A NOVEL REVERSE ELECTRODIALYSIS APPLICATION TO GENERATE POWER FROM LOW-GRADE HEAT

A.Tamburini[a], A. Cipollina[a], M. Bevacqua[a], L. Gurreri[a], M. Papapetrou[b], W. Van Baak[c], G. Micale[a]

[a]Dipartimento di Ingegneria Chimica, Gestionale, Informatica, Meccanica, Università degli Studi di Palermo, Palermo, Italy

[b]Wirtschaft und Infrastruktur GmbH & Co Planungs-KG (WIP), Sylvensteinstr. 2, 81369, Munich, Germany

[c]FUJIFILM Manufacturing Europe BV, Oudenstaart 1, P.O. Box 90156, 5000LJ, Tilburg, The Netherlands

www.red-heat-to-power.eu

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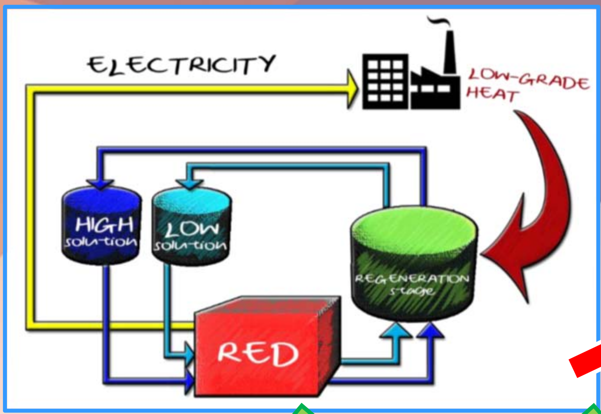
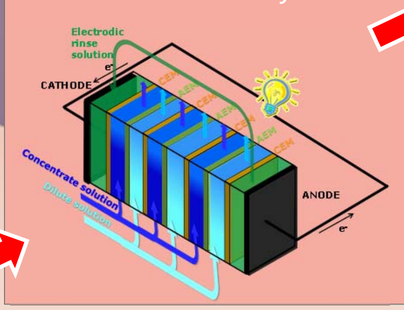
INTRODUCTION: The urgent need to reduce dependency on fossil fuels and concerns of the negative impact of many dated and unsustainable industrial processes on the environment are topics of crucial importance nowadays. These have led the interest towards heat recovery technologies for the utilisation of waste heat from industrial processes to continuously grow. Only some heat engines are able to operate at low temperature level (<100°C), but none of them is able to achieve satisfactory value of efficiency. In this regard, a closed cycle based on the use of **Reverse Electrodialysis** is theoretically able to operate at very low temperature will be presented in the following.



Reverse Electrodialysis unit



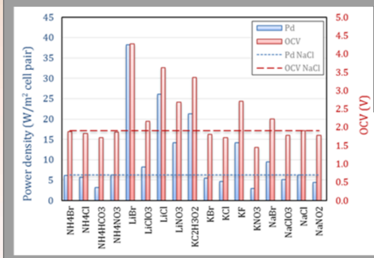
RED optimization via modeling

Performance of the RED unit with different salts

RED model assumptions:

- all solutions' and cell pairs' variables are evaluated at the average conditions between inlet-outlet of the feed channels;
- membrane properties (permselectivity, resistance) are kept constant (i.e. independent of the solute employed);
- solvent transport through membranes is neglected;
- polarization phenomena are neglected;
- ideal current distribution (i.e. no parasitic currents)

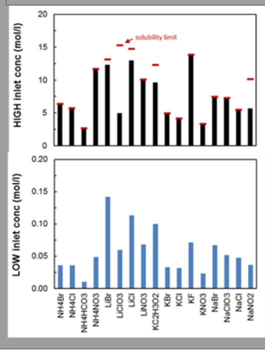
Results



Max power densities and OCVs achievable

High Pd with Li⁺ based monovalent salts

Optimal (i.e. for Pd,max) feed solutions concentrations

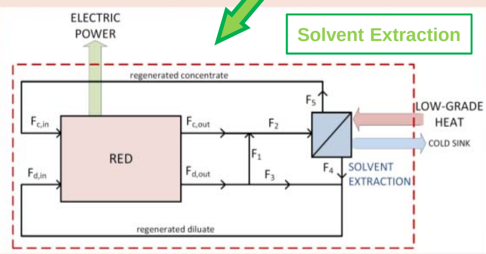


Optimal concentrate concentration equal to the solubility limit for most salts

Optimal dilute concentration lies in a relatively narrow range (0.01 M and 0.15 M) for all the investigated salts.

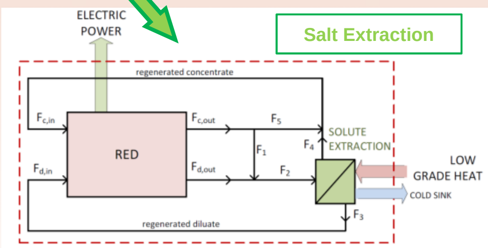
Regeneration strategies

Solvent Extraction



The amount of salt transferred in the RED stack from the concentrate solution to the diluted one is rebalanced by the preliminary addition of stream F_1 to F_2. Then stream F_2 is subjected to the necessary solvent excess extraction which results into two exiting streams, i.e. one solute rich F_5 and one solute free F_4, which regenerate the two input streams necessary for RED system operation.

