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Research Article

Pressure Transient Analysis of CO_2 Rich Gas Reservoir using Pseudo Pressure Approach

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Abstract

This study involves pressure transient analysis of CO_2 *rich gas reservoir using pseudo pressure approach. Pressure transient or any other analysis in gas reservoir can be interpreted using pressure, pressure square or pseudo pressure approach. Previously the pressure tests in gas reservoir were interpreted with diffusivity equation solved for liquid (using simple pressure approach). But unfortunately in case of gas reservoir the properties of gas are highly affected with change in pressure. This problem was firstly addressed during 70's by Al-Hussainy and Ramey, when they conceived the idea of real gas pseudo pressure function, which laid the basis for all gas pressure transient analysis and rate transient analysis equations to be solved in terms of pseudo pressure approach rather than pressure approach, but their work is only limited to the sweet gas. Pressure dependence of gas properties is further complicated when natural gas contains higher amount of contaminant gases such as* CO_2, H_2S *and* N_2*. The main objective of this research is to employ the different approaches of pseudo pressure function in pressure transient analysis of gas reservoir with high concentration of* CO_2*. Furthermore this study involves the comparative analysis of results estimated with different pressure approaches.*

Keywords: *Pseudo-pressure,* CO_2 *Reservoir, Pressure transient analysis, Pressure buildup analysis, Pressure drawdown analysis, Pressure functions.*

1. Introduction

In Pressure or Rate Transient Analysis, flow equation is solved with some assumptions. Two main assumptions are: Constant compressibility and Constant viscosity. In case of liquid, above assumptions are relevant, and their equation can be solved analytically. This is referred to as the "liquid flow solution", and forms the basis of all Pressure and Rate transient analysis. But in case of gas, these suppositions are applicable with very limited conditions. Beyond the range of these conditions inaccuracy in results can occurs due to high compressibility of a gas, thus the viscosity (μ) and compressibility factor (z), are not constant but changes with pressure.

Pressure transient tests in gas reservoirs can be interpreted using pressure (p), pressure square (p^2) and pseudo-pressure m(p) functions (Aziz, *et al,* 1976). Choice of any pressure function depends upon the physical properties of the reservoir. If natural gas contains impurities such as CO_2, H_2S and N_2 the gas viscosity and deviation factor must be adjusted in order to yield accurate results. Thus we can adjust the compressibility factor up to 80% concentration of contaminant gases from the available contents. But unfortunately, viscosity correction correlation from the available contents is limited to just 15% concentration of contaminant gases. When pressure test of higher CO_2 concentrated reservoir interpreted with common viscosity correlations yield inaccuracy in physical properties of the reservoir, thereby indicating the incorrect flow efficiency of the wells (Jokhio, 2001). In order to cope with these difficulties a complete system of pseudo-pressure estimation method need to be developed to interpret pressure transient and deliverability of the wells of high CO_2 concentrated reservoirs

2. Methodology

In this research, all the pressure data is converted into pseudo pressures using the two different approaches. The first is with (Tiab, 1984) pseudo pressure function whiles the second one with conventional method of (Hussainy, *et al*, 1966).

2.1 Tiab pseudo pressure function

(Tiab, 1984) presented a new method for correlating real gas pseudo-pressure values of gas reservoirs containing huge amounts of CO_2. He developed the

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simple mathematical function which do not requires any kind of corrected viscosity or compressibility.

$$m(p) = \frac{2M_t}{\mu_a} p^2 \tag{1}$$

Where, M_t is the total reduced property correlation factor given by

$$M_t = (M_c + M_r)T_{pr} \tag{2}$$

$$M_c = \sum_{j=1}^{6} C_j (C_O + 1)^{J-1} \tag{3}$$

Table 1 CO_2 Concentration correlation coefficients (Tiab, 1984)

