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 using limited information

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:

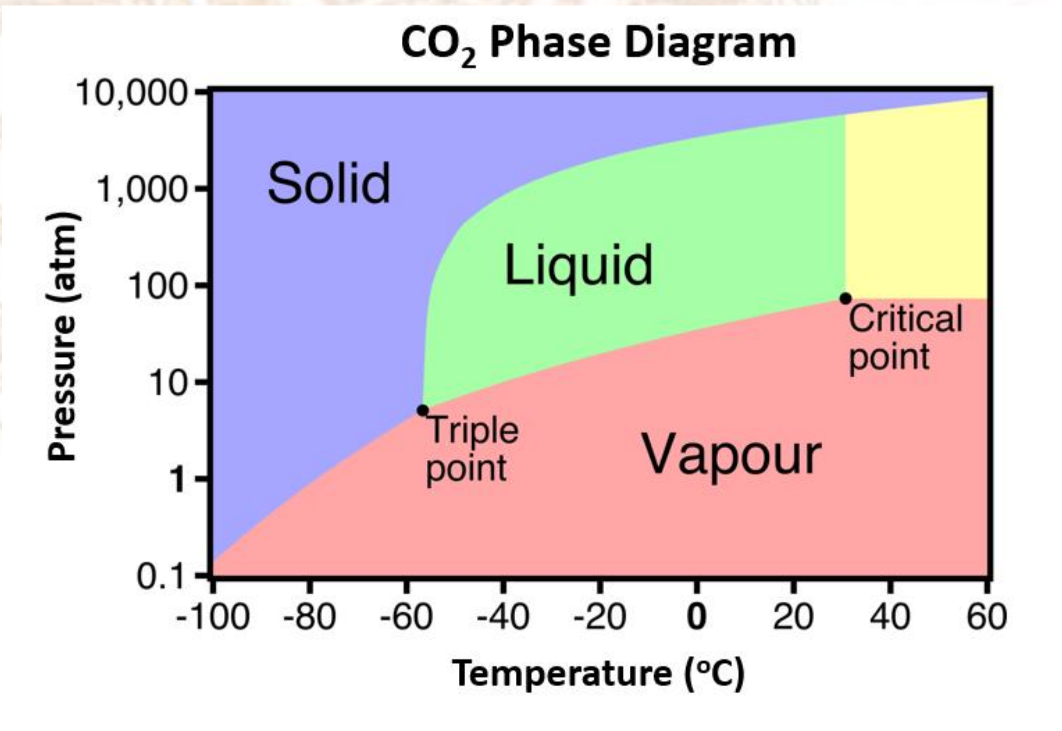
https://aeon-petro.com/supplement/shop/

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 an abandoned gas reservoir using limited information. This is typically the case when screening potential storage reservoirs. We will calculate the volume of CO_2 (at standard conditions) that can fill the reservoir. For the purpose of these calculations, we will not consider additional CO_2 that might be sequestered in the connate water within the reservoir.

CO_2 Sequestration in an Abandoned Gas Reservoir Using Limited Information

Here are the data for the abandoned gas reservoir:

Depth = 6,500 ft
Initial pressure (P_i) = Sequestration Pressure (P_s) = 2,900 psia = 200 bars
Current pressure (P_r) = 400 psia
Reservoir Temperature (T_r) = 112 ^oF = 572 ^oR = 44 ^oC
Gas gravity = 0.7
Reservoir area = 3,300 acres
Cumulative Gas Production = 85 Bscf

The assumption for sequestration is that CO_2 will be injected into the reservoir until the reservoir pressure is equivalent to the initial pressure. At the current pressure, there is some residual gas in the reservoir that must be accounted for in the calculations.

Step 1: Calculate the gas expansion factors for the residual gas in the reservoir at current and original conditions

From available charts and calculations,

$z_i = 0.757$
$z_a = 0.941$

$$Gas\ Expansion\ Factor\ at\ Initial\ Conditions = Eg_i = 35.3 * \frac{2{,}900}{(572) * (0.757)}$$

