Flexible, tailored solutions and world-class expertise across the globe

SPE – Geochemistry Overview

June 2023

OPC UK LTD | 1-2 Apollo Studios, Charlton Kings Rd, London NW5 2SB | +44 (0)207 4281111 | london@opc.co.uk | www.opc.co.uk

Oilfield Production Consultants (OPC)

- OPC are a globally renowned leader in the provision of subsurface engineering, geosciences and production engineering consultancy services to the E&P industry

- World class expertise in Well Testing, Pressure Transient Analysis, Reservoir Modelling, Integrated Upstream Projects (FDP), Competent Person Reporting (certified by LSE)

- OPC has three provisions:
  - Technical projects and studies
  - Consultant services
  - Software and technical training

34 Years	45 Countries
761 Clients	6,289 Projects

Offices


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Who am I?

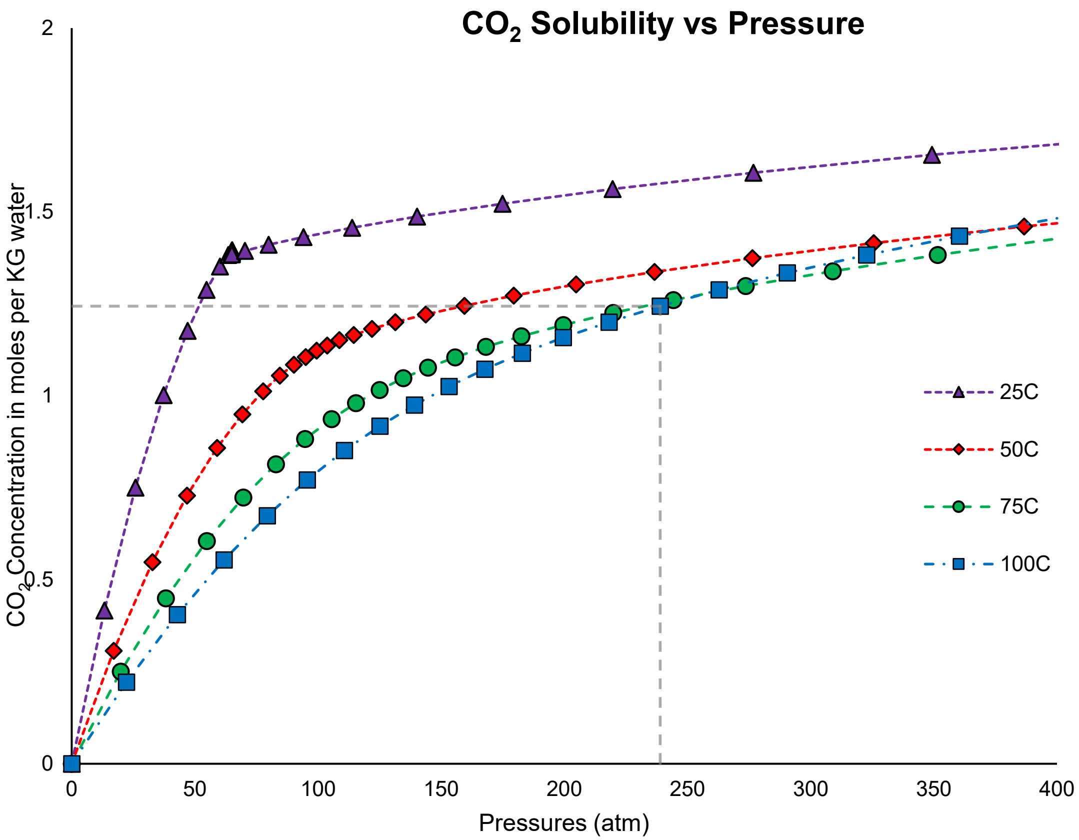
- Background in geoscience
- Masters @ UCL in fluid-rock-CO_2 interactions
- Published author on the subject
- Working in industry for 2 years
  - >10 CO_2 storage projects with OPC

Not Indiana jones

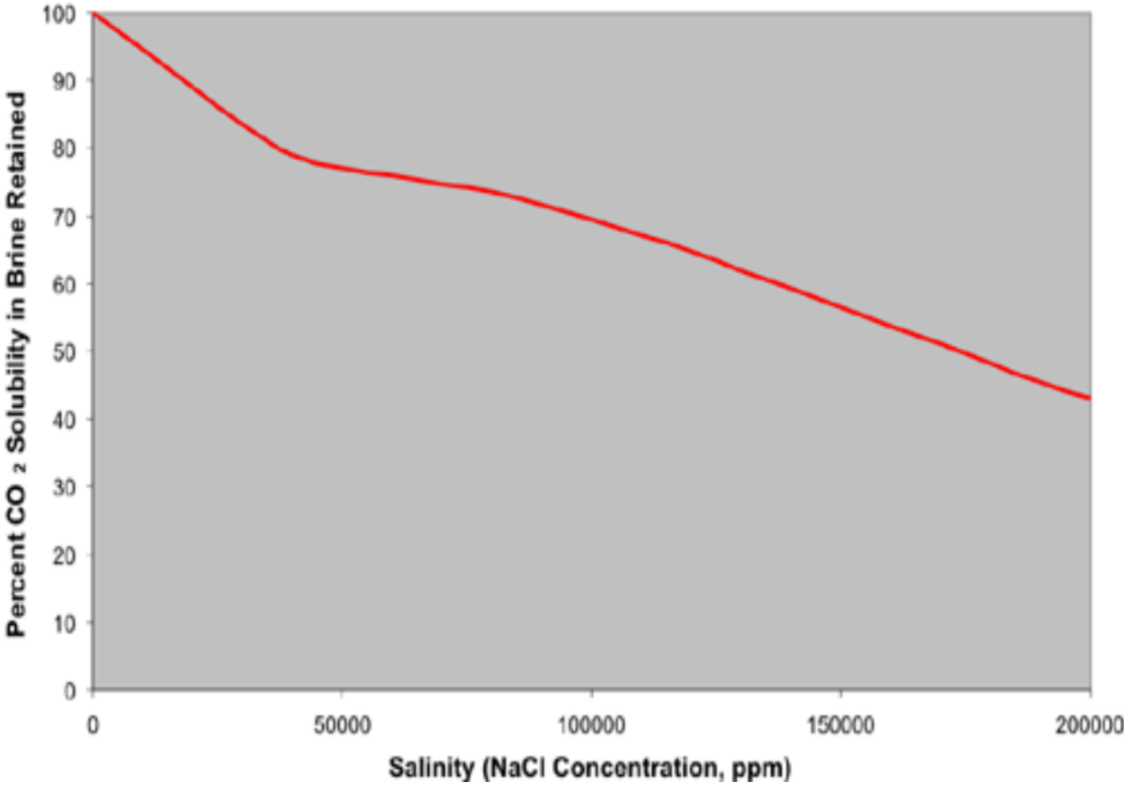
Deccan traps scouting for basalts

Expected Subsurface CO_2 Reactions

CO_2 + Water



CO_2 Solubility as a function of pressure and temperature calculated in PHREEQC using the Peng-Robinson Equation of State.



