



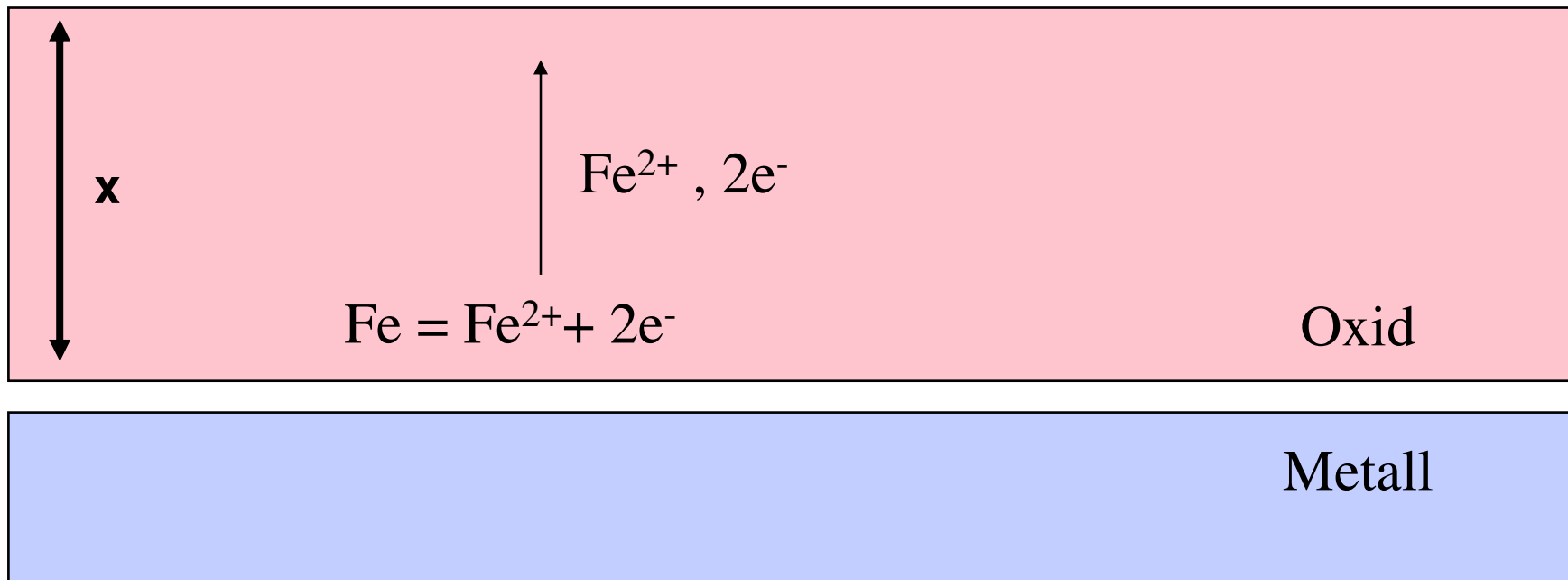
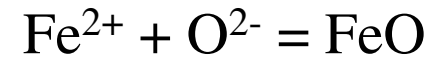
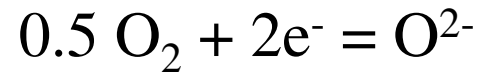
Corrosion of heat exchanger materials

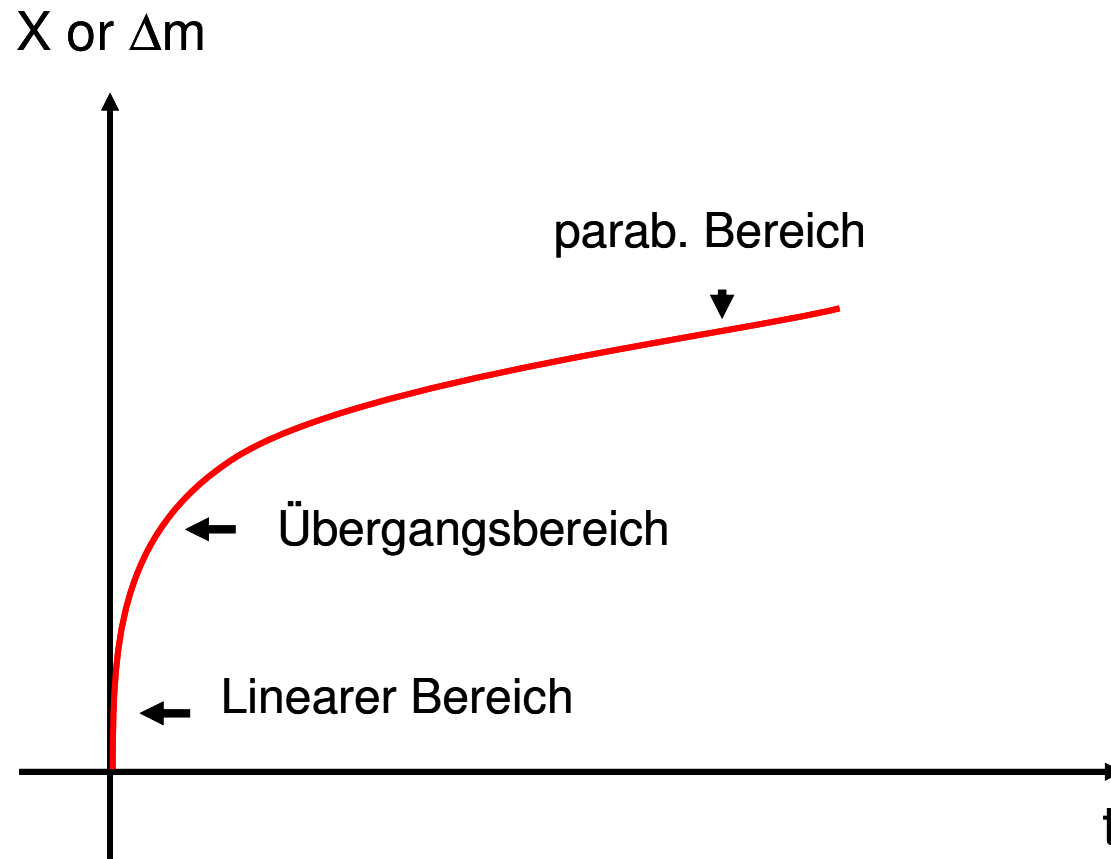
M. Spiegel

Aachen, den 5.06.2008

Oxidation and Passivation

<p>550 °C</p> <p>Low alloyed steels</p> <p>2.25 Cr-1Mo St. 35.8</p> <p>$\text{Fe}_3\text{O}_4/\text{Fe}_2\text{O}_3$</p>	<p>600 – 1200 °C</p> <p>Ferritic, austenitic steels Ni-based alloys, IMP</p> <p>Fe-9-12%Cr, Fe-18Cr-10Ni MCrAlY, FeAl, NiAl</p> <p>Oxide layers</p> <p>Spinelle Cr_2O_3 Al_2O_3</p>	<p>> 1200 °C</p> <p>Ceramics</p> <p>MoSi_2, SiC, Si_3N_4</p> <p>SiO_2</p>
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$$\frac{dx}{dt} = \frac{k'_p}{x}$$

