The 16th IWA Leading Edge Conference on Water and Wastewater Technologies

10 – 14 June 2019 / Edinburgh, United Kingdom

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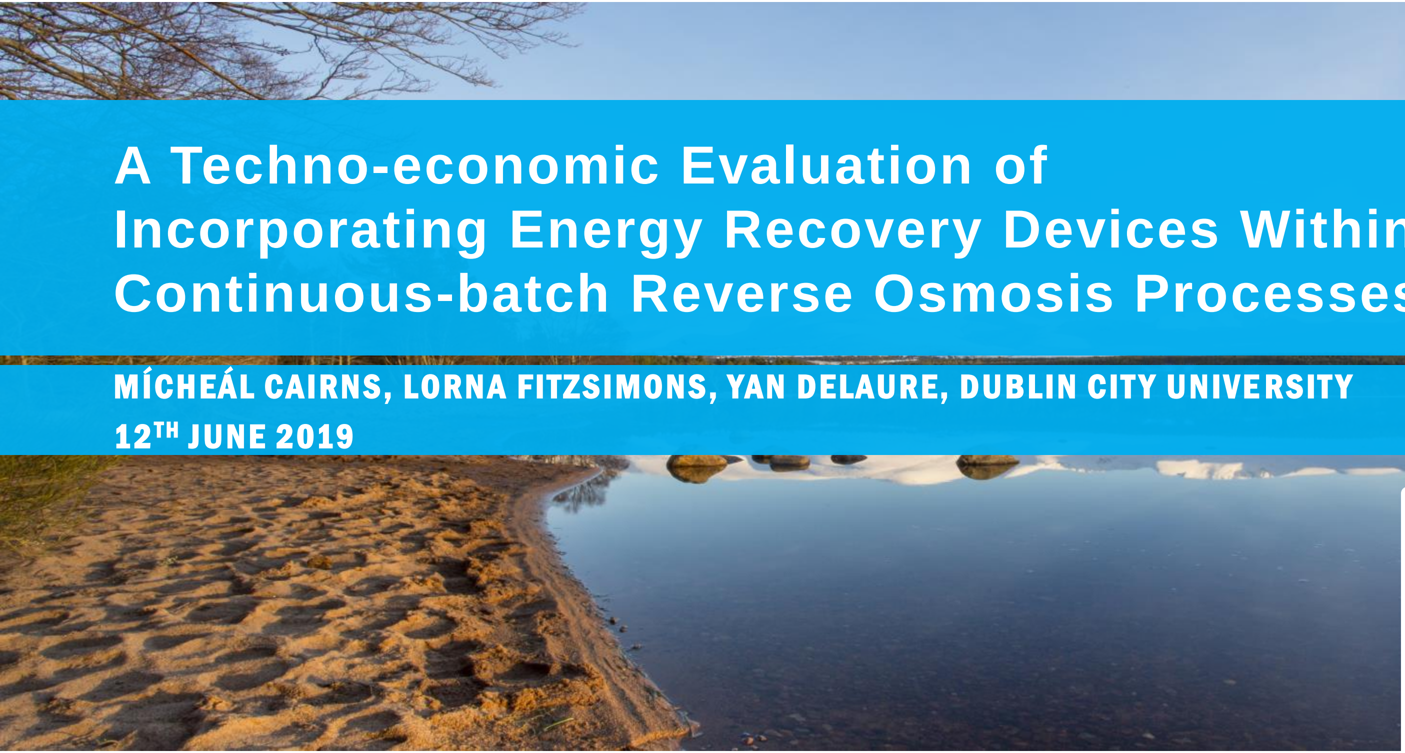

A Techno-economic Evaluation of Incorporating Energy Recovery Devices Within Continuous-batch Reverse Osmosis Processes

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12TH JUNE 2019

inspiring change

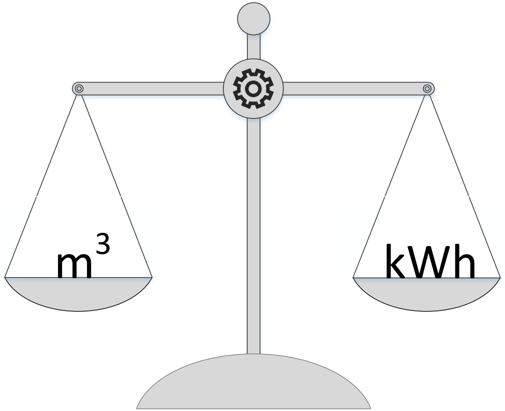
H2020-Water-1b-2015

This project has received funding from the European Unions's Horizon 2020 research and innovation programme under grant agreement no 689785.