As CO_2 mixes with H_2O it forms carbonic acid which is acidic (~pH 3).

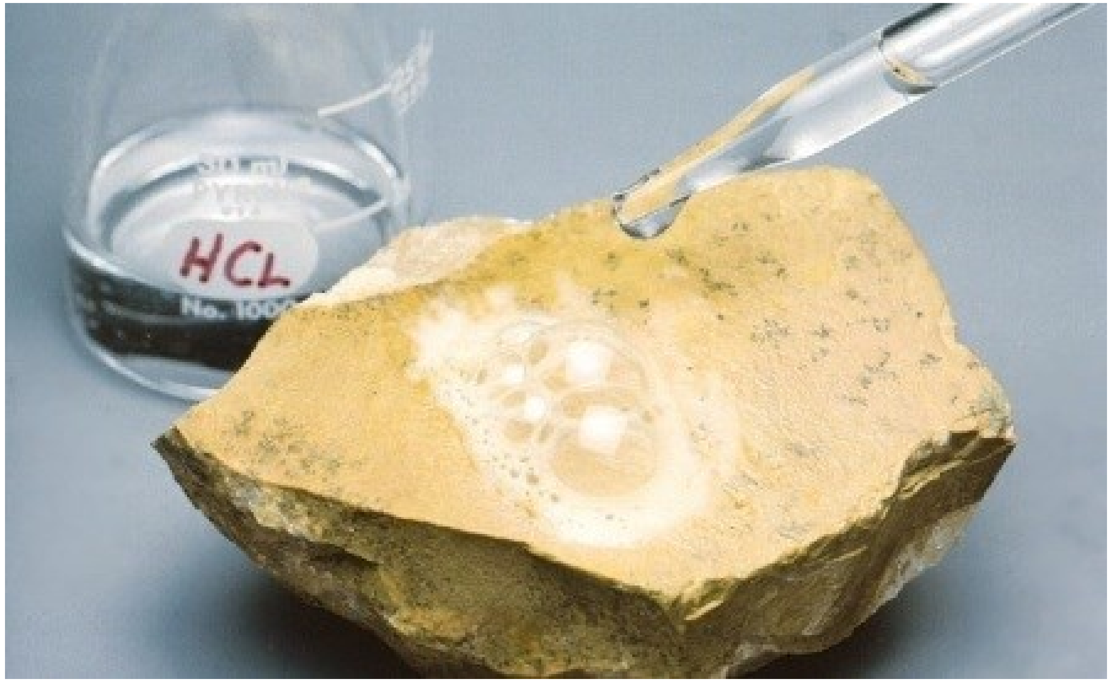
$$CO_2 + H_2O(aq) = H_2CO_3(aq) + H^+$$

CO_2 + Water + Rocks

- Formation of carbonic acid (H_2CO_3(aq) + H^+) increases the pH of fluid ~ pH3

- May lead to the **dissolution** of mineral assemblages and **precipitation** of others dependent on T/P

- Most minerals/rocks show little reactivity in the short term
  - Certain minerals (calcite) will dissolve readily in the presence of carbonic acid at T> 30°C and release Ca^{2+}



H_2CO_3(aq) + H^+ + $CaCO_3$ = dissolution

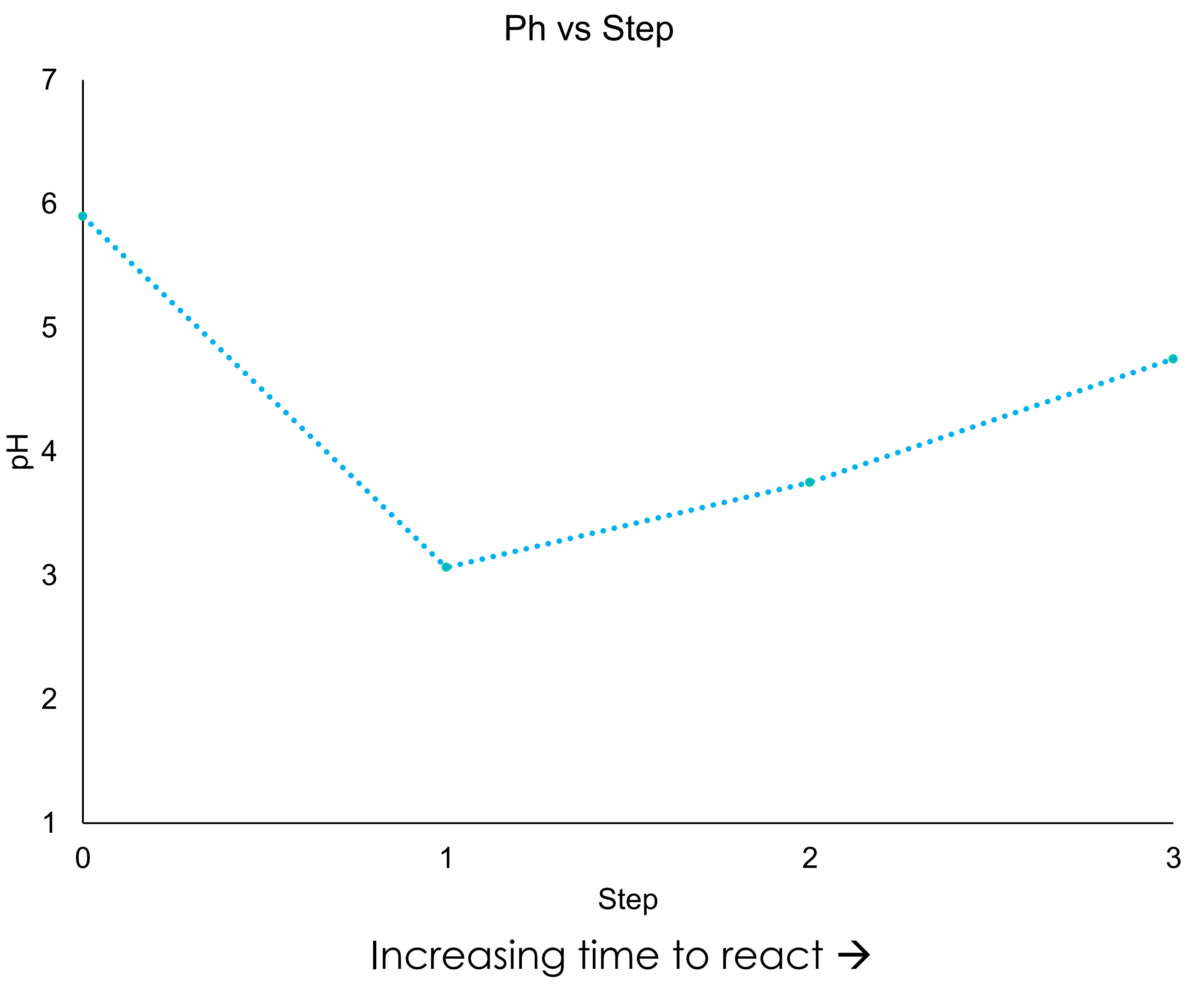
Rate and extend of the dissolution dependent on the amount of rocks that will buffer the system

