Aeon Petroleum Consultants Quarterly Newsletter

Aeon Petroleum Consultants is a professional engineering firm registered in the State of Texas. We specialize in estimating resources and reserves. Our intent on publishing this newsletter is to highlight topics of interest to those involved in estimating, reviewing, or reporting oil and gas resources and reserves.

In this issue, we will discuss the following:

- Aeon Petroleum Consultants website
- CO2 Sequestration
    - Sequestration in an Abandoned Gas Reservoir
    - Sequestration in an Aquifer

We hope to make this quarterly newsletter informative and useful. If there are any topics you would like us to discuss in future newsletters, please contact us on our website and let us know.

Aeon Petroleum Consultants Website

The website for Aeon Petroleum Consultants can be found at:

www.aeon-petro.com

The website contains topics and items that should be of interest to those estimating, reviewing or reporting oil and gas resources and reserves. Besides listing the services that Aeon Petroleum Consultants can provide to the oil and gas industry, there are items available for download, software created by Aeon Petroleum Consultants available for download or demo, videos, and resource and reserve guidelines for viewing and download.

Check out our offerings here:

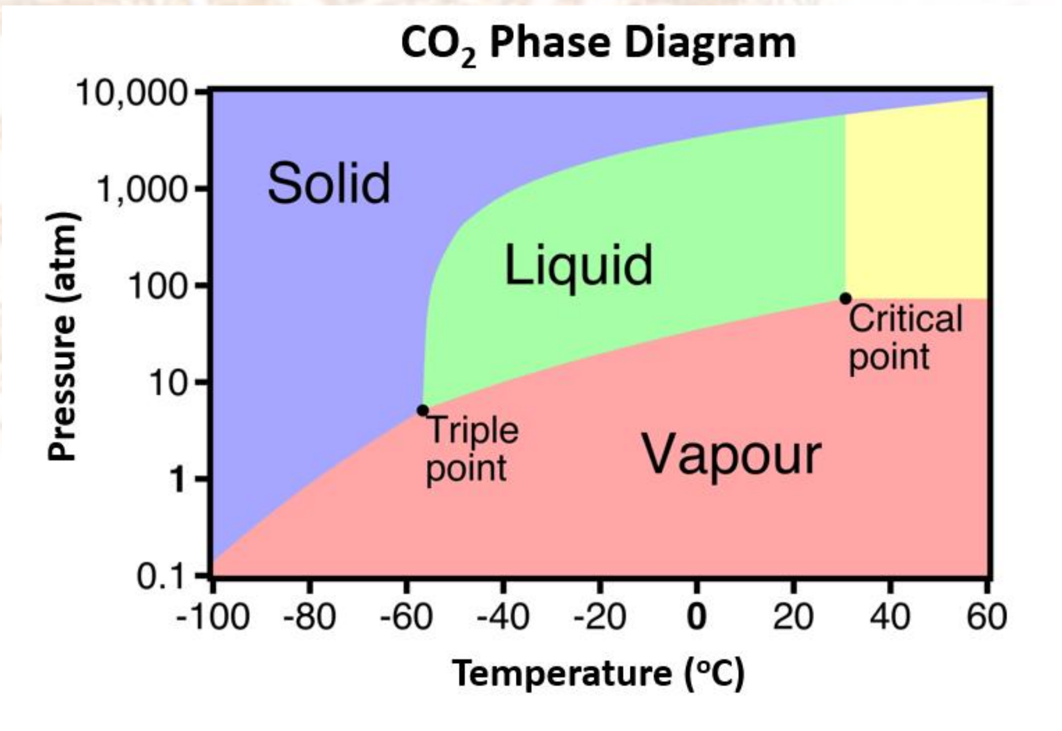
https://aeon-petro.com/supplement/shop/

Please feel free to contact us regarding our services, software, or items you would like us to discuss in these newsletters.

CO_2 Sequestration

Of particular interest lately is the idea of injecting CO_2 created from the burning of fossil fuels into underground reservoirs. This is known as sequestration.

