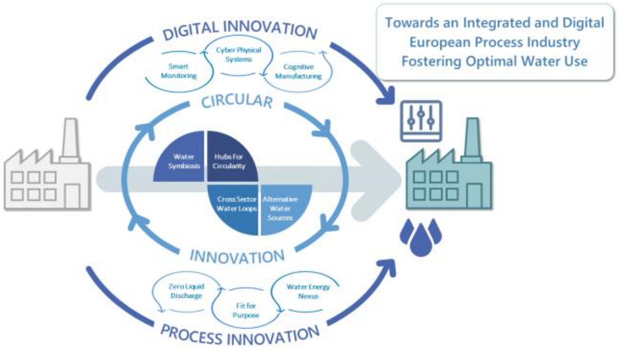

Figure 1. AquaSPICE vision, strategy and offerings.

The AquaSPICE overall goal is the development and validation of water efficiency management and optimisation methodologies, technologies and tools that will carry process industries forward to a near-zero water footprint target with minimum freshwater consumption and water-borne emissions. The project follows a systemic approach in water management where optimal efficiency can be achieved through an adaptation of appropriate technologies and practices in different levels

Finally, AquaSPICE enables and facilitates the immediate uptake, replication and up-scaling of innovations, by providing comprehensive strategic, business and organizational plans that offer a range of well-defined and pre-packaged solutions, suitable for various cases with quite different characteristics.

3. Project Innovation Pillars

AquaSPICE develops, integrates, demonstrates and offers innovation that transverses three pillars (see Figure 1):

i. **Process Innovation**: A comprehensive set of advanced technologies and practices, combining energy and substances recovery are installed, operated and assessed within AquaSPICE's case studies, leading to novel solutions for water saving, treatment and recycling. These are being diligently selected through background review and case-specific needs (a) to bring tangible improvements per case study while ensuring transferability to many relevant settings in European industries.

ii. **Circular Innovation**: Closed-loops including water re-use options at different levels (in-process, in-factory, water industrial symbiosis, cross-sectorial – see Figure 2) are established, considering also different water sources. These demonstration schemes are being designed, monitored and evaluated using systemic methodologies and tools, based on holistic modelling concepts, like dynamic Life Cycle and Life-Cycle-Cost Assessment.

iii. **Digital Innovation**: The novel concept of a water-specific Cyber-Physical-System (WaterCPS) syntheses digital twins of industrial and value chain entities to provide advanced water-saving awareness and optimised water efficiency at different industrial levels. Based on analytics-AI-learning methodologies, WaterCPS will bring in cognitive-manufacturing methods and tools for dynamic process adaptation after route-cause analysis for detecting non-optimal water use, in order to continuously minimise freshwater consumption and emissions. Underlying WaterCPS, a real-time monitoring and distributed data management system, connects the physical and digital worlds through smart sensor networks, IIoT and cloud/edge technologies.

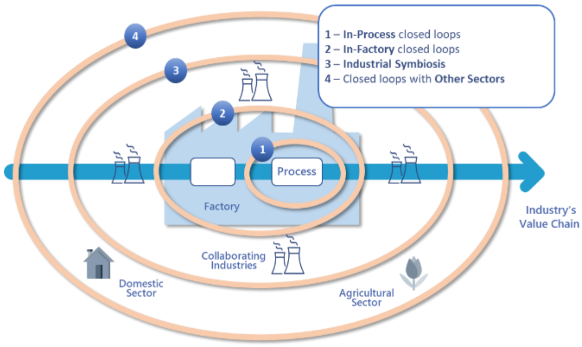

Figure 2. Industrial Water Circular Practices in AquaSPICE.

4. Project Partners and their Roles

AquaSPICE's consortium, consisting of 28 partners from 11 countries, was formed mainly on two criteria. Its R&D activities require a multi-disciplinary approach to benefit from state-of-art (SotA) in industrial water treatment/ recovery/recycle/re-use technologies, sensor networks, data analytics, process modelling and optimisation and progress in further fields such as cyber physical systems, digital twins, digital cognition/inference and cyber security. An analysis to the main project areas of expertise shows that 12 partners provide expertise and technology on industrial water recycle/reuse (RWTH, KWR, ICCS, EUT, UGENT, VITO, UNIPVM, LBE, HZ, EVIDES, ARETUSA, TUC); 4 on water environments and platforms (WE, WL, ARETUSA, VITO); 4 on industrial processes, modelling, optimization and symbiosis (TUC, AUEB, UOH, STRANE); 3 in knowledge engineering, virtualization and AI (ICCS, EUTMAG); 6 on monitoring networks and other ICT technologies (MAG, EURECAT, ICCS, VITO, UGENT, KWR); 4 in enterprise/business, organization planning and marketing (STRANE, BDG, ACCELI, ABS); and 5 large industries, some multinational, with highly skilled teams.

