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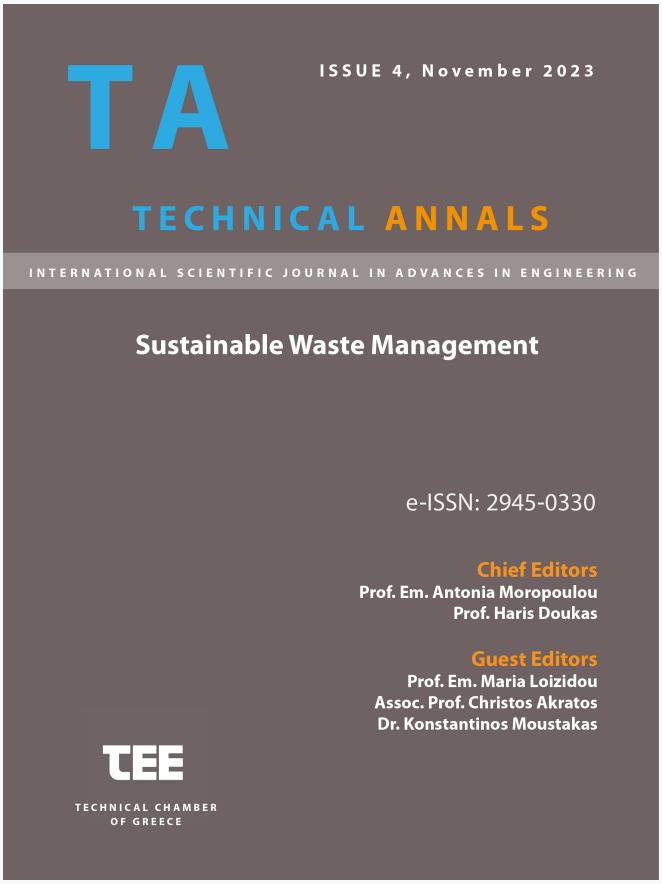

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Design of an innovative system for the detoxification of pharmaceutical wastewater

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Abstract
The concentration of Active Pharmaceutical Ingredients (APIs) in wastewater is directly affected by the increasing worldwide use of pharmaceuticals. The release of the wastewater may contaminate the surface water and marine life. Conventional wastewater treatment plants (WWTPs) are unable to remove completely all APIs. The most frequently used methods are conventional activated sludge system (CAS) and membrane biological reactors (MBR); based on studies the removal percentage of APIs in these methods was lower than 10% in some compounds. Catalytic hydrogenation is a highly effective water treatment process that offers superior selectivity and reactivity compared to traditional methods, without the use of any chemicals. There is no need for additional wastewater treatment to remove any toxic byproducts that may be produced, making the process cost-effective and efficient. The catalytic reactions of hydrogenation are also rapid reactions with short residence times and smaller reactors, reducing both the operations and installation costs. The main components of the proposed pilot system are a mixing tank, a filtration system, a water electrolysis unit operating with Renewable Energy Sources (RES), and a catalytic reactor where the concentrated stream from the filtration system will be treated. In this reactor, the pharmaceutical compounds in the presence of a catalyst will be hydrogenated and converted to non-critical organic matter. The designed system fully operates with renewable energy-solar energy, under room temperature and pressure conditions.

Keywords: APIs, wastewater, pharmaceutical industries

1 Introduction

1.1 Environmental Problem

In recent decades, there has been a significant surge in the use of pharmaceuticals, placing an increasing burden on the environment due to their widespread release [1,2]. Human and veterinary drugs enter the environment primarily through manufacturing processes, improper disposal, and metabolic excretion. Numerous studies confirm the presence of pharmaceuticals in aquatic ecosystems, particularly antibiotics, which comprise a substantial portion of global pharmaceutical consumption. Antibiotic residues have been identified in various water sources, including surface waters [4],

groundwater [3], seawater, drinking water [5], municipal wastewater treatment plant effluents [6], and hospital wastewater.

