Corrosion in Dense Phase CO_2 Pipelines – Three Reasons for Concern

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Issues to be addressed

- Motivation for studying corrosion in the pipeline
- State of the Art
- When can we get corrosion
- Experimental work
  - Corrosion, water < 500 ppmw
  - Corrosion in a separate water phase (water ingress)
  - Depressurization and the effect on the corrosivity

Significant reduction i CO_2 emission

↓

Transport and injection of large amounts of CO_2 (2-3x)

↓

Huge amount of pipes

<u>Emission 2010: 30 Gt CO_2</u>

12" pipelines ~1700
36" pipelines ~190

} **20%, 1.5 m/s**

Need to define a safe operational window

Dense phase CO_2 transport, State of the Art

- CO_2 injection for EOR > 30 years (USA)
- More than 100 installations, more than 5000 km pipeline
- C-steel: Good experience with clean and dry CO_2
- Reported corrosion when water accumulates
- CRA: ”Wet” CO_2, Sleipner, short distance
- Thousands of papers/corrosion studies for pCO_2 < 20 bar
- Few studies for pCO_2 > 50 bar
- Less than 5 publications presenting data with flue gas impurities
- Not much focus on corrosion in the CCS community (GHGT 10)

Will corrosion be a problem?

Good experiences with CO_2 transport in USA!

Is CCS different?

Concentrations of impurities in dried CO_2

	SO_2	NO	H_2S	CO	N_2 /Ar/O_2
COAL FIRED PLANTS					
Post- combustion capture	<100	<100	0	0	100
Pre-combustion capture(IGCC)	0	0	100- 6 000	300- 4 000	300- 6 000
Oxy-fuel	5 000	100	0	0	37 000
GAS FIRED PLANTS					
Post-combustion capture	<100	<100	0	0	100
Pre-combustion capture	0	0	<100	400	13 000
Oxy-fuel	<100	<100	0	0	41 000

Source: Intergovernmental Panel on Climate Change (IPCC)

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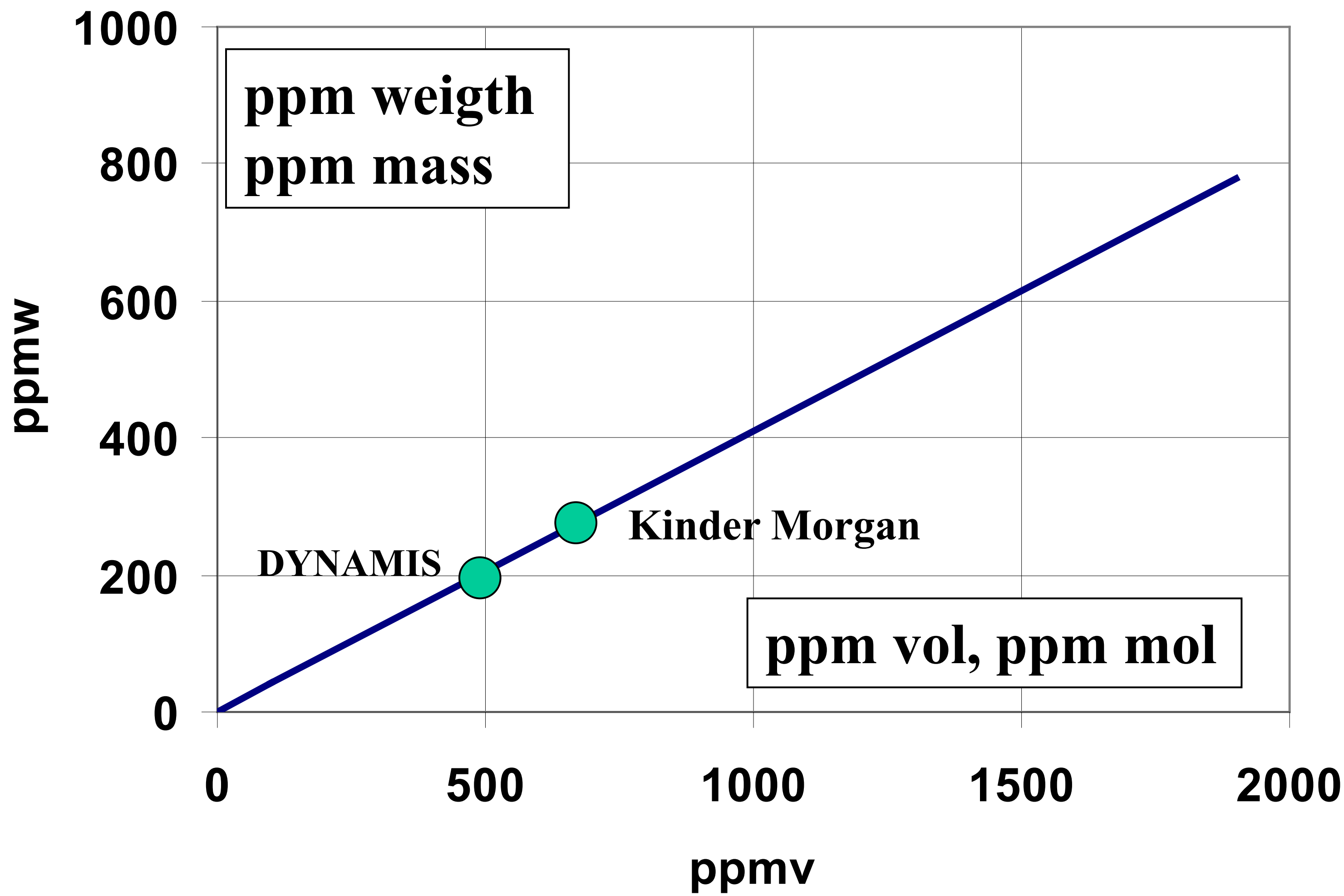
20”, 1.5 m/s
100 ppmv
1000 tons/year

Source: Intergovernmental Panel on Climate Change (IPCC)

ppmv vs. ppmw



ppm weigth
ppm mass
ppm vol, ppm mol
DYNAMIS
Kinder Morgan
ppmw
ppmv
1000
800
600
400
200
0
0
500
1000
1500
2000

Corrosion scenarios in dense phase CO_2 systems?