RESEARCH OVERVIEW

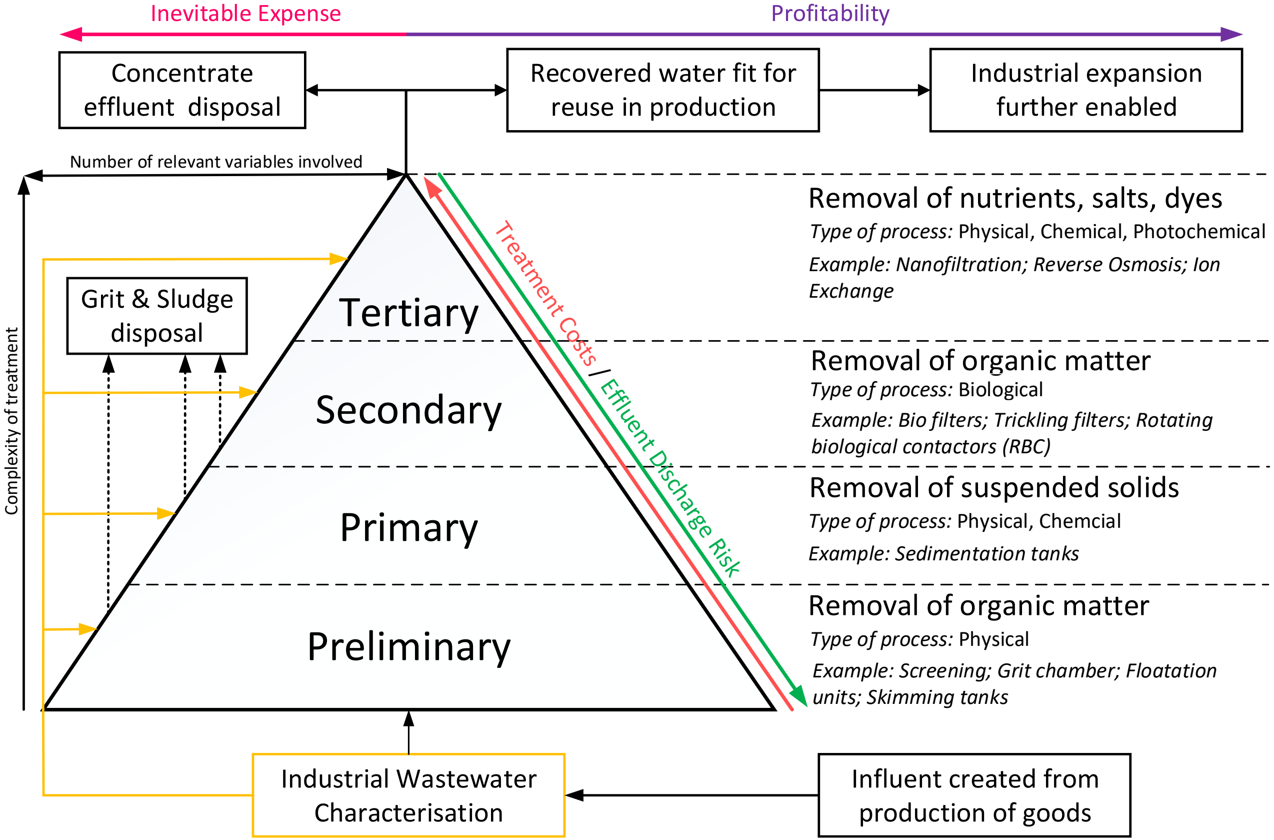
- Industrial motives encouraging industrial wastewater (IW) treatment?
  - Potable water costs
  - Wastewater disposal costs
  - Stringent environmental legislation
  - Rapid industrial expansion requirements

- The viability of treating IW is usually a function of many site specific conditions and variations:
  - Production process variations
  - Heterogeneous wastewater characterisation
  - Varying IW treatment process operating conditions



- Based upon these factors, to what extent does wastewater recovery become feasible for SME scale industrial users?

