Circular Economy: Recovery, Reuse & Valorization

Alternative Water Sources

KEYWORDS: Alternative Water Sources / Capture Condensate from Air / Reclaimed Water / Hydrate-Based Desalination

New technologies to obtain alternative water sources, including the use of adsorption processes to recover water from the air, tertiary/quaternary treatments of urban wastewater, and hydrate-based desalination.

Introduction

As water usage continues to exceed sustainable rates and greater quantities of pollutants come in contact with once pristine water sources, more people are becoming concerned as to where their water will come from. By 2030, the world is projected to face a 40% global water deficit under the business-as-usual scenario. There are now more than two billion people who live in places that are experiencing high water stress. Global Water Institute figures suggest that 700 million people around the world could be displaced by intense water scarcity by 2030 – which is just a decade away. In addition to this, climate change is increasing the frequency and intensity both of droughts and storm events, while higher air temperatures necessitate greater water use for crop irrigation and livestock. For these reasons, alternative water sources, such as rainwater harvesting, captured condensate from the air, water reuse (greywater, urban wastewater), and desalination, as well as moving towards more holistic, integrated approaches to water management are becoming more popular for meeting the global water needs that may not be satisfied by a single water source.

Current Development

Captured condensate from air

Atmospheric water harvesting can be made by several approaches including direct harvesting, fog harvesting, or water from moist harvesting. The latter option has the advantage of allowing to obtain water from the air at lower relative humidity than typically used with fog. Among the technological options for reclaiming liquid water from the available atmospheric moisture, sorption-based atmospheric water generators are one of the most promising, especially due to the recent development of novel materials, such as Metal-organic frameworks (MOFs), that are ideal for this application due to their unique water adsorption properties and efficient renewability at moderate temperatures. The main advantage of this technology is that no extra stress will be imposed on the natural ecosystems, and will mitigate the existing pressure on water resources, such as fresh groundwater and (small) rivers. Two MOF samples were tested, Al-Fumarate and CAU-10. CAU-10 is suitable for water capture in arid regions ($P/P_o < 0.3$) due to the presence of a steep step at low relative pressures. Al-Fum displays a sharp uptake for relative pressures between 25 % and 38.5 %. CAU-10 presented higher water adsorption comparatively with Al-Fum. The TSA process is capable of producing 84.0 $L \cdot day^{-1}$ and 81.3 $L \cdot day^{-1}$ for a TSA column volume equal to 0.98 and 0.35 m^3, respectively, using a purge temperature of 373 K and condensation temperature – 283 K.

Reuse of urban wastewater

Recycled water sourced from urban wastewater treatment plants, represents a constant flux of safe water over time for different applications, including irrigation of crops and green hydrogen production through water electrolysis. This water is in abundant supply and volume and is consistent throughout the year. Right now, much of the recycled water produced is discharged back into the environment due to legislative and cost barriers that limit its use. This presents an opportunity for water utilities to generate more value from recycled water by using it for agriculture and H_2 production, and at the same time reach the goal established by Portuguese authorities to reuse 10% of urban wastewater before 2025 and 20% by 2030.

Tertiary/quaternary treatments, including ozonation, UVC/H_2O_2, UVC/chlorine, UVC/persulfate, photo-Fenton, nanofiltration, adsorption, and its combination, have been tested for the removal of contaminants of emerging concern (CECs), bacterial disinfection, and toxicity reduction, targeting high-quality water for irrigation of crops. This work was/is being carried out under several R&D projects, including NOR-WATER (Interreg, http://nor-water.eu/en/home/), OZONE4WATER (FCT, https://ozone4water.com/) and SERPIC (WaterJPI, https://www.serpic-project.eu/). Under the NOR-WATER project, it was concluded that the combination of ozonation (specific ozone dose of 1.2 g O_3 per g of DOC-Dissolved Organic Carbon) with activated carbon adsorption, reduced the concentration of CECs and microbiological parameters below the limit of quantification. Regarding toxicity, no toxic effect was detected on zebrafish embryos using a dilution factor of 2.