Based on the literature [7-9], the number of residues (ng/L to low μg/L) that remain even after wastewater treatment can still induce toxic effects. The persistence of these residues is attributed to the extensive use of pharmaceuticals worldwide, both in human and animal contexts. This continuous usage results in the continuous introduction of pharmaceuticals into the environment, leading to their bioaccumulation. Despite the relatively short environmental half-lives of pharmaceuticals, their continuous presence and impact on the environment are described as pseudopersistent. This term reflects the ongoing introduction of pharmaceuticals into ecosystems, contributing to their sustained presence and potential ecological consequences. Some pharmaceuticals remain in the aquatic matrix because they are highly polar and non-volatile.[8]

Many of these pollutants possess endocrine-disrupting qualities, and are non-biodegradable, toxic, or persistent, emphasizing the need for their degradation and removal before being released into the environment. This becomes particularly crucial when considering the reuse of treated water for irrigation, a process known as wastewater reclamation. In this context, there is a heightened concern as these contaminants may accumulate in soil and crops.[10] The significance of wastewater reclamation lies in its contribution to better water resource management, as it generates water of adequate quality for non-potable uses. These non-potable uses do not necessitate water that meets drinking water standards. By reclaiming water, we can substitute it for freshwater, resulting in substantial freshwater conservation that would otherwise be wasted. However, the reclaimed water must be devoid of persistent, toxic, endocrine-disrupting, or non-biodegradable contaminants to ensure its suitability for reuse without posing risks to the environment and agriculture.

Conventional WWTPs are capable of removing only some contaminants. Non-biodegradable contaminants may not be treated adequately and be released into the environment, as is documented by several studies.[11]

In a study conducted by Verlicchi et al. in 2012 [6], they collected and analyzed data from 264 WWTPs located across various global regions. Out of the 264 WWTPs investigated in this study, 244 were CAS systems and 20 were MBR. The study identified five compounds—diclofenac, ibuprofen, indomethacine, ketoprofen, mefenamic acid, and tramadol—with removal percentages lower than 10%. The researchers noted that the presence of certain pharmaceutical compounds in the effluent released from WWTPs into surface water bodies could pose a medium to high-acute risk to aquatic life.

This study highlighted that some pharmaceutical compounds, individually non-toxic, were being released into the environment at high daily mass loads. This raised concerns about potential negative effects on aquatic life over the long term, considering chronic exposure and a mixture of toxicities. Additionally, they found the presence of several pharmaceuticals, including ibuprofen, ketoprofen, diclofenac, ofloxacin, and azithromycin, in sewage sludge.

Several independent studies have suggested that the repetitive application of biosolids, sludge, or even the irrigation of wastewater rich in pharmaceutical residuals to agricultural soils may lead to an increase in the concentration of these compounds in the

soil over time. This could have implications for key ecological functions, such as the carbon cycle, and may impact the environment significantly.[12] Five hundred fifty-nine different pharmaceuticals have been detected globally in the wastewater matrices of sewage, WWTP effluent, effluent, and sludge. A close relationship between occurrences in treatment plants effluent and surface waters can be assumed since most treatment plants discharge directly into surface waters, such as rivers and lakes.[13]

More than a hundred different pharmaceutical substances were found in several European countries and the United States of America in the aquatic environment (surface water, groundwater, and /or drinking water).[13]

In 2016, the United Nations recognized the urgent need for immediate action to address the global threat of antimicrobial resistance (AMR). While the contribution of antibiotic release from manufacturing sites constitutes a relatively small portion of overall antibiotic emissions into the environment, poorly controlled discharges in certain manufacturing sites can lead to elevated levels of active residues in water, soil, and sediments surrounding these areas, creating hotspots of AMR. Acknowledging this concern, the pharmaceutical industry has undertaken commitments to mitigate the release of antibiotics into the environment resulting from its operations.

To achieve this goal, a coalition of companies collaborated to specifically tackle issues related to antibiotic residues discharged from manufacturing sites. Beyond establishing a framework outlining minimum environmental expectations for antibiotic manufacturers, this alliance, dedicated to combating antimicrobial resistance, also sets science-based targets for receiving waters. These targets, expressed as predicted no-effect concentrations (PNECs) for antibiotics discharged during manufacturing operations, mark a significant step forward in establishing a quantitative basis for implementing effective methods to reduce the environmental impact of manufacturing emissions.

In March 2019, the Commission adopted the European Union Strategic Approach to Pharmaceuticals in the Environment (PiE) which focuses on addressing the environmental impacts of all stages of the lifecycle of pharmaceuticals (both human and veterinary), from design and production through use to disposal.

The proposed system is expected to align with and contribute to several important European environmental policies and objectives. These include the Circular Economy package of 2018, Water Framework Directive 2000/60/EC, a strategy against the pollution of water that sets environmental quality standards, Directive 2008/105/EC which sets environmental quality standards (EQS) for priority substances and certain other pollutants, Directive 2000/60/EC which aims to achieve good surface water chemical status, Commission Implementing Decision C(2020)5205 and the selection of substances for the 4th Watch List under the Water Framework Directive, as well as the reference Document for the Production of Large Volume Organic Chemicals. The key targets of the 2030 Climate & Energy Framework are to reduce greenhouse gas emissions from 40% to at least 55%, increase the share of renewable energy from 32% to 42.5%, decrease energy consumption from 32.5% to 36%, and achieve a 39% improvement in energy efficiency by 2030.