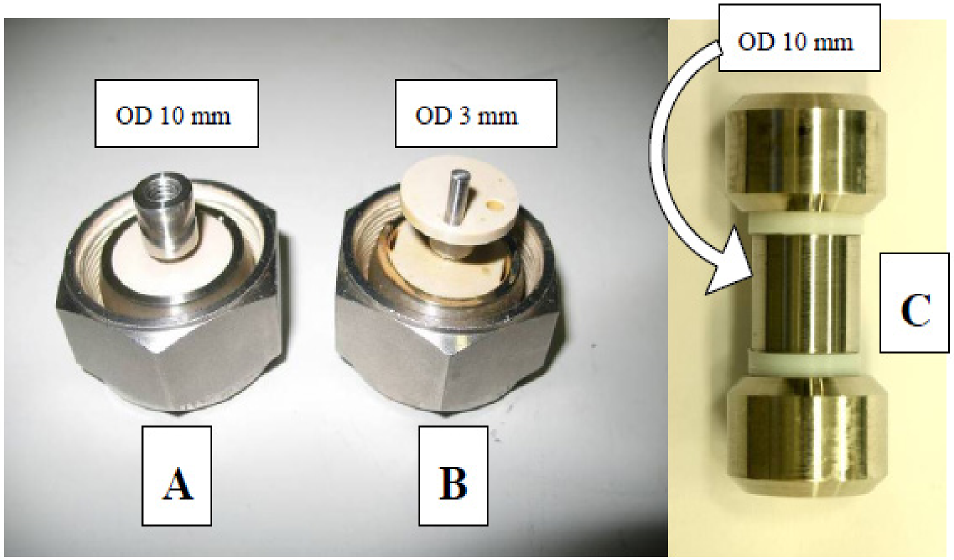
- Impurities and low water content
  - O_2
  - H_2S, S
  - CH_4, N_2, Ar ++
  - SO_x and NOx, CO
  - MEG, TEG, amines, salt

  } Affects water solubility, the corrosion mechanisms and the phase properties +++

- Free water phase
  - Insufficient drying, water may condense/precipitate from the CO_2 phase
  - Accidental/unforeseen water ingress } Network and different sources
- Shut down, depressurization and accumulation
- Re-using existing infrastructure, deposits (UDC)

Autoclave experiments

200 - 550 bar

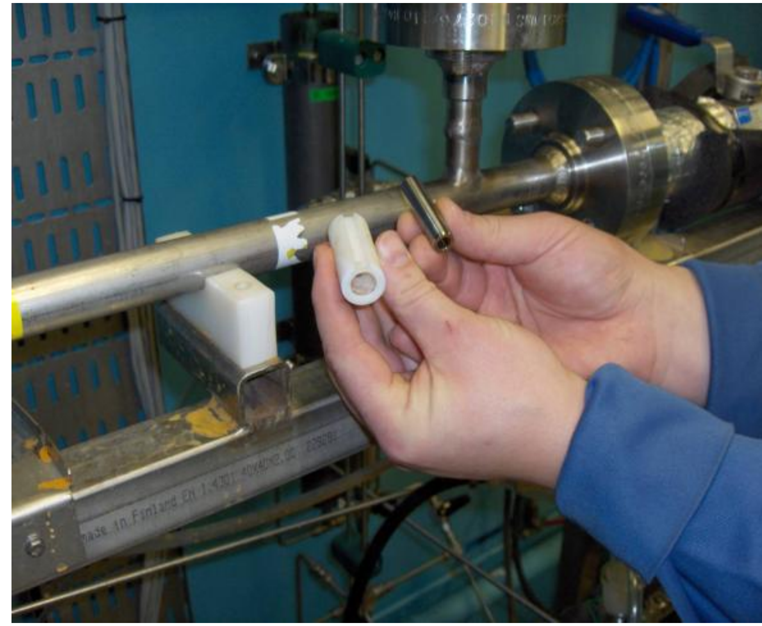


High pressure filling system

Good mixing

Mobilization of corrosive phase ($<10^{-3}$)