T_{pr}	C_1	C_2	C_3	C_4	C_5	C_6
1	0.6668	-0.392	0.2178	0.0556	-0.083	0.0189
1.05	0.6753	-0.401	0.2273	0.0527	-0.083	0.0193
1.1	0.6836	-0.409	0.2355	0.0507	-0.084	0.0193
1.15	0.6918	-0.416	0.2426	0.0492	-0.085	0.0200
1.2	0.6999	-0.423	0.2490	0.0482	-0.086	0.0203
1.25	0.6979	-0.424	0.2515	0.0468	-0.086	0.0203
1.3	0.6981	-0.426	0.2541	0.0459	-0.086	0.0204
1.35	0.6983	-0.428	0.2562	0.0451	-0.086	0.0205
1.4	0.6983	-0.429	0.2579	0.0445	-0.086	0.0206
1.45	0.6972	-0.429	0.2590	0.0440	-0.086	0.0206
1.5	0.6971	-0.430	0.2602	0.0436	-0.087	0.0206
1.55	0.6970	-0.431	0.2611	0.0433	-0.087	0.0207
1.6	0.6967	-0.431	0.2619	0.0430	-0.087	0.0207
1.65	0.6965	-0.432	0.2626	0.0428	-0.087	0.0207
1.7	0.6962	-0.432	0.2631	0.0426	-0.087	0.0208
1.75	0.6959	-0.432	0.2636	0.0425	-0.087	0.0208
1.8	0.6956	-0.432	0.2640	0.0424	-0.087	0.0208
1.85	0.6952	-0.433	0.2642	0.0422	-0.087	0.0208
1.9	0.6949	-0.433	0.2645	0.0421	-0.087	0.0208
1.95	0.6945	-0.433	0.2647	0.0421	-0.087	0.0208
2	0.6941	-0.433	0.2648	0.0420	-0.087	0.0208

$$\mathrm{M_r} = 0.5\left(\frac{\mathrm{C_{pr}}}{\mathrm{P_{pr}}} - 1\right) \tag{4}$$

$\mathrm{C_{pr}}$ (reduced-pressure correlating factor)

$$\mathrm{C_{pr}} = 0.6669\mathrm{P_{pr}} + 0.502 \tag{5}$$

2.2 Conventional method

(Hussainy and Ramey, 1966) conceived the idea of real gas potential commonly known as pseudo-pressure function which accounts for the effect of variations of viscosity (μ) and gas compressibility factor (Z) on actual gas flows.

The m(p) can be calculated as:

$$\mathrm{m(p)} = 2\int_{\mathrm{P_m}}^{\mathrm{P}} \frac{\mathrm{P}}{\mu \mathrm{Z}} \mathrm{dP} \tag{6}$$

By applying the trapezoidal rule to above eq. the equation will take the following form.

$$\mathrm{m(p)} = \left(\frac{\mathrm{P}}{\mu \mathrm{Z}}\right)_{\mathrm{P}} \times \mathrm{P} \tag{7}$$

Gas compressibility factor can be calculated using (Gopal, 1977) gas compressibility algebraic equation.

$$\mathrm{Z} = \mathrm{P_{pr}}(\mathrm{G_1 T_{pr}} + \mathrm{G_2}) + \mathrm{G_3 T_{pr}} + \mathrm{G_4} \tag{8}$$

Where;
$\mathrm{G_1, G_2, G_3}$ and $\mathrm{G_4}$, are Gopal constants for various ranges of pseudo-reduced properties. Given in the Table 2.

Table 2 Gopal Equations for Estimating Gas Compressibility Factor

P_r	T_r	Equations	Eq. No
0.2 to 1.2	1.05 to 1.2	$P_r(1.6643T_r - 2.2114) - 0.367T_r + 1.4385$	1
	1.2+ to 1.4	$P_r(0.5222T_r - 0.8511) - 0.0364T_r^* + 1.0490$	2
	1.4+ to 2.0	$P_r(0.1391T_r - 0.2988) + 0.0007T_r^* + 0.9969$	3⁺
	2.0+ to 3.0	$P_r(0.0295T_r - 0.0825) + 0.0009T_r^* + 0.9967$	4⁺
1.2+ to 2.8	1.05 to 1.2	$P_r(-1.3570T_r + 1.4942) + 4.6315T_r - 4.7009$	5⁺⁺
	1.2+ to 1.4	$P_r(0.1717T_r - 0.3232) + 0.5869T_r + 0.1229$	6
	1.4+ to 2.0	$P_r(0.0984T_r - 0.2053) + 0.0621T_r + 0.858$	7
	2.0+ to 3.0	$P_r(0.0211T_r - 0.0527) + 0.0127T_r + 0.9549$	8
2.8+ to 5.4	1.05 to 1.2	$P_r(-0.3278T_r + 0.4752) + 1.8223T_r - 1.9036$	9⁺
	1.2+ to 1.4	$P_r(-0.2521T_r + 0.3871) + 1.608T_r - 1.6635$	10⁺
	1.4+ to 2.0	$P_r(-0.0284T_r + 0.0625) + 0.4714T_r - 0.0011^*$	11
	2.0+ to 3.0	$P_r(0.0041T_r + 0.0039) + 0.0607T_r + 0.7927$	12
5.4+ to 15.0	1.05 to 3.0	$P_r(0.711 + 3.66T_r)^{-1.4667} - 1.637/(0.319T_r + 0.522) + 2.071$	13

Viscosity of the gas can be calculated using the (Carr *et al*, 1954) graphical correlations. This is the most widely used viscosity chart for sweet as well as for sour gases in the oil and gas industry.

