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Well Testing in Iranian Gas Reservoir: A Case Study

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Abstract

This paper investigates two gas wells production data, has considered non-Darcy effect in reservoir and the results of this event on well and reservoir parameters.
Then data analysis by software has been used to suggest models of flow and production for each well in order to characterize permeability, skin factor, reservoir boundary (in case of existence) and non-Darcy effect on skin.
Core analysis, seismic, well logging and well testing are four common ways of measuring the properties of the reservoir rock.
Due to the smallness of the core samples compared with the dimensions of the reservoir, reservoir heterogeneity and also the errors in core experimental analysisthe information obtained from the core cannot be representative of the properties of the reservoir rock.
On the other hand, the results of seismic and well logging are general and don't conclude exact results.
So, well testing can be considered as the most exact, quickest and the cheapest way of measuring the properties of the reservoir rock. Since the pressure data used in well testing, offer a general view of the reservoir and can be a desirable totality of the whole reservoir properties including permeability, wellbore storage, skin factor and non-darcy factor in the gas reservoir.
Accomplishment of the tests and analysis of the data obtained from the gas reservoir (dry gas or retrograde gas) faces special problems due to the high velocity and consequently the making of flow turbulence and non-darcy effect.

Keywords: Well test, Non darcy, Dry gas, Retrograde gas, Skin factor, Permeability,Back pressure, Flow rate, Reservoir, Boundary.

Contents

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1. Introduction

In Petroleum Engineering, in order to analysis reservoir performance and forecasting the future of production, reliable information about reservoir conditions is important. Many of these data can be determined by the pressure transient testing, drawdown test and build-up pressure test are the most important pressure transient testing in Reservoir engineering. Pressure Transient test includes measuring pressure differences in terms of time and estimating the well fluid and rock properties. All this information can be used to predict reservoir function. Performing these tests and analysis of data obtained in gas reservoir (dry gas or gas condensate) have specific problems some of which are as follows:

- High speed gas flow around wells and therefore creating a turbulent flow and non-Darcy effect in the flow and determining the value of its coefficient.
- Determining the actual amount of change caused by fluid compression.
- Determination of real rock permeability to fluid formed around the wells.

One of the tests often conducted in gas wells is back pressure test. The required procedure to perform this back pressure test consist of some specific steps:

Step1. Close the gas well sufficiently long for the formation pressure to reach the volumetric average pressure $\overline{p}_r$.

Step2.Place the well on production at a constant flow rate $Q_{g1}$for a sufficient time to allow the bottom-hole flowing pressure to stabilize at p_{wf1}which is the pseudo-steady state.

Step3.Report step 2 for several rates and stabilized bottom-hole flow pressure is recorded at each corresponding flow rate. If three or four rates are used, the test may be referred to as a three-point or four-point flow test.

In this paper the data is analyzed from two gas wells in Iran that back pressure test is performed with interpret software.

1.1. Turbulence Equations

Three formulae commonly used to address turbulence in reservoir.They are:

The Forchheimer equation:

$$\frac{dp}{dr} = \frac{\mu q}{k} + \beta \rho q^2 \qquad (1)$$

The Laminar-Inertial-Turbulent(LIT) equation:

$$\overline{p}_r^{\,2} - p_{wf}^{\,2} = aQ_g + bQ_g^2 \qquad (2)$$

The Simplified AOF equation:

$$Q_g = C(\overline{P}_r^2 - P_{wf}^2)^n \qquad (3)$$

These formulas are different expression of the same phenomenon.

1.2. The Forchheimer Equation

The Darcy law has been introduced for laminar flow (which is a flow with Re <1).

In Darcy flow the velocity is very low and flow rate is directly proportional to pressure gradient. This equation (the Darcy law)is commonly applicable to oil wells according to their low flow velocity. But in a gas reservoir,because of its high velocity, this proportionality is not applicable between flow rate and pressure gradient. Therefore we should use a nonlinear equation like Forchemier Equation to explain the relation between flow rate and pressure drop.

