McDonald, Jeffrey

Molly and Jeff,
In response to Molly's request for our calculations using the Nicot method, attached is an explanation and spreadsheet with the calculations.

The attached spread sheet, shows calculations of AoR critical pressure calculations based on Equations 7 and 9 of the Nicot et al. (2009). The 3 Nicot test case example calculations are also provided to demonstrate correspondence (or lack thereof) with calculation results presented in Nicot's paper. It should be realized that the assumptions and pressure gradient conditions considered by Nicot et al. (2009) are not necessarily correspondent to normal basin settings/conditions like the FutureGen site, where an existing initial/ambient pressure gradient condition exists that would support upward flow potential from the injection reservoir to the base (or in proximity the base) of the lowermost USDW. Given these reservations, critical pressure calculations based on Nicot's equations 7 and 9 provided an estimate value of 13.4 and 13.8 psi, respectively for FutureGen site conditions. It should be noted that this calculated critical pressure does not take into account the observed hydraulic head conditions at the FutureGen site, which indicate that under ambient conditions, the reservoir is overpressured relative to the lowermost USDW.

Tyler

Nicot et al. (2009) input parameters

Fgen Properties		
Gravity	9.80665	m/s^2
Top of Injection Formation	3904	ft depth
Base of USDW	1942	ft depth
Injection Formation TDS	47,000	TDS
Borehole Range of Salinity	3.7-43.3	g/L
Reservoir Density	1.0331	kg/L
USDW Density	0.999014	kg/L
Density of Reservoir fluid at USDW conditions	1.034	kg/L
fluid density difference at base of USDW, $\rho_i - \rho_u$	0.03236	kg/L
Observed Temp for base of St. Peter	81.48	°F
Projected Pressure for base of St. Peter	806.39	psi
Salinity of St. Peter reservoir fluid	3730	ppm
fluid density of St. Peter reservoir fluid at Obs. T, Proj. P, and salinity	1.00164	g/cm3

32.17405 ft/s2
3838 (Elmhurst)

based on a "rounded average"
Mt. Simon - St. Peter salinity
Obs. T, Projected P, and salinity for Mt. Simon Top
freshwater density at STP conditions
see St. Peter T, P conditions below

kg/L

Nov. 2013 Schlumberger fluid temp. survey

Projected value from linear regression of MDT, packer test, and geon

Kelley et al. (2012)

http://www.csgnetwork.com/water_density_calculator.html

Earlougher 1977

depths are ft bgs
Kelley et al. 2012

http://www.csgnetwork.com/water_density_calculator.html
Earlougher 1977
http://www.csgnetwork.com/water_density_calculator.html

mechanical test results

T = 97.99 °

F, P = 1712.47 psi, TDS = 47,000 ppm

	Examples	California Site
Top Inject. Res., z_i		2277
USDW Base, z_u		1215
Depth Diff., $\Delta z = z_i - z_u$		1062
TDS Inject. Res.		20
TDS USDW		0.5
Initial Borehole Salinity Range		0.5 - 20
USDW Density at USDW Conditions, ρ_u		
Res. Density at USDW TP Conditions, ρ_{iu}		
Lambda Density Grad. of Res. @ Constant TDS, $\lambda_{\rho iu} = (\rho_{iu} - \rho_i)/\Delta z$		-1.16E-05
Epsilon Initial Density Grad., $\varepsilon = (\rho_i - \rho_u)/\Delta z$		3.75E-07
Final Density Diff. at USDW Base, ρ_{iu}		0.0118
Final Density Diff. at USDW Base, ρ_{iu}		0.7359
Nicot Equation		**Equation 9**
Max. Admiss. Press.		0.58
Max. Admiss. Press.		8.412
Max. Admiss. Press.		0.058
Nicot Equation		**Equation 7**
Max. Admiss. Press.		0.21
Max. Admiss. Press.		3.046
Max. Admiss. Press.		0.021
Nicot Equation 7 Verification		
Right-Side Eqn		2073.82
Critical Pressure, ΔP_c		2073.82
Critical Pressure, ΔP_c		2.0738E-03
Critical Pressure, ΔP_c		0.30
Critical Pressure, ΔP_c		0.02
Nicot Equation 9 Verification		
$\lambda - \varepsilon$, summation		-6.36E-03
Right-Side Eqn		5.67E+04
Critical Pressure, ΔP_c		56669.04
Critical Pressure, ΔP_c		5.6669E-02
Critical Pressure, ΔP_c		8.22
Critical Pressure, ΔP_c		0.57