With the help of pseudo-critical properties and apparent molecular weight the Fig. 1 is used to calculate the viscosity at 1 atm. And denoted asμ_1. Then with the help of pseudo-reduced properties we can obtain the viscosity ratio $\frac{\mu_g}{\mu_1}$ with from Fig. 2. Finally, the viscosity at desired condition (μ_g) is calculated by multiplying the viscosity at 1 atm. (μ_1) by viscosity ratio$\frac{\mu_g}{\mu_1}$.

$$\mu_g = \frac{\mu_g}{\mu_1}(\mu_1) \tag{9}$$

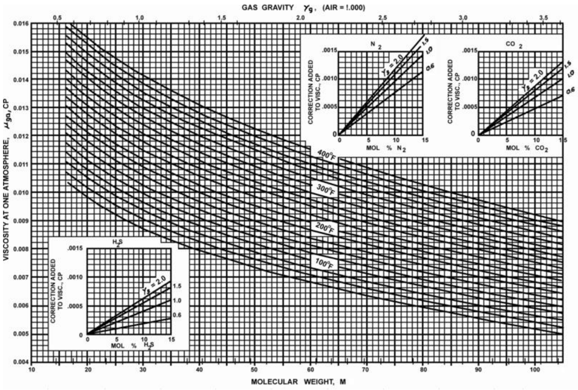

Fig. 1 Gas Viscosity $\mu_1$at 1 atm. (Carr *et al*, 1954)

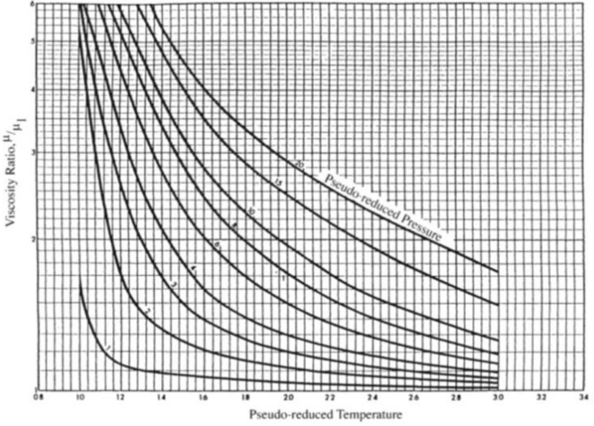

Fig. 2 Viscosity Ratio (Carr *et al*, 1954)

After successfully converting the pressure data into pseudo pressures the CO_2rich gas reservoir's pressure transient analysis is carried out to estimate some properties like: permeability, skin, flow efficiency.After calculating the desired properties by employing both approaches of pseudo pressure functions. The results of both the approaches are compared to find out the errors.

3. Results

Reservoir properties and gas composition data is given in the Table 3 and 4 respectively.

Table 3 Reservoir Properties (Jokhio, 2001)

Parameter	Symbol	Value
Porosity	ϕ	0.13
Pressure	P	2533 Psia
Thickness	h	86 ft
Specific Gravity	γ_g	1.518
Res. Temperature	T	168 °F
Total compressibility	C_t	2.8×10^{-4} psi^{-1}
Viscosity	μ	0.065 cp
Well bore radius	r_w	0.33

Table 4 Gas Composition (Jokhio, 2001)

Comp.	$\mathbf{M.wt}$	$\mathbf{Y_i}$	$\mathbf{T_{ci}}$	$\mathbf{P_{ci}}$	$\mathbf{Y_i \times M.wt}$	$\mathbf{Y_i \times T_{ci}}$	$\mathbf{Y_i \times P_{ci}}$
$\mathbf{CO_2}$	44.01	0.98256	547.47	1071	43.24247	537.9221	1052.322
$\mathbf{N_2}$	28.016	0.01606	227.29	493	0.449937	3.650277	7.91758
$\mathbf{CH_4}$	16.042	0.00138	343.06	667.8	0.022138	0.473423	0.921564
$\sum$					$\mathbf{M_a}$	$\mathbf{T_{pc}}$	$\mathbf{P_{pc}}$
					43.71454	542.0458	1061.161