It is obvious from this nonlinear equation that pressure drop in a non-Darcy flow more than that in a Darcy flow. Non-Darcy effects in wellbore is produced due to velocity increase. So we can’t use apparent skin factor, S_o, but total skin factor, S:

$S=S_o+Dq$

In this equation D is non-Darcy coefficient that is depended on β coefficient .

β coefficient can be obtained from experimental methods. In gas reservoirs, it is more suitable to useForchemier equation as follow:

$$\frac{1}{K_a} = \beta\left(\frac{G}{\mu}\right) + \frac{1}{K}$$

$$\frac{1}{K_a} = \frac{M(P_o^2 - P_L^2)}{2\mu ZRTGL}$$

This equation can be used for an experimental sample and with information about the sample.Plotting $1/K_a$ vs G/μ for that, will result values of β and k.

β is a rock properties for a special type of flow can be obtained from below relationship:

$$D = 2.223\times10^{-15}\left[\frac{\gamma gkh}{\mu h^2 \rho rw}\right]\beta$$

one of empirical relationship that be used to obtained β is

$$\beta = 4.257 \times 10^{8} \phi^{-1.787} K^{0.9478}$$

1.2.1. The Laminar-Inertial-Turbulent (LIT) Equation

In equation 2 ,"a" and "b"are obtained by:

$$a = \left(\frac{1422T\mu gz}{kh}\right)\left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + S\right]$$

$$b = \left(\frac{1422T\mu gz}{kh}\right)D$$

Where a=laminar flow coefficient

b=inertial-turbulent flow coefficient

The term (aQ_g) in Equation 2 represents the pressure-squared drop due to laminar flow while the term (bQ_g^2) accounts for the pressure –squared drop due to inertial-turbulent flow effects.

Equation 2 can be linearized by dividing both side of the equation by Q_g to yield:

$$\frac{\overline{p}_r^{\,2} - p_{wf}^2}{Q_g} = a + bQ_g$$

The coefficients"a" and "b" can be determined by plotting $P_r^2 – P_{wf}^2/Q_g$ versus Q_g on a Cartesian scale and should yield a straight line of "b" slope and "a" intercept.

1.2.2. The Simplified AOF Equation

Based on the analysis for flow data obtained from a large number of gas wells, Rawlins and Schellhardt [1] postulated that the relationship between the gas flow rate and pressure can be expressed by Equation 3.

The exponent "n" is intended to account for the additional pressure drop caused by the turbulent gas flow. Depending on the flowing conditions, the exponent "n" may vary from 1.0 for completely laminar flow to 0.5 for fully turbulent flow. The performance coefficient "C" in equation 3 is included to account for :

- Reservoir rock properties
- Fluid properties
- Reservoir flow geometry

Equation 3 is commonly called the **deliverability** or **back-pressure equation.**If the coefficient of the equation (i.e., n and C) can be determined , the gas flow rate Q_g at any bottom-hole flow pressure P_{wf}can be calculated and the IPR curve constructed.

2. Well Test Data and Analysis

2.1. Well#1

In this well back-pressure test that includes four production stages (drawdown) and a closing of the well stage (build-up) is performed as follows:

Opening wells with flow rate 19564 Mscf / d until the flow pressure stabilization of wells bottom and top, and gradual increase of flow rate to 39058 Mscf / d , 55797 Mscf / d and72395 Mscf/d . Performing back- pressure test and, finally closing the well for 17.5 hours for the build-up pressure test.

Among the four above-mentioned stages, only a range of data from the final build-up pressure test can be analyzed.The model has beendescribed below.

2.2. Build-Up Pressure Analysis in Period 17.5 Hours

Model obtained is close to Radial composite model with constant pressure boundaries. Permeability rates obtained from the above analysis has been calculated 114.3 md that for this area it represents the strong reservoir properties. Figure 1 shows log-log plot model of the well behavior and the selected model, and results of the software. Figure 2 also shows production history (pressure in terms of time) for the total test that has a relatively good matching with pressure data.