The overall aim of this study is to design a system for the detoxification of wastewater from the pharmaceutical industry. This will be achieved by developing and implementing an innovative, economically viable, and cost-efficient system for

transforming pharmaceutical compounds into non-toxic substances (a novel detoxification process). The system will be able to treat the wastewater generated from production activities, ensuring the safe reuse of treated water for irrigation, cleaning, and cooling purposes. Ensuring in this way that no APIs would end up in the wastewater sewage system without being processed and detoxified by the system.

2 Applied techniques for the detoxification of pharmaceutical substances in wastewater

2.1 Conventional Methods

Pharmaceuticals are now recognized by the scientific community as chemicals of emerging concern (CEC) that were found to be harmful to aquatic life, the ecosystem, and potentially human health.[14] Conventional WWTPs are not designed to remove pharmaceutical compounds from wastewater and as a result, pharmaceuticals are released into surface waters.[13-16]

Conventional wastewater treatment facilities typically use biological degradation using an activated sludge process, whereas advanced facilities have treatment processes, such as membrane filtration (reverse osmosis), ozonation, and advanced oxidation technologies. Pharmaceuticals are a diverse group of chemicals, with varying physical and chemical properties. Treatment efficacy depends on these physical and chemical characteristics (e.g. hydrophobicity), their reactivity towards different treatment processes, and process control, such as solids retention time, temperature, and hydraulic retention time. Many pharmaceuticals are hydrophobic, which makes them less effectively removed by sorption into sludge. This means that treatment removal efficiency can vary significantly between different treatment facilities or at different times within the same facility.[17]

Membrane filtration has been used more extensively recently as a tertiary treatment step, but this method can not remove pharmaceutical pollutants effectively. Moreover, in membrane filtration, the membranes get clogged and need regeneration which increases the cost of the method. This method needs a high initial investment and has a high operating cost.

Ultraviolet radiation needs a very high initial investment and high operating costs due to high energy demand. Electro-oxidation also has high operating costs and is only efficient when the effluent is conductive. Another drawback of this method is that electron fouling occurs as a result of the deposition of material on the electrode. Disinfection of wastewater using chlorine may produce harmful by-products.

Advanced Oxidation Processes (AOPs) are studied extensively by the scientific community, but very few WWTPs have applied AOPs. Advanced oxidation processes usually require high treatment time and high energy costs, and methods like Fenton oxidation or Fenton-Zeolite catalysis need additional process steps for the separation of the catalyst or the removal of toxic products and additional reagents like ozone, hydrogen peroxide, or ultraviolet light. These additional requirements increase the installation and operating costs further. Table 1 shows the results of several studies that

illustrate the removal rates that different wastewater treatment processes can expect. These are based on observations of treatment processes ranging from single-unit processes to full-scale wastewater treatment facilities found in the various studies.[18]

Table 1. Results of several studies illustrate the removal rates that can be expected by different wastewater treatment processes.

Treatment Process	Removal Range (%)	Water Source	Studied Area	Reference
Conventional wastewater treatment processes				
Activated Sludge	11-99	Raw Sewage	Australia	Watkinson, Murby & Costanzo (2007)
	7-100	Primary settled sewage	Europe, Japan	DWI (2007)
	<20-80	Primary settled sewage	France	Gabet-Giraud et al. (2010)
	-193-86	Primary settled sewage	Europe	Vieno, Tuhkanen & Kronberg (2007)
	8-98	Not specified	Brazil, Europe, Japan	Ziylan & Ince (2011)
Biological filtration	6–71	Primary settled sewage		DWI (2007)
Primary settling	3–45	Not specified	Brazil, Europe, Japan	Ziylan & Ince (2011)
Coagulation, filtration, and settling	5–36	Not specified		

Sand filtration	0–99	Activated sludge effluent		
Advanced wastewater treatment processes				
Ozonation	1-99	Activated Sludge effluent	Brazil, Europe, Japan	Ziylan & Ince (2011)
	86-100	Secondary effluent	France	Gabet-Giraud et al. (2010)
Ozonation/ultrasound and sonocatalysis	23–45	Not specified	Europe, India, Japan, Turkey, USA	Ziylan & Ince (2011)
Ozonation and catalytic ozonation	> 9–100			
UV irradiation	29	Not specified	Brazil, Europe, Japan	Ziylan & Ince (2011)
Photolysis (UV/ hydrogen peroxide)	52-100	Not specified	Europe, India, Japan, Turkey, USA	Ziylan & Ince (2011)
Dark and light Fenton	80-100			
UV/ TiO_2	>95			
Biomembrane	23-99	Treated effluent	Brazil, Europe, Japan	Ziylan & Ince (2011)
Microfiltration and RO	91-100	Secondary treated effluent	Australia	Watkinson, Murby & Costanzo (2
Reverse osmosis	62–97	Secondary treated effluent	France	Gabet-Giraud et al. (2010)