At standard conditions, CO_2 is a gas. Occasionally we see CO_2 as a solid (dry ice) that is used in the food industry during transportation and storage. When dry ice changes phase it sublimes from a solid phase to a gas phase. Liquid CO_2 is never present under atmospheric conditions. The phase diagram for CO_2 is shown below:



It should be noted in looking at the diagram that in many sequestration projects, the phase of CO_2 will be in the “yellow” area of the graph. This is the super-critical phase.

Injecting CO_2 into reservoirs is not a new concept. The oil and gas industry has been injecting CO_2 into oil reservoirs for decades to increase recovery of oil. This is especially prevalent in the Permian Basin where gas plants have been built to separate the produced CO_2 and purify it for reinjection. The CO_2

for these projects did not come from fossil fuel burning however, but from natural CO_2 reservoirs like Sheep Mountain, McElmo Dome, and Doe Canyon located in the Rocky Mountains.

For the sequestration of CO_2 from the burning of fossil fuels, there are two types of reservoirs of interest. The first is abandoned oil and gas reservoirs and the second are saltwater aquifers. The choice of which to use depends (or should depend) on the economics of the situation. The items to consider for the choice are as follows:

- Reservoir volume available for CO_2 sequestration
- Volume of CO_2 to be sequestered
- Time over which CO_2 is to be injected
- Distance from source of CO_2 to injection reservoir
- Cost of drilling/completing/working over injection wells
- Operating expenses of injection operations
- Pipeline capital and operating expenses

In the case of abandoned oil and gas reservoirs, CO_2 is stored in the remaining hydrocarbon space in the reservoir and dissolved in the water saturated area of the reservoir. For aquifers, CO_2 is merely dissolved in the water in the reservoir. Calculations of the potential CO_2 storage must be made on each reservoir of interest to determine their viability for CO_2 storage.

In this newsletter, we are going to show how to calculate the reservoir volume available to CO_2 sequestration for both an abandoned gas reservoir and an aquifer. We will calculate the volume of CO_2 that can fill these reservoirs at standard conditions. For the purpose of these calculations, we will assume fresh water in the gas reservoir and aquifer because data are available for the calculations. When water is to be stored in an aquifer, water samples should be taken and PVT analysis made to determine CO_2 solubility. Salt content reduces the ability of CO_2 to be dissolved and stored, and in some cases this reduction can be quite high.

CO_2 Sequestration in an Abandoned Gas Reservoir

Here are the data for the abandoned gas reservoir:

Depth = 5,500 ft
Initial pressure (P_i) = Sequestration Pressure (P_s) = 2,400 psia = 165 bars
Current pressure (P_r) = 200 psia
Reservoir Temperature (T_r) = 122 ^oF = 582 ^oR = 50 ^oC
Gas gravity = 0.7
Sequestration z (z_s) = 0.757, Current z (z_r) = 0.974
Porosity = 18% (0.18)
Sw = 25% (0.25)
Reservoir thickness (h) = 22 feet
Assumed area (A) = 640 acres (1 square mile)

Step 1: Calculate reservoir volume

$$Reservoir\ Volume = 43{,}560 * h * A * \emptyset = 43{,}560 * 22 * 640 * 0.18$$
$$= 110.4 * 10^6 ft^3$$

Step 2: Calculate water volume

$$Water\ Volume = Reservoir\ Volume * Sw = 110.4 * 10^6 ft^3 * 0.25$$
$$= 27.6 * 10^6\ ft^3$$

Step 3: Calculate residual gas volume remaining in reservoir at standard conditions

$$Current\ Gas\ Expansion\ Factor = E_{gr} = 35.3 * \frac{P_r}{T_f * z_r} = 35.3 * \frac{200}{582 * 0.974}$$

$$= 12.5\ scf/ft^3$$

$$Residual\ Gas\ Volume = Reservoir\ Volume * (1 - Sw) * E_{gr}$$
$$= 110.4 * 10^6 * (1 - 0.25) * 12.5 = 1{,}035\ MMscf$$