Meanwhile, figure 3 shows skin vs rate graph.The slope represents non-Darcy coefficient which has been calculated as 0.0003781 D / Mscf .

2.3. Software's Output

In the case of this well, as mentioned above, the reservoir is of Radial composite type. In such reservoirsthe pressure drop around the well is causing a part of gas to condense. So two region of radial flow is performed in the reservoir each has a different viscosity and permeability:

i. radial flow related to the area near the well.
ii. radial flow related to the area far from the well.

For Interpret software, there are also two defined parameters which have been calculated for this case as follow

(pch)1/2=0.22 Storativity Ratio $\left(\frac{\phi_1 c_{t1} h_1}{\phi_2 c_{t2} h_2}\right)$

$(kh/\mu)1/2 = 0.23$ Mobility Ratio $\left(\frac{k_1 h_1/\mu_1}{k_2 h_2/\mu_2}\right)$

the results that be obtained from data analysis by software is presented in table 1

2.4. Calculation of Productivity Coefficient for well#2

Figure 4 illustrates productivity coefficient curve with LTI method and also a and b constants (table 2)

Figure 5 illustrates productivity coefficient curve with Simplified AOF equation and also C and n constants (table 3)

2.5. Well #2

In this well too, back-pressure test includes four production stages (drawdown) and a closing of the well stage (build-up) is performed as follows:

Opening wells with flow rate of 40472 Mscf / d until the stabilization of bottom and top flow pressures of the well, and gradual increase of flow rate to 57700 Mscf / d , 58916 Mscf / d and 70441 Mscf/d . Performing back-pressure test and, finally closing the well for 17.5 hours for the build-up pressure test.

The same as before, among the four above-mentioned stages, only a range of data from the final build-up pressure test can be analyzed.The model has beendescribed below.

2.6. Build-Up Pressure Analysis in Period 17.3 Hours

Model obtained is close to Radial composite and Dual porosity model with constant pressure boundaries. Permeability rates obtained from the above analysis has been calculated 24.16 md that represents the average reservoir properties of this area. Figure 6 shows log-log plot of the well behavior of the selected model, and the results of the software. Figure 7 also shows production history (pressure in terms of time) for the total test that has a relatively good matching with pressure data.

Figure 8 shows skin vs rate graph and non-Darcy coefficienthas been calculated as 9.0021 E-5 D / Mscf.

2.7. Calculation of Productivity Coefficient for Well#2

Figure 9 illustrates productivity coefficient curve with LTI method and also “a” and “b” constants (table 4)

Figure 10 illustrates productivity coefficient curve with Simplified AOF equation and also “C” and “n” constants (table 5)

2.8. Software’s Output

The results that be obtained from data analysis by software is presented in table 6.

3. Conclusion

After wells’ data analysis using appropriate software and selecting the best answer, the following results has been obtained:

i. For precise determination of each permeability parameter and the skin factor, enough time during the top well test and record of pressure data should be considered.

ii. The gas condensation due to reservoir pressure drop around the wells affects both overall permeability and the overall amount of compressibility.
Having relationships that can describe change of these two parameters along with pressure can help a lot in the correct analysis of data.

iii. wellbore storage (Cs) have a dramatic effect on changes in k, s. Therefore, its exact determination can be helpful in accurate determination of k, s.

iv. Non Darcy flow in single phase is important just in high velocity and low permeability ,in other hand second part of Forcheimer equation is comparable with first part just in upper conditions.

Forcheimer Equation:

$$\frac{dp}{dr} = \frac{\mu q}{k} + \beta \rho q^2$$

v. In addition to mechanical damage, perforation and etc…, skin effects on condensate blockage and non-Darcy flow effects.in these type of reservoirs, condensate blockage and non Darcy flow effects are very important. By the way in these reservoirs formation of liquid blockages decrease productivity in wellbore.

vi. The interpretation of well testing indicates selection of radial composite model for wells number 2&3, because of the pressure drop under dew point pressure and formation of condensate in wellbore.