Ultrasound	24–100	Not specified	Europe, India, Japan, Turkey, USA	Ziylan & Ince (2011)

Activated sludge processes can achieve higher removal efficiency than simple biological filters, as shown in Table 1. Removal rates for pharmaceuticals can vary [19], depending on sludge age, activated sludge tank, temperature, and hydraulic retention time. [20] Advanced wastewater treatment processes, such as ozonation, membrane treatment, and advanced oxidation, can achieve higher removal rates (up to 100%) for pharmaceuticals compared with conventional processes. For example, another bench-scale study showed that advanced oxidation processes can achieve up to 100% removal of diclofenac.[21]

Predicting removal rates for pharmaceuticals is feasible within wastewater treatment processes for substances with very similar chemical structures. Challenges arise when attempting to predict removal rates across different wastewater treatment facilities. Beta-blockers, in particular, exhibit highly variable removal rates, and these rates can differ significantly depending on the specific wastewater treatment facility.

For instance, beta-blockers like betaxolol, bisoprolol, carazolol, and metoprolol show notable removal by activated sludge processes, with reported removal rates ranging from 65% to about 90% [20,22]. However, results for other beta-blockers like sotalol and propranolol, where removal rates are less than 20% and approximately 32% are reported in different studies [20,23]. This variability highlights the practical difficulties in predicting removal rates across diverse wastewater treatment facilities.

Overall, the existing treatment processes face several drawbacks, including the generation of toxic by-products, the incomplete destruction of APIs to comply with stringent PNEC values, high operating and energy costs due to the frequent replacement of equipment, and limited applicability to only specific groups of APIs.

2.2 Catalytic Hydrogenation

Catalytic hydrogenation is a highly effective water treatment process that offers superior selectivity and efficiency compared to traditional methods, without using any chemicals.[24,25] This process results in the production of substances that are either non-toxic or significantly less toxic and easily biodegradable.[26] This is a crucial aspect for the potential application of this process in WWTPs, as it eliminates the need for additional wastewater treatment to remove any toxic by-products that may be produced. This also has financial implications, making the process more cost-effective and efficient. The catalytic reactions of hydrogenation are also rapid reactions that allow short residence times and smaller reactors, reducing both the operations and installation costs.[27]

AOPs, widely applied in treating industrial wastewater from sectors like pulp and paper, dyeing, and petrochemicals, effectively address the presence of harmful and stubborn organic pollutants.[28,29] Catalysts play a crucial role in AOPs, offering benefits such as heightened reaction rates, the feasibility of compact reactors, shorter reaction times, and enhanced efficiency.[30,31,32] Heterogeneous catalysis holds an edge

over homogeneous catalysis by eliminating the need for an extra step in the process—specifically, the recovery of the catalyst. Catalytic wet air oxidation (CWAO) decomposes more easily even the refractory substances and reduces the stringency reaction conditions.[27]

Based on some publications [27,30,31], noble metals such as Rh, Pd, and Pt have higher catalytic activity and resistance to metal leaching than base metal oxide catalysts. A strong oxidizing agent like hydrogen peroxide will generate hydroxyl radicals with high oxidative power and can also be used in CWAO to further reduce the stringency of reaction conditions.[32] Hydrogen peroxide due to its low cost can be used as a source of the OH radicals, in the presence of a catalyst (Rh, Pt, Pd) using hydrogen, in excess of oxygen/air, and can produce hydrogen peroxide in situ. In situ production of hydrogen peroxide reduces, also, the cost of the operation. Results of some publications show that in situ production of hydrogen peroxide has actual effects on the CWAO of pharmaceuticals.[27]

The effects of the nature of the active phase as well as the feed gas composition have been examined, and the results strongly suggested that the maximum conversion of paracetamol of 90% was reached in just 30 min of reaction over 1 wt.% Rh/Al_2O_3, when using pure hydrogen in the feed. Toxicity tests that followed showed a dramatic decrease in the toxicity of the product solutions, indicating that catalytic hydrogenation of pharmaceuticals might be a promising method for the elimination of their toxicity, as can be used for the degradation of wide spectrum organic compounds in aqueous solutions since the method is non-selective.