Step 4: Calculate residual gas volume remaining in reservoir at sequestration conditions

$$Sequestration\ Gas\ Expansion\ Factor = E_{gs} = 35.3 * \frac{P_s}{T_f * z_s}$$

$$= 35.3 * \frac{2400}{582 * 0.757} = 192.3\ scf/ft^3$$

$$Residual\ Gas\ Volume\ at\ Sequestration\ Conditions = \frac{Residual\ Gas\ at\ SC}{E_{gs}}$$

$$= \frac{1{,}035}{192.3} = 5.4 * 10^6 ft^3$$

Step 5: Calculate free volume available for CO_2 sequestration

$$Free\ Volume$$
$$= Reservoir\ Volume - Water\ Volume - Residual\ Gas\ Volume$$
$$= (110.4 - 27.6 - 5.4) * 10^6 = 77.4 * 10^6 ft^3$$

Step 6: Determine CO_2 density at standard conditions and sequestration conditions (sequestration pressure)

The density of CO_2 at standard conditions is $\rho_{sc}CO_2 = 0.115\ lb/ft^3$

The density of CO_2 at sequestration conditions (original reservoir conditions) is found on a chart as shown on the following page. This chart is from *Improved Oil Recovery* by the Interstate Oil Compact Commission, 1983.

TABLE 3 — DENSITY OF CO_2, g/cm^3

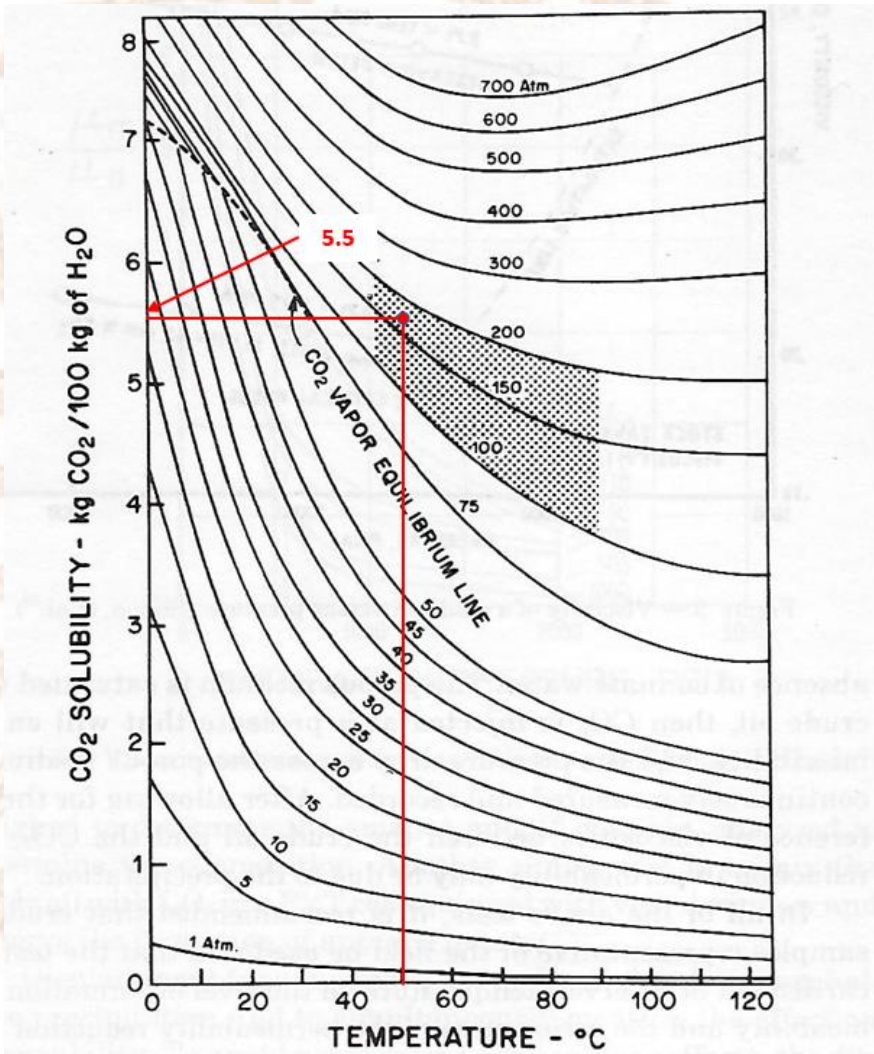
Temperature °C	Pressure, bars										
	25	50	75	100	150	200	250	300	350	400	450
0	.0601	.947	.954	.969	.997	1.0170	1.0350	1.0530	1.0670	1.0792	1.0900
10	.0561	.864	.891	.914	.950	.9770	1.0000	1.0190	1.0350	1.0502	1.0635
20	.0527	.1423	.810	.855	.901	.9335	.9600	.9832	1.0030	1.0200	1.0351
30	.0499	.1251	.655	.782	.850	.8887	.9190	.9460	.9685	.9882	1.0054
40	.0476	.1135	.2305	.638	.785	.8415	.8771	.9077	.9339	.9559	.9755
50	.0456	.1052	.1932	.3901	.705	.7855	.8347	.8687	.8990	.9233	.9451
60	.0437	.0984	.1726	.2868	.604	.7240	.7889	.8292	.8634	.8905	.9139
70	.0421	.0930	.1584	.2478	.504	.6605	.7379	.7882	.8270	.8575	.8321
80	.0406	.0883	.1469	.2215	.430	.5935	.6872	.7466	.7898	.8243	.8516
90	.0391	.0845	.1381	.2019	.373	.5325	.6359	.7040	.7522	.7909	.8212