CONVENTIONAL IW TREATMENT PROCESS

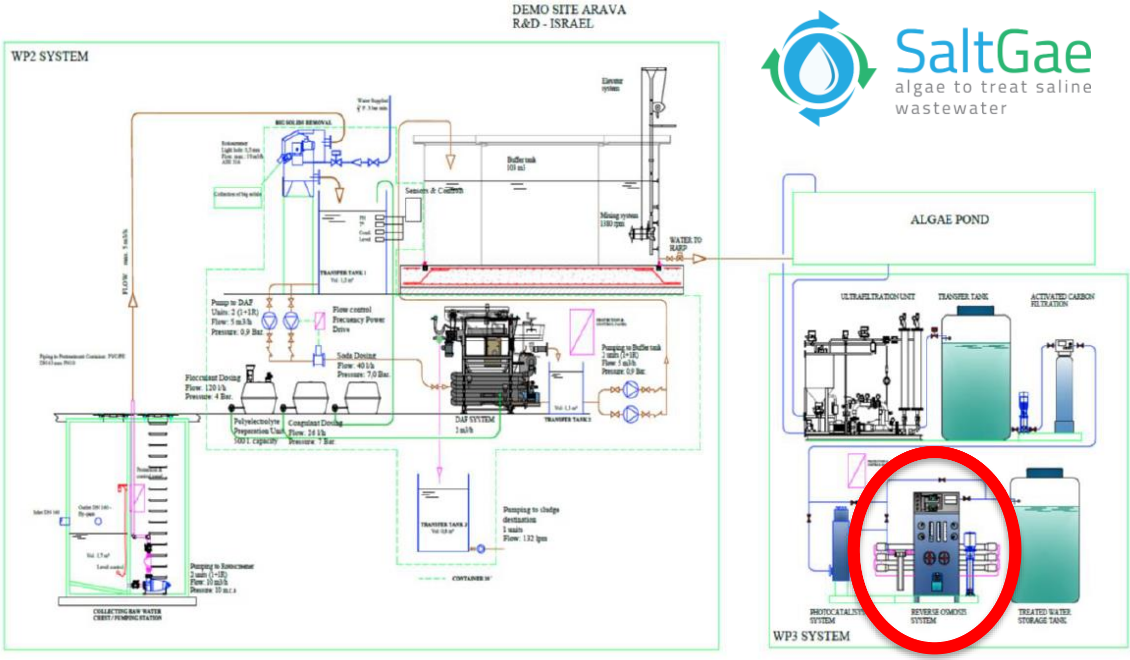


- Tertiary treatment is usually required before water recovery is possible.
- At this end stage, process costs must be minimised otherwise treatment becomes less feasible.
- Industrial users seek innovative solutions that emphasise both water recovery and resource recovery valorisation.

THE SALTGAE TREATMENT PROCESS

- To develop and demonstrate a techno-economically viable solution for the treatment of saline wastewaters.
- Demo site details:

Site	Koto	Archimede Ricerche	Arava
Location	Ljubljana	Milan	SE Israel
WW Type	Tannery	Dairy	Aquaculture
Flowrate (m^3/day)	1	20	25-35
Salinity (g/l)	25-50	2-30	2-5
Organics (mg 0^2/l)	10,000	5,000	1,000