Loop experiments

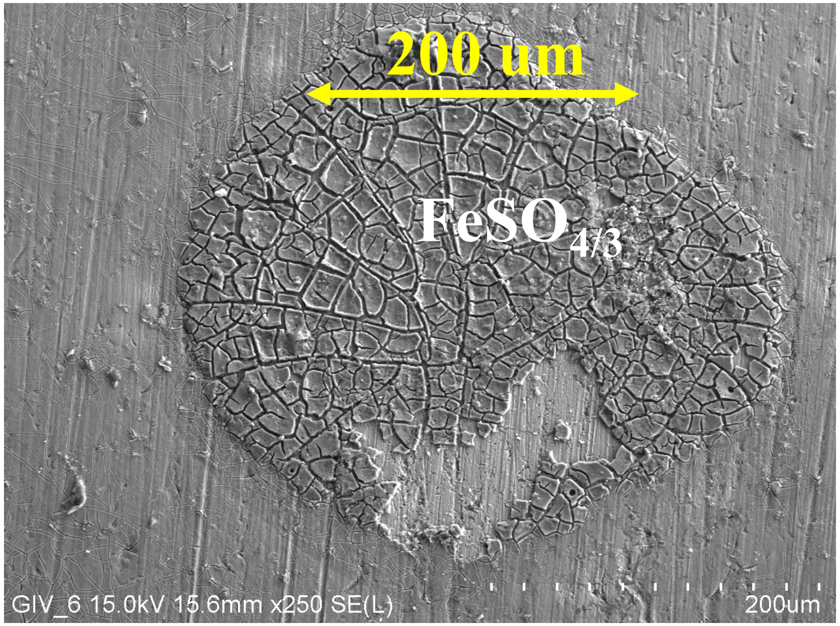


Alloy C 276
Pressure: 200 bar
Flow:0.1-3 m/s
Iron counts
Electrochemistry

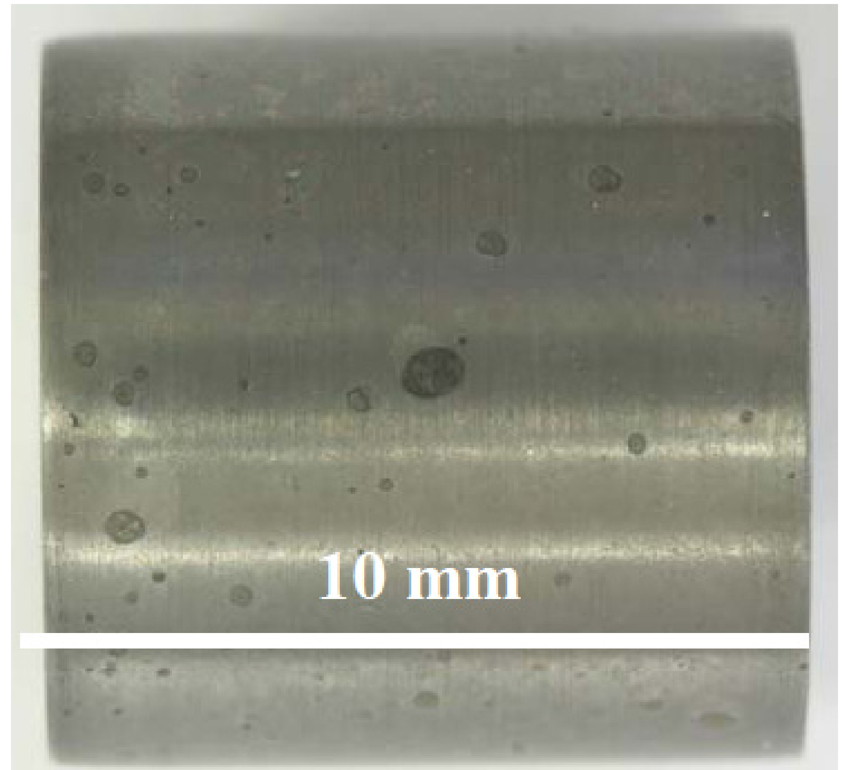
Autoclave experiments, 100 bar, 25 °C

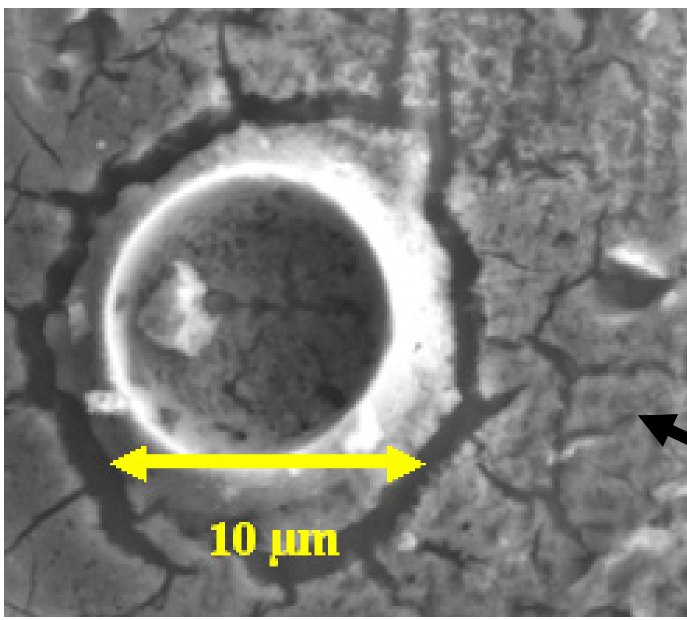
Exp. No:	IFE 4a	IFE 5a	IFE 5b	IFE 6a	IFE 6b	IFE 6c
H_2O, ppm wt	500	200	500	500	500	200
SO_2, ppm wt	0	500	500			
NO_2, ppm wt				500	200	100
Exposure, days	18	14	14	10	10	10
Weight loss Cor. rate, mm/y	<0.01	<0.01	0.02	1.6	0.7	0.17
Pitting attack		Y	Y			