$$= 236.4\ scf/ft^3$$

$$Gas\ Expansion\ Factor\ at\ Abandonment\ Conditions = Eg_a$$

$$= 35.3 * \frac{400}{(572) * (0.941)} = 26.2\ scf/ft^3$$

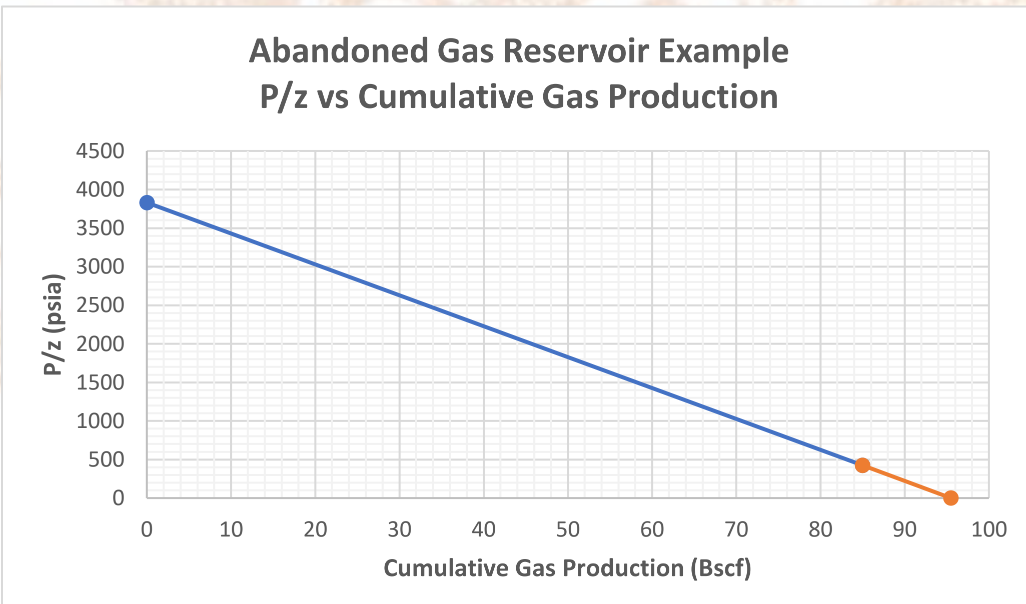
Step 2: Calculate recovery factor

$$Recovery\ Factor = \frac{Eg_i - Eg_a}{Eg_i} = \frac{236.4 - 26.2}{236.4} = 0.89 = 89\%$$

Step 3: Calculate original gas-in-place (OGIP)

$$OGIP = \frac{Cumulative\ Production}{Recovery\ Factor} = \frac{85}{0.89} = 95.5\ Bscf$$

Another method is to plot P/z vs pressure and extrapolate to zero P/z to find OGIP as shown here:



Step 4: Calculate reservoir volume

$$Reservoir\ Volume = \frac{OGIP}{Eg_i} = \frac{95.5 * 10^9}{236.4} = 404 * 10^6\ ft^3$$

Step 5: Calculate residual gas volume at standard conditions

$$Residual\ Gas = OGIP - Cumulative\ Gas = 95.5 - 85 = 10.5\ Bscf$$

Step 6: Calculate reservoir volume of residual gas at sequestration conditions (initial pressure)

$$Residual\ Gas\ Reservoir\ Volume = \frac{Residual\ Gas\ at\ SC}{Eg_i} = \frac{10.5 * 10^9}{236.4}$$
$$= 44.4 * 10^6\ ft^3$$

Step 7: Calculate reservoir volume available for sequestration

$$Sequestration\ Volume = Reservoir\ Volume - Residual\ Gas\ Volume$$
$$= (404 - 44.4) * 10^6 = 359.6 * 10^6 ft^3$$

Step 7: Calculate the density of CO_2 at standard conditions and initial reservoir conditions

The density of CO_2 at standard conditions is $\rho_{scCO2} = 0.115\ lb/scf$

The density of CO_2 at sequestration conditions (initial 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 interpolating between 40° and 50°C at 200 bars (2,900 psia), we get

$$\rho_{iCO2} = 0.81912\frac{g}{cc} = 51.1\ lb/ft^3$$

Step 8: Calculate weight of CO_2 to fill the reservoir

$$Pounds\ of\ CO_2 = Sequestration\,Volume * CO_2Density = 359.6 * 10^6 * 51.1 = 18.4 * 10^9\ lbs = \mathbf{9.2 * 10^6}\ \boldsymbol{tons}$$

Step 8: Calculate volume of CO_2 at standard conditions to fill the reservoir

$$Volume\ of\ CO_2 = \frac{Pounds\ of\ CO_2}{CO_2Density\ at\ SC} = \frac{18.4 * 10^9}{0.115} = \mathbf{160}\ \boldsymbol{Bscf}$$

As can be seen, an estimate of CO_2 sequestration in abandoned gas reservoir can be made using quite limited data. This method lends itself to the development of a screening process for the selection of appropriate sequestration reservoirs using publicly available information.