5. Project Use Cases and Expected Outcomes

AquaSPICE's innovations emanate from the requirements of 5 Case Studies, involving 7 industrial actors (Dow, BASF, Water-Link, Solvay, ARETUSA, Agricola and TUPRAS) in 5 EU countries (Germany, Netherlands, Belgium, Italy and Romania) and 1 associated country (Turkey).

Figure 3. AquaSPICE Innovation Early Adopters.

CS#1 – Technology focus for fresh water intake reduction at Dow: Two industrial location are examined: The Boehlen location of Dow and I-Parc Dow Terneuzen, both strive to reduce their freshwater intake intensity by: (i) enhancing the internal recycle of various process water streams – these comprise but are not limited to cooling tower blowdown and dilution steam blowdown streams; (ii) creating a next level of site water management by using smart monitoring, algorithms and control on raw water, discharge and recycle streams.
CS#2 – Water treatment and re-use within peroxide production units at SOLVAY, ARETUSA: The Rosignano Solvay industrial site is examined togrthrt with Consorzio ARETUSA, established as a PP, in order to deliver more sustainable water management.Within AquaSPICE, industrial water cycles may still be optimised towards increased energy and carbon efficient water re-use. The pilot-plant will be validated in real environment along with a techno-economic feasibility assessment and digital integration with the industrial production site.
CS#3 – Sustainable and robust water system for the industrial zone of Antwerp at BASF, WL: The Port of Antwerp is the leading European oil and chemical cluster in Europe and home to key industrial players in chemicals production. The largest water user in the port of Antwerp is the BASF site.The area is, facing increased problems of managing freshwater resources – for drinking water, industry and transport (inland shipping) – in terms of both water quantity and water quality. This requires the development of integrated water-smart strategies for industrial processes demonstrating water recycling technologies and real-time smart monitoring and management systems.
CS#4 – Sustainable water use in meat production in the circular economy at AGRICOLA: Water is a critical resource for the poultry, meat and agricultural industry. The pilot case study to be implemented at AGRICOLA will employ smart solutions for sustainable water reuse and resource recovery, with the objective of improving water efficiency monitoring and achieving process optimisation.
CS#5 – Water treatment and re-use within refinery at TUPRAS: Oil & gas refining industry is highly water intensive, requiring vast amounts of water, used as cooling water, service water, firefighting water, demineralization water and for steam production. The Tupras Izmit Refinery is consuming both fresh water from the lake and treated wastewater from its own wastewater recovery plants. In order to increase the water reuse opportunities and decrease freshwater intake from the lake, any attempt approaching near zero discharge goal is considered seriously.

6. Sustainability and future work

The key innovation of the AquaSPICE project is the development of WaterCPS. This is a Cyber-Physical System (CPS) specialized to enhancing water efficiency in the Process Industry. Water efficiency enhancement is approached from three directions: (a) diagnostic (monitoring water efficiency, diagnosing problems, estimating improvement margins); (b) production chain enhancement (application of SotA water recovery technologies & practices); and (c) optimization (of water use/recovery/reuse processes).
As the name WaterCPS implies, it consists of a physical part and a cyber (digital) part. The physical part comprises of the industry's existing production line(s) and value chain(s), plus the new SotA water efficiency technologies & practices selected, configured and deployed by AquaSPICE. The cyber part consists of the Digital Twin (incl. its knowledge core, models and cognitive services & tools), the Real Time Monitoring system (RTM) and the WaterCPS digital Platform (incl. data/control connections & management, interfaces & user applications, access control components). The RTM plays the role of intermediary between the physical system and its digital twin, with its sensors incorporated as part of the physical system and its data communication & management components incorporated as part of the cyber system.
The expectation from AquaSPICE is that the cyber part of WaterCPS and its integration with the water efficiency technologies & practices, will create significant added value for them and have a measurable impact on water efficiency by supporting the above mentioned three directions to water efficiency enhancement.