Factsheet – Nutrient recovery via ion exchange (IEX) and hollow fibre membrane contactor (HFMC)

AUTHORS: Ana Soares, Pete Vale, Jung Eun Kim, Jan Hofman

DATE: 16/12/2021

VERSION: V5

Disclaimer

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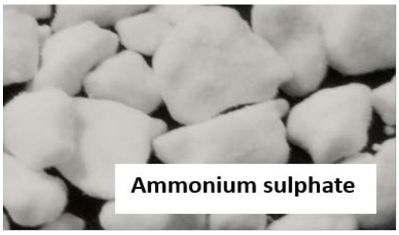
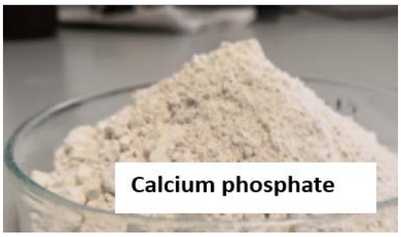
Ion exchange (IEX) & hollow fibre membrane contactor (HFMC)





Unique selling points:

- ✓ High recovery rates: up to 90% of ammonia and 90% of phosphorous
- ✓ High product water quality which can be used in the chemical and fertiliser industry
- ✓ Low energy consumption
- ✓ Simple equipment and low maintenance cost
- ✓ Compact system with very small footprint
- ✓ No sludge production
- ✓ No start-up period required

Description of the technology

Ammonia (NH_4^+) and **phosphate** (PO_4^{3-}) are key components for fertiliser production and have a crucial role on the security of food production. On the other side, these nutrients are pollutants present in wastewater streams, and if untreated, these can have adverse effects on receiving water bodies such as algal blooms and toxicity problems. Recovery and reuse of these nutrients is highly beneficial for the environment and economy. **Ion exchange (IEX)** is one of the promising technologies for recovering nutrients from wastewater streams. One of the most promising ion exchangers for phosphorus removal from wastewater is the synthetic hybrid anion exchanger (HAIX) resin: a polymeric base where amorphous iron hydroxide nanoparticles (HFO-NP) have been dispersed. Two processes take place within the HAIX: the exchange of anions (Cl^-, SO_4^-) between the polymeric base and the liquid phase and the adsorption of phosphorus (as divalent anion HPO_4^{2-} and monovalent anion H_2PO_4 onto the HFO-NP via Lewis acid interactions. HAIX has been used to efficiently remove phosphorus from phosphorus rich streams (including urine, municipal wastewater, surface waters, sludge dewatering liquors) but mostly in lab conditions and only recently its feasibility was shown in SMART-plant as a tertiary treatment process.

Currently, the most used ion exchange media for ammonium removal are zeolites. These contain a crystalline aluminosilicate mineral within a framework of silica and aluminium tetrahedra linked by their corners through oxygen atoms. Cations present in the wastewater (usually NH_4^+, Na^+, Ca^{2+}, K^+ and Mg^{2+}) can penetrate inside cages and channels within the zeolite matrix and be exchanged with the surroundings. Engineered zeolites, like the one used in NEXT-GEN, have suffered chemical modifications to increase theire selectivity towards ammonium.

Both ion exchange media must be regenerated when the desired effluent concentration is reached. The regenerant solutions used are 10% KCl and 2% NaOH to regenerate the synthetic zeolite and the HAIX, respectively. The nutrients can then be recovered from the saturated