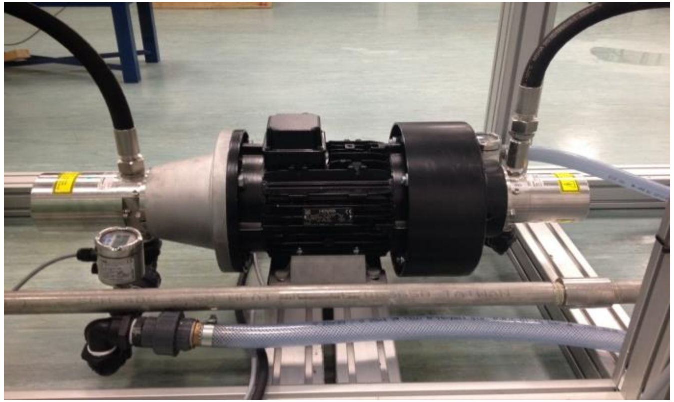


SaltGae
algae to treat saline wastewater

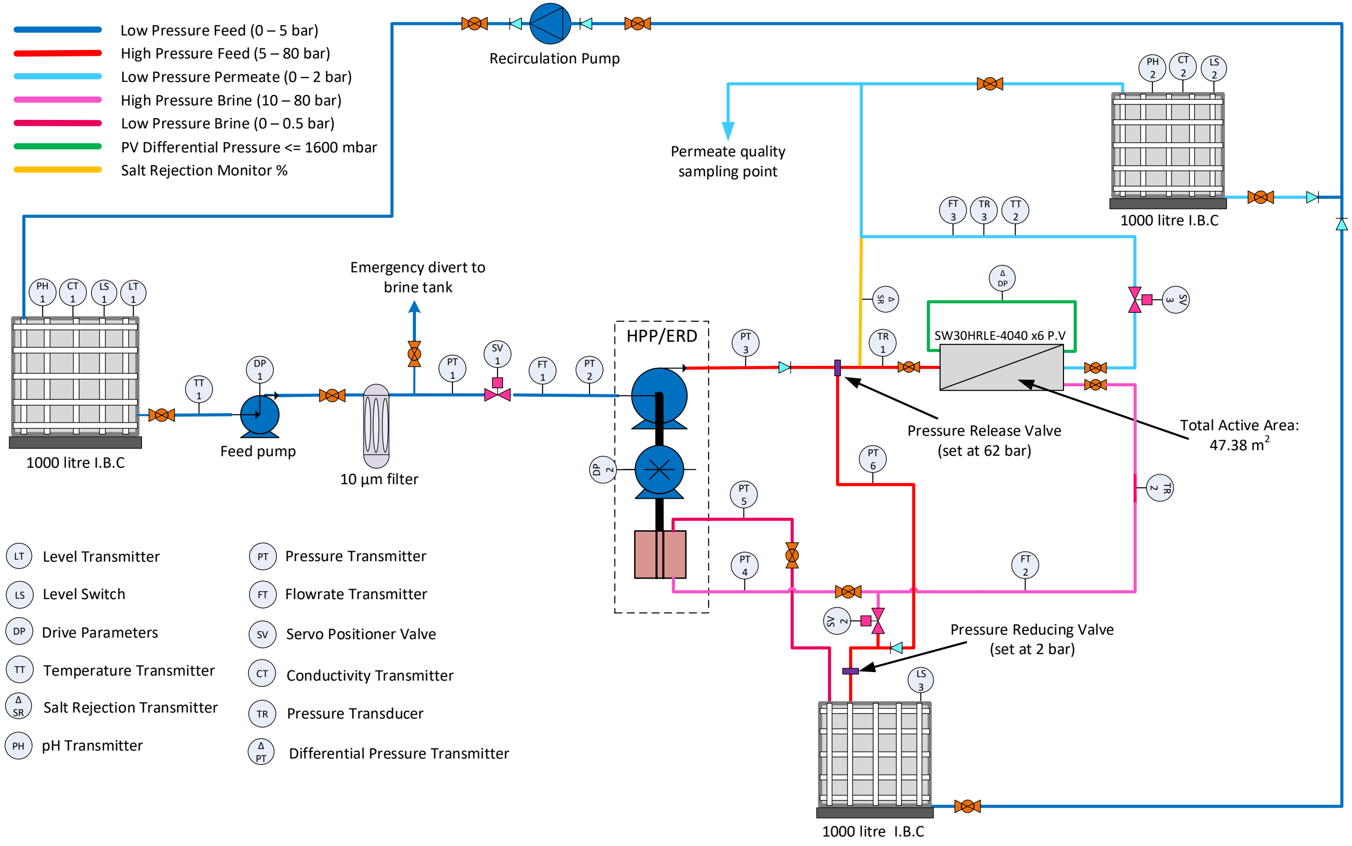
INVESTIGATION DETAILS

- Objectives:
  - To design and manufacture a pilot scale reverse osmosis (RO) test rig.
  - Investigate optimal treatment control strategies for varying IW compositions.
  - Complete a detailed evaluation study between closed loop water recuperation and its respective energy requirements.
  - Review the effects of site specific conditions and variations on RO performance.

- Plan:
  - Use Process – Power – Energy analysis to investigate IW treatment and freshwater. extraction at the relevant flowrates and salinities.
  - Use this data to conclude as to whether ERDs are feasible within the treatment of small scale industrial saline flows.



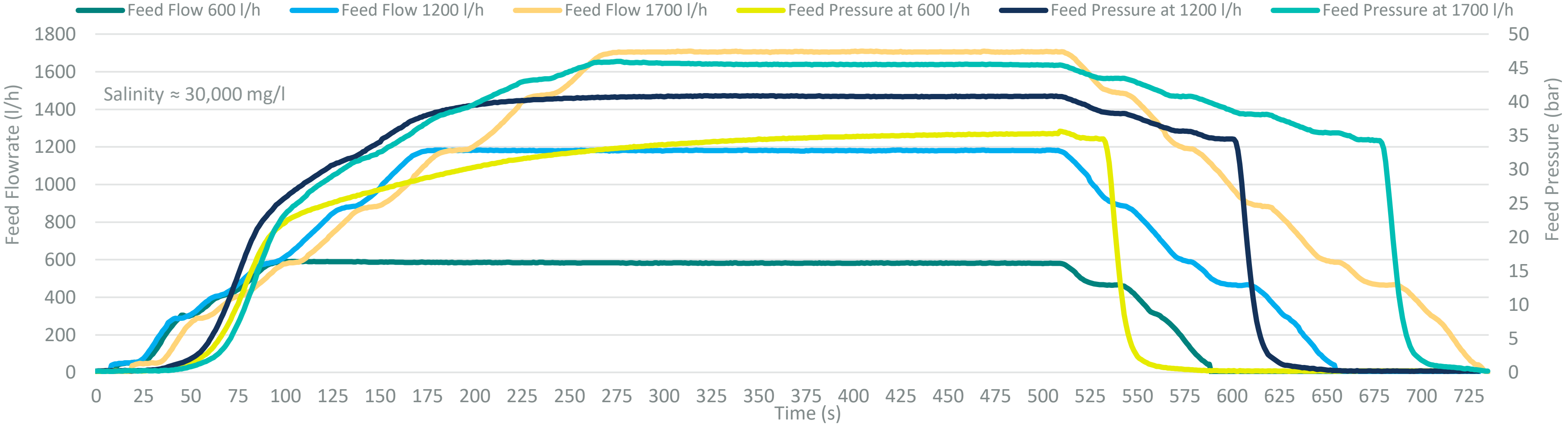
REVERSE OSMOSIS SUBSYSTEM P&ID



- A single-pass configuration designed for trialling/testing high pressure pumps (HPPs) and energy recovery devices (ERDs) under realistic RO operating conditions.
- All ERD class types can be trialled accurately within the system.
- Processing can be performed under batch, semi-batch and continuous operations.