H_2O solubility ~ 1200 ppmw



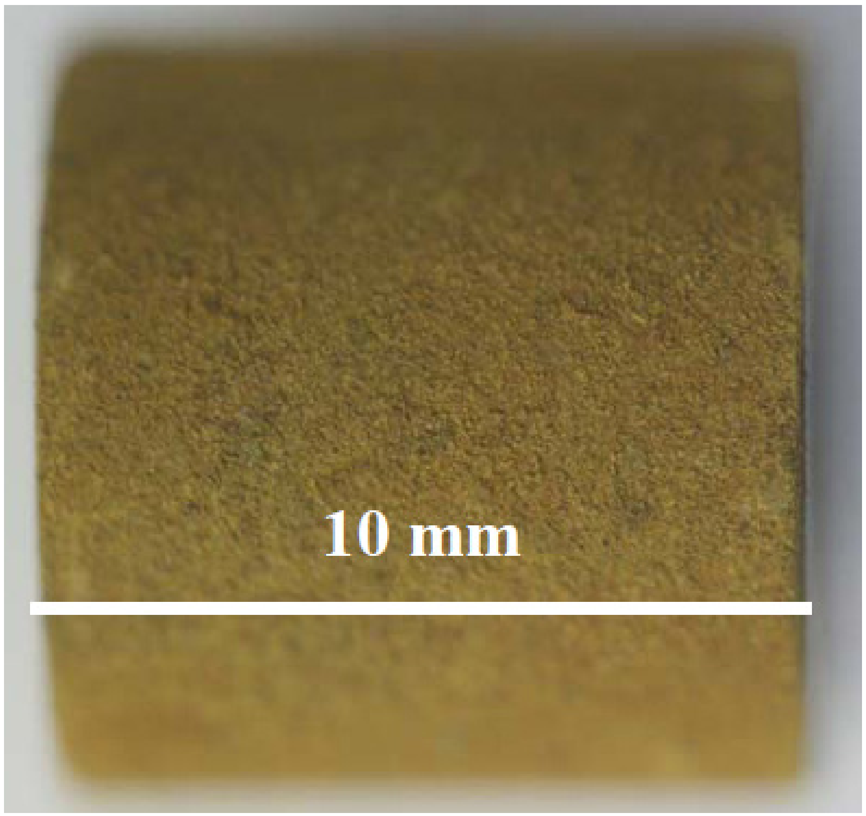
500 ppmw SO_2 and H_2O

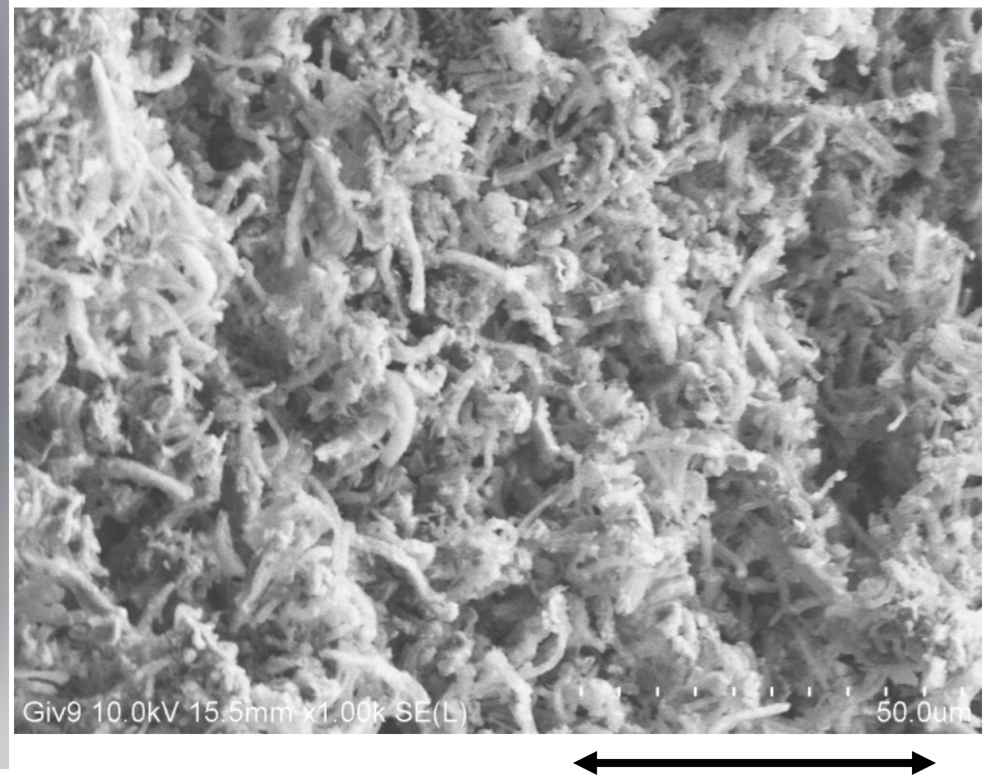




200 ppmw H_2O

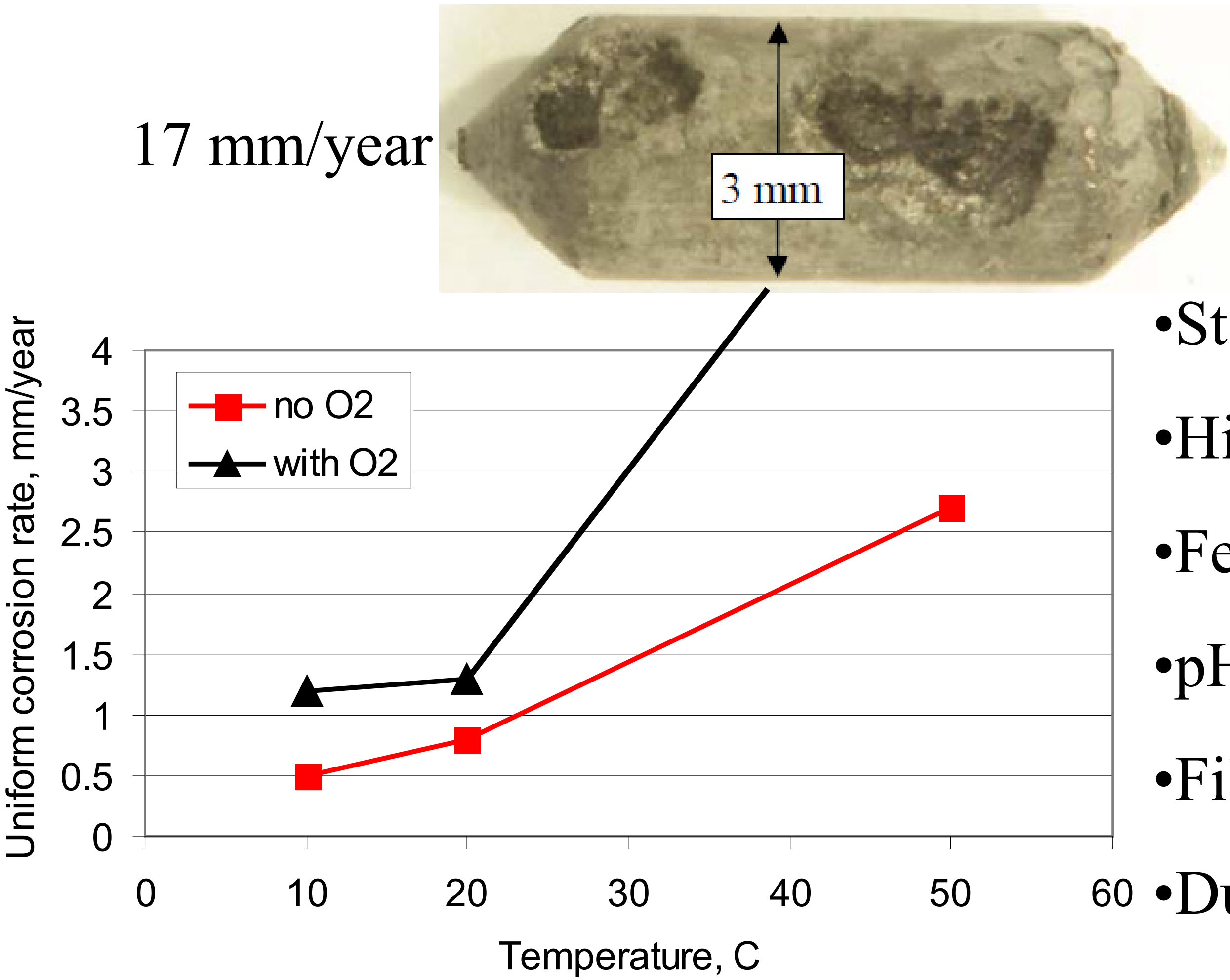
500 ppmw NO_2 and H_2O





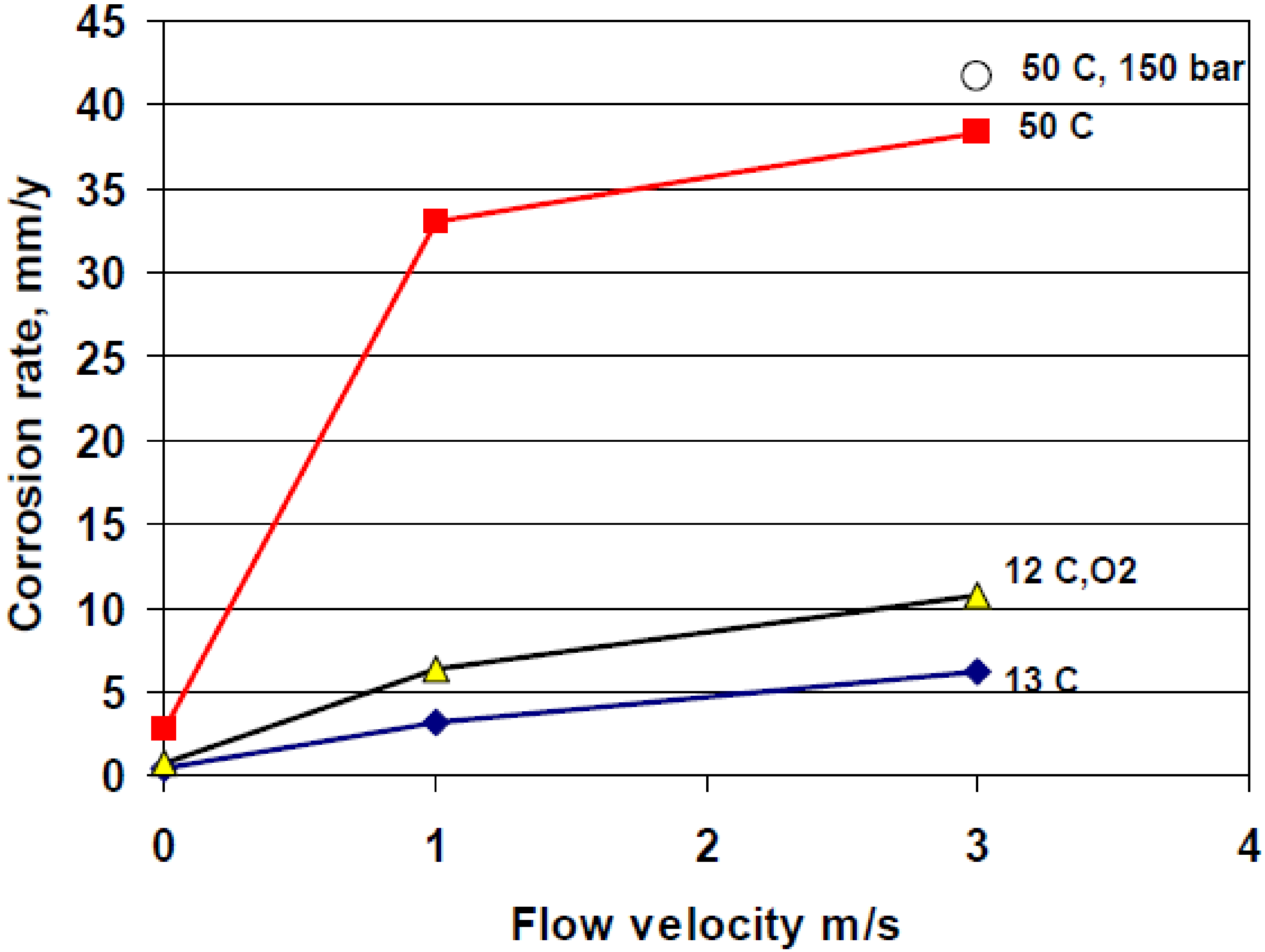