3 Design of a Pilot System for the detoxification of pharmaceutical wastewater from a pharmaceutical industry in Cyprus

The specific objectives of this study are to install such a system in a large pharmaceutical industry in Europe and thus to avoid APIs release in the wastewater sewage system, convert about 1,5 kg of APIs to nontoxic compounds, save 3,650 m^3 of potable water annually, reuse and recycle clean water for manufacturing plants or use for irrigation purposes, minimize the system's environmental footprint using renewable energy sources, transfer the project's results to other pharmaceutical companies across Europe, communicate and promote public awareness at local and regional levels, draft policy recommendations to the EU and create an effective value chain through the socio-economic impact of the proposed actions.

The proposed reactor initial design is based on published experimental data.[27,30,31,32] Some modifications of the initial design are expected after the replication of these studies with real wastewater solutions. Ultimately, the whole pilot system is designed according to the specific requirements of the pharmaceutical industry.

The pharmaceutical facility's equipment cleaning is expected to generate approximately 10 m^3/day, hence the proposed system is designed with a capacity of 10 m^3/day. The main components of the pilot system are a mixing tank where the effluents from pharmaceutical facilities are mixed, a Reverse Osmosis (RO) system, with a capacity

of 420 L/h, that minimizes the volume of the wastewater going through the catalytic reactor by 80-90% close to 370 L/h. This approach minimizes both the size and cost of the reactor. A water electrolysis unit operating with renewable energy sources, especially solar energy. The concentrated stream from the RO system, approximately 50 L/h or 1.2 m^3/day, will be driven to and treated in the catalytic reactor. In this reactor, the pharmaceutical compounds, at room temperature (25 ^{0}C), under atmospheric pressure (1.3 atm), and in the presence of a catalyst will be hydrogenated and converted to non-critical organic matter, the reaction time is 30 min-2 hours. As a result of the hydrogenation process applied to pharmaceutical compounds, water with very low or no toxicity is produced, suitable for irrigation purposes, heat exchange systems, or cleaning. The energy consumption of the RO system is expected around 3 kWh/m^3 inlet or 30 kWh/day and the energy consumption of the catalytic reactor is around 5 kWh/m^3.

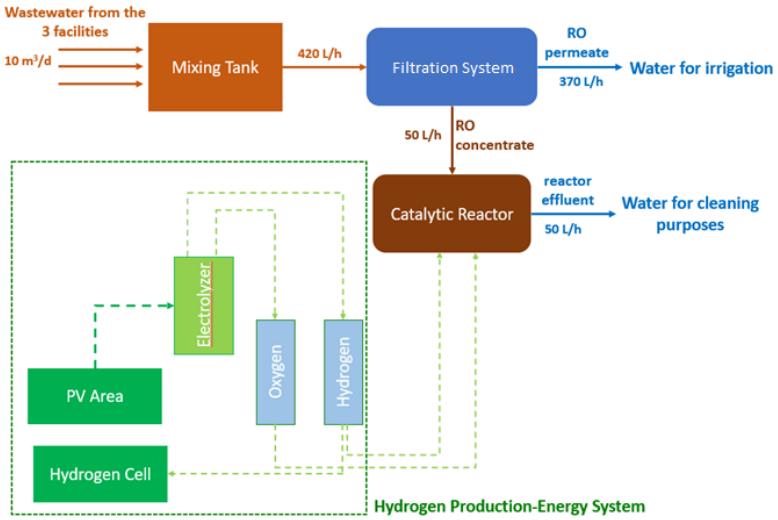

Fig. 1: Process flow Diagram

The catalytic reactor is an autoclave Continuous stirring tank reactor (CSTR) equipped with a catalyst basket. For the catalytic experiments, a special flow apparatus suitable for three-phase catalytic experiments (solid-liquid-gas) was used. To maximize the contact area between the solid-liquid-gas phase and minimize the possible external mass transfer phenomena the reactor's inlet and outlets as well as the catalytic basket designed adequately. The catalytic reactor was designed to work in a batch mode of 60-100 L/h, with low gas flow close to 1-2ml/min. The liquid phase (pharmaceutical wastewater known concentration of APIs), solid phase, and gas phase hydrogen/oxygen gas mixture were under continuous flow at about 1.3 atm total pressure and 25^{o}C. The design and specifications of the catalytic reactor are derived from the outcomes of bench-scale tests that were conducted.[24] The system will fully operate with renewable energy (solar).

The system focuses on the reduction of pressures from chemical pollutants in the water environment by reducing emissions of priority substances and other chemicals

identified as river basin-specific pollutants at the source, through the use of appropriate substitutes or alternative technologies.