3.1 Pressure buildup analysis

Table 5 Pressure Buildup Data (Jokhio, 2001)

Time **hrs**	Pressure $\mathbf{P_{ws}}$	Time **hrs**	Pressure$\mathbf{P_{ws}}$
0	2495.449	15	2528.934
0.25	2513.286	20	2530.034
0.50	2515.934	25	2530.887
0.75	2517.483	30	2531.584
1	2518.583	35	2532.173
2	2521.232	40	2532.684
4	2523.881	45	2533.134
8	2526.531		

Producing time $t_p = 96$ hrs
Flow rate, $q = 8400$ Mscf

Table 6 shows the converted values of pressures into pseudo-pressure using the (Tiab, 1984) pseudo pressure approach

3.1.1 Tiab's pseudo pressure function

Table 6 Time, Pressure and Pseudo-pressure for Buildup Test (With Tiab's Method)

t	HTR	$\mathbf{P_{ws}}$	$\mathbf{P^2}$	$\mathbf{P_{pr}}$	$\mathbf{C_{pr}}$	$\mathbf{M_r}$	$\mathbf{M_t}$	$\mathbf{m(P_{ws})}$
0	-	2495.449	6227266	2.351622	2.070297	-0.05982	0.51205	3.75E+08
0.25	385	2513.286	6316607	2.368431	2.081506	-0.06057	0.511173	3.80E+08
0.5	193	2515.934	6329924	2.370926	2.083171	-0.06068	0.511044	3.81E+08
0.75	129	2517.483	6337721	2.372386	2.084144	-0.06075	0.510968	3.81E+08
1	97	2518.583	6343260	2.373422	2.084835	-0.0608	0.510915	3.81E+08
2	49	2521.232	6356611	2.375919	2.0865	-0.06091	0.510786	3.82E+08
4	25	2523.881	6369975	2.378415	2.088165	-0.06102	0.510658	3.83E+08
8	13	2526.531	6383359	2.380912	2.08983	-0.06113	0.51053	3.83E+08
15	7.4	2528.934	6395507	2.383177	2.091341	-0.06123	0.510414	3.84E+08
20	5.8	2530.034	6401072	2.384213	2.092032	-0.06127	0.51036	3.84E+08
25	4.84	2530.887	6405389	2.385017	2.092568	-0.06131	0.510319	3.85E+08
30	4.2	2531.584	6408918	2.385674	2.093006	-0.06134	0.510286	3.85E+08
35	3.742857	2532.173	6411900	2.386229	2.093376	-0.06136	0.510258	3.85E+08
40	3.4	2532.684	6414488	2.386711	2.093697	-0.06138	0.510233	3.85E+08
45	3.133333	2533.134	6416768	2.387135	2.09398	-0.0614	0.510211	3.85E+08

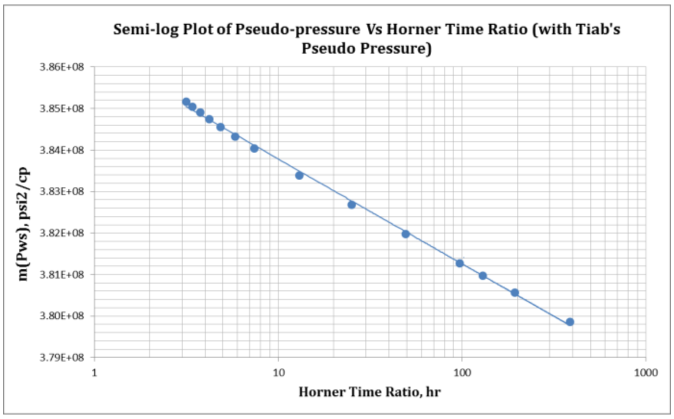

Fig. 3 Semi-log Plot of Pseudo-pressure vs. HTR (with Tiab's Pseudo Pressure)