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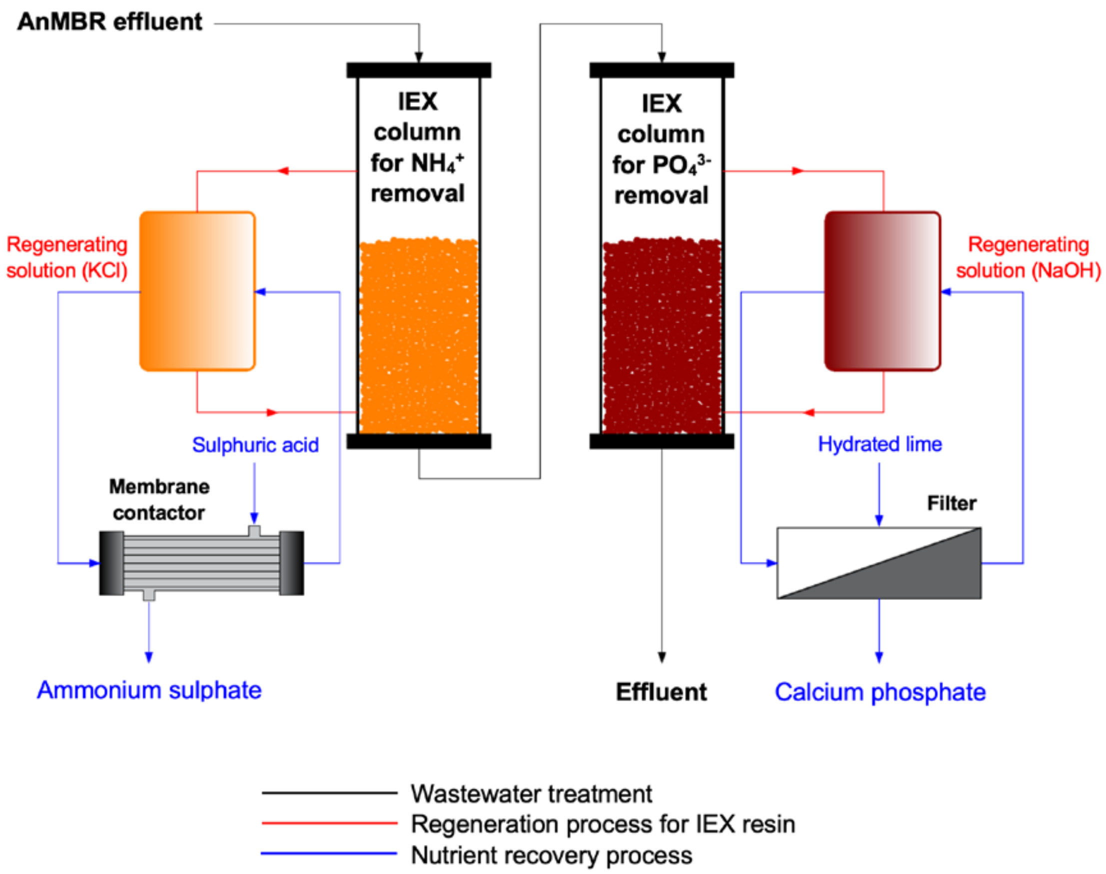
regenerants. Ammonia is recovered in the form of **ammonium sulphate**, $(NH_4)_2SO_4$ via a **membrane stripping** system with sulphuric acid (H_2SO_4). In addition, for P recovery, PO_4^{3-} is produced in the form of **calcium phosphate,** $Ca_5(PO_4)_3OH$ using a **hydroxyapatite production system** with the addition of hydrated lime to the NaOH regenerant. Ion exchange resins are regenerated using KCl and NaOH and thus reused in the IEX (**Flow scheme of the technology**).

Flow scheme of the technology



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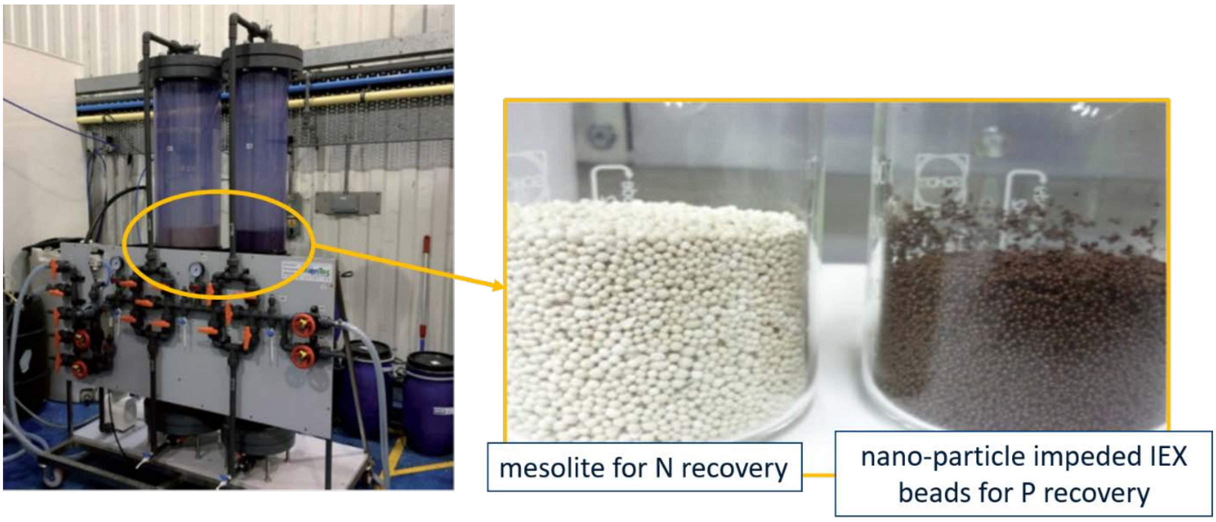
Pictures of the technology



Ion exchange process with 2 columns for N and P removal

Synergetic effects and motivation for the implementation of the technology

✓ **Reduction of environmental impacts**

Compared with the conventional aerobic process, anaerobic processes (i.e. anaerobic membrane bioreactor, AnMBR) could provide benefits of direct energy recovery, significant energy savings and additional treatment of excess sludge. However, AnMBR is ineffective at removing nutrients (ammonium and phosphate). High concentrations of nutrients in wastewater effluents can cause eutrophication with detrimental effects on the receiving waters. Coupling the existing treatment processes such as AnMBR with IEX processes can significantly reduce nutrient concentrations in the effluents and thus direct eutrophication emissions.