* Believe Nicot is off by one decimal place and 0.021 bar is the correct value

Texas Site 1	Texas Site 2		Conversions/Constants		
			from	mutiplier	to
2500	2500	m	$kg/L \cdot ft/s^2$	1.94032	lb/ft^3
700	700	m	$kg/L \cdot m/s^2$	6.365879469	lb/ft^3
1800	1800	m	ft^2	144	in^2
60	60	g/L	pg	62.3664	lb/ft3
0.5	0.5	g/L	kg	2.204623	lb
0.5 - 20	0.5 - 20	g/L	kg/L	62.3664	lb/ft3
		kg/L	MPa	145.0377	lb/in^2
		kg/L	MPa	1.00E-06	Pa
		kg/L	Pa	1.45E-04	lb/in^2
-1.10E-05	-1.10E-05	kg m/L	bar	14.50377	lb/in^2
-3.81E-06	-6.98E-06	kg m/L	m	3.28084	ft
0.0379	0.03222	kg/L	g	9.80665	m/s^2
2.3637	2.0094	lb/ft^3	g	32.17405	ft/s^2
			ρ_{fw}	0.999014	kg/L
5.6	5.15	bar	m^3	1000	L
81.221	74.694	psi			
0.560	0.515	Mpa			

		bar
		psi
		Mpa
		$k\,g/m\,s^2$
		Pa
		MPa
		lb/in^2
*		bar

-6.47E-03	-3.62E-03	kg m/L
5.55E+05	5.05E+05	$k\,g/m\,s^2$
554783.77	504881.65	Pa
5.5478E-01	5.0488E-01	Mpa
80.46	73.23	lb/in^2
5.5	5.05	bar

	Examples FutureGen Calculations
Top Inject. Res., z_i	1189.94 m
USDW Base, z_u	591.92 m
Depth Diff., $\Delta z = z_i - z_u$	598.02 m
TDS Inject. Res.	47 g/L
TDS USDW	3.7 g/L
Initial Borehole Salinity Range	3.7 - 47 g/L
USDW Density at USDW Conditions, ρ_u	1.0016 kg/L
USDW Density at freshwater STP Conditions, ρ_{ufw}	0.9990 kg/L
Res. Density at USDW TP Conditions, ρ_{iu}	1.0340 kg/L
Res. Density at Reservoir TP Conditions, ρ_i	1.0331 kg/L
Lambda Density Grad. of Res. @ Constant TDS, $\lambda_{\rho iu} = (\rho_{iu} - \rho_i)/\Delta z$	-1.52E-06 kg/L m
Epsilon Initial Density Grad., $\varepsilon = (\rho_i - \rho_u)/\Delta z$	5.26E-05 kg/L m
Final Density Diff. at USDW Base, ρ_{iu}	0.0324 kg/L
Final Density Diff. at USDW Base, ρ_{iu}	2.0182 lb/ft^3
Nicot Equation 7	
Right-Side Eqn	92249.36 k g/m s^2
Critical Pressure, ΔP_c	92249.36 Pa
Critical Pressure, ΔP_c	9.2249E-02 MPa
Critical Pressure, ΔP_c	13.38 lb/in^2
Critical Pressure, ΔP_c	0.92 bar
Nicot Equation 9	
$\lambda - \varepsilon$, summation	-1.62E-02 kg/L m
Right-Side Eqn	9.49E+04 k g/m s^2
Critical Pressure, ΔP_c	94861.23 Pa
Critical Pressure, ΔP_c	9.49E-02 MPa
Critical Pressure, ΔP_c	13.76 lb/in^2
Critical Pressure, ΔP_c	0.95 bar

Conversions/Constants

from	mutiplier	to
$kg/L \cdot ft/s^2$	1.94032	lb/ft^3
$kg/L \cdot m/s^2$	6.3659	lb/ft^3
ft^2	144	in^2
pg	62.3664	lb/ft3
kg	2.2046	lb
kg/L	62.3664	lb/ft3
MPa	145.0377	lb/in^2
Mpa	1.00E+06	Pa
bar	14.50377	lb/in^2
m	3.28084	ft
g	9.80665	m/s^2
g	32.17405	ft/s^2
ρ_{fw}	0.999014	kg/L
m^3	1000	L