Corrosion rate 1.6 mm/y

Free water phase (50 vol%), stagnant conditions

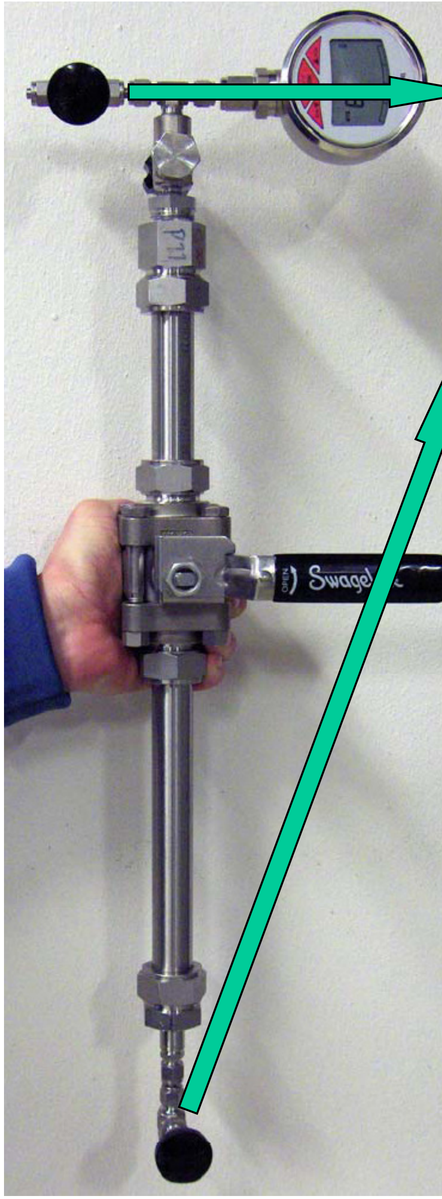


- Start pH 3-3.2
- High cm^2/cm^3 ratio
- Fe^{2+} 90-900 ppm
- pH shift
- Film formation
- Duration 2-3 weeks