Example Step Reactions

1. Injected CO_2 dissolves in 'stuck' indigenous fluids (pH 5-7) forming carbonic acid (pH 3) depending on T/P & salinity

2. Certain minerals if they exist readily dissolve in the CO_2 charged water increasing the pH of the fluid (pH4-6).
   I. Includes the dissolution of silicates (usually slow)

3. Formation of new minerals removes CO_2 from fluid which results in pH increasing



Modelling

- Main technique is equilibrium / batch modelling using PHREEQC 3.0 + specialised database

- **Inputs**:
  - Indigenous fluid chemistry
  - Pressure & temperature at xyz (taken from sim. model)
  - pCO_2 (+ impurities taken from sim. model)
  - Minerology

- **Outputs**:
  - Expected equilibrated water chemistry (S.I of mineral assemblages i.e what dissolves/precipitates)

<u>Driver of software far more important than the tool itself</u>

Examples

Table 10: WJU03 Saturation Indices

Hours.	pH	Calcite	Boehmite	Chalcedony	Magnesite	Dolomite	Goethite	Ankerite
1	4.69	-7.1078	0.6352	-0.8308	-8.6273	-14.7783	-1.0134	-12.4995
5	5.58	-5.3556	2.1581	-0.83	-6.8704	-11.2692	1.659	-8.965
24	5.58	-5.2971	2.266	-0.6904	-6.808	-11.1483	1.7954	-8.77
144	7.44	-1.4657	2.4731	-0.4287	-2.9704	-3.4793	6.3656	-2.2284
192	7.6	-1.1655	1.7852	-0.5005	-2.6914	-2.9001	6.3202	-2.1336
528	7.71	-0.9188	2.3503	-0.4071	-2.4369	-2.3989	6.4229	-1.8943
720	7.97	-0.3823	2.1314	-0.2954	-1.8627	-1.2882	6.5445	-1.4962
1440	8.2	0.1001	1.9368	-0.2513	-1.2975	-0.2405	6.5898	-1.1984
2160	8.4	0.4966	1.7698	-0.2227	-0.8573	0.5961	6.6156	-0.976
Moles Precipitated		1.616e-05	1.811e-06			0	3.606e-06	
PCO_2 Applied								
3 bars	8.4	1.8506	1.9271	-0.2207	0.6788	3.4862	6.7047	4.4229
10 bars	8.4	1.9076	2.265	-0.2157	0.7755	3.6399	6.7953	5.1553
30 bars	8.4	1.9477	2.6252	-0.2129	0.8508	3.7553	6.8937	5.8112
Moles Precipitated		1.608e-04	1.818e-06		0	2.215e-05	3.604e-06	2.641e-09

Table 11: WJS2C Saturation Indices

Hours.	pH	Calcite	Boehmite	Chalcedony	Magnesite	Dolomite	Goethite	Ankerite
1	4.5	-7.5259	0.1001	-0.8828	-8.7064	-15.2755	-1.4473	-13.1615
5	5.5	-5.5105	2.0683	-0.8017	-6.6942	-11.2478	1.6334	-9.0654
24	6.39	-3.7307	2.6099	-0.8017	-4.9144	-7.6883	4.4354	-5.3736
144	6.88	-2.7047	2.6699	-0.5629	-3.9013	-5.6491	5.8492	-3.4238
192	7.21	-1.9991	2.4744	-0.3939	-3.2121	-4.2544	6.4873	-2.4101
528	7.42	-1.5182	2.1697	-0.2031	-2.7713	-3.3327	6.7745	-1.8519
720	7.63	-1.0331	1.9752	-0.0412	-2.2478	-2.3241	6.9707	-1.3807
1440	7.78	-0.6972	2.2218	0.076	-1.8828	-1.6231	7.0982	-1.0673
2160	7.91	-0.4047	2.1126	0.1676	-1.5919	-1.0398	7.1945	-0.8085
Moles Precipitated			1.313e-06	2.069e-05			1.337e-05	
PCO_2 Applied								
3 bars	7.91	1.5844	2.0559	0.1666	0.464	3.0053	7.2196	5.1129
10 bars	7.91	1.6652	2.2559	0.1681	0.5596	3.1816	7.2755	5.8074
30 bars	7.91	1.7513	2.5244	0.1696	0.6718	3.3799	7.349	6.4621
Moles Precipitated		1.709e-04	1.322e-06	2.101e-05	0	3.760e-05	1.316e-05	2.417e-07