✓ **Mining wastewaters as an alternative source of fertiliser production**

Nutrients recovery from wastewater results in reduced production of energy-intensive fertilisers in many commercial agricultural sectors. As food production consumes a significant amount of fertiliser, an integrated AnMBR and IEX system can enhance the supply of adequate quality of fertiliser to the market. This will boost resource recovery from wastewater streams, development of reuse/recovery technologies and production of acceptable fertiliser cost thus satisfying end-users.

✓ **No energy requirement for nitrification or phosphorus removal**

The ion exchange process allows for the selective removal and recovery of nutrient in their ionic state, without the need for any biological transformation. And thus 100% of the energy that would be used in the nitrification step and aeration of the stage of the biological phosphorus removal can be saved.

✓ **No sludge production from nitrogen and phosphorus removal**

In contrast to the microbial nitrogen removal via nitrification and denitrification, microbial phosphorus removal the ion exchange process does not rely on microorganisms and thus, does not produce additional sludge that must be disposed of later on.

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Requirements of the technology and operating conditions

It is required to have nearly no solids and low organic matter. This is because solids will cause plugging in IEX columns and elevated organic matter concentration can cause biological fouling of the media.

Operating conditions

Technology	Parameter		Units	Mean	Reference
Ion exchange	IEX Influent	Flow rate	m^3/day		NextGen D1.3 (in prep.), NextGen D1.5 (in prep.)
		Temperature	°C		
	IEX Effluent	Flow rate	m^3/day		
		Temperature	°C		
Membrane stripping system	Regenerant NH_4-N		mg/L	400-1000	
	Ammonia mass transfer, KLa		L/h	0.5-2	
	N recovery rate		%	95	
	H_2SO_4 consumption		tons/year	0.2	
Hydroxyapatite production system	Regenerant PO_4-P		mg/L	500-1000	
	Ca:P ratio		-	1.5-4	
	P recovery rate		%	95	
	CaOH consumption		tons/year	0.4	

Key performance indicators

Technology	Parameter		Units	Min	Max	Reference
Ion exchange (IEX)	IEX Influent	pH	-			Huang et al. (2020) NextGen D1.3 (in prep.), NextGen D1.5 (in prep.)
		BOD_5	mg/L	10	25	
		COD	mg/L	68	142	
		TSS	mg/L	0	0	
		NH_4-N	mg/L	6	40	
		PO_4-P	mg/L	2	7	
		SO_4	mg/L	0	0	
	IEX Effluent	pH	-			
		BOD_5	mg/L	7	17	
		COD	mg/L	54	113	
		TSS	mg/L	0	0	
		NH_4-N	mg/L	1	10	
		PO_4-P	mg/L	0.5	2	
		SO_4	mg/L	0	0	
	N removal efficiency		%	75	83	
	P removal efficiency		%	71	75	
Membrane stripping system	N recovery rate		%	-	95	
	$(NH_4)_2SO_4$ production		tons/year	-	0.53	
Hydroxyapatite production system	P recovery rate		%	-	95	
	$Ca_5(PO_4)_3OH$ production		tons/year	-	0.63	

Links to related topics and similar reference projects

Nutrients recovery technology	Reference
Anaerobic digestion	Case study "Braunschweig"(NextGen)

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Air stripping and scrubbing	Case study "Altenrhein & Braunschweig" (NextGen)

References

Huang, X., Guida, S., Jefferson, B., & Soares, A. (2020). Economic evaluation of ion-exchange processes for nutrient removal and recovery from municipal wastewater. *npj Clean Water, 3*(1), 1-10. doi:https://www.nature.com/articles/s41545-020-0054-x

NextGen D1.3 New approaches and best practices for closing the water sector (in prep.), NextGen, Deliverable D1.3, Grant Agreement Number 776541. https://mp.nextgenwater.eu/d/Publication/73

NextGen D1.5 New approaches and best practices for closing the materials cycle in the water sector (in prep.), NextGen, Deliverable D1.5, Grant Agreement Number 776541. https://mp.nextgenwater.eu/d/Publication/10

Outlook

Case study specific information will be provided, when the results of the other work packages are available:

- Lessons learned from the case study
- Outcome of the assessments
- Legal and regulatory information concerning the whole value chain concerning the technology
- Business opportunities

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