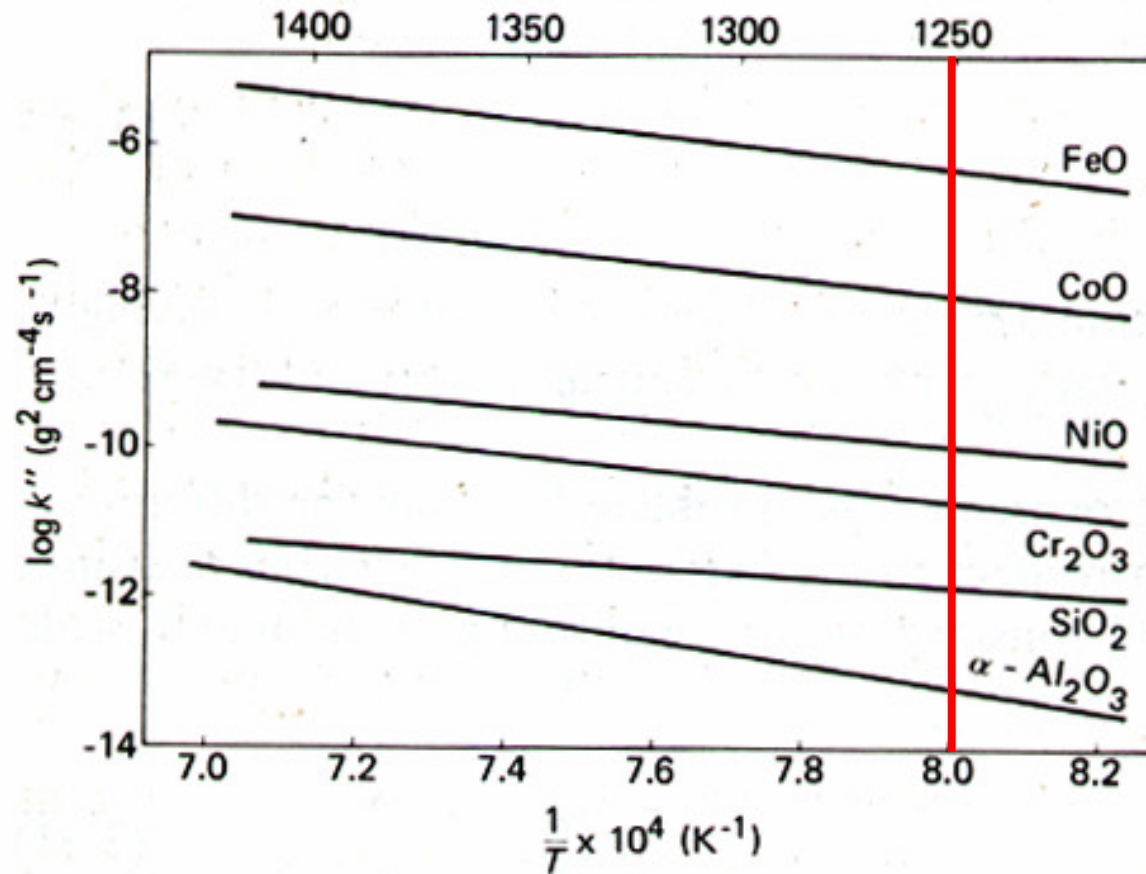
$$x^2 = 2k'_p t$$

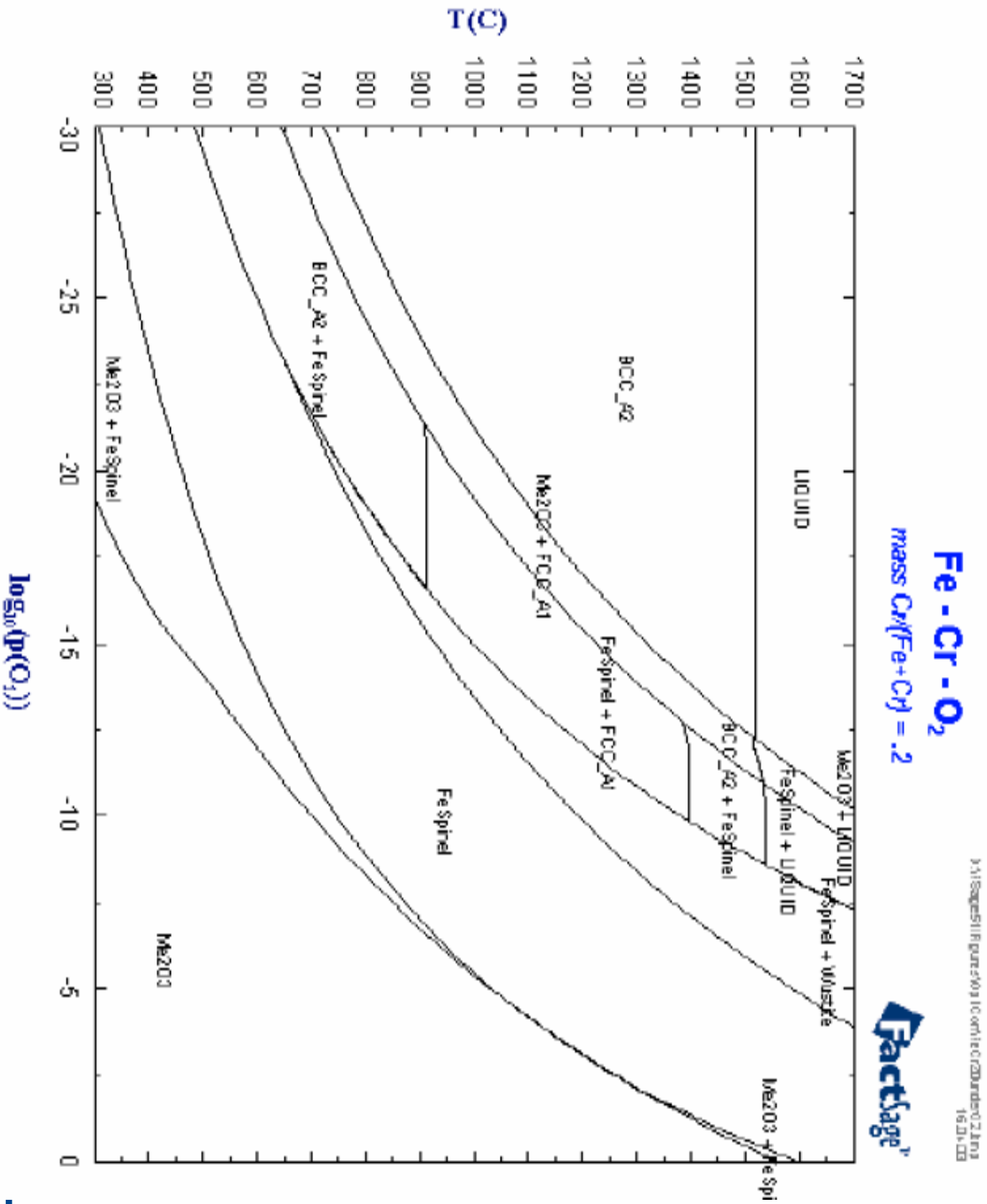
$$[k'_p] = \text{cm}^2/\text{s}$$

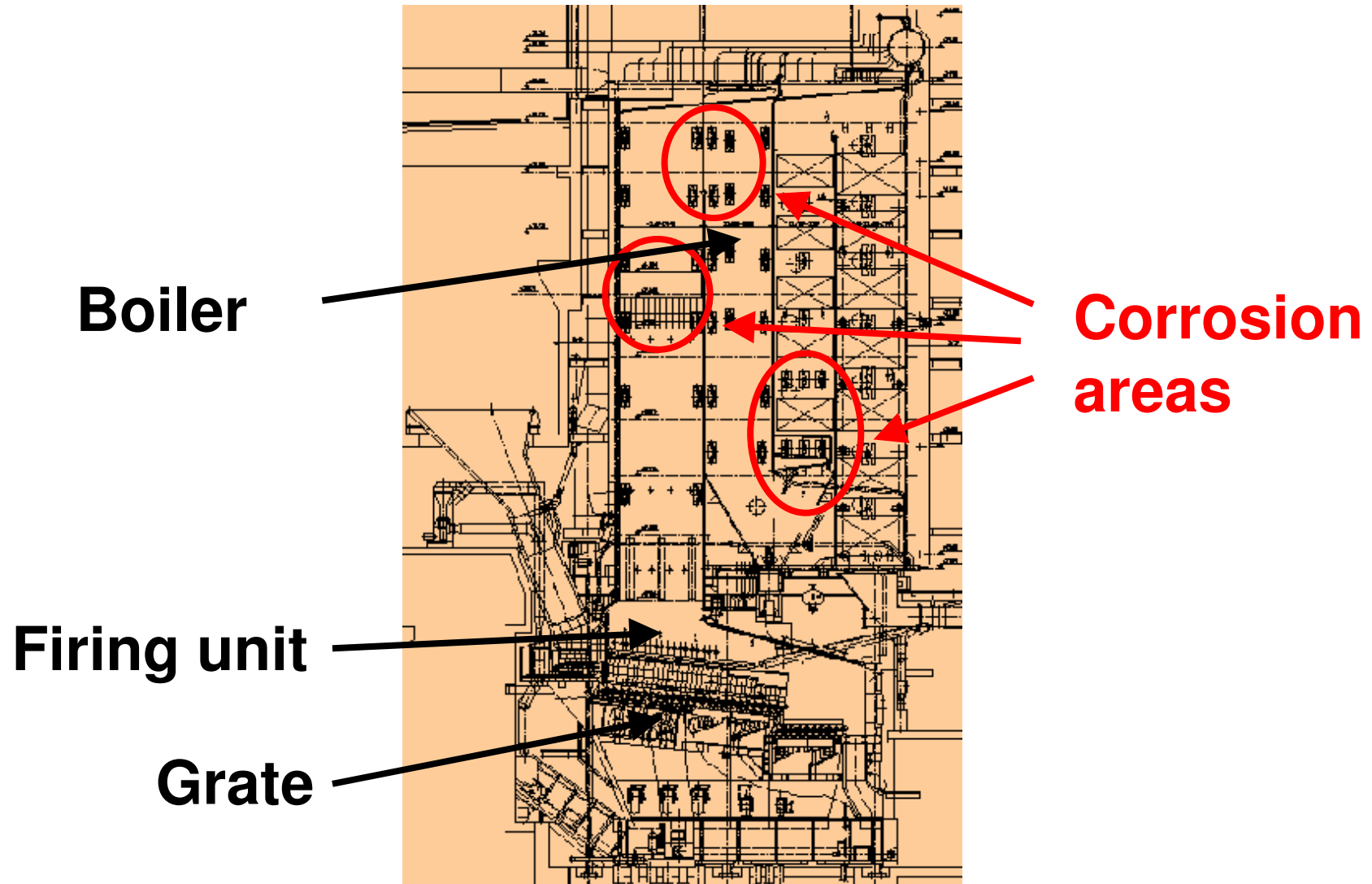
$$[k''_p] = \text{g}^2 / \text{cm}^4 \text{ s}$$

Parabolic growth: Diffusion control

Parabolic constants of oxides





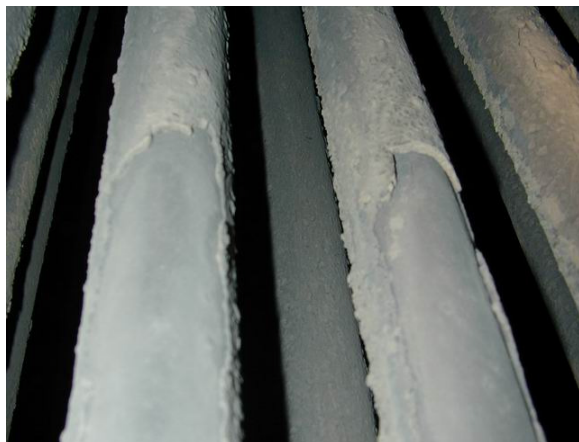


Gaseous and solid combustion products

	Cl wt.%	S wt.%	Na ₂ O wt.%	K ₂ O wt.%	CaO mg/kg	Pb mg/kg	Zn mg/kg
RA	0.5	0.2	1.5	0.3	3.0	1000	1500
Altholz	0.01-0.44	0.02-0.58	0.05	0.7	4.5	40-700	170-950
Holz	0.005-0.02	0.02-0.1	0.02-0.05	0.2-0.5	0.35-1	<5	<35
Braunkohle	0.005- 0.012	0.1-2	0.01-0.3	0.002- 0.1	2-3.5	1.5-5	20-30
Steinkohle	<0.2	0.5-1.1	0.01-0.1	0.05-0.4	0.05-5.5	20-80	20-120

Chlorine > Sulfur > heavy metals > Alkali-elements

Waste > Biomass > Coal

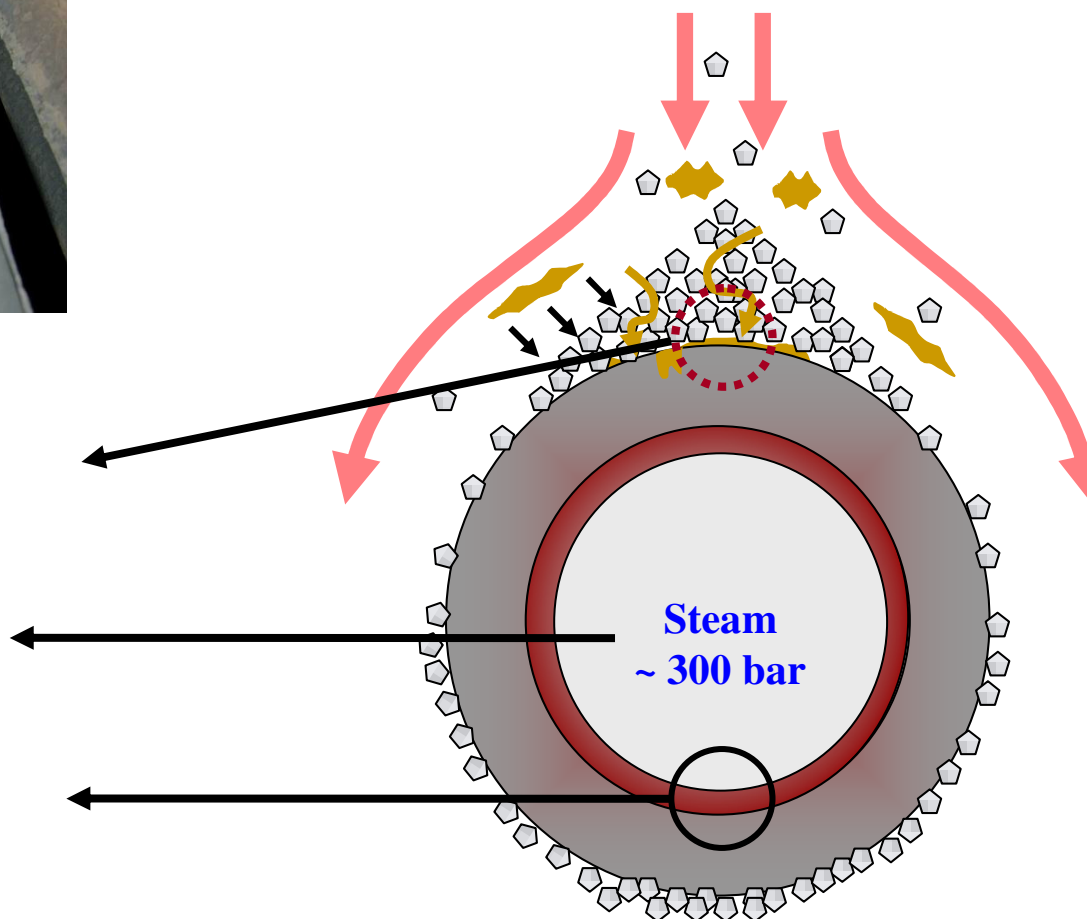


Combustion gas (CO, HCl, SO₂,..., solids)