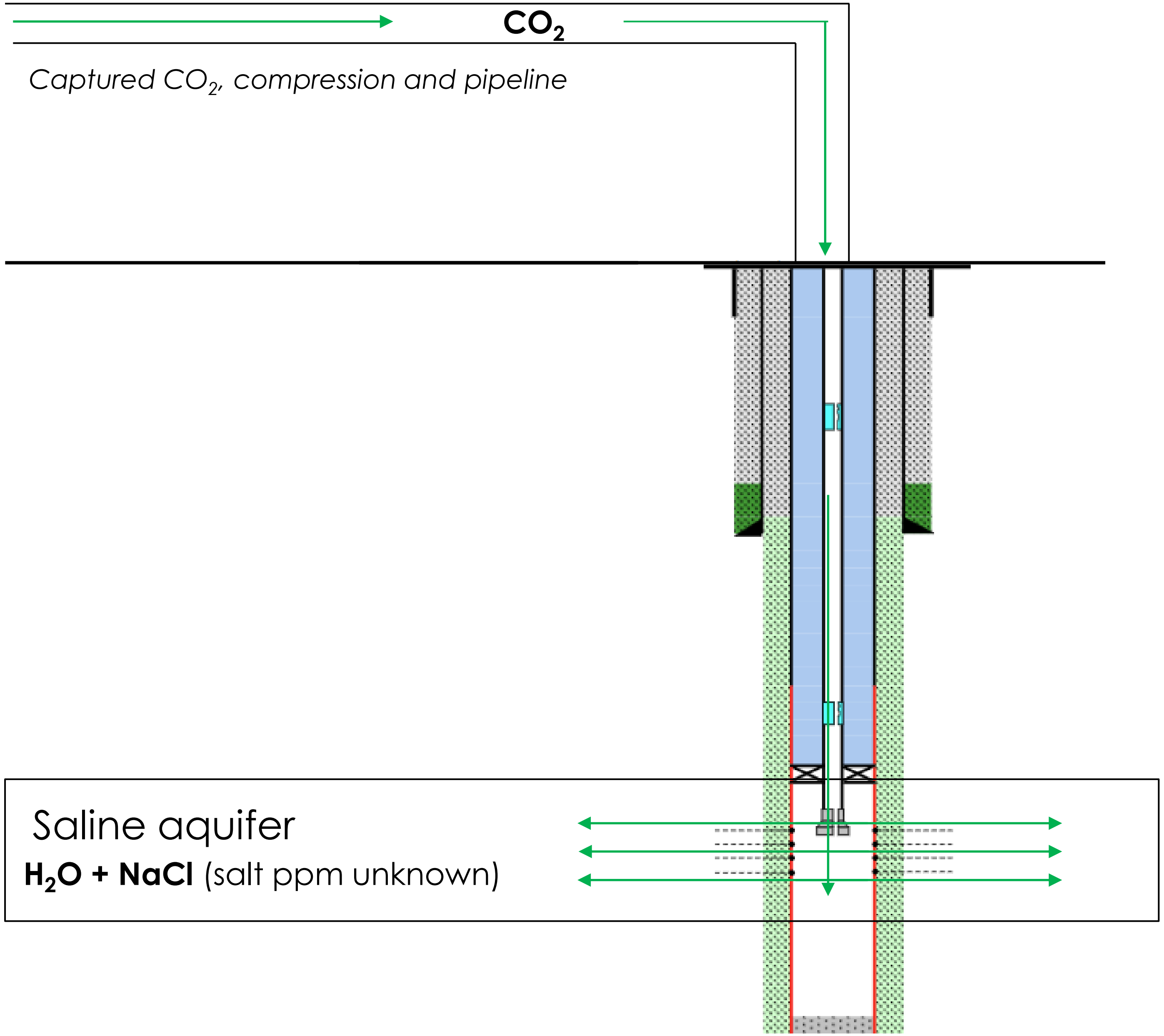
```
        Al              1.785e-04   1.785e-04
        C               1.427e+00   1.427e+00
        Ca              7.638e-02   7.638e-02
        Cl              2.772e+00   2.772e+00
        Fe              8.336e-07   8.336e-07
        K               7.318e-03   7.319e-03
        Mg              4.789e-02   4.789e-02
        Na              2.518e+00   2.518e+00
        Si              1.751e-04   1.751e-04

----------------------------Description of solution---------------------------

                                          pH  =   3.133      Charge balance
                                          pe  =   0.028      Adjusted to redox equili
                        Density (g/cm³)  =   1.10765
                             Volume (L)  =   1.10464
                      Activity of water  =   0.891
                         Ionic strength  =   2.459e+00
                     Mass of water (kg)  =   1.000e+00
               Total alkalinity (eq/kg)  =   2.544e-03
                    Total CO2 (mol/kg)  =   1.427e+00
                       Temperature (°C)  =  25.00
                Electrical balance (eq)  =   4.092e-12
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   0.00
                             Iterations  =  25
                                Total H  = 1.110593e+02
                                Total O  = 5.838374e+01

----------------------------Distribution of species---------------------------

                                                    Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   H+              8.101e-04   7.366e-04    -3.091    -3.133    -0.041     0.00
   OH-             1.784e-11   1.165e-11   -10.749   -10.934    -0.185     0.02
   H2O             5.553e+01   8.906e-01     1.744    -0.050     0.000    18.07
Al           1.785e-04
   Al+3            1.773e-04   1.175e-05    -3.751    -4.930    -1.179   -39.22
   Al(OH)+2        1.167e-06   1.591e-07    -5.933    -6.798    -0.865   -26.31
   AlH3SiO4+2      6.768e-08   9.229e-09    -7.170    -8.035    -0.865    -7.81
   Al(OH)2+        6.472e-10   4.467e-10    -9.189    -9.350    -0.161     2.03
   Al(OH)3         7.860e-13   7.860e-13   -12.105   -12.105     0.000    13.00
   Al(OH)4-        4.717e-16   3.255e-16   -15.326   -15.487    -0.161    11.39
   NaAl(OH)4       4.673e-16   4.673e-16   -15.330   -15.330     0.000    53.59
   Al(CH3COO)2+    9.824e-19   6.780e-19   -18.008   -18.169    -0.161    50.82
C(-2)        8.152e-22
   C2H4            4.076e-22   4.076e-22   -21.390   -21.390     0.000    45.52
C(-3)        1.125e-09
   C2H6            5.626e-10   5.626e-10    -9.250    -9.250     0.000    51.20
C(-4)        5.424e-04
   CH4             5.424e-04   5.424e-04    -3.266    -3.266     0.000    37.32
C(2)         1.186e-11
   CO              1.186e-11   1.186e-11   -10.926   -10.926     0.000    33.62
C(4)         1.427e+00
   CO2             1.423e+00   2.438e+00     0.153     0.387     0.234    33.24
```

Implications

- If rock does not buffer CO_2 charged fluid (pH 3) – implications for well/cement design (even far away from injector – connate water saturation)
- Injection of CO_2 into fresh/low salinity fluids = increase storage capacity through solubility trapping
  - Although is dependent on surface area
- All systems are rock ‘dominated’ & buffered
  - Interesting in the case of chalk/carbonate reservoirs