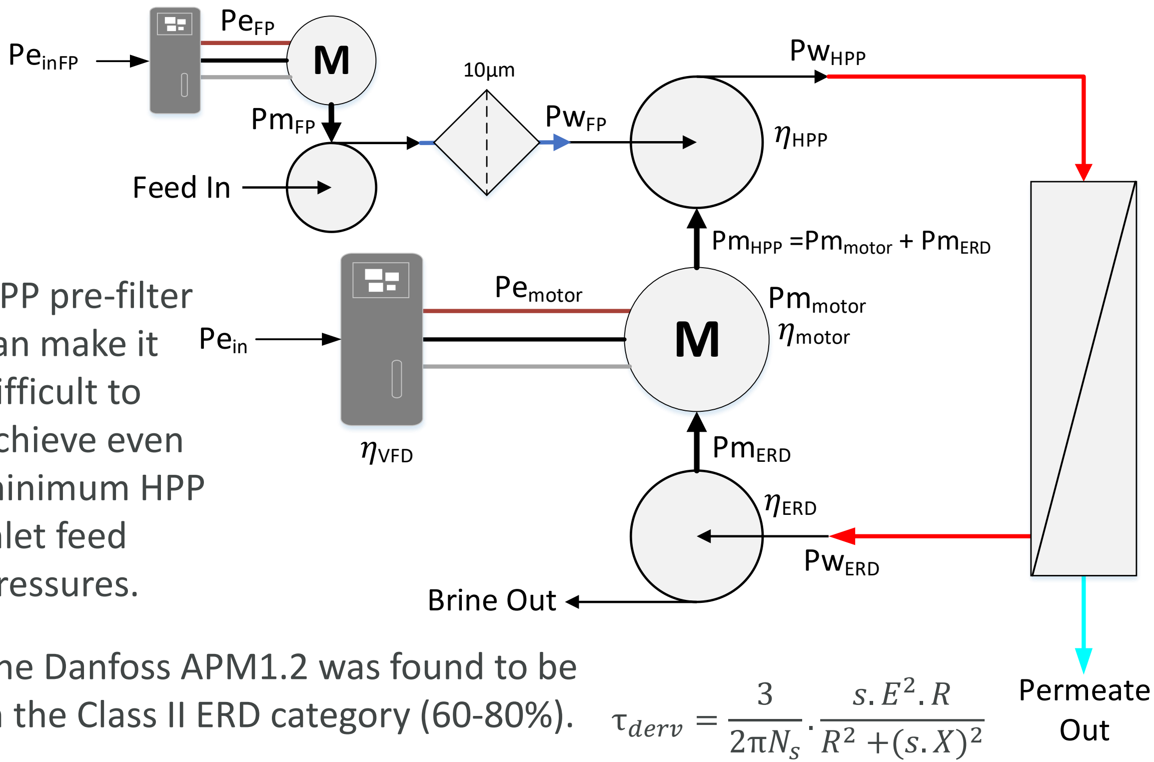
PROCESS ANALYSIS

Variable Details	Steady State Performance																		Units
Feed Flowrate	600						1200						1700						l/h
Feed Salinity	5	10	15	20	25	30	5	10	15	20	25	30	5	10	15	20	25	30	g/l
Feed Temperature	18.07	17.55	18.04	19.41	20.25	20.67	18.41	17.92	18.47	19.79	20.56	20.98	19.12	18.54	19.84	20.25	20.92	21.34	°C
RO Feed Pressure	8.39	13.45	18.16	24.47	29.91	35.68	13.25	18.45	23.42	29.82	35.79	40.84	17.51	23.47	28.56	34.78	40.67	45.49	bar
RO Recovery	33.71	33.89	35.18	32.39	33.4	33.19	36.71	36.47	35.88	34.98	35.16	35.01	36.90	37.27	36.44	35.83	35.57	35.20	%
Salt Rejection	97.76	98.69	98.47	98.63	98.42	98.63	99.20	98.97	99.08	98.55	98.84	98.89	99.44	99.52	99.18	99.28	99.11	99.08	%
Permeate Salinity	115.7	150.0	211	277.8	396.2	415.6	66.52	99.13	132	293.7	302.9	345.5	29.38	50.63	92.47	152	243.5	285	mg/l
Permeate pH	7.266	6.958	6.903	7.024	6.954	6.889	7.139	7.153	7.044	7.219	7.186	7.001	6.823	7.22	7.062	6.97	7.078	7.249	-
Brine Salinity	7.83	15.21	21.41	30.04	37.94	45.53	8.450	15.21	22.48	31.38	40.65	48.45	8.895	15.42	23.43	33.33	40.55	48.31	g/l