From the above Fig. 3 we obtain the following data

Slope $m = 2.4 \times 10^6$ psi²/cp/cycle

Pressure at 1hr $m(P_{ws})_{1hr} = 381.3 \times 10^6$ psi²/cp

Using the properties given in the Table 1, reservoir permeability is estimated as:

$$k = 1637 \frac{(8400)(628)}{(2.4 \times 10^6)(86)}$$

$$k = 41.83 \text{ md}$$

Apparent skin factor can be calculated as

$$S = 1.153 \left[\frac{381.3-375}{2.4} - \log\left(\frac{41.83}{(0.13)(0.065)(2.8\times10^{-4})(0.33^2)}\right) + 3.23\right]$$

$$S = -2.71$$

Flow efficiency of the well is estimated as

$$FE = \left(1 - \frac{0.87(2.4)(-2.71)}{381.3-375}\right) \times 100$$

$$FE = 189.8\ \%$$

3.1.2 Pseudo Pressure with Conventional Method

Table 7 shows the converted values of pressures into pseudo-pressure using (Hussainy, *et al*, 1966) pseudo pressure approach.

Table 7 Time, Pressure and Pseudo-pressure for Buildup Test (With Conventional Method)

t	HTR	P_{ws}	P_{pr}	Z	μ	P/μZ	$m(P_{ws})$
0	-	2495.449	2.351622	0.480818	0.040088	129465.4	3.23E+08
0.25	385	2513.286	2.368431	0.47952	0.040364	129849.7	3.26E+08
0.5	193	2515.934	2.370926	0.479327	0.040404	129910	3.27E+08
0.75	129	2517.483	2.372386	0.479215	0.040429	129940.2	3.27E+08
1	97	2518.583	2.373422	0.479135	0.040446	129964	3.27E+08
2	49	2521.232	2.375919	0.478942	0.040486	130024.5	3.28E+08
4	25	2523.881	2.378415	0.478749	0.040528	130078.6	3.28E+08
8	13	2526.531	2.380912	0.478556	0.040568	130139.2	3.29E+08
15	7.4	2528.934	2.383177	0.478381	0.040605	130191.8	3.29E+08
20	5.8	2530.034	2.384213	0.478301	0.040622	130215.7	3.29E+08
25	4.84	2530.887	2.385017	0.478239	0.040636	130231.6	3.30E+08
30	4.2	2531.584	2.385674	0.478189	0.040647	130246.1	3.30E+08
35	3.742857	2532.173	2.386229	0.478146	0.040656	130259.2	3.30E+08
40	3.4	2532.684	2.386711	0.478109	0.040664	130270	3.30E+08
45	3.133333	2533.134	2.387135	0.478076	0.04067	130282.8	3.30E+08

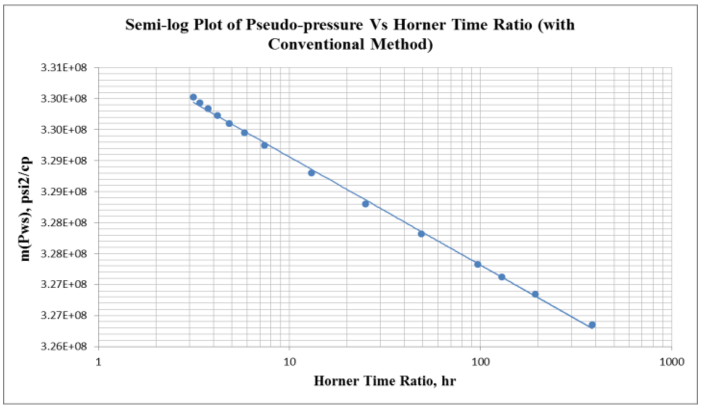

Fig. 4 Pseudo-pressure vs. HTR (conventional method)

From the above Fig. 4 we obtain the following data

Slope $m = 1.9 \times 10^6$ psi²/cp/cycle

Pressure at 1hr $m(P_{ws})_{1hr} = 327.5 \times 10^6$ psi²/cp

Using the properties given in the Table 1, reservoir permeability, skin and flow efficiency is estimated as:

$$k = 52.84 \text{ md}$$

$$S = -3.12$$

$$FE = 214.6\%$$

3.2 Pressure drawdown analysis

Table 8 Pressure Drawdown Data (Jokhio, 2001)