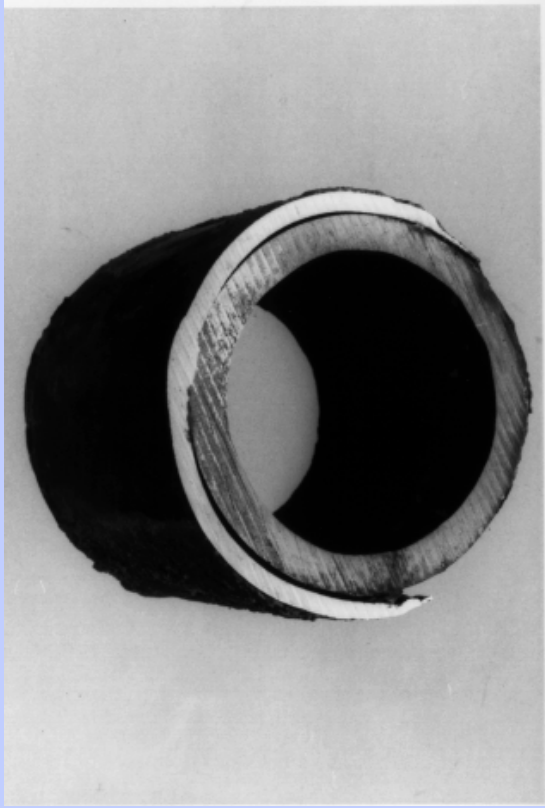
Fireside Corrosion
Condensate-Metal-Gas

Creep strength

Steam oxidation

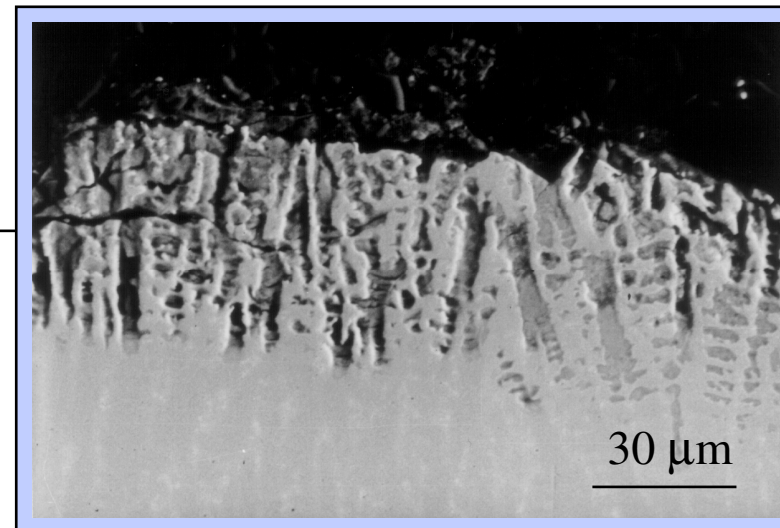
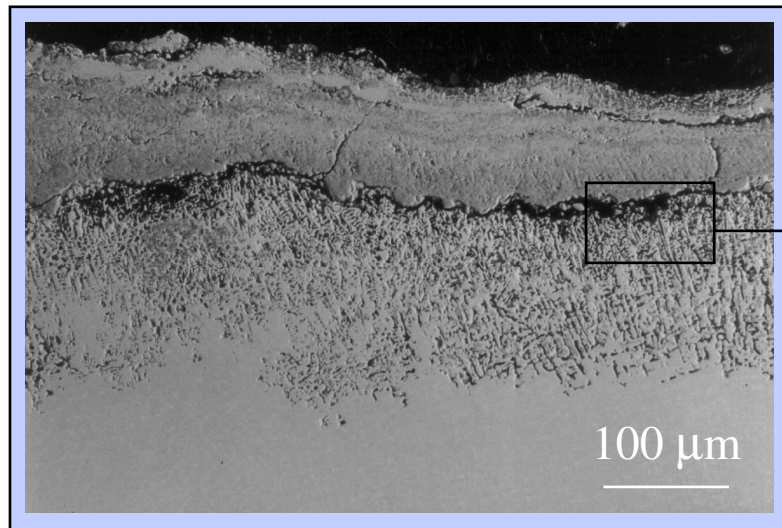


Corrosion of heat exchangers Examples



Corrosion of heat exchangers

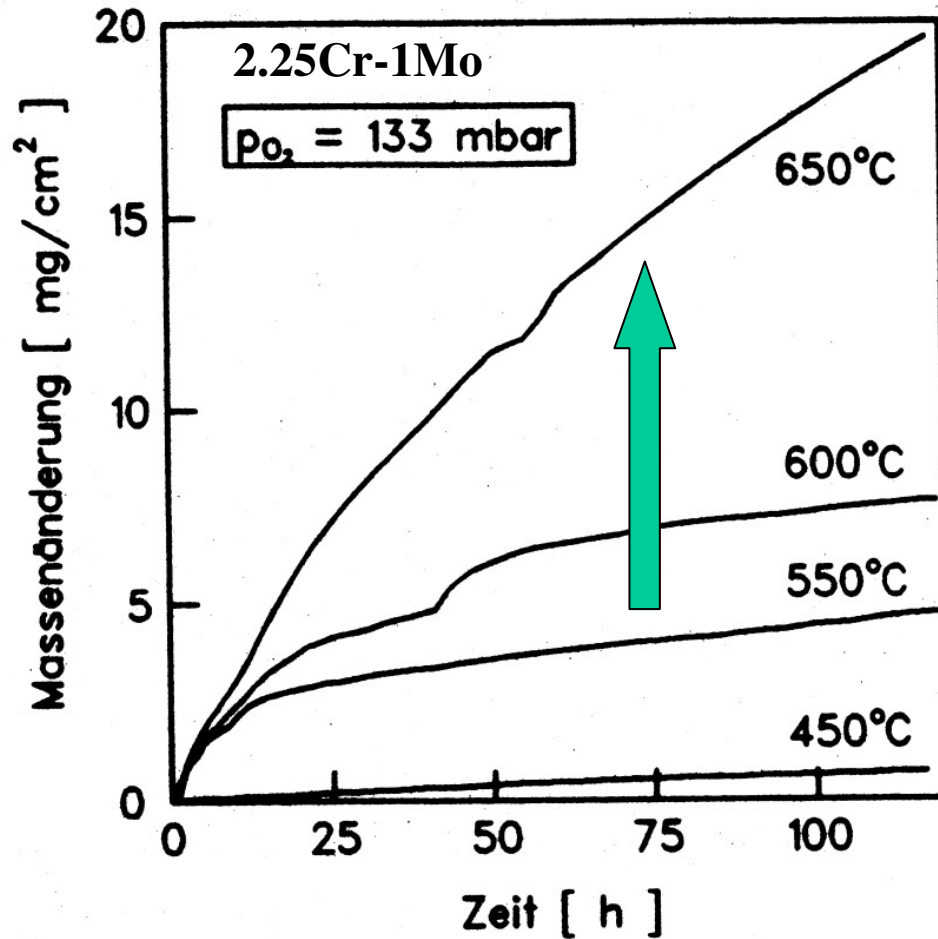
Examples



Corrosion layer of (Fe, Cr, Ni) -
oxides, Metal-chlorides (Ni, Cr,
Fe)

Corrosion penetrates along
dendritic structures

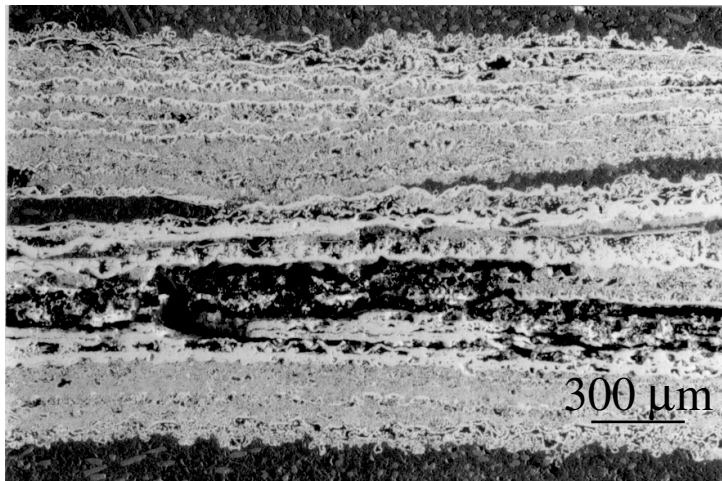
Ar - 500 vppm HCl – O₂



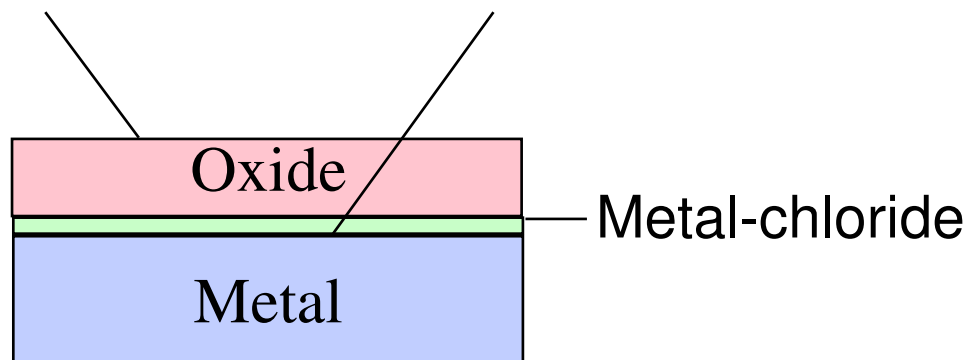
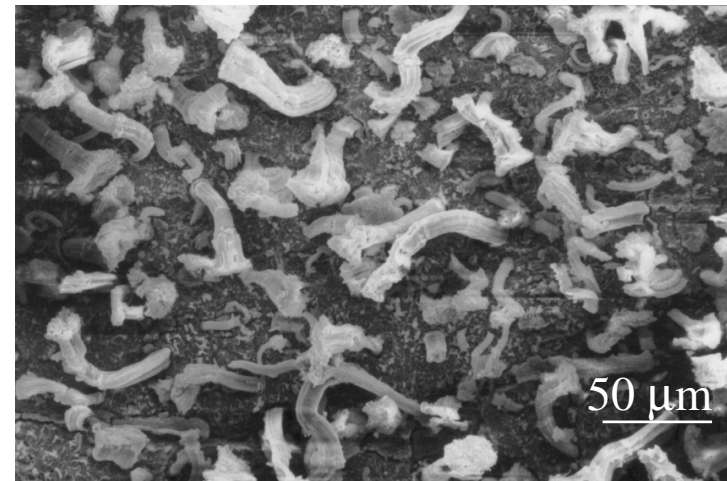
Strong accelerated oxidation

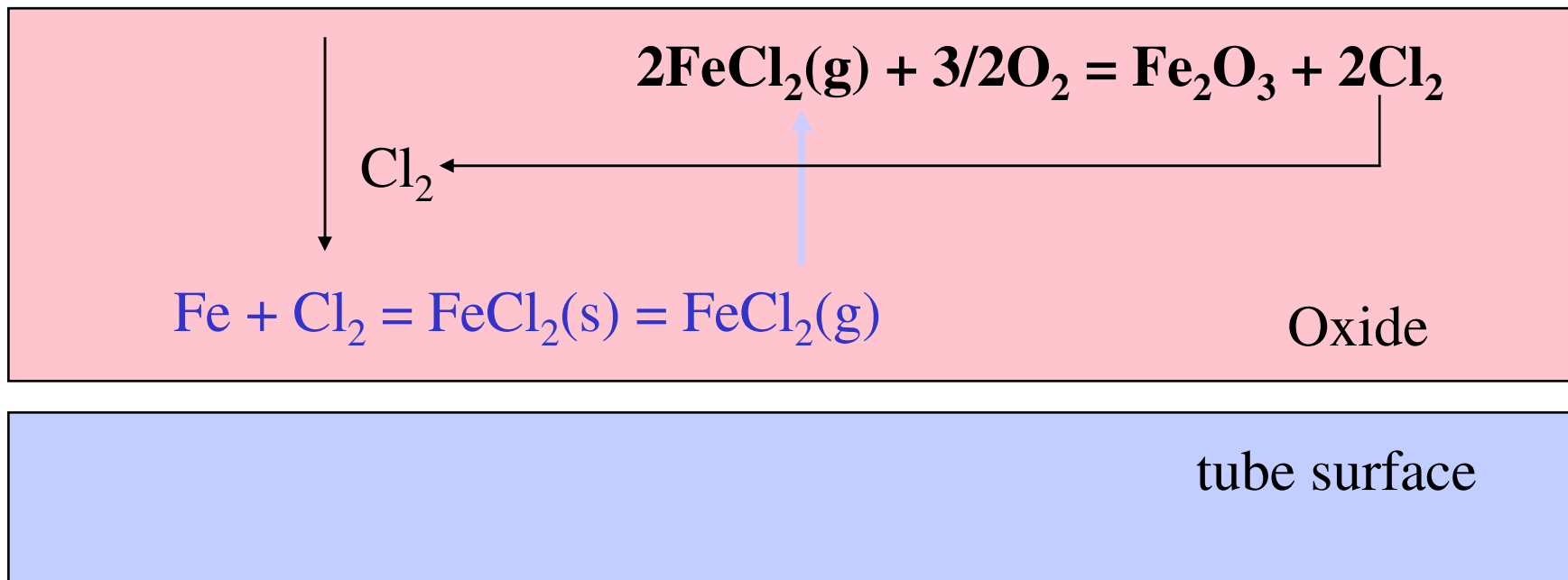
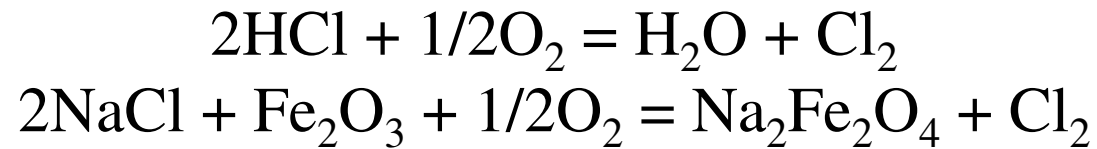
Temperature dependent