Near well-bore dry out

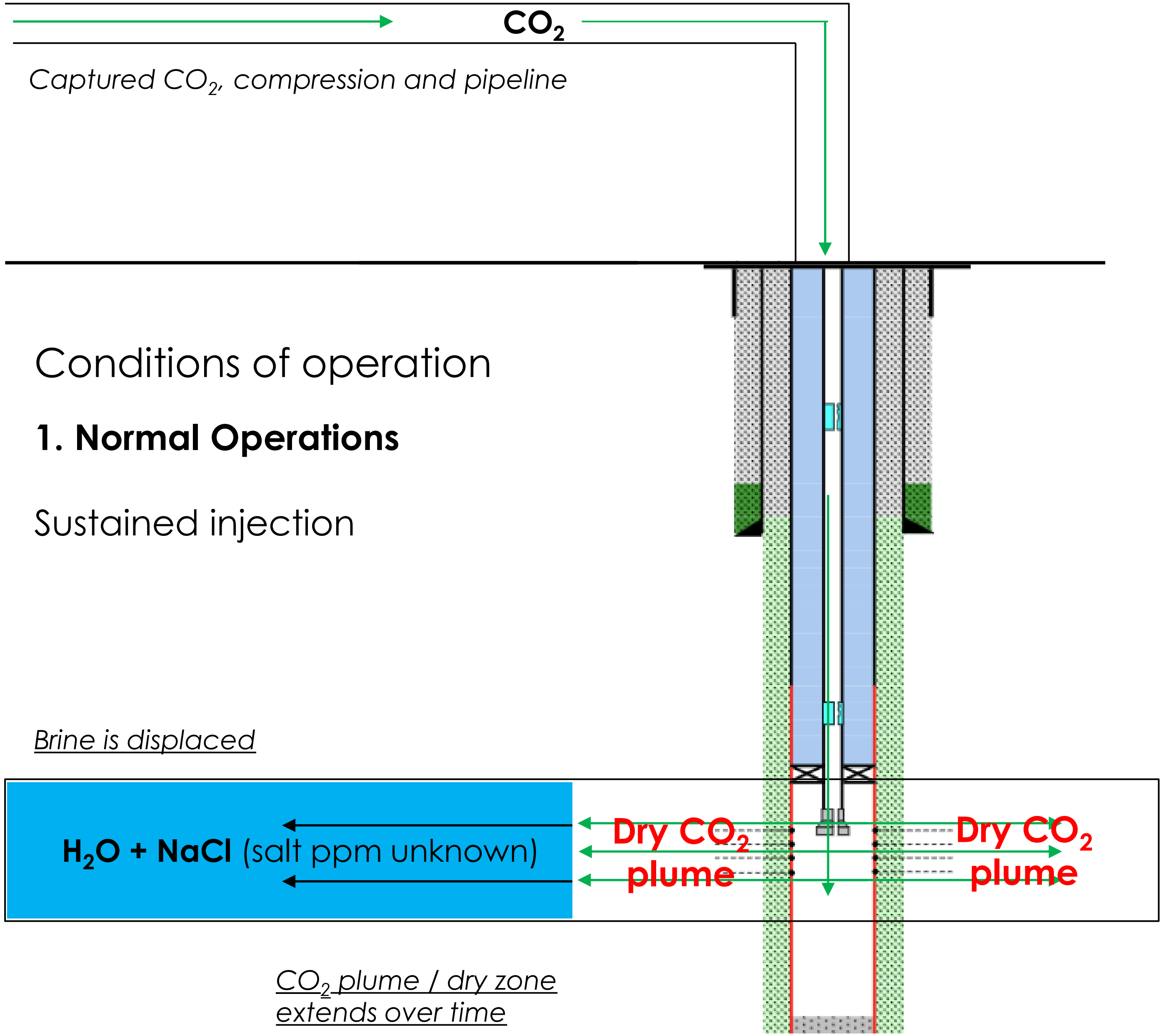
Overview


CO_2
Captured CO_2, compression and pipeline
Saline aquifer
H_2O + NaCl (salt ppm unknown)

Conditions of operation

1. Normal Operations

Sustained injection



CO_2

Captured CO_2, compression and pipeline

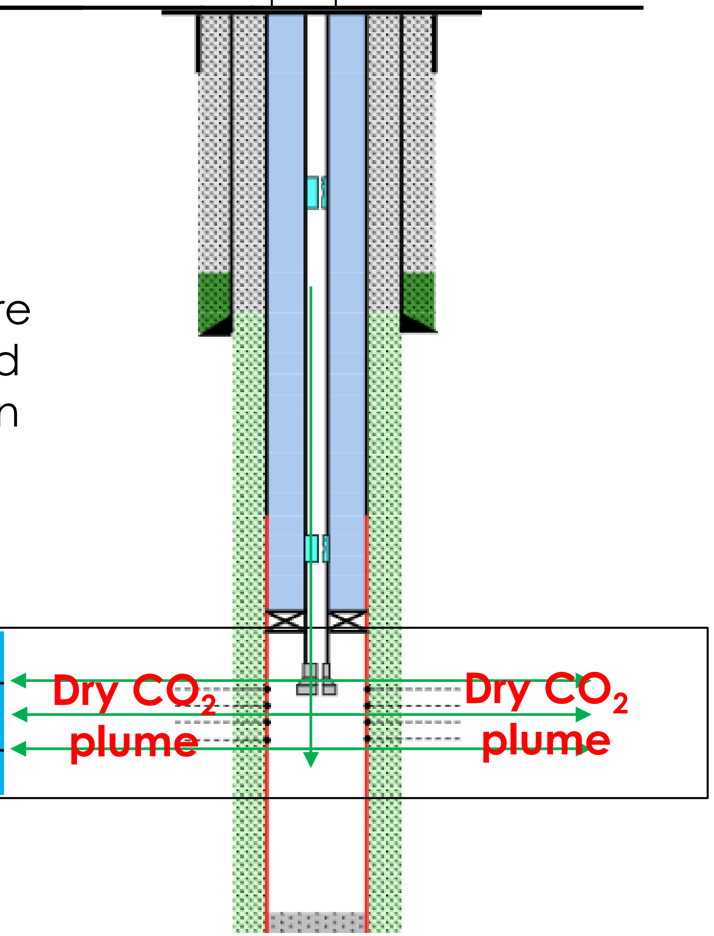
Framing the issue

Problems:

2. Near well-bore dry out. CO_2 dehydrates the near well-bore area by **displacing brine**, and causing the **solids** dissolved in the water to **precipitate**

Brine is displaced

H_2O + NaCl (salt ppm unknown)

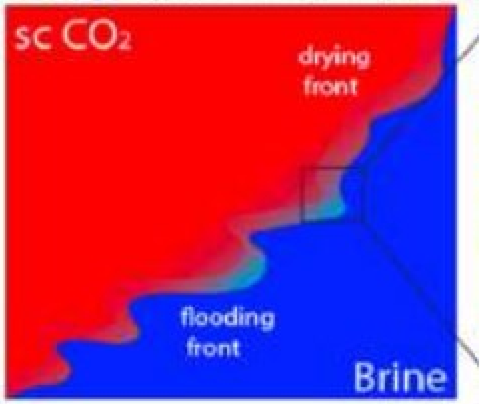


CO_2 plume / dry zone extends over time

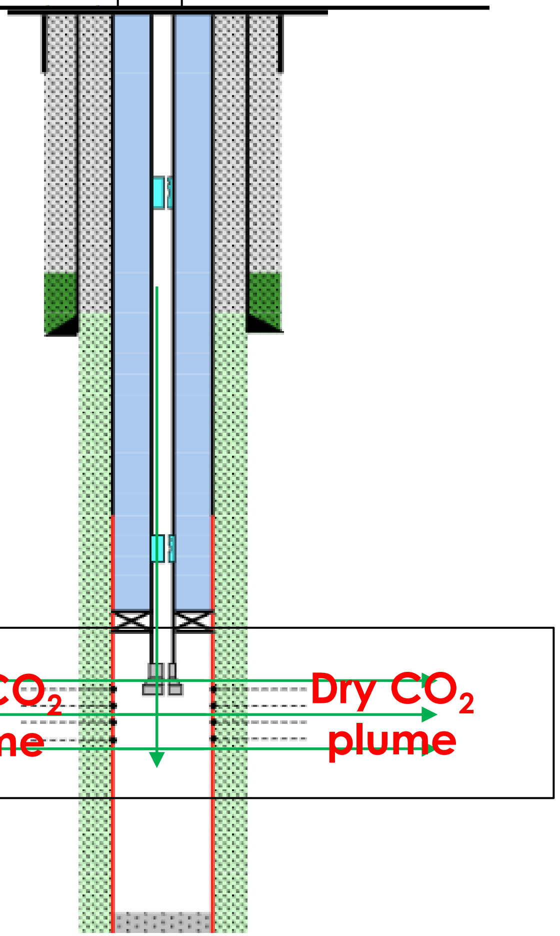
CO_2

Captured CO_2, compression and pipeline

Framing the issue



Brine is displaced



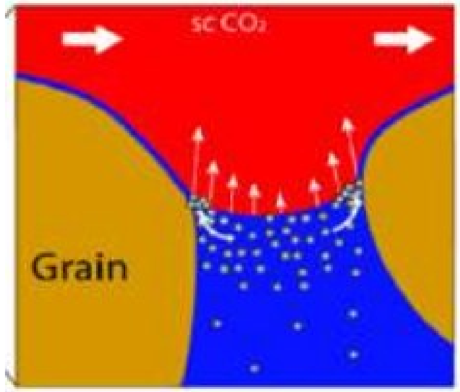
H_2O + NaCl (salt ppm unknown)