4. Suggestions

According to the results of this research and the practical experience in well testing operations, following suggestions about planning for testing and better analysis of the results can be expressed briefly:

- It is recommended that for performing top well testing a longer time should be taken into consideration in order to obtain more precise information for analysis.

- Since during drilling operations the overall properties of each part of the layer including type of rock, fluid pressure, and its presence are remarkable. Knowing the drilling history helps perform moreaccure top well tests and as a result leads to better analysis of data in these experiments.
- There are different ways to deal with Condensate Blockage that can be expressed as follows:
  - creating hydraulic fracturing in (silicate reservoir) and acidizing(in carbonate reservoirs)
  - Horizontal or inclined wells to increase the level of contact in formation, although fluid around the wells will be formed, in this case the time required to reach this stage is longer.
  - Surfactant injection in order to change wettability
  - injection of dry gas and solvable can move some of the liquid gas.

Abbreviation

Ft foot
Kh Permeability Thickness
Psia Pound Square Absolute
Mscf Thousand Standard Cubic feet
mdMili Darcy

Nomenclature

Ct total compressibility,psi-1
Cg gas compressibility,psi-1
C Wellbore Storage,bbl/psi
D Non-darcycoefficient,day/mscf
d 1 distance to the boundary,ft
Ri Radius investigation,ft
R1 Distance from the well to the interface,ft
S0 Zero skin
St total skin
K Permeability,md
μ Viscosity
ρ Density

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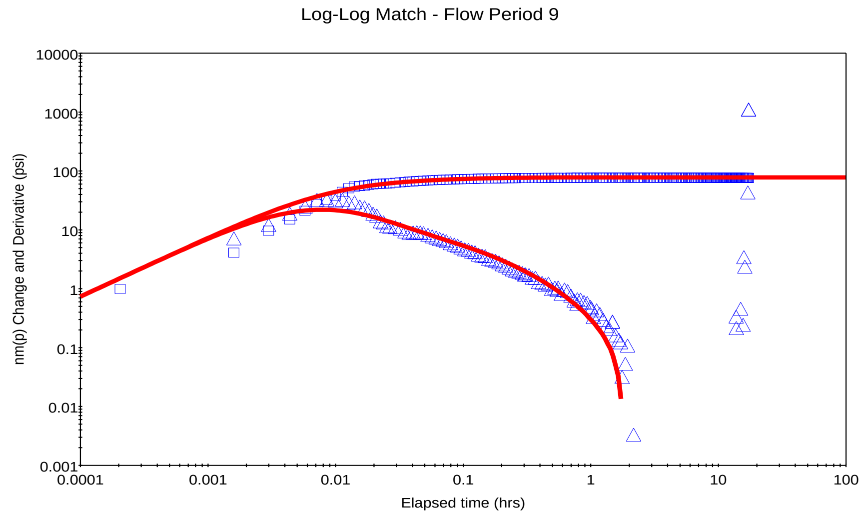