Free water, flowing conditions, 100 bar



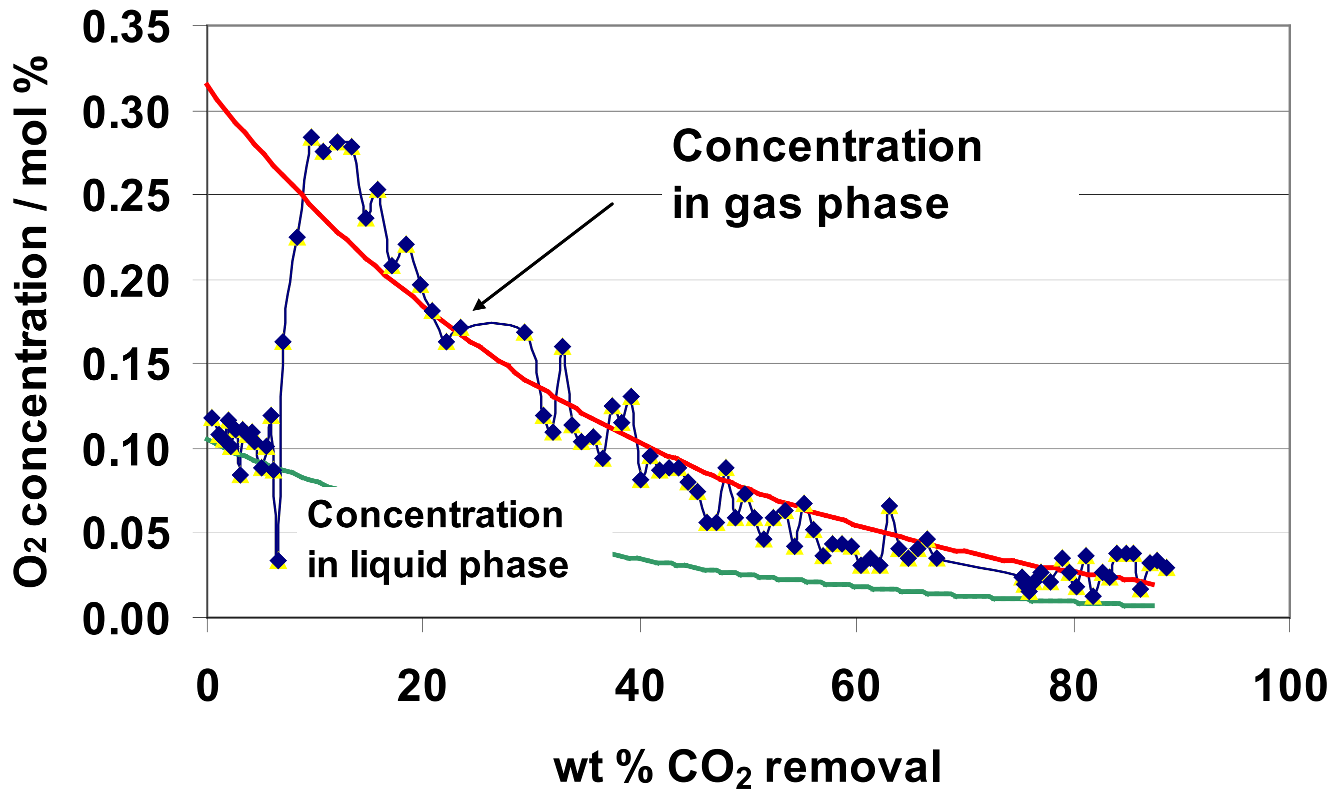
Partitioning



GC: NO_2, SO_2
Dew meter

Partitioning coefficients (gas/liquid)

O_2	H_2S	SO_2	H_2O