CO_2 plume / dry zone extends over time

CO_2

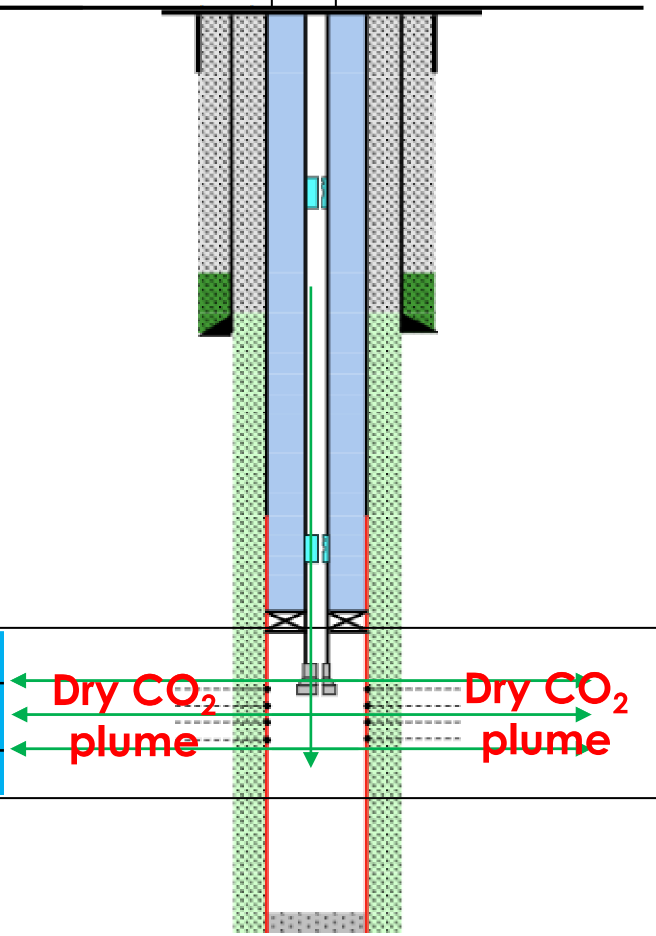
Captured CO_2, compression and pipeline

Framing the issue



Brine is displaced

H_2O + NaCl (salt ppm unknown)

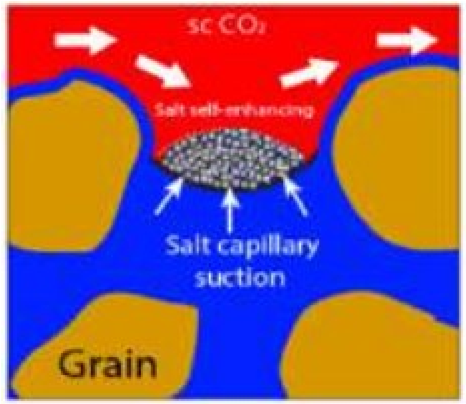


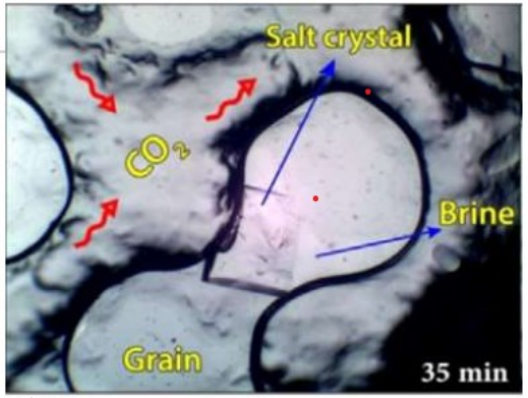
CO_2 plume / dry zone extends over time

CO_2

Captured CO_2, compression and pipeline

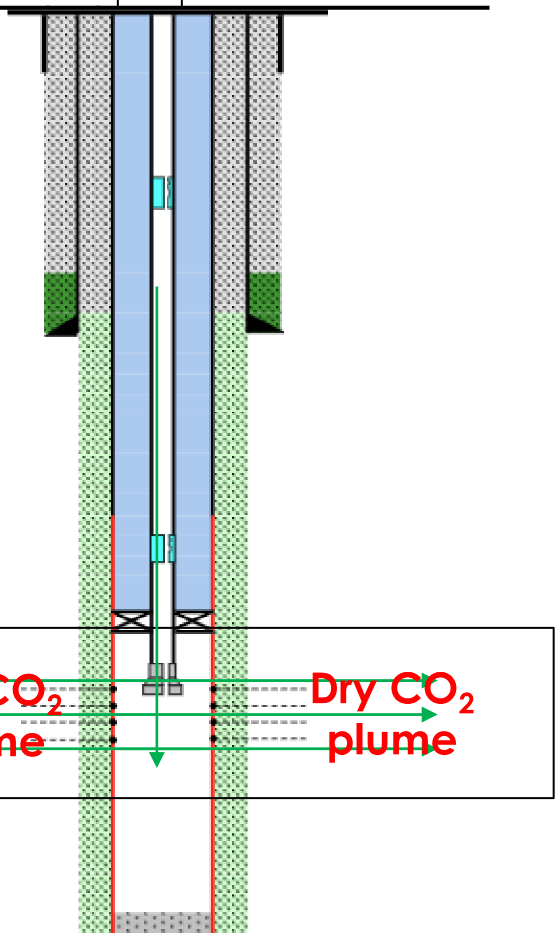
Framing the issue





Brine is displaced

H_2O + NaCl (salt ppm unknown)



CO_2 plume / dry zone extends over time

Captured CO_2, compression and pipeline

Framing the issue

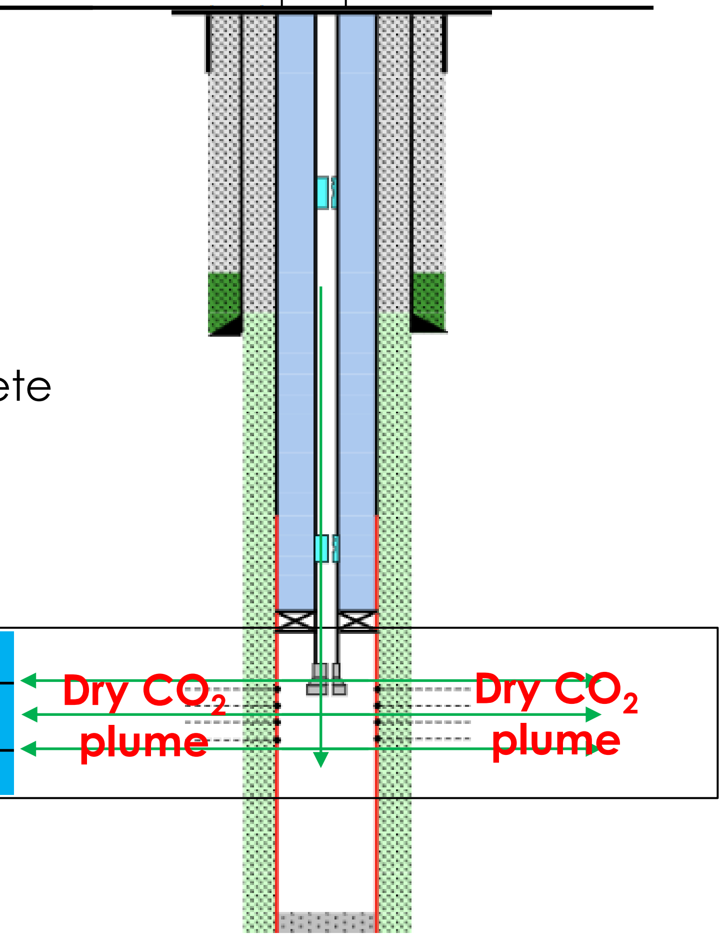
Near well-bore dry out

Reservoir Problems

1. Permeability decline
2. Porosity decline
3. Injectivity decline or complete loss of injectivity
4. Poor well performance