The system aims to design a novel technology for the treatment of pharmaceutical wastewater. Its operation requires no water consumption, thus saving 10 m^3 of potable water daily, in its place the same quantity of recycled water will be used. This means that 3,650 m^3 of potable water will be saved per year and about 5,220 g of APIs will not be released to the urban wastewater. The method utilised in this project can operate under mild temperature (i.e., environmental) and pressure (i.e., atmospheric) conditions, a fact that greatly reduces operating costs.

3.1 Monitoring Protocol

To monitor and evaluate the progress of the designed system, as well as the environmental impact of the proposed technology, a monitoring protocol is required to be established. The impact and the progress of the system will be evaluated by measuring specific indicators throughout its development and implementation.

The pharmaceutical industry generates process wastewater containing a variety of pollutants. The composition of pharmaceutical wastewater is complex, and it usually has a high concentration of organic matter, high toxicity, high conductivity, and is difficult to degrade. Even after secondary treatment, there are still trace amounts of suspended solids and dissolved organic matter.[33] Basic physicochemical parameters that are recorded to characterize pharmaceutical wastewater are the mentioned indicators pH, conductivity, the concentration of chloride ions, Biological Oxygen Demand (BOD_5), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), turbidity, concentration of total Nitrogen, the concentration of total Phosphorus, toxicity of wastewater, and concentration of pharmaceutical substances.

The design of the system is based on the detoxification of some pharmaceutical substances which are listed on the 4th Watch List under the Water Framework Directive. [34] A mechanism that provides high-quality monitoring information on the concentrations of potentially polluting substances in the aquatic environment to support future prioritization exercises in line with Article 16(2) of Directive 2000/60/EC Water Framework Directive and improves the protection of the aquatic environment and human health via the environment. The designed system focuses on the detoxification of Lincomycin, belongs to lincosamides, Lorazepam belongs to benzodiazepine, Dexamethasone Phosphate, Co-amoxiclav, Cloxacillin Sodium, Hyoscine Butylbromide, Diazepam, Dicloxacillin, Lincomycin, Amikacin, Amoxicillin/Clavulanic Acid, Amoxicillin.

The design and operation of the system are focused on wastewater with physicochemical characteristics that are presented in Table 2:

Table 2: Physico-chemical characterization of tested effluents.

Parameter	Value close to
BOD_5 (mg/l)	12-1055
Cl^- (mg/l)	12-6100
Conductivity (µS/cm)	100-12000
pH (20 ºC)	4.5-9
TP (mg/l)	0.1-436
TN (mg/l)	1.6-130
COD (mg/l)	4-73600
TDS (mg/l)	1.2-215
TSS (mg/l)	0.1-428
TU50 (5min, 15min,30min) Microfox	<1
Turbidity (FAU)	2-1640

The water quality in the RO permeate stream, which constitutes approximately 80-90% of the initial wastewater stream, will closely resemble that of distilled water. As for the RO retentate stream, it will share similar physico-chemical characteristics with the RO permeate stream, with the exception of higher concentrations and toxicity of APIs. The goal is to reduce the toxicity of pharmaceutical substances by approximately 70-90% through treatment in the catalytic reactor.

The conversion of selected API is studied over monometallic catalysts of Rh using different reducing feed gas compositions, as the conversion of the APIs is clearly affected by the nature of the active phase of the catalyst. The catalytic performance of the selected active phase is examined further and in detail, at different reaction times and different concertation of APIs. The toxicity of the product solution is studied before and after every reaction and for a range of APIs concertation, with the aim of verifying that the produced water follows the requirements for water reuse based on regulation (EU) 2020/741 of the European Parliament and the Council.

4 Conclusions

Wastewater from pharmaceutical industries ends up initially in the city's central sewage system and then in the WWT. Generally, WWST are not able to completely remove all pharmaceutical compounds.

Enhancing the efficiency and effectiveness of solutions and treatment options for recycled or reclaimed water involves implementing specific strategies. These strategies include the development of concepts for alternative water supply, wastewater treatment, and the reuse, recovery, and recycling of resources. Implementing source control methods and cost-effective on-site technologies to address the discharge of emerging pollutants and pathogens into wastewater treatment systems. Establishing water treatment innovation hubs in regions lacking appropriate sewer systems and sanitation facilities. These hubs should focus on smart technologies and decentralized systems, particularly for alternative water sources. Finally, implementing systematic approaches to prevent the loss of water, energy, and resources in industrial production and water/wastewater infrastructure.

This study aims at the development, testing, and demonstration of an innovative system for the treatment of wastewater produced by the pharmaceutical industry. The system will detoxify APIs, that would otherwise pass through the sewage system causing the well reported environmental problem associated with APIs accumulation. Furthermore, this system will return purified water of high quality to be re-used by the industry and will be suitable for being replicated, transferred, or mainstreamed.