2.5-3	0.6-0.8	0.04-0.06	0.2-0.3



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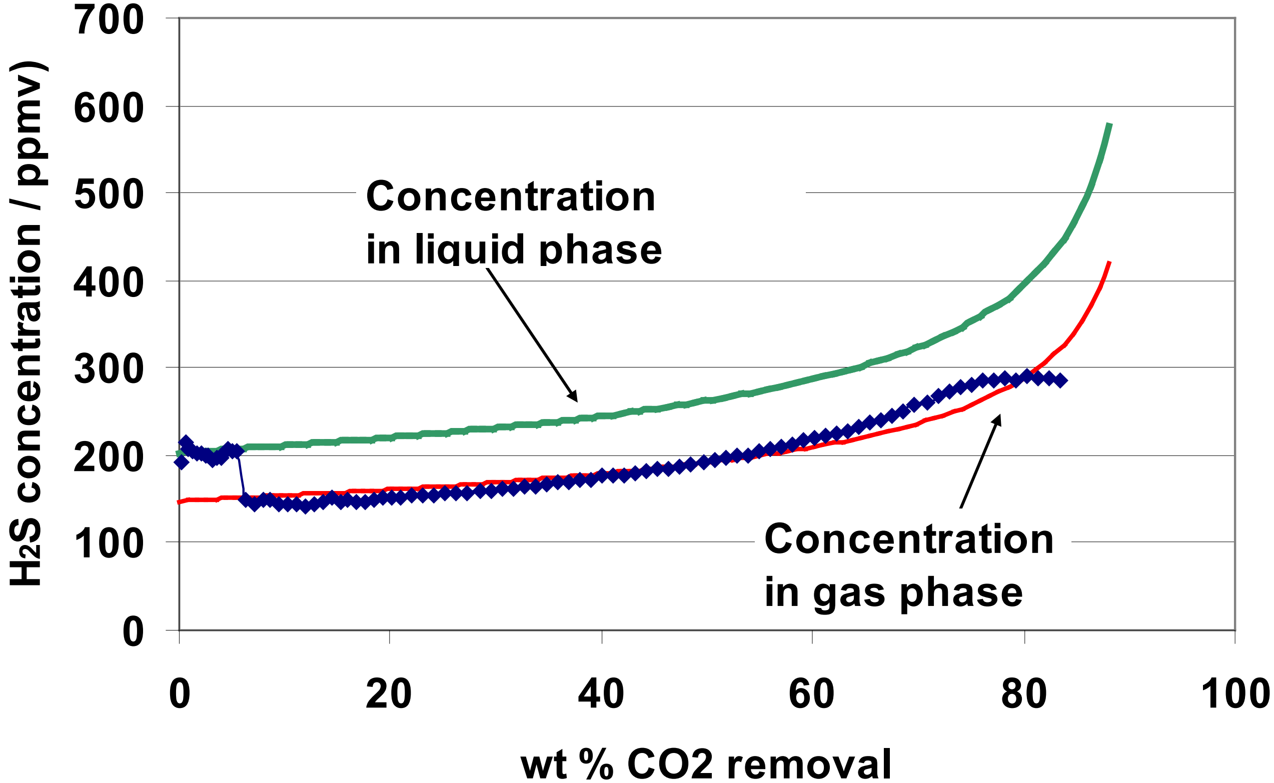
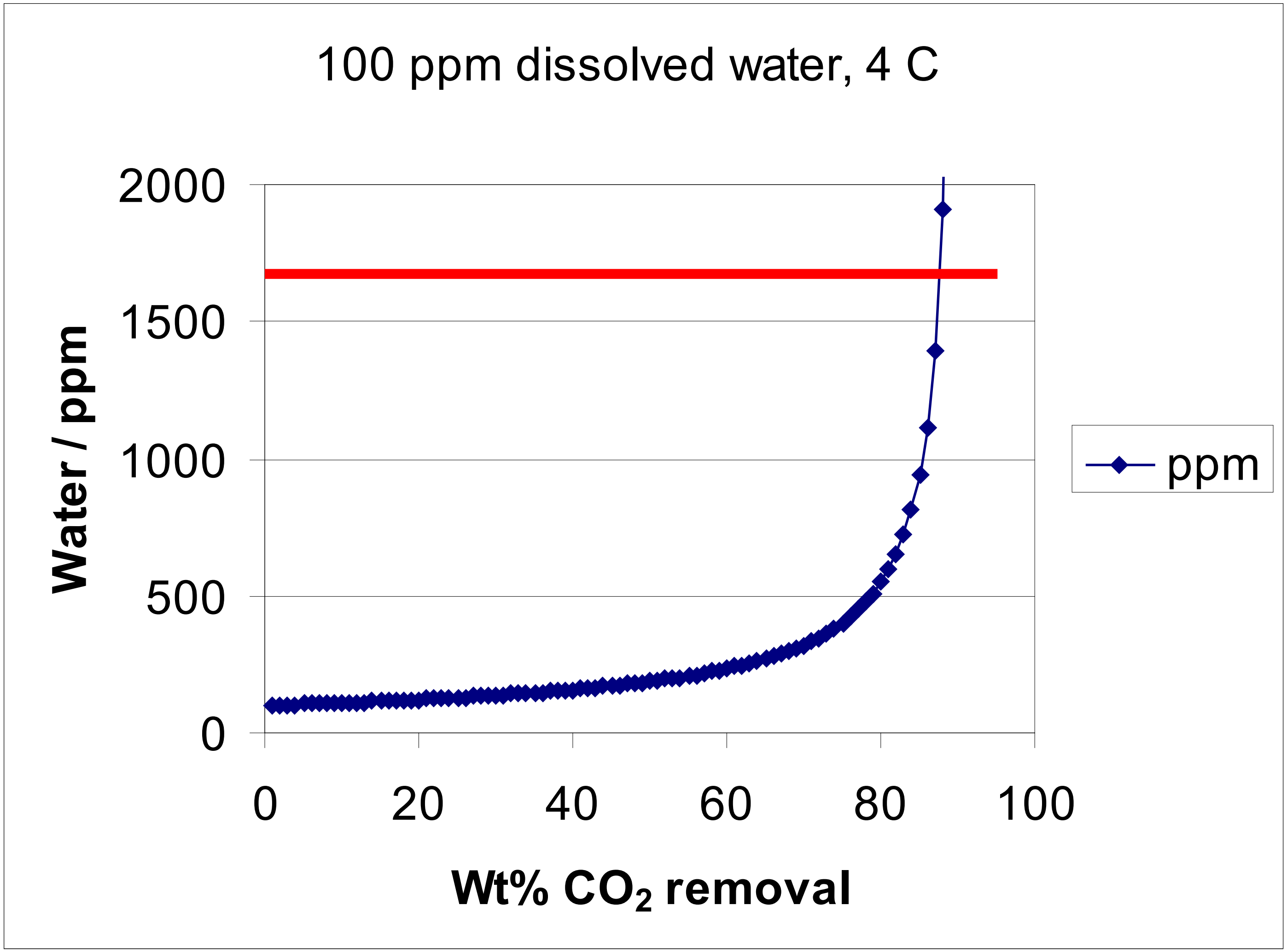