Fig-1. Log-log plot of well#1

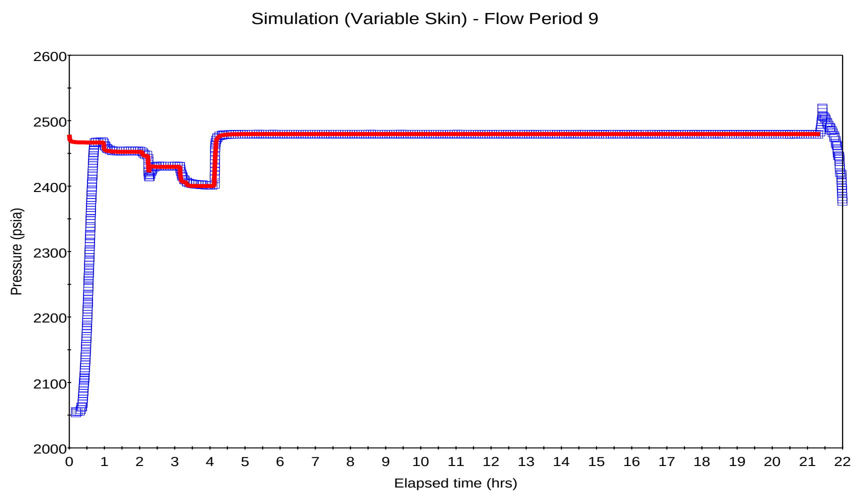

Fig-2. production history of well#1

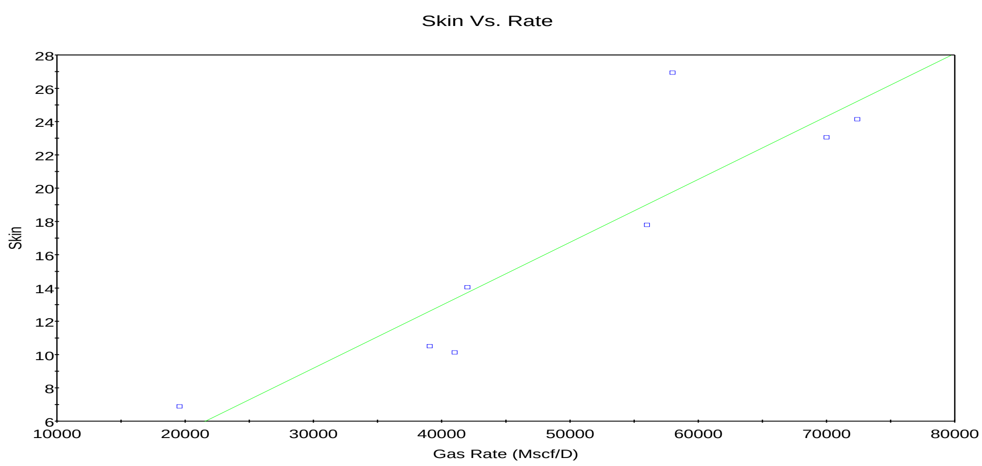

Figure-3. Skin vs rate of well#1

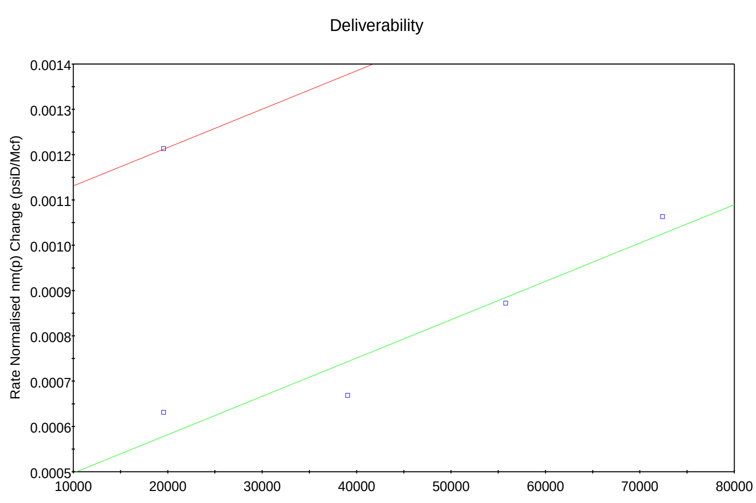

Figure-4. LIT plot of well#1

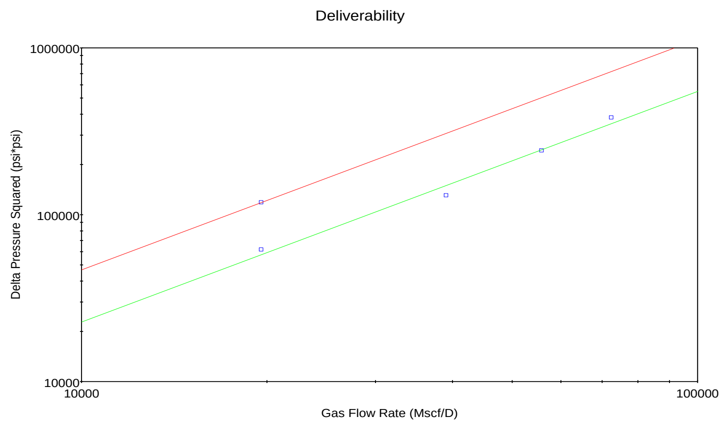

Figure-5. C and n plot of well#1

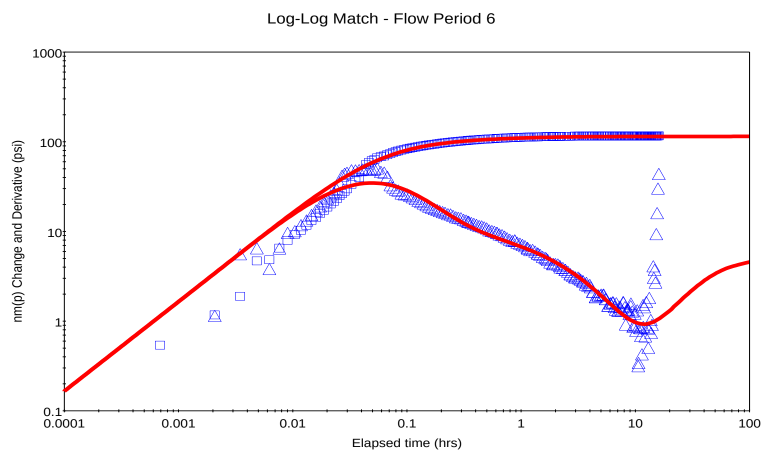

Fig-6. Log-log plot of well#2

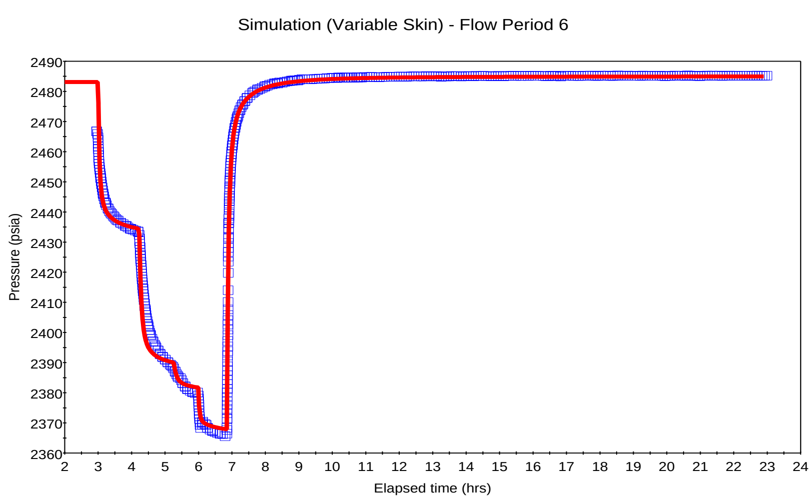

Fig-7. Production history of well#2

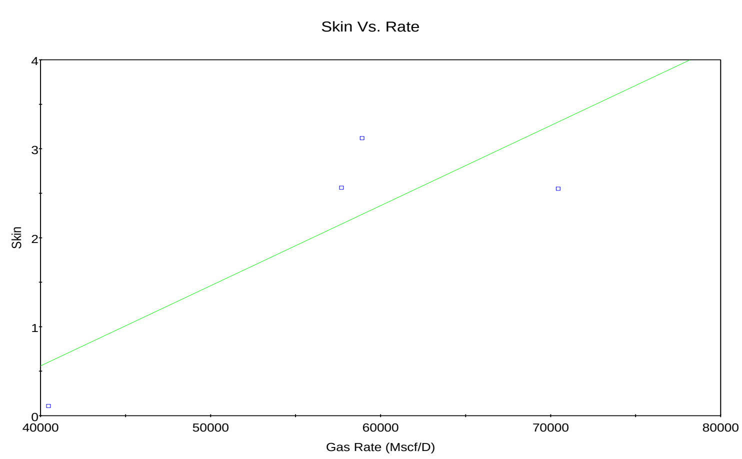

Figure-8. Skin vs rate of well#2