The system will be able to be applied to the pharmaceutical industry in Cyprus and other pharmaceuticals, and chemical industries producing paints, cosmetics, chemicals for industry and laboratory use, petrochemicals, polymers, plastics, and specialty chemicals. manufacturing facilities in the Europe (EU) and around the world.

The proposed technology can be applied also, to already existing and operating new WWTPs as an additional tertiary treatment, to eliminate or considerably decrease the toxicity of the effluent of the plant or detoxify the effluent to be able to be biologically treated. The technology can be applied to urban WWTPs as well as smaller WWTPs for smaller communities, hospitals, and nursing homes. It must be highlighted that the proposed solution will be examined (on an industrial scale) for the first time in the European Union and globally. Experimental data and outcomes of our bench scale test will soon published.

References

1. P. Verlicchi, M. Al Aukidy, E. Zambello, Occurrence of pharmaceutical compounds in urban wastewater: Removal, mass load and environmental risk after a secondary treatment—A review, Sci. Total Environ. 429 (2012) 123–155.
2. Michael, L. Rizzo, C.S. McArdell, C.M. Manaia, C. Merlin, T. Schwartz, C. Dagor, D. Fatta-Kassinos, Urban wastewater treatment plants as hotspots for the release of antibiotics in the environment: A review, Water Res. 47 (2013) 957–995.

3. F. Sacher, F.T. Lange, H.-J. Braunch, I. Blankerhorn, Pharmaceuticals in groundwaters: Analytical methods and results of a monitoring program in Baden- Wurttemberg, Germany, J. Chromatorg. A 938 (2001), 199–210.
4. S.D. Constanzo, J. Murby, J. Bates, Ecosystem response to antibiotics entering the aquatic environment. Mar. Pollut. Bull. 51 (2005) 218–223.
5. A.J. Watkinson, E.J. Murby, D.W. Kolpin, S.D. Costanzo, The occurrence of antibiotics in an urban watershed: From wastewater to drinking water, Sci. Total Environ. 407 (2009) 2711–2723.
6. C. McArdell, E. Molnar, M.J.F. Suter, W. Giger, Occurrence and fate of macrolide antibiotics in wastewater treatment plants and in the Glatt Valley watershed, Switzerland, Environ. Sci. Technol. 37 (2003) 5479–5486.
7. K.C. Makris, S.A. Snyder, Screening of pharmaceuticals and endocrine disrupting compounds in water supplies of Cyprus, Water Sci. Technol. 62(11) (2010), 2720–2728.
8. M.D. Hernando, E. Heath, M. Petrovic, D. Barcelo, Trace-level determination of pharmaceutical residues by LC-MS/MS in natural and treated waters. A pilot survey study, Anal. Bioanal. Chem. 385 (2006) 985–991.
9. P.E. Stackelberg, E.T. Furlong, M.T. Meyer, S.D. Zaugg, A.K. Henderson, D.B. Reissman, Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water treatment plant, Sci. Total Environ. 329 (2004) 99–113.
10. 4J. Radjenović, M. Petrović, D. Barceló, and M. Petrović, Advanced mass spectrometric methods applied to the study of fate and removal of pharmaceuticals in wastewater treatment, TrAC – Trends Anal. Chem., 2007.
11. Li, B. and Zhang, T., Mass flows and removal of antibiotics in two municipal wastewater treatment plants, 2011, Chemosphere, vol. 83, issue 9, 1284-1289.
12. Yang, Y., Ok, Y.S., Kim, K.-H., Kwon, E.E., Tsang, Y.F., Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: A review, 2017, Sc. Total Environ., Vol. 596-597, 303-320.
13. Tim aus der Beek, Frank-Andreas Weber, Axel Bergmann, Pharmaceuticals in the environment: Global occurrence and potential cooperative action under the Strategic Approach to International Chemicals Management (SAICM), Umweltbundesamt Texte 67/2016.
14. Emmanuel Sunday Okeke, Timothy Prince Chidike Ezeorba, Charles Obinwanne Okoye, Yao Chen, Guanghua Mao, Weiwei Feng , Xiangyang Wu, Environmental and health impact of unrecovered API from pharmaceutical manufacturing wastes: A review of contemporary treatment, recycling and management strategies, Sustainable Chemistry and Pharmacy Volume 30, December 2022.
15. Brooks, B.W, 2014, Fish on Prozac (and Zoloft): ten years later, Aqua. Toxicol 1151, 61-67.
16. Gretchen M. Bruce, Richard C. Pleus, and Shane A. Snyder, Toxicological Relevance of Pharmaceuticals in Drinking Water, Environ. Sci. Technol. 2010, 44, 14, 5619–5626.
17. Niina M Vieno, Heli Härkki, Tuula Tuhkanen, Leif Kronberg, Occurrence of pharmaceuticals in river water and their elimination in a pilot-scale drinking water treatment plant, Environ Sci Technol. 2007 Jul 15;41(14):5077-84.
18. WHO Library Cataloguing-in-Publication Data, Pharmaceuticals in drinking-water, 2012 Gomez Cortes, L., Marinov, D., Sanseverino, I., Navarro Cuenca, A., Niegowska, M.
19. Barbara Kasprzyk-Hordern, Richard M Dinsdale, Alan J Guwy, The removal of pharmaceuticals, personal care products, endocrine disruptors, and illicit drugs during