Brine is displaced

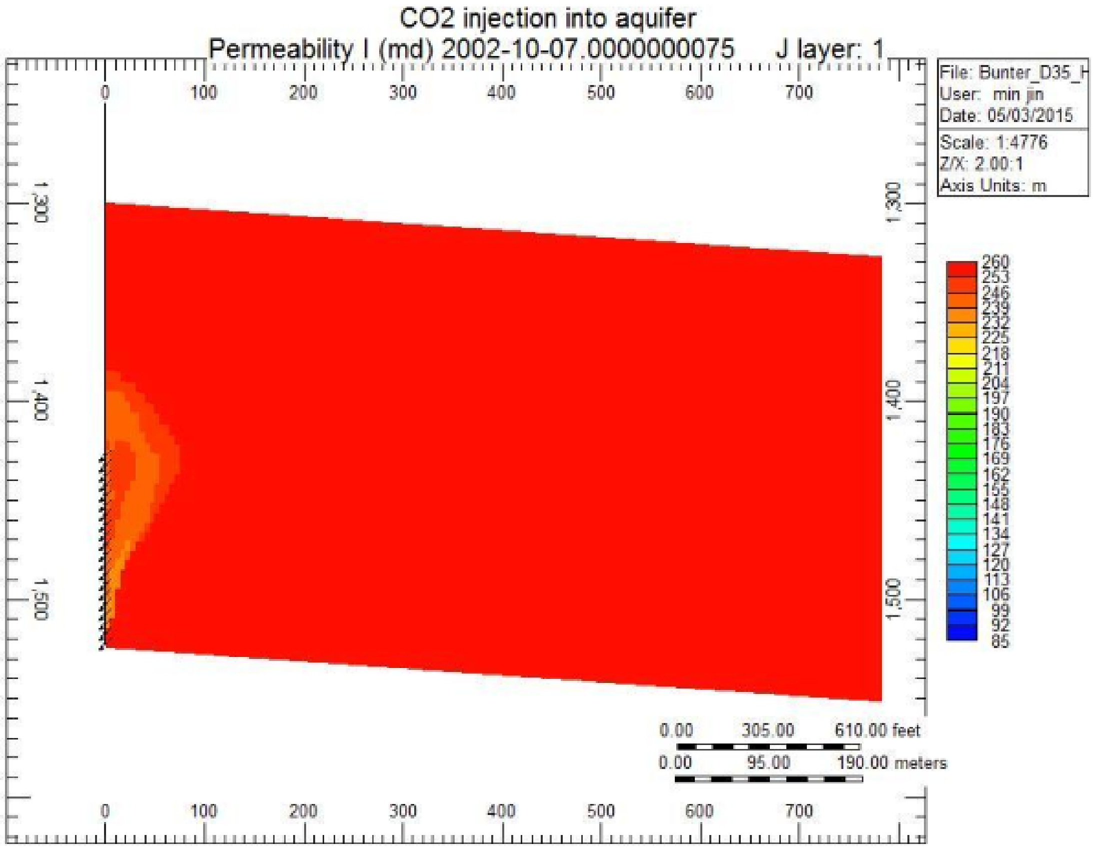
H_2O + NaCl (salt ppm unknown)