Thick and porous oxide layer

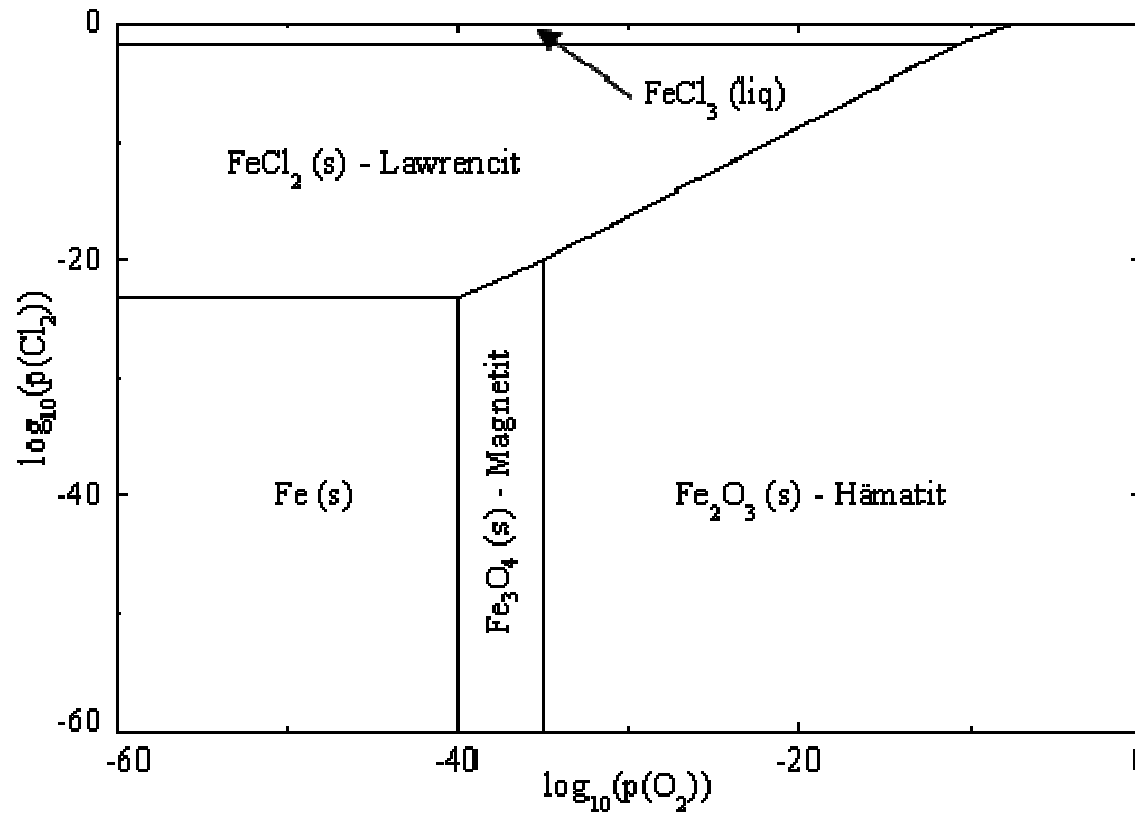


Formation of FeCl_2 at the Metal/oxide interface

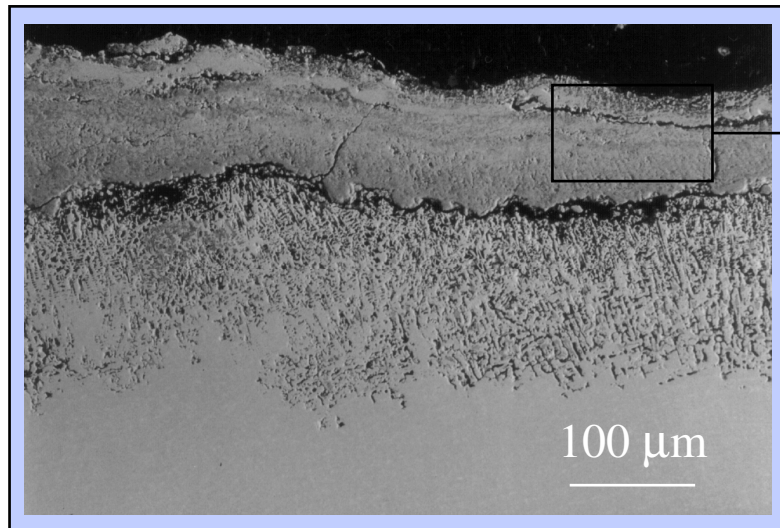




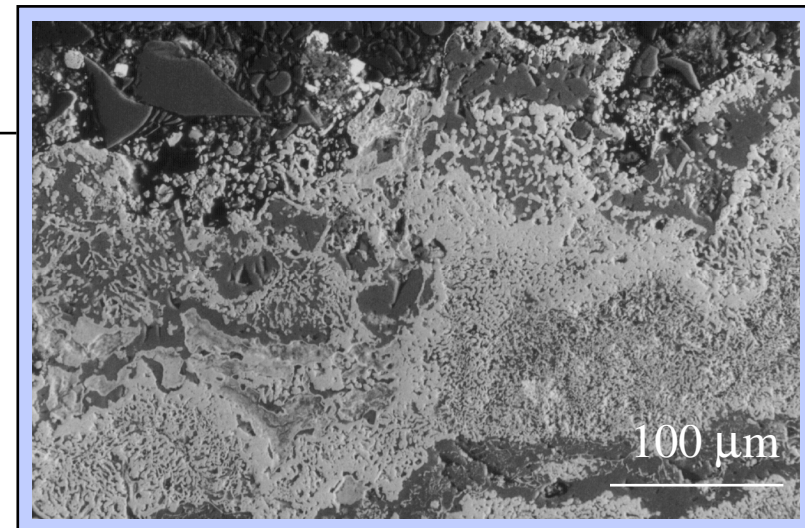
320 °C, FactSage calculation



Corrosion of heat exchangers
Fireside Corrosion: molten salts



Corrosion layer of (Fe, Cr, Ni) -
oxides, Metal-chlorides (Ni, Cr,
Fe)

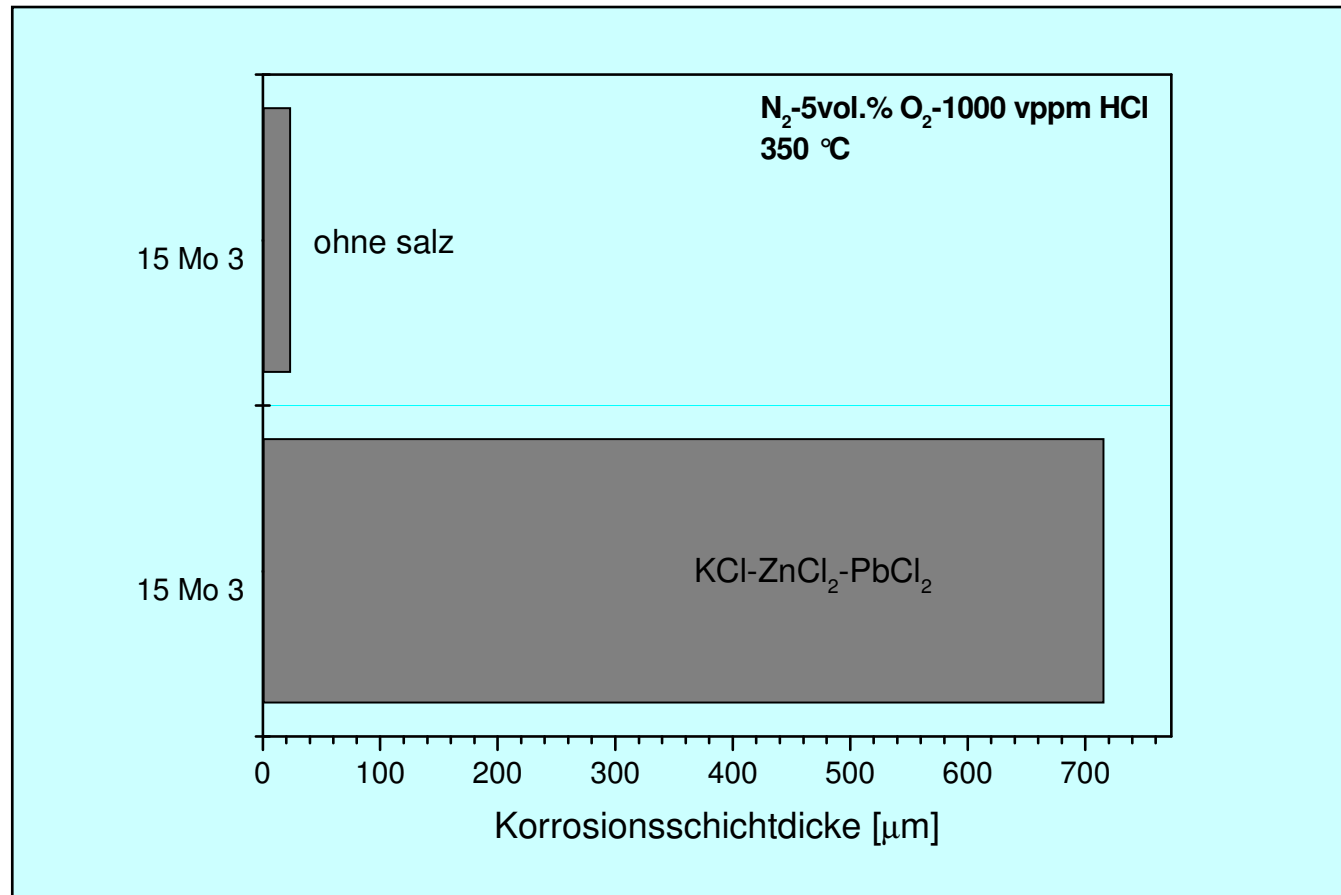


porous oxides in solidified
melts

composition [wt. %]	Melting point [°C]
ZnCl ₂	318
PbCl ₂	498
48ZnCl ₂ - 52 KCl	250
82ZnCl ₂ - 18 KCl	262
84ZnCl ₂ - 16 KCl	262
73ZnCl ₂ - 27PbCl ₂	300
31NaCl - 69PbCl ₂	410
21KCl - 79PbCl ₂	411
17NaCl - 83PbCl ₂	415
39ZnCl ₂ - 50KCl - 11PbCl ₂	275
35ZnCl ₂ - 48NaCl - 17PbCl ₂	350
16NaCl - 40KCl - 44PbCl ₂	400
K ₂ SO ₄ - Na ₂ SO ₄ - ZnSO ₄	384
KCl - ZnCl ₂ - K ₂ SO ₄ - ZnSO ₄	292
K ₂ SO ₄ - Na ₂ SO ₄ - CaSO ₄	776