100	.0378	.0810	.1305	.1877	.333	.4815	.5880	.6630	.7160	.7571	.7911
150	.0325	.0674	.1054	.1461	.2337	.3267	.4151	.4925	.5549	.6079	.6501
200	.0288	.0586	.0898	.1220	.1900	.2591	.3271	.3907	.4491	.5006	.5443
250	.0257	.0518	.0788	.1065	.1629	.2192	.2743	.3274	.3773	.4237	.4672
300	.0233	.0468	.0707	.0951	.1434	.1923	.2388	.2850	.3279	.3691	.4072
350	.0213	.0427	.0643	.0857	.1292	.1725	.2137	.2540	.2928	.3284	.3637
400	.0197	.0393	.0591	.0788	.1178	.1565	.1942	.2308	.2650	.2979	.3293
450	.0183	.0365	.0547	.0726	.1086	.1441	.1786	.2117	.2431	.2738	.3019
500	.0171	.0340	.0509	.0677	.1009	.1339	.1658	.1962	.2253	.2536	.2802
550	.0160	.0319	.0477	.0635	.0945	.1250	.1546	.1833	.2104	.2370	.2614
600	.0151	.0301	.0449	.0597	.0887	.1174	.1450	.1722	.1979	.2227	.2457
650	.0143	.0284	.0424	.0563	.0837	.1107	.1368	.1626	.1872	.2102	.2321
700	.0135	.0269	.0402	.0534	.0794	.1048	.1296	.1538	.1767	.1992	.2205
750	.0128	.0256	.0382	.0508	.0754	.0995	.1233	.1460	.1682	.1895	.2101
800	.0122	.0244	.0364	.0484	.0718	.0948	.1173	.1391	.1603	.1806	.2009
850	.0117	.0233	.0348	.0462	.0686	.0906	.1123	.1328	.1532	.1729	.1924
900	.0112	.0223	.0333	.0442	.0657	.0868	.1073	.1272	.1468	.1657	.1841
950	.0107	.0213	.0319	.0422	.0630	.0832	.1026	.1222	.1404	.1589	.1764
1000	.0103	.0205	.0307	.0407	.0604	.0797	.0986	.1174	.1350	.1527	.1697

At 50°C and interpolating to 165 bars (2,400 psia), we get

$$\rho_s CO_2 = 0.7292 \frac{g}{cc} = 45.5\ lb/ft^3$$

Step 7: Determine the solubility of CO2 in water

For a brine, the solubility should be determined using a water sample and performing PVT analysis. For the purpose of this example, we will use CO_2 solubility from a chart of data taken on fresh water solubility. The chart is shown on the next page and is from the same reference Improved Oil Recovery.