CO_2 plume / dry zone extends over time

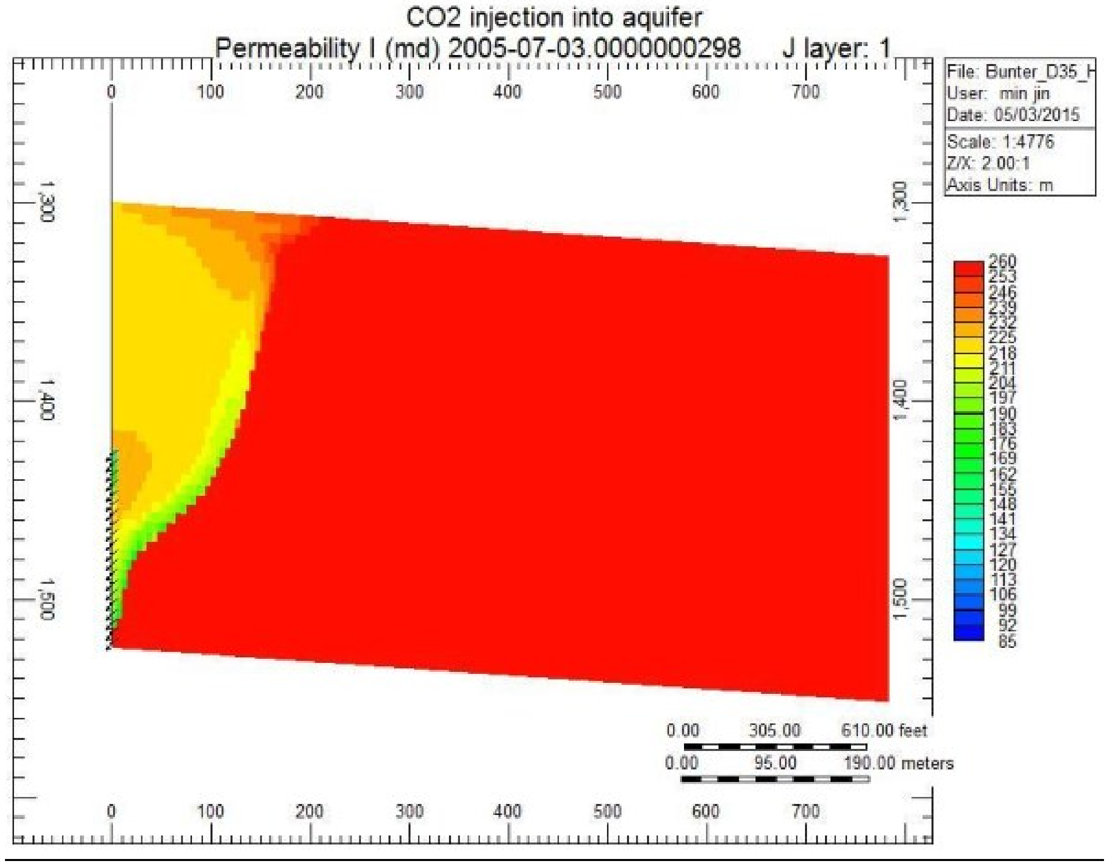
Permeability Decline

<u>*1000 days*</u>



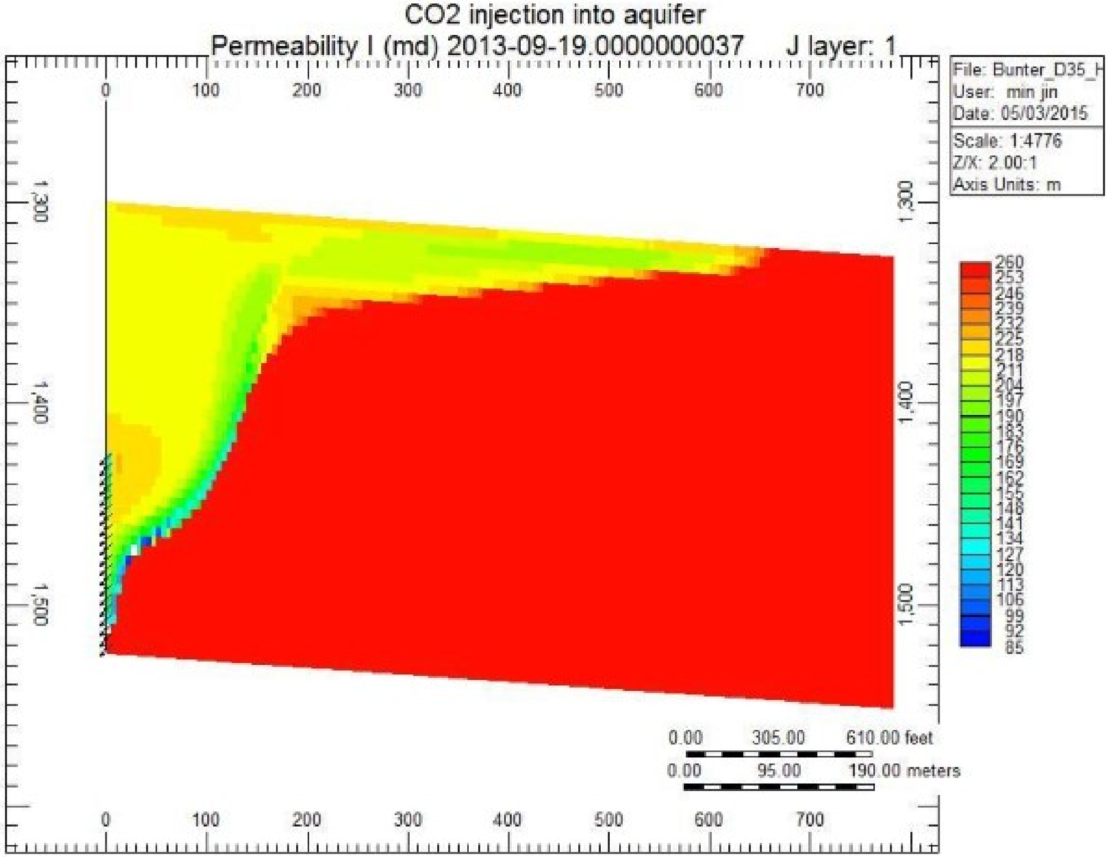
Permeability Decline

2000 days



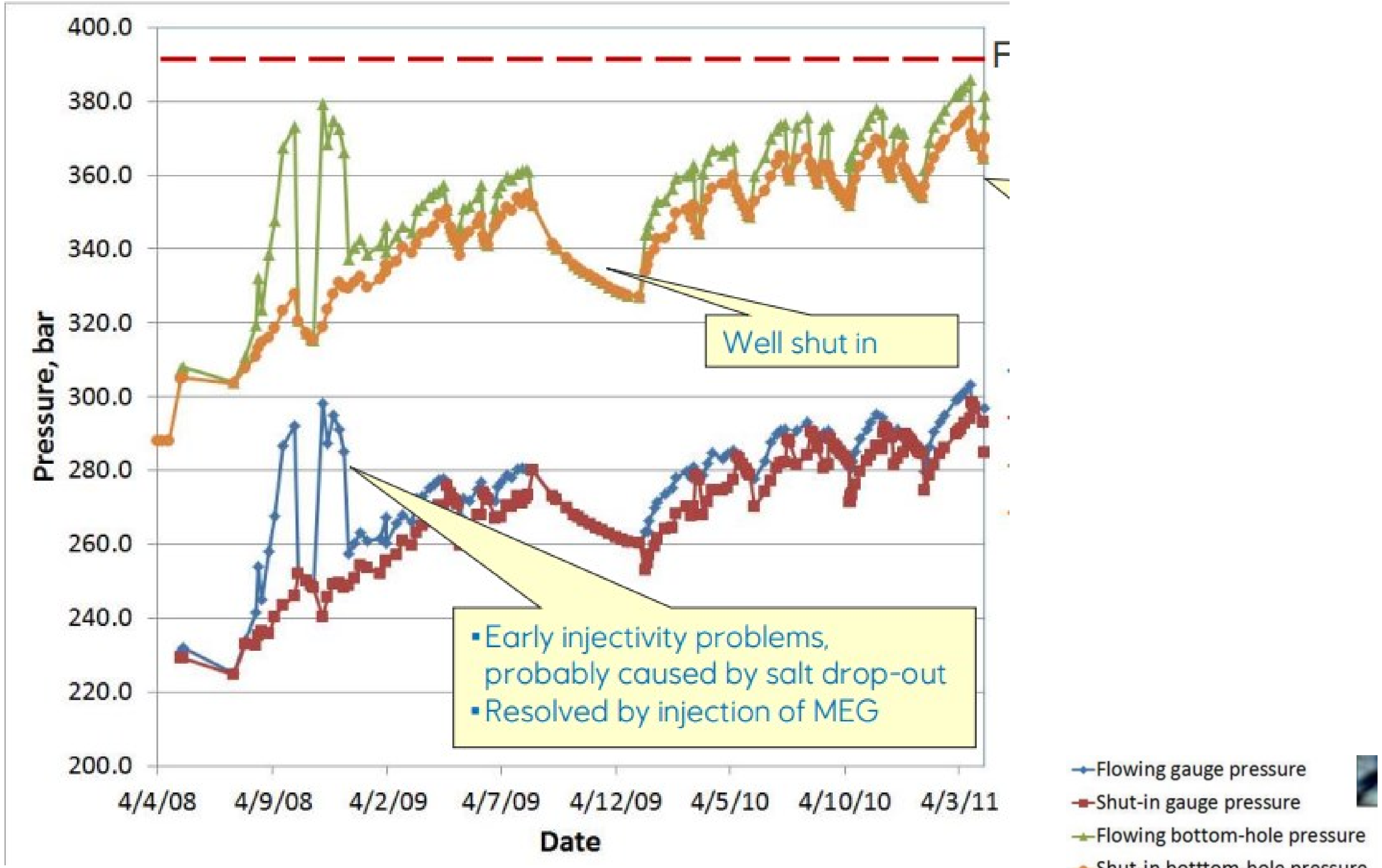
Permeability Decline

5000 days – 40% reduction in permeability



Examples

Snøhvit



Thank you

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opc.co.uk

max.richards@opc.co.uk