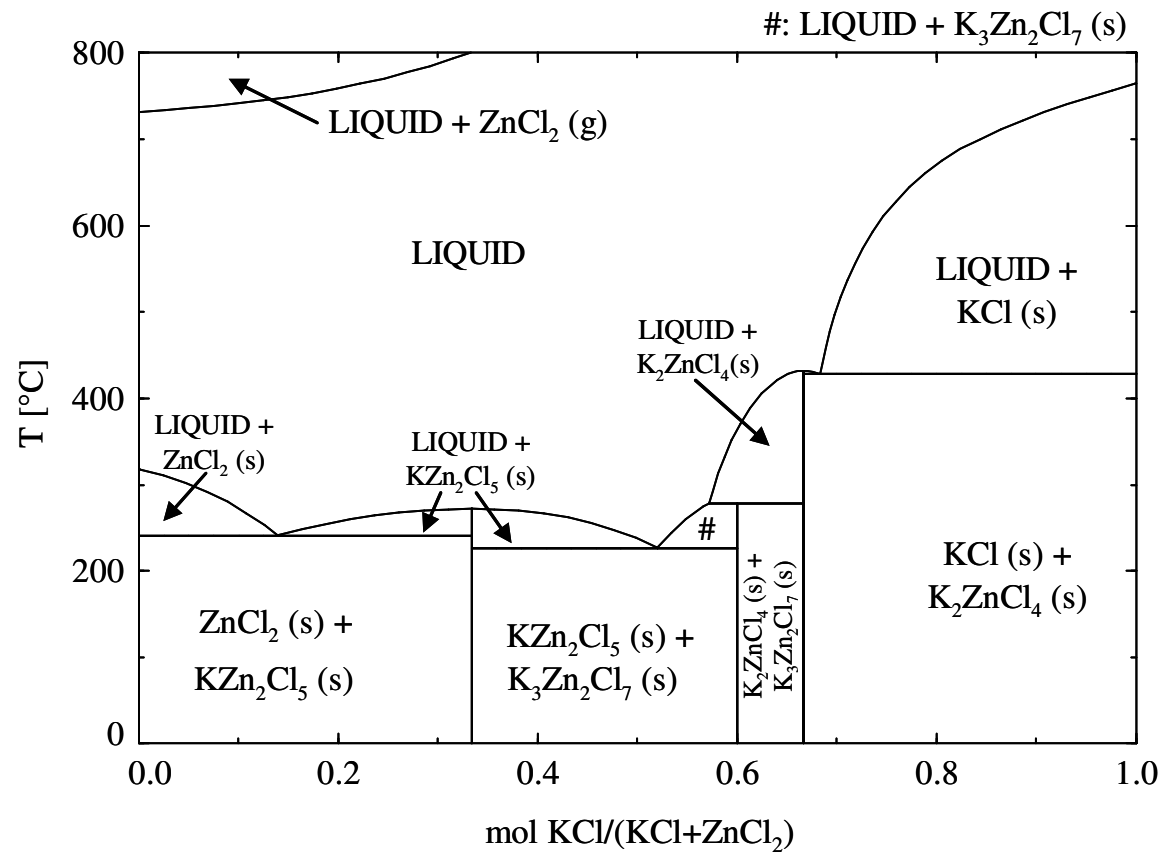
Corrosion of heat exchangers

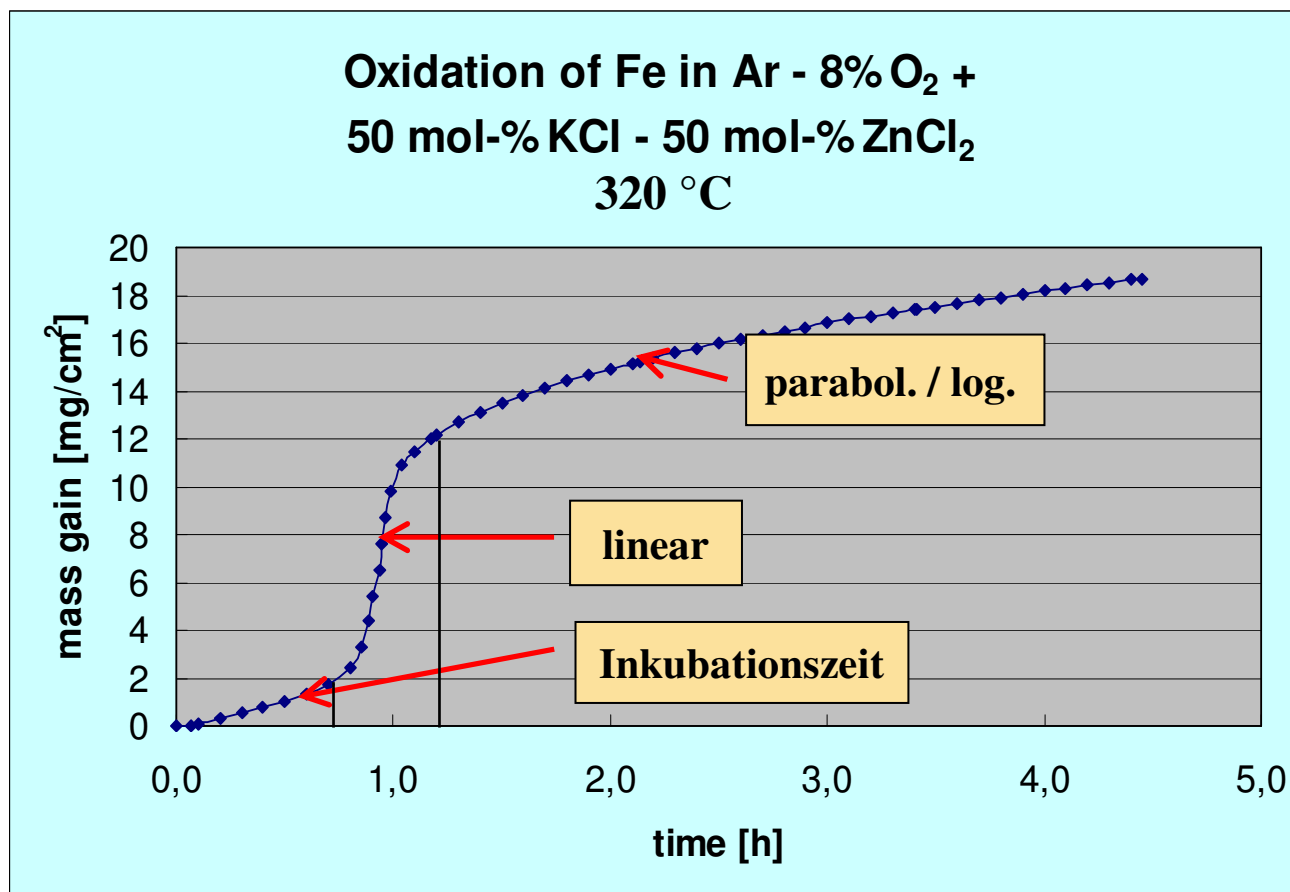
Fireside Corrosion: molten salts



Corrosion of heat exchangers
Fireside Corrosion: ZnCl₂-KCl eutectic

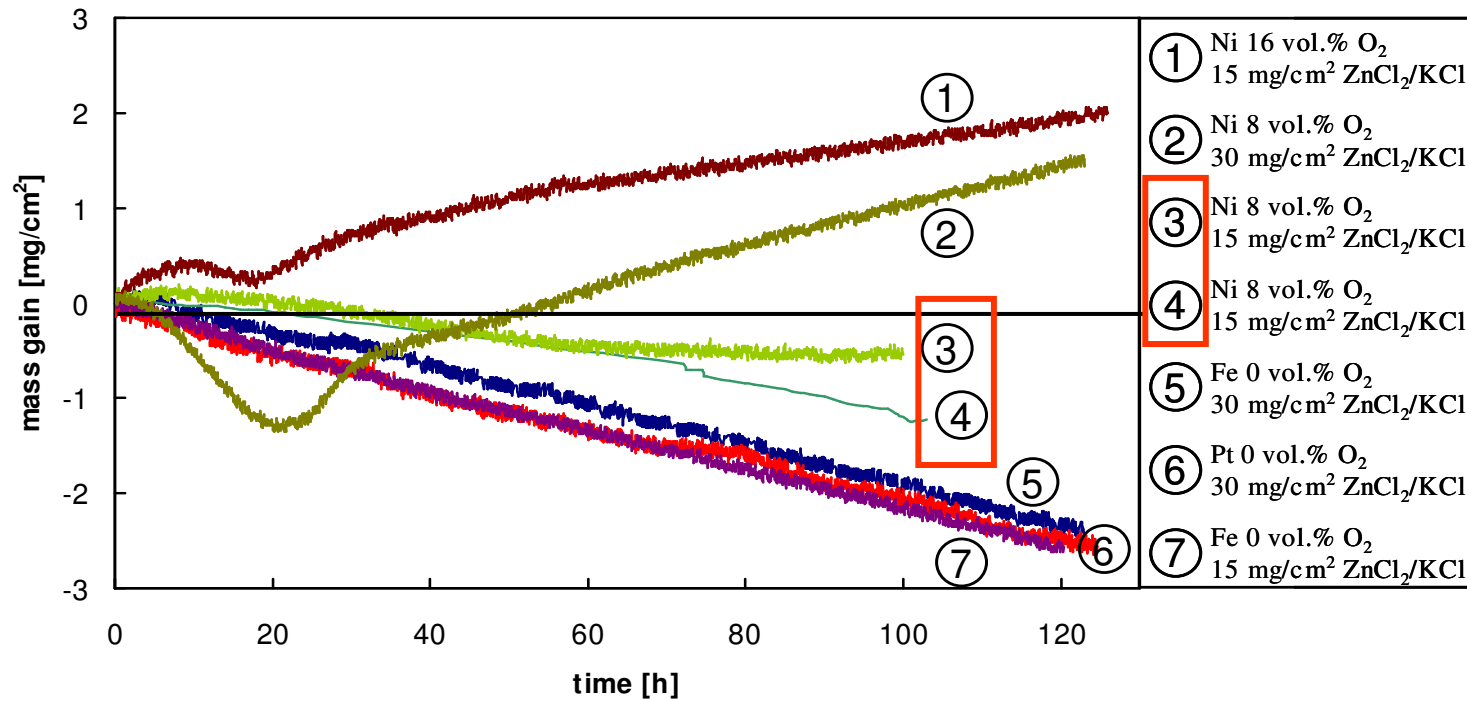
Phase diagramm: FactSage calculation



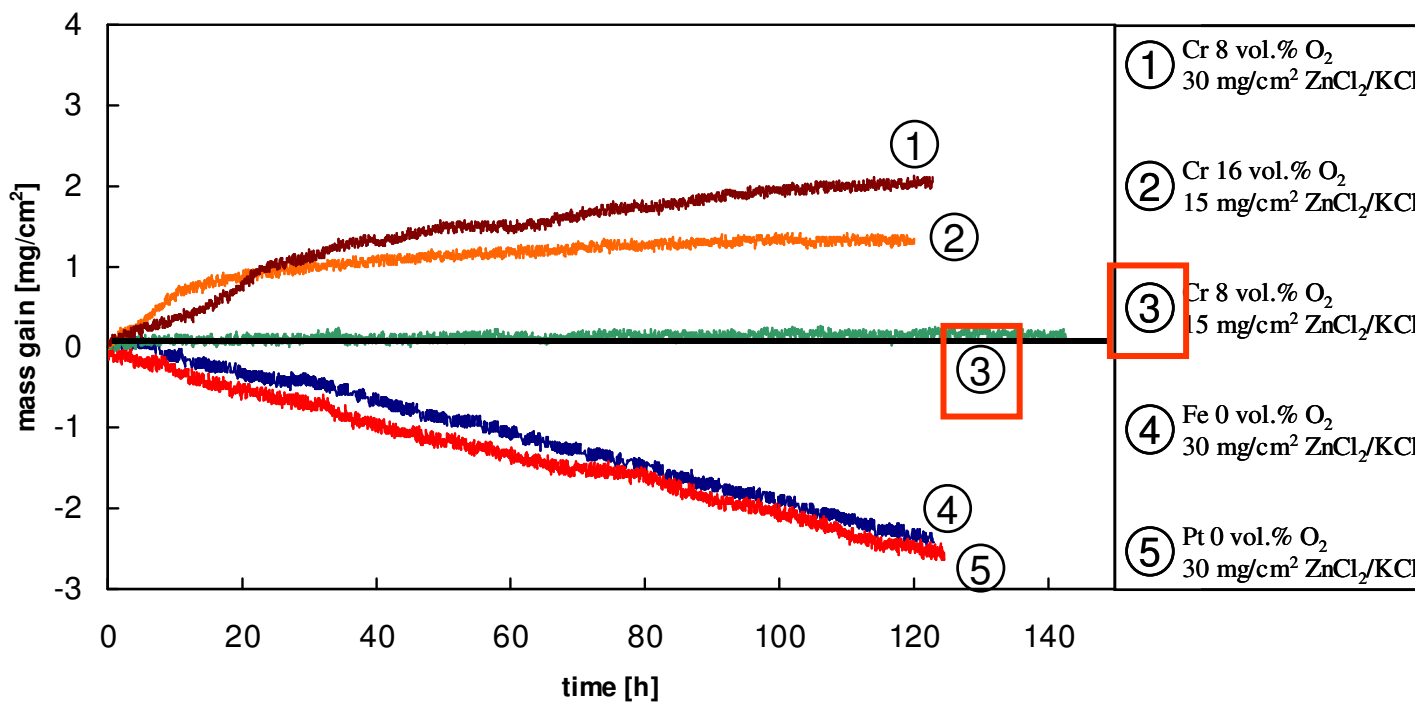