Timehrs	Pressure P_{si}	Time hrs	Pressure P_{si}
0	2533.3	100	2492.7
0.25	2515.6	110	2492.3
0.5	2512.9	120	2492.0
0.75	2511.4	130	2491.7
1	2510.3	140	2491.4
2	2507.6	150	2491.1
4	2505.0	160	2490.9
8	2502.3	170	2490.6
15	2499.9	180	2490.4
20	2498.8	190	2490.2
25	2498.0	200	2490.0
30	2497.3	300	2488.5
35	2496.7	400	2487.4
40	2496.2	500	2486.5
45	2495.7	600	2485.8
50	2495.3	700	2485.2
60	2494.6	800	2484.7
80	2493.5	900	2484.3
90	2493.1	1000	2483.9

3.2.1 Tiab's Pseudo Pressure Function

Table 9 shows the converted values of pseudo-pressure using the (Tiab, 1984) pseudo pressure approach.

Table 9 Time, Pressure and Pseudo-pressure for Drawdown Test (With Tiab's Method)

t	P_{wf}	P^2	P_{pr}	C_{pr}	M_r	M_t	$m(P_{wf})$
0	2533.3	6417609	2.387291	2.094084	-0.06141	0.510203	3.85E+08
0.25	2515.6	6328243	2.370611	2.082961	-0.06067	0.51106	3.80E+08
0.5	2512.9	6314666	2.368067	2.081264	-0.06056	0.511192	3.80E+08
0.75	2511.4	6307130	2.366653	2.080321	-0.06049	0.511265	3.79E+08
1	2510.3	6301606	2.365617	2.07963	-0.06045	0.511319	3.79E+08
2	2507.6	6288058	2.363072	2.077933	-0.06033	0.511451	3.78E+08
4	2505	6275025	2.360622	2.076299	-0.06022	0.511579	3.78E+08
8	2502.3	6261505	2.358078	2.074602	-0.06011	0.511712	3.77E+08
15	2499.9	6249500	2.355816	2.073094	-0.06001	0.51183	3.76E+08
20	2498.8	6244001	2.35478	2.072402	-0.05996	0.511884	3.76E+08
25	2498	6240004	2.354026	2.0719	-0.05992	0.511924	3.76E+08
30	2497.3	6236507	2.353366	2.07146	-0.05989	0.511958	3.76E+08
35	2496.7	6233511	2.352801	2.071083	-0.05987	0.511988	3.75E+08
40	2496.2	6231014	2.352329	2.070768	-0.05985	0.512013	3.75E+08
45	2495.7	6228518	2.351858	2.070454	-0.05983	0.512038	3.75E+08
50	2495.3	6226522	2.351481	2.070203	-0.05981	0.512057	3.75E+08
60	2494.6	6223029	2.350822	2.069763	-0.05978	0.512092	3.75E+08
80	2493.5	6217542	2.349785	2.069072	-0.05973	0.512147	3.75E+08
90	2493.1	6215548	2.349408	2.06882	-0.05971	0.512167	3.75E+08
100	2492.7	6213553	2.349031	2.068569	-0.0597	0.512186	3.74E+08
110	2492.3	6211559	2.348654	2.068317	-0.05968	0.512206	3.74E+08
120	2492	6210064	2.348371	2.068129	-0.05967	0.512221	3.74E+08
130	2491.7	6208569	2.348089	2.06794	-0.05965	0.512236	3.74E+08
140	2491.4	6207074	2.347806	2.067752	-0.05964	0.512251	3.74E+08
150	2491.1	6205579	2.347523	2.067563	-0.05963	0.512266	3.74E+08
160	2490.9	6204583	2.347335	2.067438	-0.05962	0.512276	3.74E+08
170	2490.6	6203088	2.347052	2.067249	-0.05961	0.512291	3.74E+08
180	2490.4	6202092	2.346864	2.067123	-0.0596	0.512301	3.74E+08
190	2490.2	6201096	2.346675	2.066998	-0.05959	0.512311	3.74E+08
200	2490	6200100	2.346487	2.066872	-0.05958	0.512321	3.74E+08
300	2488.5	6192632	2.345073	2.065929	-0.05952	0.512395	3.73E+08
400	2487.4	6187159	2.344037	2.065238	-0.05947	0.51245	3.73E+08
500	2486.5	6182682	2.343188	2.064672	-0.05943	0.512495	3.73E+08
600	2485.8	6179202	2.342529	2.064232	-0.0594	0.51253	3.73E+08
700	2485.2	6176219	2.341963	2.063855	-0.05937	0.51256	3.72E+08
800	2484.7	6173734	2.341492	2.063541	-0.05935	0.512585	3.72E+08
900	2484.3	6171746	2.341115	2.06329	-0.05934	0.512605	3.72E+08
1000	2483.9	6169759	2.340738	2.063038	-0.05932	0.512625	3.72E+08