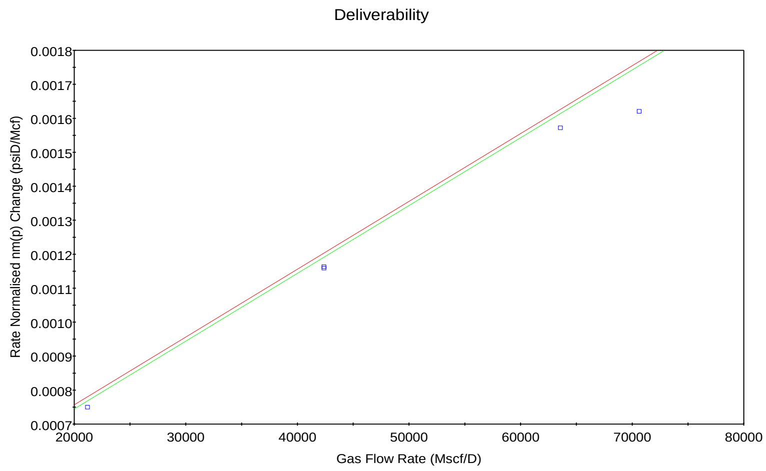

Figure-9. LIT plot of well#2

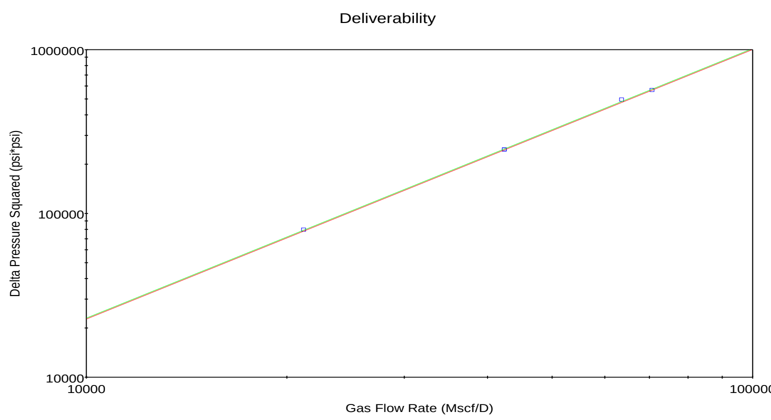

Figure-10. C and n plot of well#2

Table-1. Well test analysis result for well#1

Parameter	Interprete
Reservoir	Raddial composite
Boundaries	Constant pressure
Pi(psia)	2473.5
Kh(md.ft)	83896
K (md)	114.3
C(bbl/psi)	0.914
S(0)	-2.124
D(day/mscf)	.0003781
St	27
d 1(ft)	120
R1(ft)	149

Table-2. Result LIT method for well#1

Pr	2479.52	psia
a	0.0010474	Psi/(Mscf/D)
b	8.458E-9	Psi/(Mscf/D)**2
AOFP	3.514E+5	Mscf/D

Table-3. Result C& n method for well#1

Pr	2479.52	psia
n	0.7238	-
c	4.149	Mscf/D/Psi**2n
AOFP	3.402E+5	Mscf/D

Table-4. Result LIT method for well#2

Pr	2483.11	psia
a	.00039092	Psi/(Mscf/D)
b	1.813E-8	Psi/(Mscf/D)**2
AOFP	2.7E+5	Mscf/D

Table-5. Result C& n method for well#2

Pr	2483.11	psia
n	0.6077	-
c	22.4732	Mscf/D/Psi**2n
AOFP	3.005E+5	Mscf/D

Table-6.well test analysis result for well#2

parameter	Interprete
Reservoir	Radial composite,doual porosity
Boundaries	Constant pressure
Pi(psia)	2483.16
Kh(md.ft)	17676
K (md)	24.16
C(bbl/psi)	1.80
S(0)	-3.035
D(day/mscf)	9.0021E-5
St	2.76
R1	89
omega	0.1
Lambda	4.07E-6
Omega2	0.098
Lambda2	8.86E-7