Water accumulation in the liquid CO_2 phase



Summary/Conclusion

- Non corrosive when the water content is significantly lower than the solubility limit in pure water and CO_2
- Corrosion can take place at water content less than 200 ppmw when SO_2 and/or NO_2 are present
- The corrosion rate in a free water phase can be huge, 10-50 mm/y
- O_2 destabilized the FeCO3 film and initiated localized attack
- Corrosivity can increases after depressurization as impurities like H_2O, SO_2, NO_2 accumulate in the remaining liquid CO_2 phase

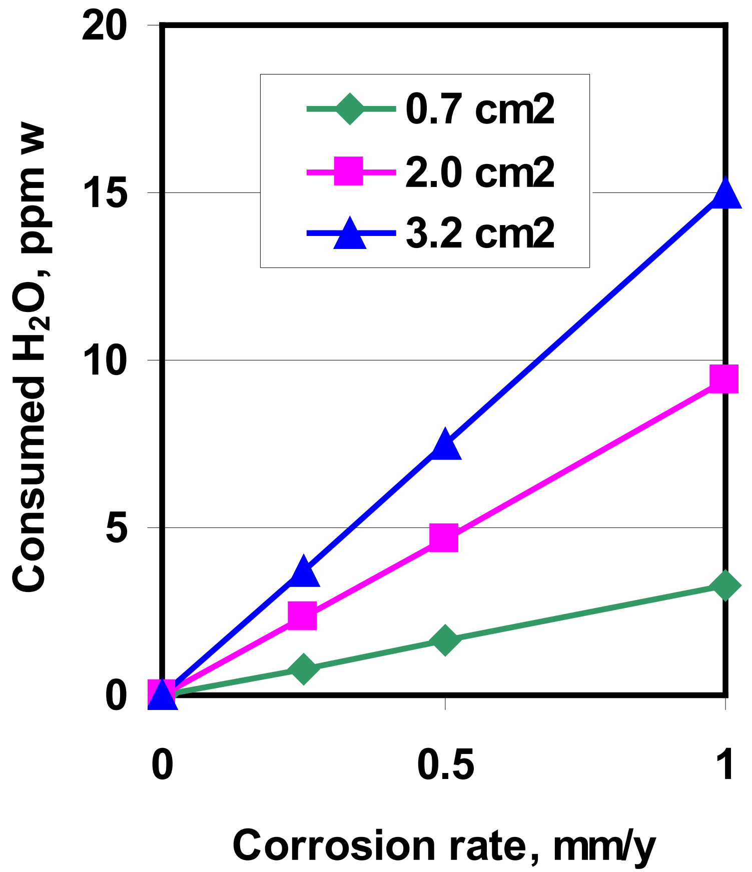
State of the Art

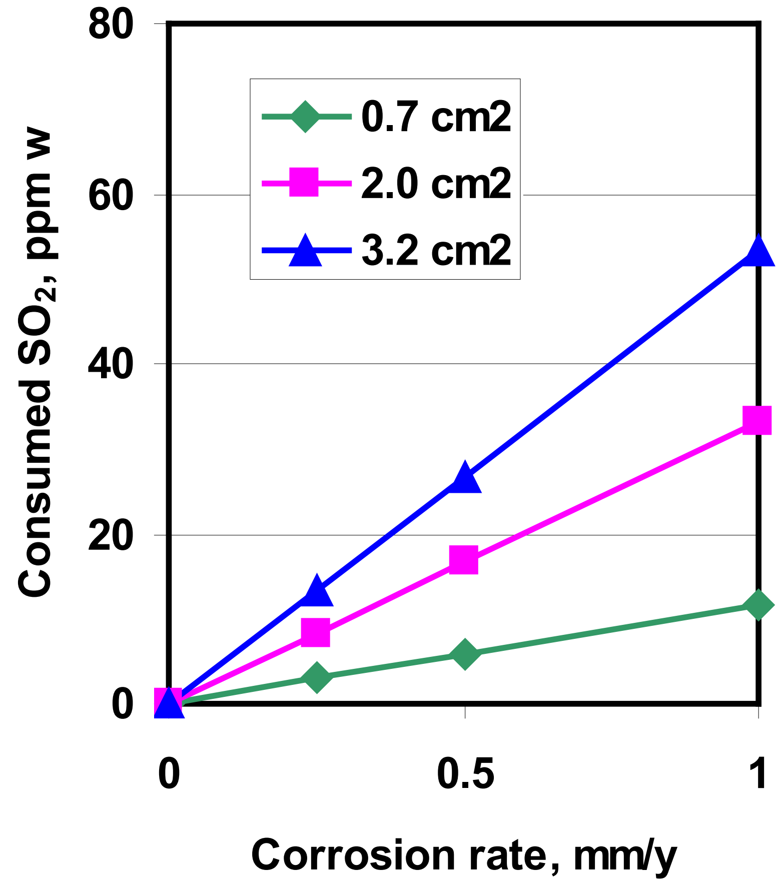
- Not much focus on corrosion in CCS community
- Less than 5 publication actually reporting corrosion data in dense phase CO_2 with flue gas impurities
- Very little is known about the effect of impurities and particularly about mixed contaminants
- The lack of data makes it difficult to predict corrosion rates and define a safe operation window for transport of dense phase CO_2 originating from different sources with different contaminants
- Corrosion should be given more attention

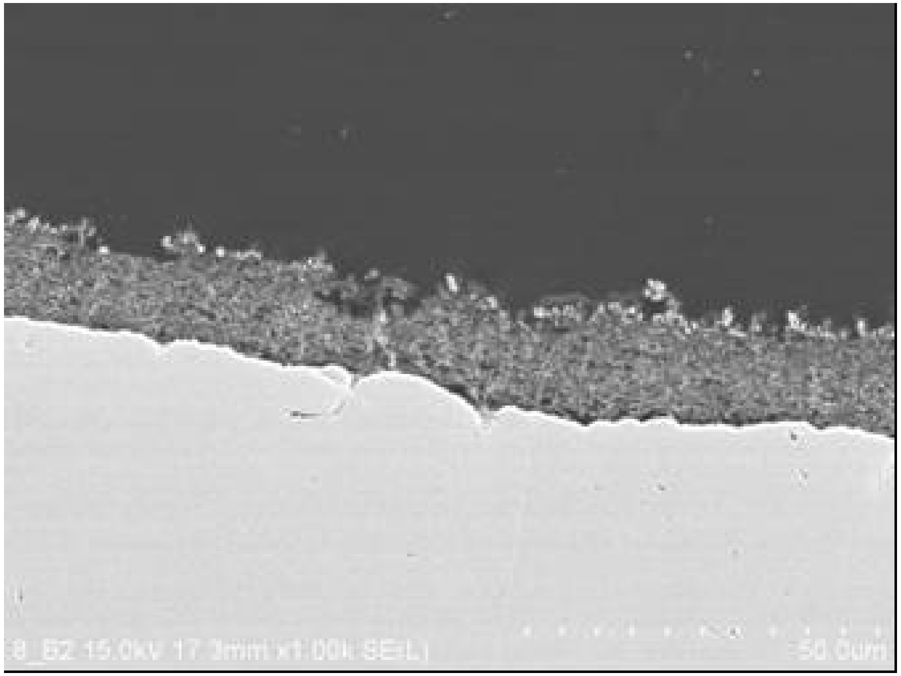
Acknowledgement

- The authors would like to acknowledge Gassco AS for financial and technical support for parts of the presented work.

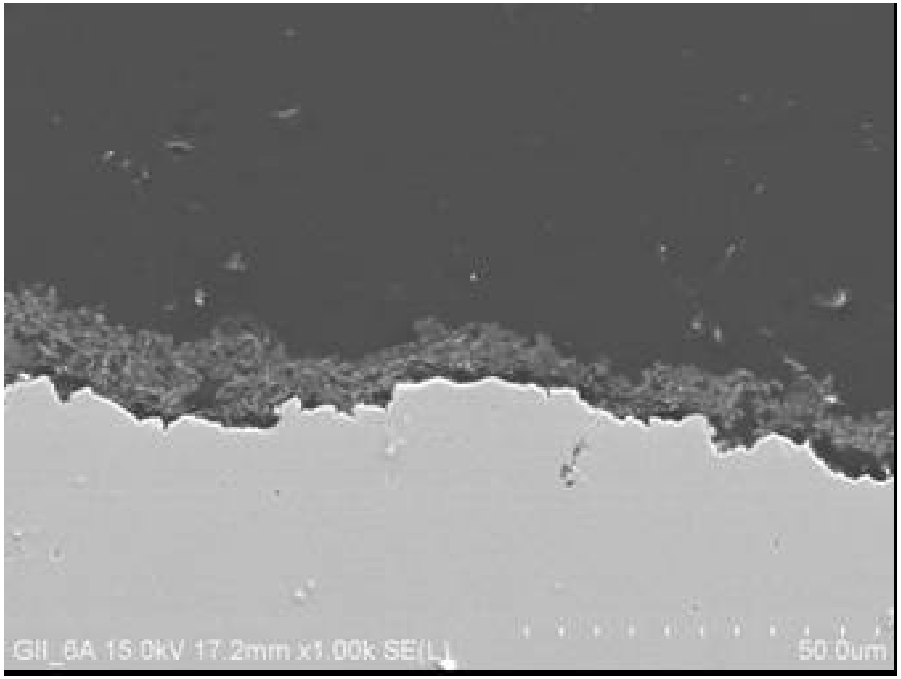
Consumption of reactants







50 C, 1 m/s



50 C, 3 m/s