The treatment solution of SERPIC (see Fig 1) is based on membrane nanofiltration, splitting the secondary wastewater flow into a permeate with negligible amounts of CECs while preserving the nutrients for route A, and a concentrate that contains the rejected pollutants for route B. The oxidant chlorine-dioxide is added to the stream of route A to receive a residual disinfection so that microbials will be avoided until the water reaches the field. Powerful oxidants (peroxosulfate, chlorine dioxide or ozone) produced electrochemically, are activated by deep UV, to minimize the CEC content in the stream of route B.

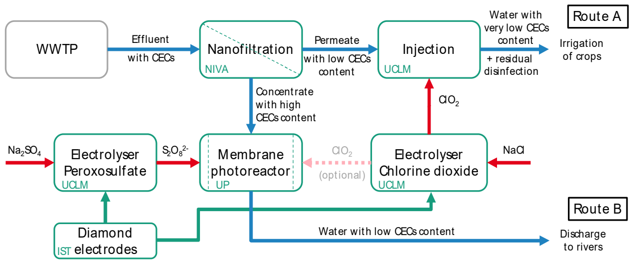

Fig 1. SERPIC multi-barrier approach for urban wastewater treatment.

Nanofiltration was effective in the removal of CECs (>90%) as also microbiological contaminants, complying with targets set by the EU regulation on minimum requirements for water reuse for agricultural irrigation. Regarding the nanfiltration concentrate, ozonation showed better results than the photochemical processes, UVC/persulfate, UVC/H_2O_2 and UVC/hypochlorite, enabling more than 80 % reduction in the majority of CECs detected, aligned with the new EU proposal for the Directive concerning urban wastewater treatment.

Hydrate-based desalination

Within the cooperation between LSRE-LCM and CoLab NET4CO2 hydrates were assessed as a dessalination technology. This research was focused on the simulation of integrated processes, using ASPEN and experimental data from the continuous production of carbon dioxide to remove salt from water. The direct use of carbon dioxide is yet not competitive with conventional desalination through Reverse Osmosis (RO). RO was used as the benchmark case for this research. For the carbon dioxide case, the cooling operations,

even considering energy integration, penalize the overall energy consumption rendering this process less competitive than RO.
Several process scenarios were assessed to establish the applicability of hydrates-based technologies. These cases included the use of propane hydrates, and process integration with the expansion of Liquidified Natural Gas injection (LNG) when received from ships for injection into pipelines. The comparison of some hydrate-based scenarios for water desalination with RO is shown in Table 1. Fig 2 shows one process diagram that was simulated with ASPEN for the techno-economical evaluation of each scenario.

NEWater project (Water4All) and agenda H2DRIVEN (Portuguese Recover and Resilience Plan) - Explore the uniquely synergistic relationship between municipal WWTPs and green hydrogen production that is both positive for the environment and partially subsidise hydrogen production via electrolysis and increases its commercial viability.