wastewater treatment and its impact on the quality of receiving waters, Water Res. 2009 Feb;43(2):363-80.
20. V Gabet-Giraud, C Miège, J M Choubert, S Martin Ruel, M Coquery, Occurrence and removal of estrogens and beta blockers by various processes in wastewater treatment plants, Sci Total Environ. 2010 Sep 1;408(19):4257-69.
21. Maria Klavarioti , Dionissios Mantzavinos, Despo Kassinos, 2009, Environ Int. 2009 Feb;35(2):402-17.
22. Ternes, T.A. (1998) Occurrence of Drugs in German Sewage Treatment Plants and Rivers. Water Research, 32, 3245-3260.
23. David Bendz, Nicklas A Paxéus, Timothy R Ginn, Frank J Loge, Occurrence and fate of pharmaceutically active compounds in the environment, a case study: Höje River in Sweden, J Hazard Mater. 2005 Jul 15;122(3):195-204.
24. V. Emzhina, E. Kuzin, E. Babusenko, N. Krutchinina, Photodegradation of tetracycline in presence of H2O2 and metal oxide based catalysts, Journal of Water Process Engineering Volume 39, February 2021.
25. Yingtao Sun, Ruixin Yi, Chun Hu, and Lai Lyu, Enhanced purification efficiency for pharmaceutical wastewater through a pollutant-mediated H2O2 activation pathway over CuZnS nano-aggregated particles, Environ. Sci.: Nano, 2022, 9, 4317-4324.
26. Junhua Li, Hong He, Chun Hu, Jincai Zhao, The abatement of major pollutants in air and water by environmental catalysis, Front Environ Sci Eng. 2013;7(3):302-325.
27. Nantia A. Pantelidou, Christodoulos P. Theologides, Georgios G. Olympiou, Petros G., Savva, Marlen I. Vasquez & Costas N. Costa, Catalytic removal of pharmaceutical compounds in water medium under an H2 stream over various metal-supported catalysts: A promising process, Desalination and Water Treatment, 1-8, 2014.
28. Meghdad Pirsaheb, Hiwa Hossaini, Hosna Janjani, Reclamation of hospital secondary treatment effluent by sulfate radicals based–advanced oxidation processes (SR-AOPs) for removal of antibiotics, Microchemical Journal Volume 153, March 2020.
29. Divya Dixit, Pooja Thanekar , Vinay M. Bhandari, Degradation of API pollutants using hydrodynamic cavitation and process intensification, Chemical Engineering and Processing - Process Intensification Volume.172, February 2022.
30. Costas N. Costa, Petros G. Savva, Jose´ Luis G. Fierro, Angelos M. Efstathiou, Industrial H2-SCR of NO on a novel Pt/MgO–CeO2 catalyst, Applied Catalysis B: Environmental 75 (2007) 147–156.
31. Costas L. Constantinou, Costas N. Costa, and Angelos M. Efstathiou, The Remarkable Effect of Oxygen on the N2 Selectivity of Water Catalytic Denitrification by Hydrogen, Environ. Sci. Technol. 2007, 41, 3, 950–956.
32. P. G. Savva, C. N. Costa & A. M. Efstathiou, The mechanism of reduction of NO with H2 in strongly oxidizing conditions (H2-SCR) on a novel Pt/MgO-CeO2 catalyst: Effects of reaction temperature, Kinetics and Catalysis September 2008.
33. Y Guo, P S Qi, Y Z Liu, A Review on Advanced Treatment of Pharmaceutical Wastewater, et al 2017 IOP Conf. Ser.: Earth Environ. Sci. 63 012025.
34. Porcel Rodriguez, E., Stefanelli, F., and Lettieri, T., Selection of substances for the 4th Watch List under the Water Framework Directive, JRC Technical Report, 2022.