POWER ANALYSIS

- Power consumption roadmap at 30 g/l:



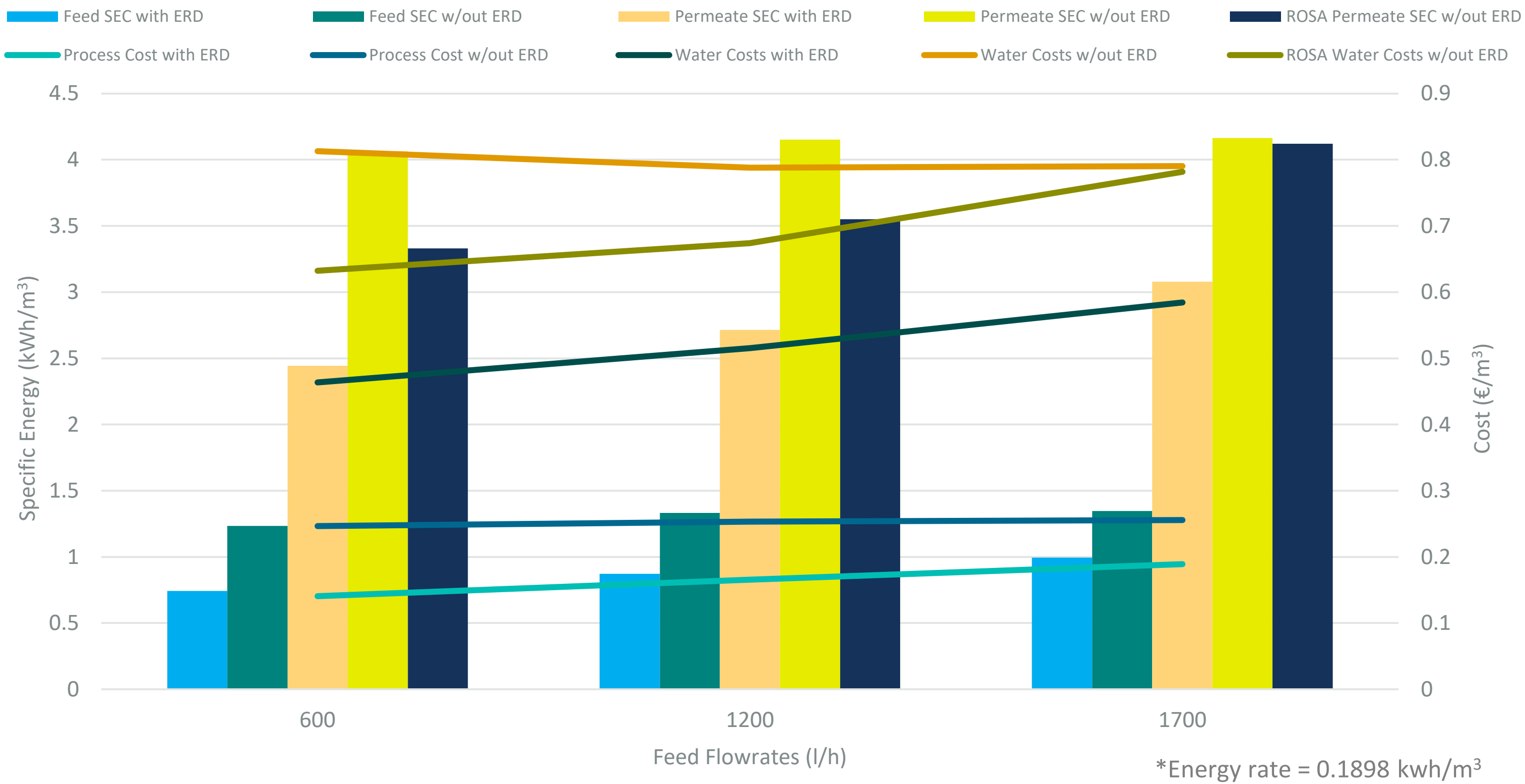
- HPP pre-filter can make it difficult to achieve even minimum HPP inlet feed pressures.
- The Danfoss APM1.2 was found to be in the Class II ERD category (60-80%).