From the chart above it can be seen that the solubility of CO_2 is 5.5 kg/100 kg, which equals 5.5 lb/100 lb water at sequestration conditions at a pressure of 165 bars and 50°C.

Step 8: Calculate the mass of CO_2 in the free volume of the reservoir

$$Free\ volume\ CO_2\ Mass = Free\ volume * \rho_s CO_2$$
$$= 77.4 * 10^6 ft^3 * 45.5\ lb/ft^3$$
$$= 3{,}522 * 10^6 lbs\ CO_2$$

Step 9: Calculate the CO_2 mass of dissolved CO2 in water

$$Dissolved\ CO_2\ Mass = Water\ Volume * Water\ Density * CO_2\ Solubility$$

$$= 27.6 * 10^6 ft^3 * 62.4 \frac{lb}{ft^3} * 5.5 \frac{lb}{100\ lb} = 95 * 10^6 lbs\ CO_2$$

Step 10: Determine the total CO_2 sequestered

The total CO_2 mass in the reservoir is:

$$Total\ CO_2 = Free\ Volume + Dissolved\ Volume = (3{,}522 + 95) * 10^6$$
$$= 3{,}617 * 10^6 lbs\ CO_2$$

$$CO_2\ Volume\ at\ Standard\ Conditions = CO_2\ Mass/\rho_{sc} CO_2 =$$
$$= 3{,}617 * 10^6 lbs/0.115\ lb/ft^3 = 31{,}450 * 10^6 ft3 = 31.45\ Bscf$$

Based on these calculations, this reservoir should be able to hold just over 31 Bscf of CO_2 up to the original reservoir pressure of 2,400 psia.

CO_2 Sequestration in an Aquifer

Let us assume the same reservoir as in the previous example, but assume the reservoir is completely filled with fresh water. Here are the data for the aquifer:

Depth = 5,500 ft
Initial pressure (P_i) = Sequestration Pressure (P_s) = 2,400 psia = 165 bars
Current pressure (P_r) = 2,400 psia
Reservoir Temperature (T_r) = 122 ^{o}F = 582 ^{o}R = 50 ^{o}C
Porosity = 18% (0.18)
Sw = 100% (1.00)
Reservoir thickness (h) = 22 feet
Assumed area (A) = 640 acres (1 square mile)

This is much simplified from the prior problem as we only need to know the reservoir pressure, temperature, volume, and solubility of CO_2 in water at reservoir conditions, and the density of CO_2 at standard conditions.

Step 1: Calculate reservoir volume

This is the same as in the previous example:

$$Reservoir\ Volume = 43{,}560 * h * A * \emptyset = 43{,}560 * 22 * 640 * 0.18$$
$$= 110.4 * 10^6 ft^3$$

Step 2: Determine the solubility of CO_2 in water

From the previous example, the solubility of CO_2 in fresh water at sequestration reservoir conditions of 50^{o}C and 165 bars is 5.5 lb/100 lb water.

Step 3: Calculate the mass of CO_2 in the aquifer

For a brine, the solubility should be determined using a water sample and performing PVT analysis. For the purpose of this example, we will use CO_2 solubility from a chart of

$$Dissolved\ CO_2\ Mass = Water\ Volume * Water\ Density * CO_2\ Solubility$$

$$= 110.4 * 10^6 ft^3 * 62.4 \frac{lb}{ft^3} * 5.5 \frac{lb}{100\ lb} = 378.9 * 10^6 lbs\ CO_2$$

Step 4: Determine CO_2 density at standard conditions

From the previous example, the density of CO_2 at standard conditions is $\rho_{sc}CO_2 = 0.117\ lb/ft^3$.

Step 5: Calculate CO_2 volumes at standard conditions

$$CO_2\ Volume\ at\ Standard\ Conditions = CO_2\ Mass * \rho_{sc}CO_2 =$$
$$= 378.9 * 10^6 lbs/0.115\ lb/ft^3 = 3{,}410 * 10^6 ft3 = 3.29\ Bscf$$

Please note that this volume is approximately 10% of the volume calculated in the previous example. For an aquifer to be considered as an injection candidate, it must have a huge volume!