Corrosion of heat exchangers
Fireside Corrosion: ZnCl₂-KCl eutectic

Nickel, 320 °C, KCl-ZnCl₂

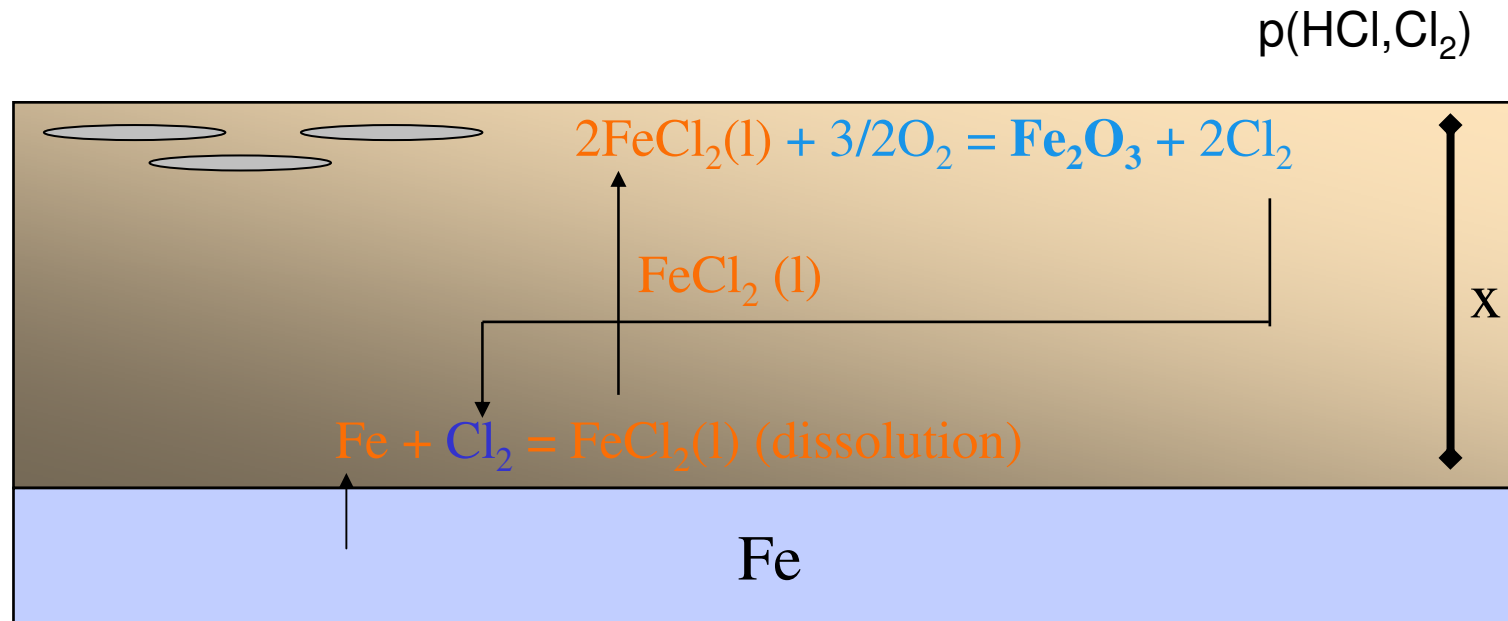


Chromium, 320 °C, KCl-ZnCl₂

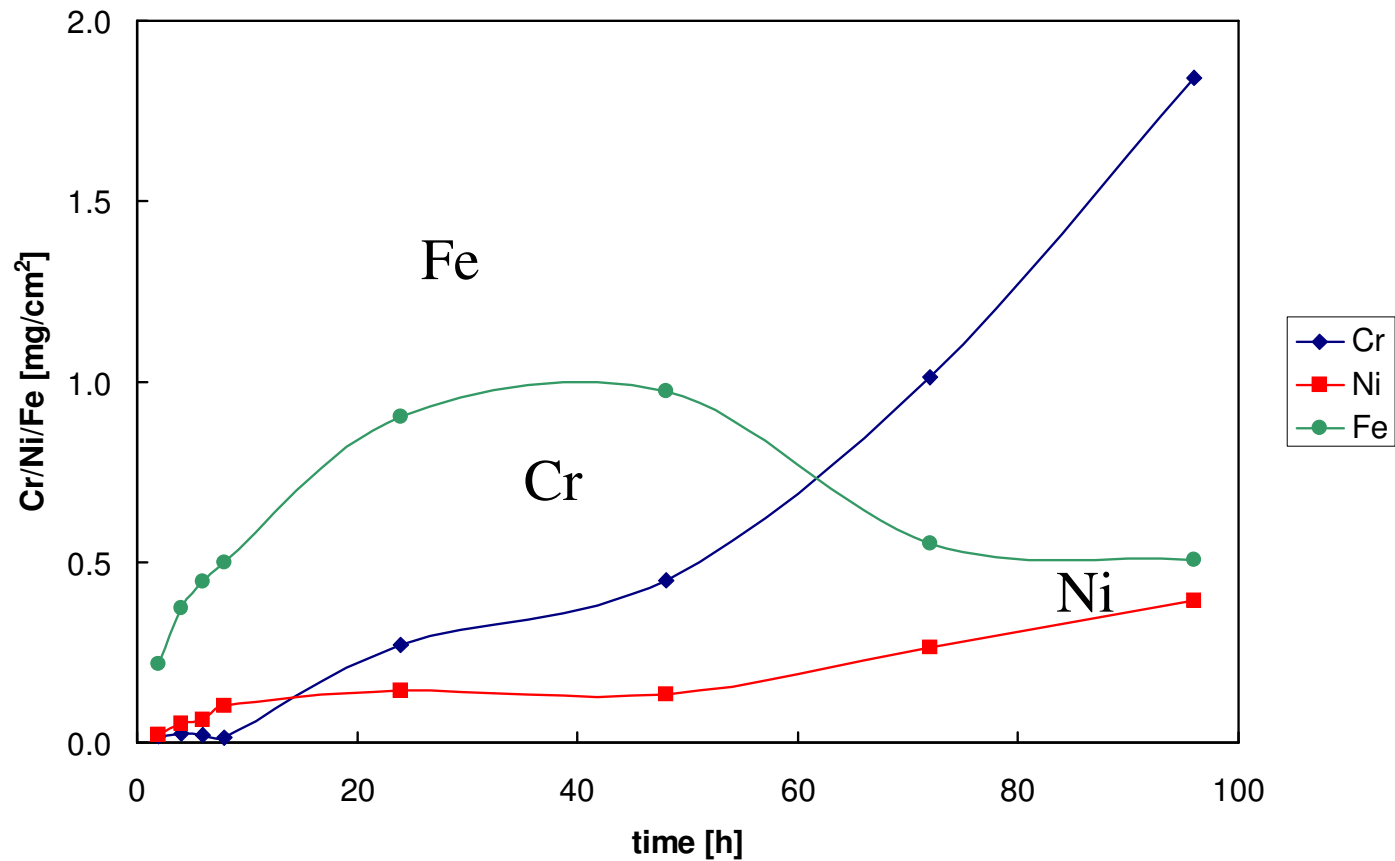


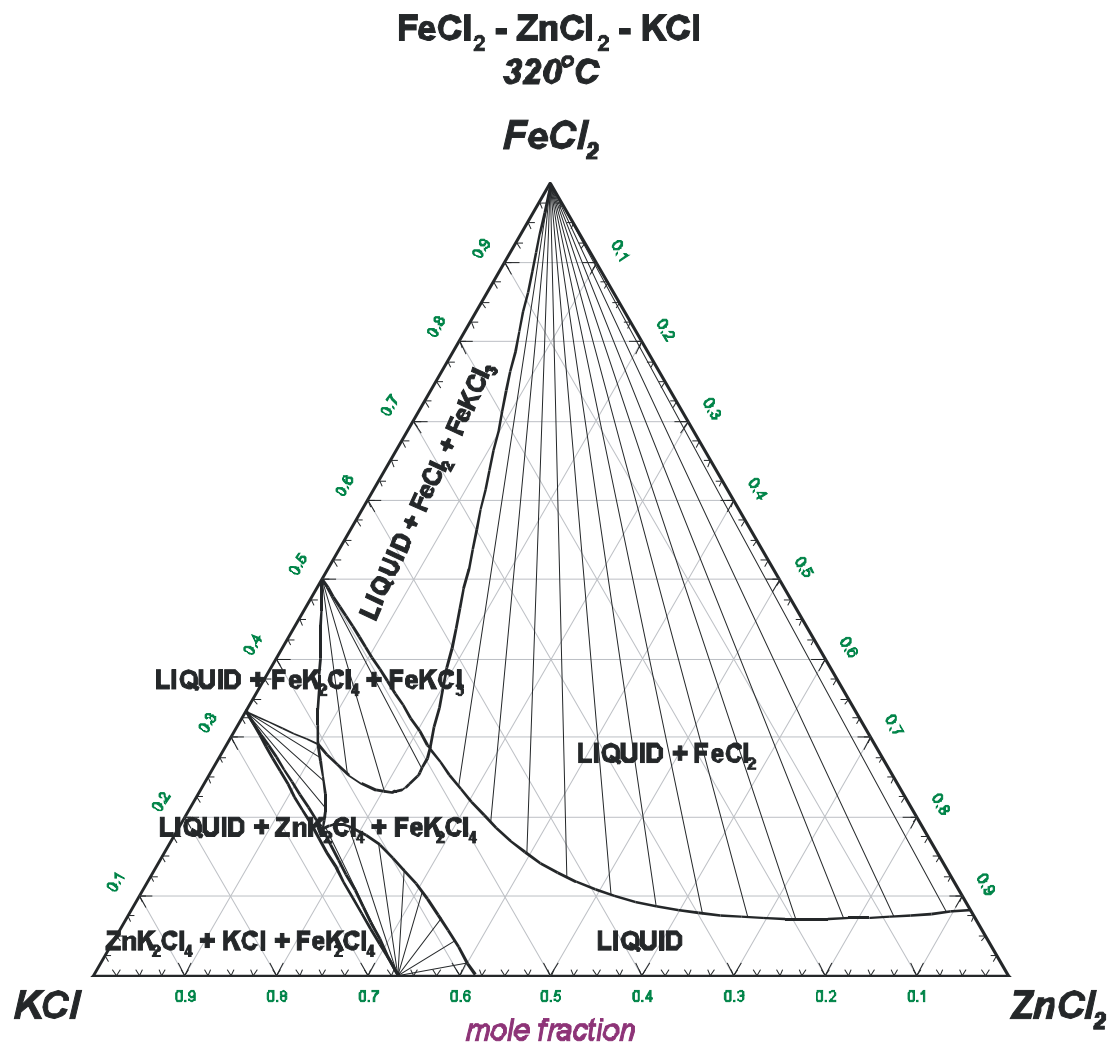
Corrosion of heat exchangers

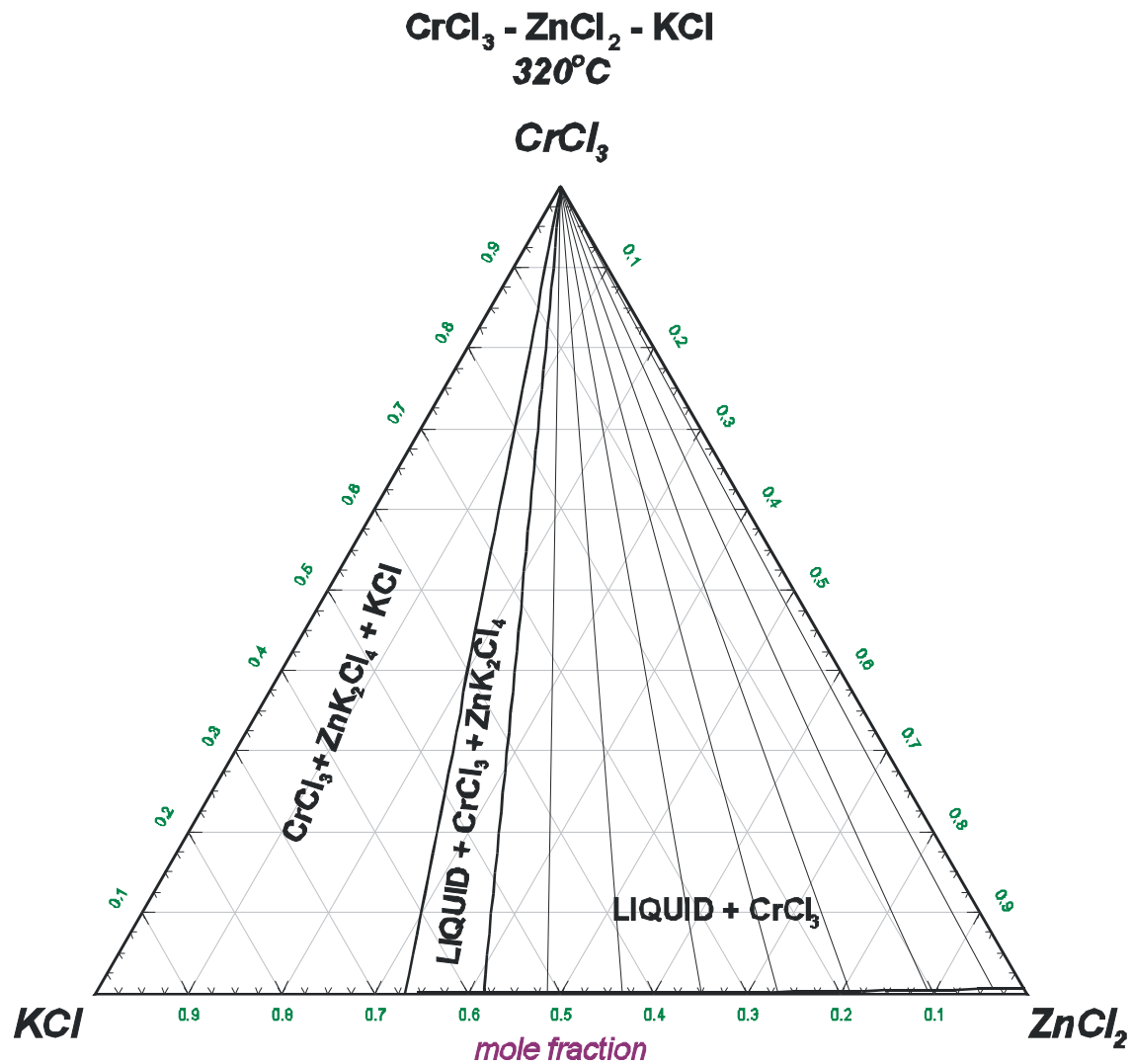