$$\tau_{derv} = \frac{3}{2\pi N_s} \cdot \frac{s.E^2.R}{R^2 + (s.X)^2}$$

Salinity	30,000 mg/l			Units
Flows	600	1200	1700	l/h
Pe_{inFP}	260.3	534.7	736.7	Watts
Pe_{in}	476.2	1084	1915	
Pe_{FP}	239.4	499.4	696.3	
Pe_{motor}	448.4	1017	1838	
Pm_{FP}	202.9	446.4	618.5	
Pm_{motor}	358.45	810.04	1497	
Pm_{HPP}	615.40	1395.6	2357	
Pm_{ERD}	256.95	576.04	860	
Pw_{FP}	19.86	38.39	24.45	
Pw_{HPP}	554.1	1298	2145	
Pw_{ERD}	375.2	844.7	1338	
η_{VFD}	94.16	93.81	95.97	%
η_{motor}	79.94	79.65	81.46	
η_{HPP}	90.00	93.00	91.00	
η_{ERD}	68.48	68.19	64.27	
$\eta_{OS\ excl\ FP}$	116.35	119.74	112.01	
$\eta_{OS\ incl\ FP}$	75.23	80.18	80.89	

ENERGY ANALYSIS

Specific Energy Consumption (SEC) of various flowrates at 30 g/l salinity (excluding feed pump)



*Energy rate = 0.1898 kwh/m^3

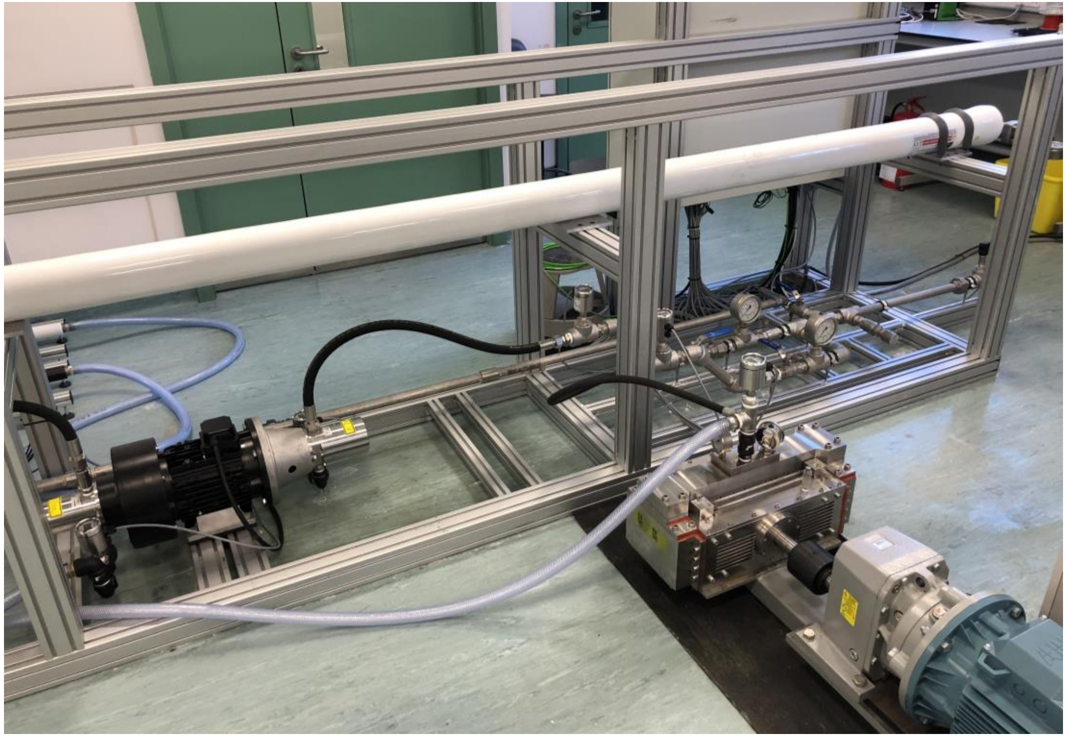
ERD cost savings	
Flow (l/h)	Reduction (%)
600	39.87
1200	35.59
1700	26.05
Water cost savings	
600	53.62
1200	48.46
1700	41.55
These values assume an industrial water rate of approx. €1/m³ (Ireland)	

- Do these figures include CAPX and OPEX?

CONCLUSIONS

- Findings:
  - Minimum HPP inlet feed pressures can be difficult to maintain at higher feed flowrates when coupled with pre-filter fouling. Overtime this can cause alarm to HPP failure.
  - The APM1.2 ERD was slightly more efficient at lower feed flowrates but has trade offs such as reduced permeate recovery and quality. This increases brine hydraulic power.
  - Higher feed flowrates require longer Start Up / Shut Down sequences. Transient periods must be kept minimal with respect process steady state durations. $t_{SU} + t_{SD} <= 475$ s/ m^3.
  - A low flow batch operation will use the minimum amount of energy during processing but it is still uncertain if these conditions are favourable for industrial clients.
  - For optimal IW treatment to exist, process solutions must adapt their treatment strategies towards the objective of producing site specific "water fit for use".
  - These strategies require the advancement of many discipline areas in order to be realised.
  - Will more stringent legislation accelerate IW treatment from the "value" to "crisis" path?
- Further work still required:
  - HPP vs HPP/ERD performance and energy benchmarking.
  - The range limits of recycling brine concentrate using a semi-batch loop configuration.
  - Life Cycle Cost Analysis – Assessing the entire RO process cost including its CAPX and OPEX.

