Destruction of environmentally hazardous pharmaceuticals with SCWO

May 2016

There is great potential in using the SCWO method for wastewater treatment with drug residues from the pharmaceutical industry. This is the conclusion from a project, where Aquarden tested its SCWO technology on wastewater from Rigshospitalet, Denmark's leading hospital, with more than 60 pharmaceuticals.

Removing hazardous substances

The purpose of this study was to treat wastewater with as many environmentally hazardous drugs as possible at one time. Some of these substances are categorized as 'List A-substances' by the Danish EPA, which are the absolute most harmful substances to the environment and personal health.

The test demonstrates that Aquardens Technologies' SCWO system is an effective technology for purifying wastewater with pharmaceutical residues and heavy metals - for the benefit of the environment and society.

- In Denmark, there are currently about 1,100 pharmaceuticals, of which only 4-500 substances are mapped according to their environmental impact. The need to remove pharmaceutical residues in wastewater will increase in the coming years. Pharmaceuticals are designed to be biologically active ingredients (API). Some antibiotics, painkillers and hormones ends today in the aquatic environment, simply because municipal treatment plants are not built to purify these substances. By developing methods like Aquardens SCWO solution it is possible to minimize emissions of these unwanted substances from point sources significantly, says Ulf Nielsen, Chief Planner of the independent, international consulting and research organization, DHI, who assisted Aquarden in testing the SCWO technology in this particular case.

Significant results

The test proves convincing results with removal of heavy metals and pharmaceutical residues. The table on the following page clearly shows that all pharmaceutical are broken down to below the $PNEC_{Freshwater}$ value. PNEC stands for Predicted No Effect Concentration and expresses the concentration at which a chemical is likely to have toxic effect on the ecosystem. The SCWO system destroys virtually all substances below their respective detection limit – save one substance – albeit still well below its PNEC value.

It is clear to see the difference between the wastewater before and after SCWO treatment.

Aquarden's SCWO process

Water usually occurs in three known phases, namely ice, liquid and vapor. Water also has a fourth phase called supercritical. It occurs when the water is heated to at least 374 °C and subjected to a pressure of at least 221 bar. In this state organic components dissolve completely and are transformed to simple and harmless compounds like CO_2 and nitrogen gas. Any salts and heavy metals precipitate concurrently in a concentrated brine. SCWO stands for Supercritical Water Oxidation, and is the technique Aquarden exploits in its Waterox solutions.

The end-product is pure water cleaned of hazardous pharmaceutical substances and heavy metals, which can be sent directly to receiving water bodies (lakes, rivers, sea), sent to the sewer without risk of extra discharge fees, or reused as process water. An added benefit of Aquarden's solution is that it is an energy efficient process in which excess heat can be recycled as room heating, or used for process purposes.

Analysis and method

The wastewater test was conducted according to the following process where DHI checked and validated the treatment results. The project took place from end of 2015 to beginning of 2016.

1. Collection of 125 liters of wastewater from Rigshospitalet. The wastewater contains thus a realistic concentration of active pharmaceutical ingredients (API).

2. The wastewater was settled at DHI and transported to Aquardens facilities where it was treated in a small-scale pilot plant.

3. Two tests with different SCWO parameters were conducted to investigate opportunities for process optimization.

4. To ensure unbiased measurements of the critical residues in the wastewater both before and after SCWO treatment, DHI sent samples off to Eurofins laboratory in Vejen, Denmark, and UITA in Duisburg, Germany, for measurement of the content of heavy metals and pharmaceuticals.

The SCWO tests at Aquarden were conducted in a small laboratory reactor, which is a replica of Aquarden's full-scale Waterox-system. The small plant can process up to 2 liters of water per hour.

Future perspectives

- Aquarden's SCWO technology draws interesting perspectives for the future treatment of hazardous compounds in wastewater. The perspective is that the method makes it possible to replace costly treatment of environmentally hazardous waste at a disposal facility with an onsite plant that can remove medicinal drugs and other toxic substances directly at the source of pollution. In this way you also save transportation of wastewater to the disposal facility. Using Aquarden's SCWO technology represents an economically attractive and effective alternative to current methods of treatment of hazardous wastewater, which is typically incineration, says Ulf Nielsen.

Measured concentrations of pharmaceuticals (ng/L) in settled wastewater and distillate:

Pharmaceutical	Therapeutic use	ABC	Before SCWO Settled water	After SCWO Distillate	$PNEC_{Fresh.}$
Amidotrizoic Acid	Contrast media		850	< 20	
Amiloride	Diuretic	B	< 50	< 50[1)]	
Atorvastatin	Lipid modifying agent	A	230	< 10	200
Azithromycin	Antibiotic	A	130	< 10	90
Bisoprolol	Beta blocking agent	B	170	< 10	35,600
Capecitabine	Cancer treatment	A	250	< 10	200
Carbamazepine	Epileptic treatment	B	180	< 10	500
Cefalexin	Antibiotic	A	< 10	< 10	
Cefazolin	Antibiotic		< 10	< 10	
Cefotaxime	Antibiotic	C	< 10	< 10	
Cilastatin	Antibiotic		< 10	< 10	
Ciprofloxacin	Antibiotic	A	26,000	51	89
Citalopram	Antidepressant	B	430	< 10	8,000
Clarithromycin	Antibiotic	A	1,100	< 10	60
Climbazole	Antifungal	A	40	< 10	
Clindamycin	Antibiotic	A	3,400	< 10	3,660
Cyclophosphamide	Cancer treatment	A	49	< 10	65,000
Diclofenac	Painkiller	A	200	< 200[1)]	100
Enalapril	High blood pressure/heart failure	C	2,200	< 10	180,000
Erythromycin	Antibiotic	A	990	< 10	200
Hydrocortisone	Corticosteroid (steroid hormone)	A	330	< 10	100,000
Ibuprofen	Painkiller	B	26,000	< 10	4,000
Ifosfamide	Cancer treatment	A	< 10	< 10	
Iohexol	Contrast media		1,600,000	< 90	
Iomeprol	Contrast media		47,000	< 50	1,000,000
Iopamidol	Contrast media		17,000	< 50	
Iopromide	Contrast media		< 50	< 50	
Ioversol	Contrast media		290,000	< 50	
Losartan	High blood pressure	B	4,500	< 10	245,000
Mefenamic acid	Antiinflammatory and antirheumatic		< 10	< 10	
Metoprolol	High blood pressure	B	3,000	< 10	
Metronidazole	Treatment of rosacea	A	5,800	< 50[1)]	12,500
Mirtazapine	Antidepressant	A	< 10	< 10	6,900
Norfloxacin	Antibiotic		730	< 10	32
Ofloxacin	Antibiotic	A	820	< 10	100
Paclitaxel	Cancer treatment	A	< 20	< 10	740
Paracetamol	Painkiller	B	790,000	< 10	9,200
Phenazone	Painkiller	A	< 10	< 10	
Prednisolone	Corticosteroid (steroid hormone)	A	710	< 10	230
Propyphenazone	Painkiller		< 10	< 10	
Ranitidine	Ulcer treatments		25	< 20[1)]	31,000
Ritalinic acid	Metabolite	B	290	< 10	77,000
Roxithromycin	Antibiotic	B	< 10	< 10	
Simvastatin	Lipid modifying agent	A	< 10	< 10	
Sulfadiazine	Antibiotic		1,400	< 10	20,000
Sulfadimethoxine	Antibiotic		< 10	< 10	
Sulfamethazine	Antibiotic	A	< 10	< 10	
Sulfamethoxazole	Antibiotic	A	4,700	< 10	120
Sulfapyridine	Antibiotic		3,500	< 10	
Tamoxifen	Endocrine therapy	A	< 10	< 10	
Tramadol*	Painkiller	B	4,200	< 10	2,250
Trimethoprim	Antibiotic	B	4,200	< 10	62,000
Venlafaxine	Antidepressant	B	1,300	< 10	100
Warfarin	Anticoagulant	A	< 10	< 10	
Zopiclone	Sedative	A	370	< 10	43
4N-Acetylsulfadiazine	Antibiotic metabolite		470	< 10	
4N-Acetylsulfamethazine	Antibiotic metabolite		< 10	< 10	
4N-Acetylsulfamethazine	Antibiotic metabolite		< 10	< 10	
4N-Acetylsulfamethoxazole	Antibiotic metabolite		9,400	< 10	120
1H-Benzotriazole	Corrosion inhibitor	A	76,000	< 10	900
Dimethylbenzotriazole	Corrosion inhibitor (derivative)	A	< 10	< 10	
4 + 5-Methyl Benzotriazole	Corrosion inhibitor (derivative)	A	4,900	< 10	1,000

The orange fields indicate that concentrations before treatment are above $PNEC_{Freshwater}$.. A-substances are the most harmful substances according to the Danish EPA. The green column shows the test results after treatment of the settled wastewater in Aquarden's SCWO lab reactor. The results clearly demonstrate that SCWO is an extremely efficient method of destroying toxic components in wastewater with pharmaceutical residues.

1) The detection limit is elevated due to matrix effects in the sample.

About Aquarden – a total solution provider

Aquarden is an expert in sustainable treatment of problematic wastewater and offers total solutions for solving the toughest wastewater challenges. Aquarden delivers consultancy, turnkey systems, and services – all customized to meet customers' specific requirements. The mission is to help clients in meeting the highest environmental standards for wastewater treatment by providing green and effective solutions. The proprietary and prize-winning Waterox-system destroys all organic and toxic compounds in wastewater completely and efficiently, and reuses energy and water.

Advantages of Waterox

- **Efficiency**: Complete elimination of xenobiotic components. No dilution, but destruction!
- **Discharge**: The final product is pure water - direct discharges to receiving water bodies
- **Emissions**: No toxic bi-products or dangerous emissions
- **Environment and resources:** Energy-efficient process with reuse of water and energy
- **Logistics**: Either onsite facilities or local cleaning stations
- **System**: Compact construction, modular, short residence time, continuous process
- **Business model:** Price per m^3 treated wastewater
- **Economy**: Competitive price. Reuse of resources

Aquarden Technologies ApS
Industrivej 17
DK-3320 Skævinge
Tel. +45 48 70 85 88
info@aquarden.com
www.aquarden.com

Aquarden's Chemical Technician in front of the laboratory reactor, where the tests of SCWO treatment of hospital wastewater, with more than 60 drug residues, took place. The unit is a small replica of the full-scale Waterox plant.

Aquarden's SCWO-based Waterox system is designed to treat the most problematic wastewater streams from e.g. pharmaceutical, biotech, and chemical industries. The system received 'The European Business Award for the Environment 2016' in Denmark and is given to a new and innovative product that significantly contributes to sustainable development and innovation.