Fireside Corrosion: molten salts

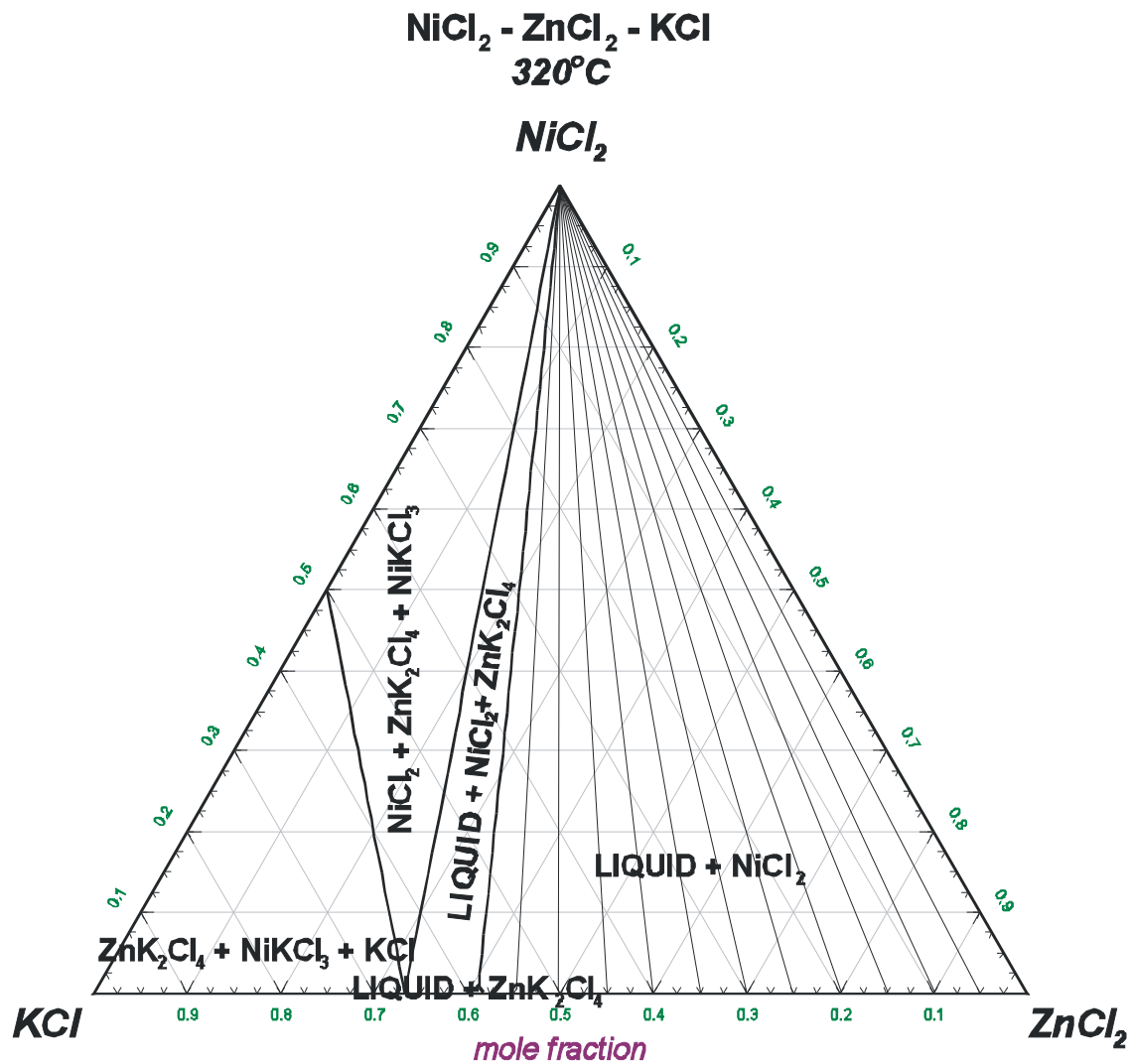


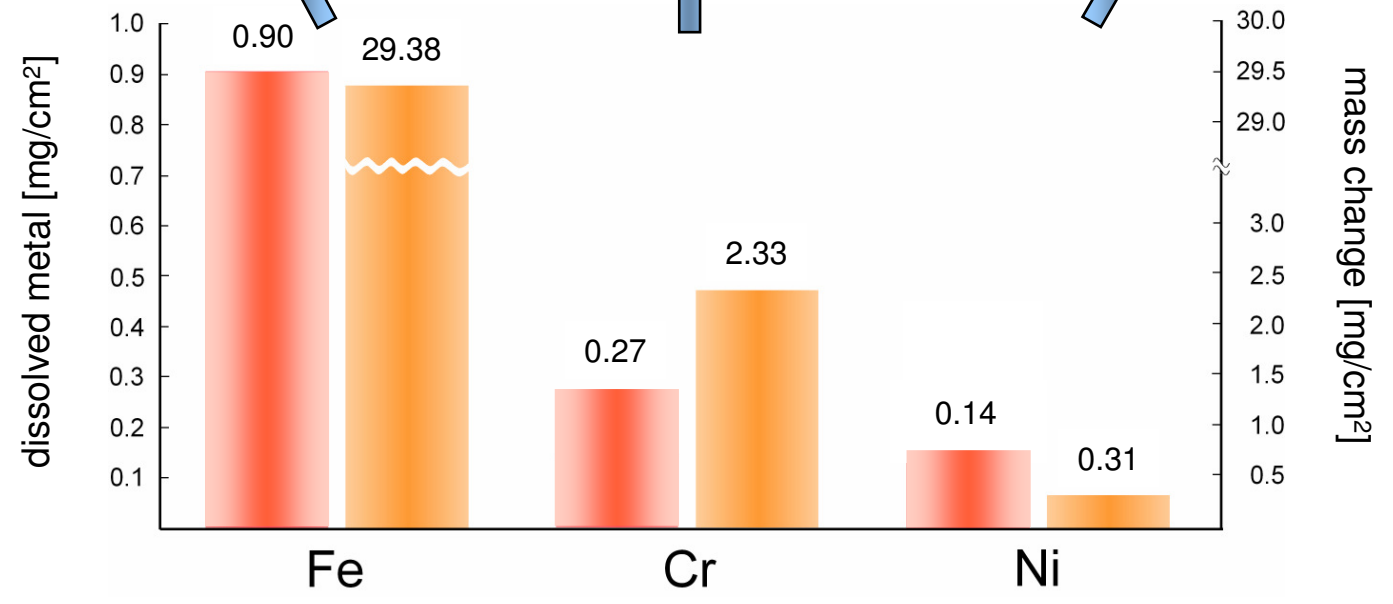
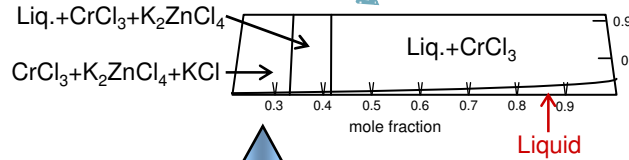
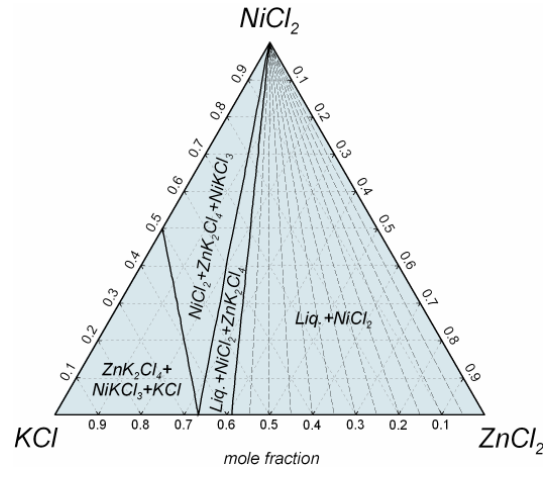
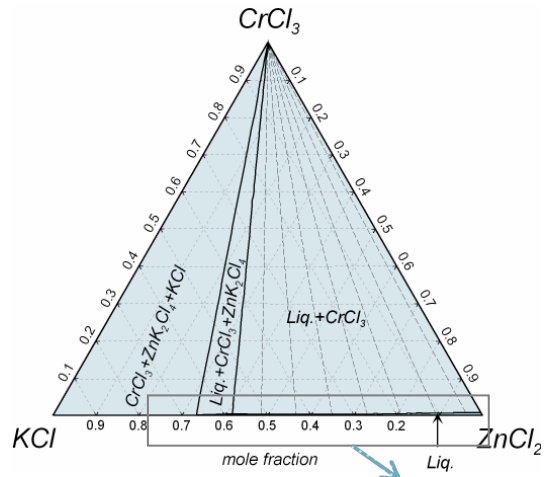
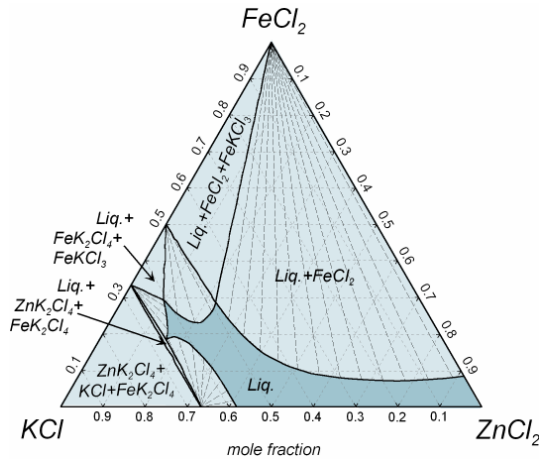
Measured solubility of chloride at 320 °C and N₂-8 % O₂