From the below Fig. 5 we obtain the following data

$$\text{Slope } m = 2.3 \times 10^6 \text{ psi}^2/\text{cp/cycle}$$

$$\text{Pressure at 1hr } m(P_{wf})_{1hr} = 379.1 \times 10^6 \text{ psi}^2/\text{cp}$$

Using the properties given in the Table 1, reservoir permeability, skin and flow efficiency is estimated as

$$k = 43.60 \text{ md}$$

$$S = -2.80$$

$$FE = 191.8\ \%$$

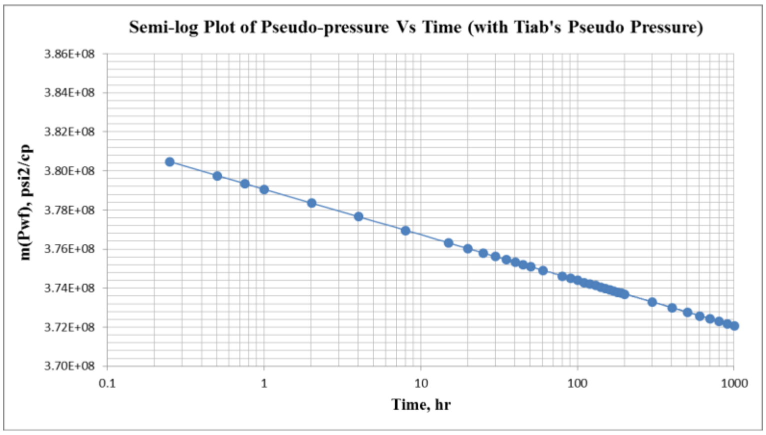

Fig. 5 Semi-log Plot of Pseudo-pressure vs. Time (with Tiab's Pseudo Pressure)

3.2.2 Pseudo Pressure with Conventional Method

Table 10 shows the converted values of pressures into pseudo-pressure using (Hussainy, *et al*, 1966) pseudo pressure approach.

Table 10 Times, Pressure and Pseudo-pressure for Drawdown Test (With Conventional Method)

t	P_{wf}	P_{pr}	Z	μ	P/μZ	$m(P_{wf})$
0	2533.3	2.387291	0.478064	0.039613	133771.3	3.39E+08
0.25	2515.6	2.370611	0.479352	0.039303	133524.7	3.36E+08
0.5	2512.9	2.368067	0.479548	0.039245	133523.8	3.36E+08
0.75	2511.4	2.366653	0.479657	0.039226	133478.4	3.35E+08
1	2510.3	2.365617	0.479737	0.039206	133465.7	3.35E+08
2	2507.6	2.363072	0.479934	0.039148	133465	3.35E+08
4	2505	2.360622	0.480123	0.039109	133407	3.34E+08
8	2502.3	2.358078	0.480319	0.039051	133406.6	3.34E+08
15	2499.9	2.355816	0.480494	0.039012	133363.4	3.33E+08
20	2498.8	2.35478	0.480574	0.038993	133347.4	3.33E+08
25	2498	2.354026	0.480632	0.038974	133353.6	3.33E+08
30	2497.3	2.353366	0.480683	0.038954	133370.5	3.33E+08
35	2496.7	2.352801	0.480727	0.038954	133326.4	3.33E+08
40	2496.2	2.352329	0.480763	0.038935	133354.6	3.33E+08
45	2495.7	2.351858	0.480799	0.038935	133317.8	3.33E+08
50	2495.3	2.351481	0.480829	0.038935	133288.4	3.33E+08
60	2494.6	2.350822	0.480879	0.038916	133301.9	3.33E+08
80	2493.5	2.349785	0.480959	0.038896	133289.5	3.32E+08
90	2493.1	2.349408	0.480989	0.038877	133325.2	3.32E+08
100	2492.7	2.349031	0.481018	0.038877	133295.7	3.32E+08
110	2492.3	2.348654	0.481047	0.038877	133266.3	3.32E+08
120	2492	2.348371	0.481069	0.038857	133312.8	3.32E+08
130	2491.7	2.348089	0.48109	0.038857	133290.7	3.32E+08
140	2491.4	2.347806	0.481112	0.038857	133268.6	3.32E+08
150	2491.1	2.347523	0.481134	0.038857	133246.5	3.32E+08
160	2490.9	2.347335	0.481149	0.038838	133296.9	3.32E+08