FUTURE RESEARCH AIMS



Dual HPP/ERD configuration for consecutive pump benchmark testing under realistic RO operating conditions.

- Saltgae HPP:
  - A novel self reciprocating HPP which does not require any feed pump.
  - No ERD integration allows for greater permeate flowrates to be achieved.
  - This enhanced flexibility in treatment can be optimised to suit more demanding and time dependant site-specific water needs.

Q & A

the international water association

- Questions?

H2020-Water-1b-2015

This research was undertaken as part of the Saltgae H2020 project to develop techno-economically viable solutions for saline wastewaters (http://saltgae.eu/ H2020-Water-1b-2005, Grant Agreement no. 689785).

REFERENCES

- Typical piston axial pump efficiency curve:
- Inlet feed conditions of different HPP+ERDs:

7. Pressure

7.1 Inlet pressure

7.1.1 APP pump: The pressure at the pump inlet (I) must be in the range: 0.5 - 5 bar (7.3 - 72.5 psi).
7.1.2 APM motor: The pressure at the motor inlet (I) must be in the range: 10 - 80 bar (145 - 1160 psi).

7.2 Outlet pressure

7.2.1 APP pump: The pressure at the pump outlet (O) must be in the range: 20 - 80 bar (290 - 1160 psi).
7.2.2 APM motor: The pressure at the motor outlet (O) must be in the range: 0.5 - 5 bar (7.3 - 72.5 psi)

Danfoss SWPE APP1.8/APM1.2

Table 12: Inlet pressure [bar] depending on size

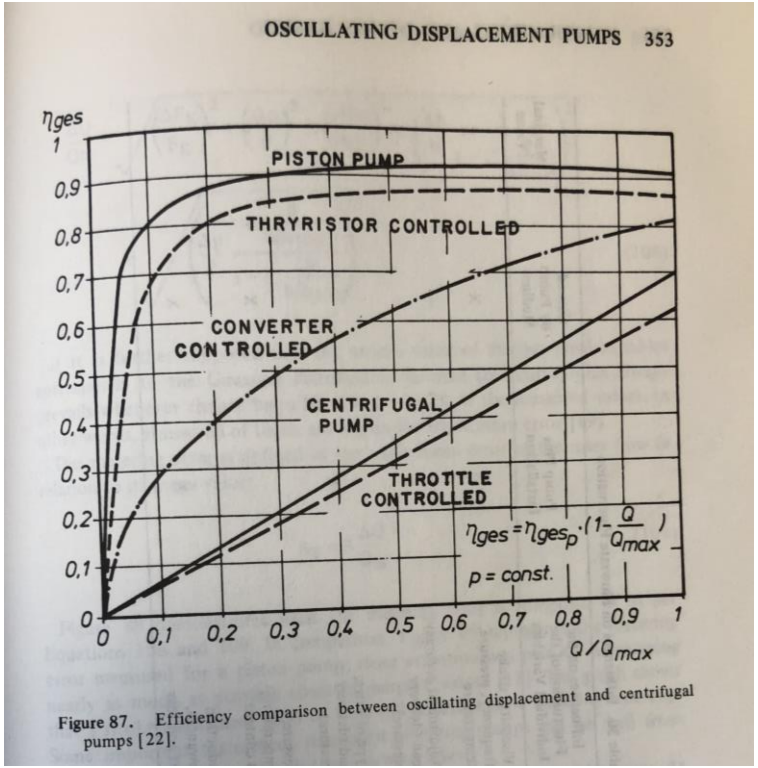
Size	Limits		Warning		Shutdown	
	Min.	Max.	Min.	Max.	Min.	Max.
14	2,5	10,0	2,3	9,0	2,0	10,0
20	3,0	10,0	2,8	9,0	2,5	10,0
65	3,5	10,0	3,3	9,0	3,0	10,0

Salinnova Salino Pressure Centre

- Power analysis equations used:

$$P_{in} = \sqrt{3}.V_{rms}.I_{rms}.PF \qquad P_m = \tau.\omega$$

$$P_w = Q.\sigma \qquad \eta_{OS} = \frac{Pw_{HPP}}{Pe_{in} + Pe_{inFP}}$$



Cheremisinoff. Nicholas - Fluid flow: Pipes, pumps and channels