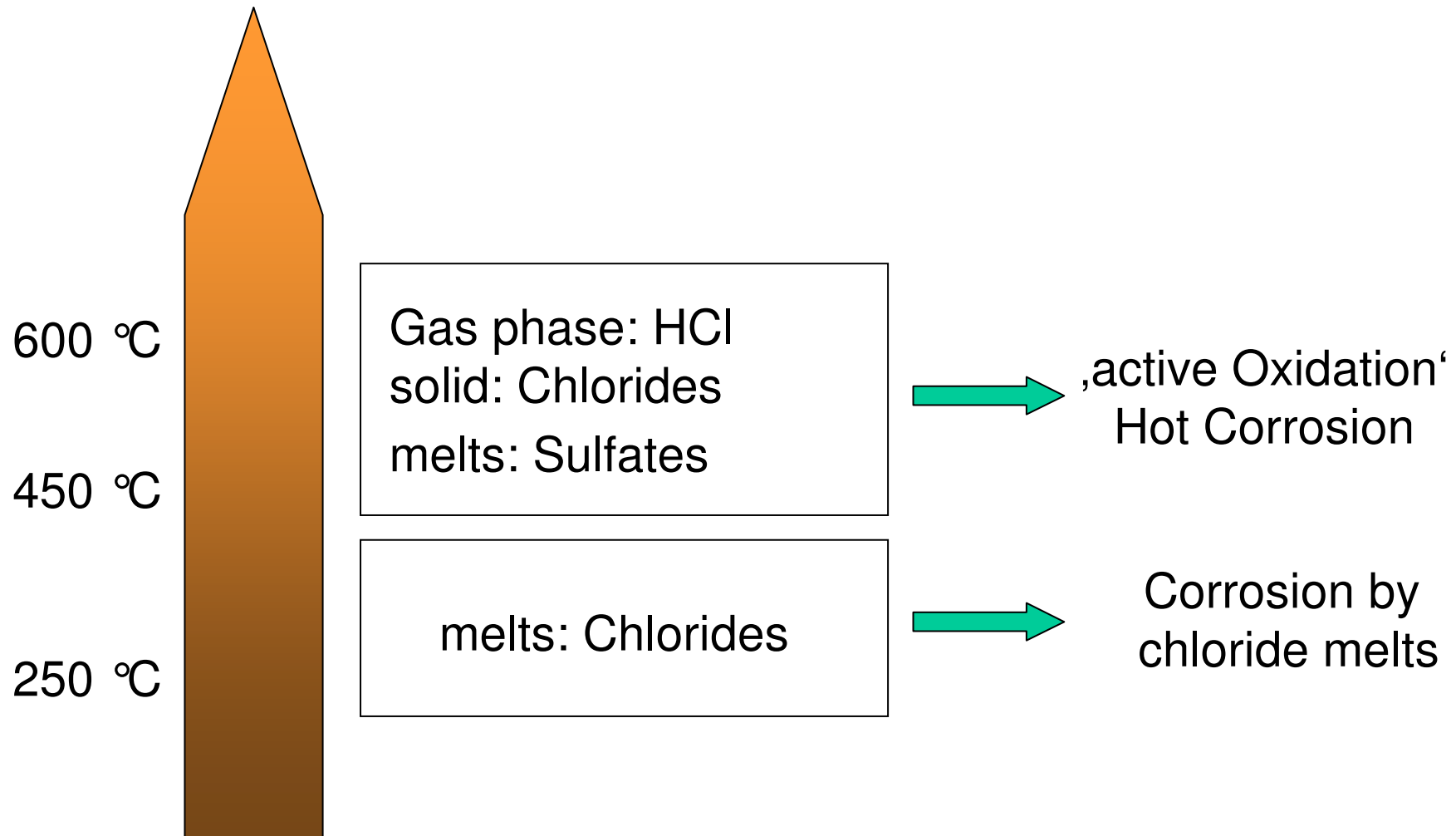




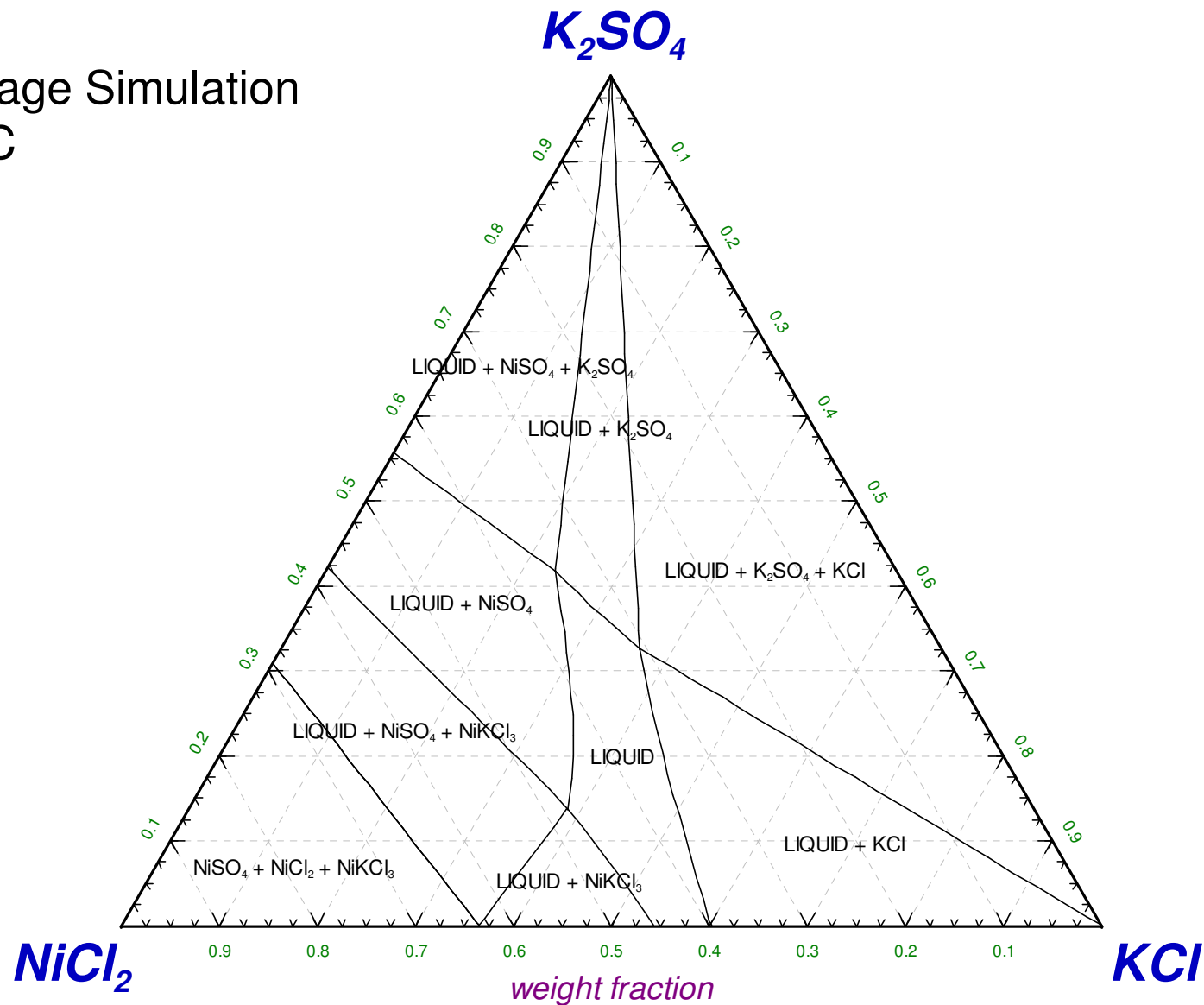




Temperature dependent corrosion mechanisms



FactSage Simulation
550 °C



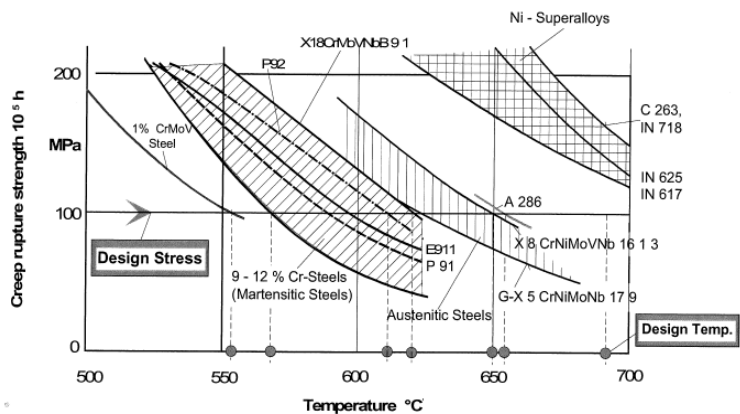
Corrosion of heat exchanger materials

24/06/08

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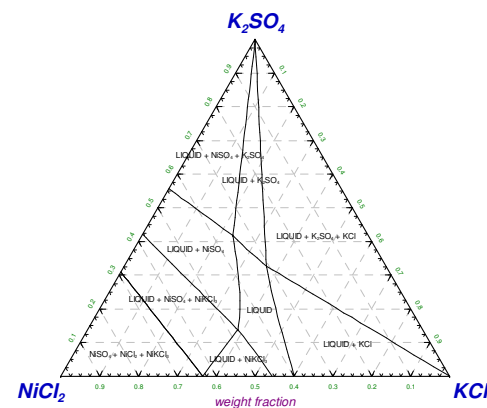
EDWW

creep strength



700 Plus

fireside corrosion



steam oxidation