170	2490.6	2.347052	0.48117	0.038838	133274.8	3.32E+08
180	2490.4	2.346864	0.481185	0.038838	133260.1	3.32E+08
190	2490.2	2.346675	0.4812	0.038838	133245.4	3.32E+08
200	2490	2.346487	0.481214	0.038838	133230.6	3.32E+08
300	2488.5	2.345073	0.481323	0.038799	133254	3.32E+08
400	2487.4	2.344037	0.481403	0.03878	133238.2	3.31E+08
500	2486.5	2.343188	0.481469	0.038761	133237.2	3.31E+08
600	2485.8	2.342529	0.48152	0.038761	133185.6	3.31E+08
700	2485.2	2.341963	0.481563	0.038741	133210.1	3.31E+08
800	2484.7	2.341492	0.4816	0.038741	133173.2	3.31E+08
900	2484.3	2.341115	0.481629	0.038722	133209.1	3.31E+08
1000	2483.9	2.340738	0.481658	0.038722	133179.6	3.31E+08

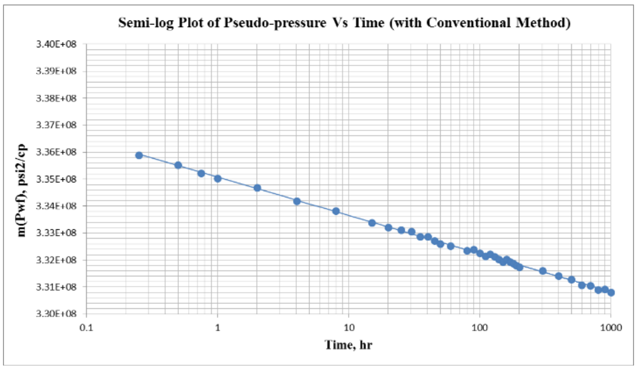

Fig. 6 Semi-log Plot of Pseudo-pressure vs. Time (with conventional method)

From the above Fig. 6 we obtain the following data

Slope $\mathrm{m} = 1.4 \times 10^6$ psi²/cp/cycle

Pressure at 1hr $\mathrm{m}(\mathrm{P_{wf}})_{1\mathrm{hr}} = 335.1 \times 10^6$ psi²/cp

Using the properties given in the Table 1, reservoir permeability, skin and flow efficiency is estimated as:

$\mathrm{k} = 71.72$ md

$\mathrm{S} = -2.79$

$\mathrm{FE} = 187.1$ %

3.3 Final results

After calculating the desired properties with both the approaches, the results are compared to find out the errors. Table 9 shows the results calculated with (Tiab, 1984) pseudo-pressure approach. And Table 10 shows the results estimated with conventional method.

Table 11 Results Estimated by employing Tiab's Pseudo-pressure Function

Parameter	Buildup	Drawdown	Errors (%)
k (md)	41.83	43.65	4.3
S	-2.71	-2.80	3.2
FE (%)	189.8	191.8	1

Table 12 Results Estimated With the Use of Pseudo-pressure Calculated through Conventional Method

Parameter	Buildup	Drawdown	Errors (%)
k (md)	52.84	71.72	35.7
S	-3.12	-2.79	10.5
FE (%)	214.6	187.1	12.8

Conclusion

In this research, pressure transient analysis of CO_2 rich gas reservoir is carried out by employing two different approaches of pseudo-pressure function. By achieving the desired results with both the approaches following conclusions are drawn from the study:

1) The results upon comparing shows less errors with Tiab's pseudo pressure approach as compared to the results estimated with conventional pseudo pressure approach.
2) The method of estimating the pseudo pressure values is simple with Tiab's pseudo pressure approach and does not requires any numerical integration while traditional tedious method requires numerical integration to evaluate pseudo pressure integral..
3) Unlike the traditional method, Tiab's pseudo pressure approach does not require any interpolation of viscosity and compressibility from the charts.

However, corrected pseudo pressure provides the only means for analyzing pressure test as long as viscosity and compressibility correction correlation for high concentration of CO_2 gases are not available. It is therefore recommended to use Tiab's pseudo pressure approach for pressure analysis of CO_2 rich reservoirs.

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