Related Sustainable Development Goals

Outputs

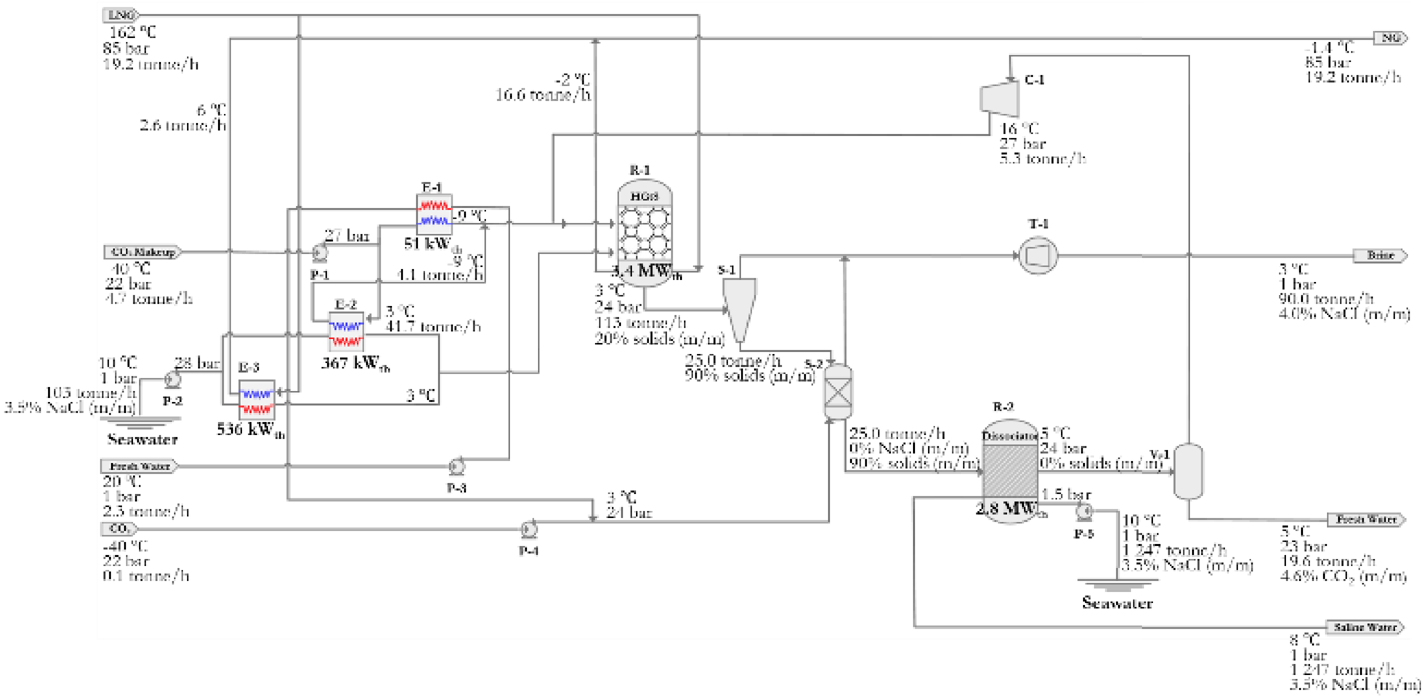

Fig 2. Hydrate-based desalination technology using CO2 as hydrate-forming gas and LNG as a cold utility.

This technology is planned for industrial exploitation, within the scope of CoLab NET4CO2 activities, so the main outputs were not published and are two theses currently under three years of confidentiality. One thesis was made in 2023 at CoLab NET4CO2 under the supervision of Ricardo J. Santos: "Experimental proof-of-concept, process simulation, and economic analysis, via Aspen Simulation, of hydrate-based desalination". The other thesis, from Isabel Fernandes ("Multiphase Flow in Mesostructured Reactors", concluded in 2023), is part of the outputs on Industrial Process Design, and has a section on this topic.

Table 1. SEC of desalination technologies.

Desalination Technologies	SEC/ $kWh \cdot m^{-3}$
CO_2	13.2
CO_2 with LNG	3.8
C_3H_8	9.1
C_3H_8 with LNG	2.7
Reverse Osmosis	3 - 4

Future Perspectives

SERPIC project – Validation of the integral treatment at pilot scale and evaluation of the produced water for irrigation in long-term tests with the help of agricultural test pots.

PhD Theses

[1] Pedro Henrique Presumido, Membrane processes for tertiary treatment of urban wastewaters: photocatalytic membrane reactor and ozone membrane reactor, PDEA, FEUP, 2023

Master Dissertations

[1] Carla de Sousa Santos, Foto-Fenton a pH neutro usando um foto-reator de membrana tubular para dosagem radial de Fe(II): Avaliação da degradação de contaminantes de preocupação emergente em águas residuais, MIEA, FEUP, 2022

[2] Gonçalo Pereira, Experimental proof-of-concept, process simulation, and economic analysis, via Aspen Simulation, of hydrate-based desalination, MEQ, FEUP, 2023

Team

Vítor Vilar Principal Researcher; Alexandre F., Professor; Ricardo J., Auxiliar Researcher; Ana Isabel Gomes, Junior Researcher, Pedro Presumido, PhD Student; **Carla Santos**, PhD Student

Funding

NOR-WATER, 0725_NOR_WATER_1_P, 2019-2022
OZONE4WATER, PTDC/EAM-AMB/4702/2020, 2021-2024
SERPIC, Aquatic/0002/2020, 2021-2024
LSRE-LCM Base Funding, UIDB/50020/2020, 2020-2023
LSRE-LCM Programmatic Funding, UIDP/50020/2020, 2020-2023
LA LSRE-LCM Funding, UID/EQU/50020/2019, 2019
LA LSRE-LCM Funding, POCI-01-0145-FEDER-006984,2013-2018
FCT Scholarships: SFRH/BD/138756/2018, 2022.10796.BD