Salt Extraction



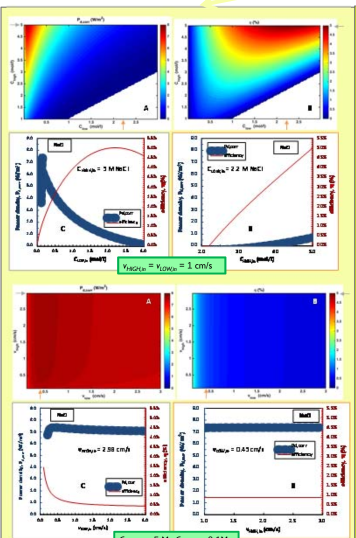
The amount of salt transferred in the RED stack from the concentrate solution to the dilute one is extracted from the dilute stream F_2 in the salt extraction unit. This results in two exiting streams, i.e. F_5 containing only the solute and F_4, a solvent rich stream, which regenerates the two input streams necessary for RED system operation.

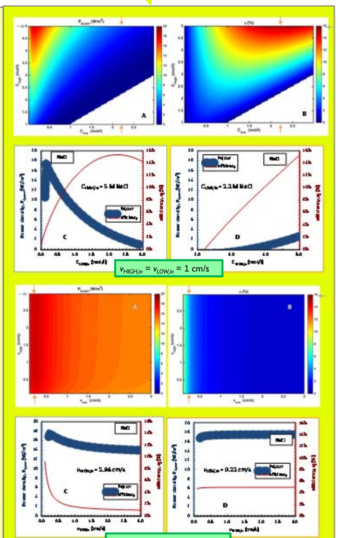
CASE STUDIES

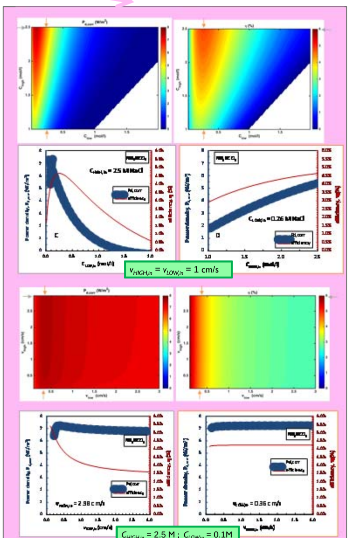
		Case study I	Case study II	Case study III
	Case study typology	State of the art	Perspectives	Perspectives
	Waste heat source temperature (°C)	90	90	60
RED stage				
	Salt	NaCl	NaCl	NH_4HCO_3
	AEM permselectivity α_{AEM} (-)	0.65	0.90	0.90
	CEM permselectivity α_{CEM} (-)	0.90	0.90	0.90
	AEM electrical resistance R_{AEM} (Ω cm²)	2.96	0.50	0.50
	CEM electrical resistance R_{CEM} (Ω cm²)	1.55	0.50	0.50
	Temperature (°C)	25	25	25
Regeneration stage				
	Typology	Solvent extraction	Solvent Extraction	Salt Extraction
	Technology	MED	MED	Thermal degradation
	Energy consumption	40 kWh_{th}/m^3 of extracted solvent	25 kWh_{th}/m^3 of extracted solvent	100 kJ/mol of extracted salt [77] and 4°C of thermal heating for F_2
Sensitivity analysis	Parameters and variation range			
	$C_{HIGH,in}$ (mol/l)	1.0÷5.0	1.0÷5.0	1.0÷2.5
	$C_{LOW,in}$ (mol/l)	0.01÷3.0	0.01÷3.0	0.01÷2.0
	$v_{HIGH,in}$ (cm/s)	0.1*÷3.0	0.1*÷3.0	0.1*÷3.0
	$v_{LOW,in}$ (cm/s)	0.1*÷3.0	0.1*÷3.0	0.1*÷3.0

Cycle Efficiencies

- **Energetic efficiency** $\eta = \frac{P_{d,corr}}{Q_{wh}}$
- **Carnot efficiency** $\eta_c = 1 - \frac{T_{cold}}{T_{hot}}$
- **Exergetic efficiency** $\eta_{ex} = \frac{\eta}{\eta_c}$

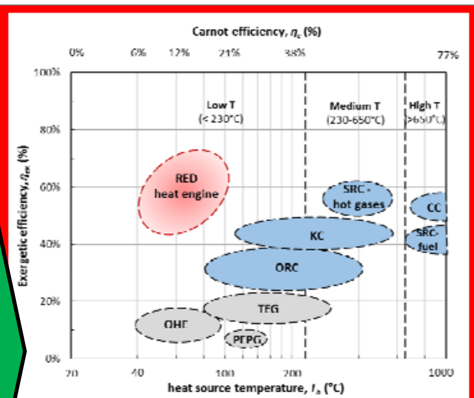






With NaCl-water solutions efficiencies up to about 15% corresponding to an exergetic efficiency of about 85% can be achieved

With NH_4HCO_3-water solutions max $P_{d,corr}$ and η are achieved at very close values of the operating parameters



State of the art technologies for the conversion of heat into power.
Grey circles refer to technologies at very early stage of development. The Carnot efficiency (on the secondary horizontal axis) is evaluated assuming a cold sink temperature of 20°C . SRC-hot gases: Steam Rankine Cycle integrated with gas turbine/other topping cycles; SRC-fuel: Steam Rankine Cycle directly fuelled by oil, coal or other fuels; KC: Kalina Cycle; ORC: Organic Rankine Cycle; TEG: Thermoelectric Generation; PEPG: Piezoelectric Power Generation with waste heat-powered expansion/ compression cycle; OHE: Osmotic Heat Engine.

RED could be promising as possible future converter of low-grade heat into electric energy

Contact person:
Giorgio Micale
giorgio.maria.micale@unipa.it

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