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Productivity Index of Horizontal Gas Well

Abdullah A. Almuraikhi

**Thesis submitted to the
College of Engineering and Mineral Resources
At West Virginia University
In partial fulfillment of the requirements
for the degree of**

Master of Science

In

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Kashy Aminian, Ph.D., Chair

Sam Ameri, Prof.

Mehrdad Zamirian, Ph.D.

Department of Petroleum and Natural Gas Engineering

Morgantown, West Virginia

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ABSTRACT

Productivity Index of Horizontal Gas Well

Abdullah A. Almuraikhi

One of the most direct techniques to evaluate gas well production capacity is by productivity index (PI). As the application of horizontal wells has significantly increased since 1980s, a number of correlations for predicting the horizontal well PI have been developed by modification of the PI correlations for vertical wells. However, the predicted PI values by different correlations differ significantly. Furthermore, there are no available guidelines for proper application of the various correlations. The objective of this research is to determine the most reliable correlation for horizontal well productivity index in a gas reservoir and identify the key parameters that impact PI of horizontal gas wells.

In order to achieve the objectives, a numerical reservoir model was utilized to determine the productivity index for a horizontal well in a gas reservoir. A parametric study was then conducted to investigate the impact of different reservoir/well parameters including reservoir thickness, lateral length, horizontal permeability, and vertical permeability on PI. The productivity index determined by the simulation model was then compared against the values predicted by different correlations. The results indicate that in all cases the Renard-Dupuy anisotropic correlation will provide the closest value to the model average PI value. Moreover, Kuchuk correlation resulted in the highest value for PI, whereas Babu-Odeh correlation value resulted in the lowest value for PI in all cases.

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NOMENCLATURE

Table 1. NOMENCLATURE

J	Productivity index, SCF/psi ² /day/cp
K	Permeability, md
K_h	Horizontal permeability, md
K_v	Vertical permeability, md
K_x	Permeability in x-direction, md
K_y	Permeability in y-direction, md
K_z	Permeability in z-direction, md
K_{ave}	Average permeability, md
P_i	Initial reservoir pressure, psi
P_{wf}	Flowing bottom-hole pressure, psi
r_{eh}	Drainage radius, ft.
r_{w'}	Effective wellbore radius, ft.
μ_g	Gas viscosity, cp
T	Temperature, °F
Z	Compressibility factor
h	Formation thickness, ft.
C_H	Shape factor
L	Horizontal well length, ft.
Z_w	Standoff, or distance of well from middle of reservoir, ft.
φ	Porosity, %
A	Area, ft ²
x_o, z_o	Coordinates measuring the center of well in vertical plane
D	Depth, ft.
a	Half major axis of drainage ellipse, ft.
X	Dimensionless drainage configuration parameter
S_R	Skin effect
P_{WD}	Dimensionless pseudo steady state pressure
S_m	Van Everdingen mechanical skin
X_e	Extent of drainage area in x-direction, ft.
P_D	Dimensionless pressure
S_x	Skin effect
S_e	Eccentricity effect in vertical direction
m	Pseudo pressure, psi ² /cp

CHAPTER 1: INTRODUCTION

1.1 Horizontal Well

Horizontal well is defined as a well that has an access to hydrocarbon reserves at wide range of angles. The interest in horizontal wells initiated in 1980s. Horizontal wells are significantly more productive than vertical wells since it allows a single well to reach multiple points in the reservoir. Also, it reduces the risk of penetrating water in gas or oil exploration.

1.2 Advantages of Drilling Horizontal Wells

The advantages of drilling horizontal wells are:

1. To reduce water and gas coning (encroachment).
2. To increased contact with the formation.
3. To increase hydrocarbon production rate since it is exposed to more of the pay zone.
4. To increase production and lower risk.
5. Higher probability to encounter natural fractures which enhances overall recovery.
6. To enable drilling under populated/protected areas.
7. To lower fluid velocities around the wellbore.

1.3 Disadvantages of Drilling Horizontal Wells

The disadvantages of drilling horizontal wells are:

1. Higher drilling and completion costs.
2. Higher risk of interfering with other wells.
3. Requires more complicated drilling and completion technologies in especially in thin zones.
4. Hole collapse and cleaning issues.
5. Hole geometry while drilling.

1.4 Productivity Index

The productivity index is measure of potential and performance of the well. PI represents the ability of a reservoir to deliver the fluid to the wellbore. Therefore, the productivity index is defined as the ratio of the flow rate to the pressure drawdown at the midpoint with a unit of (bbl/psi/day) as shown below:

$$J = \frac{q}{\Delta P} = \frac{q}{(p_r - p_{wf})}$$

where,

- J = Productivity Index, bbl/psi/day
- q = flowrate at standard conditions, bbl /D
- P_r = reservoir pressure, psi
- P_{wf} = flowing wellhead pressure, psi

1.4.1 Flow Regime

During the hydrocarbon production cycle, the producing well goes through three flow periods, flow regimes based on the production time and the boundary conditions. These three periods are:

- Unsteady state flow.
- Late transient flow.
- Pseudo steady state flow (or Steady state flow).

1.4.1.1 *Unsteady state flow*

Unsteady state flow is the starting life of a well. Also, it is known as an infinite acting that the production of a well has not reached to the boundary of the reservoir. So that the reservoir boundaries have no effect on the well performance. During this period the rate of pressure respect to time depends on both the radius and the time of production as shown below:

$$\frac{dp}{dt} = f(r, t), \text{ where } r \text{ is the radius and } t \text{ is the time.}$$

1.4.1.3 *Late transient flow*

It is a state between the unsteady state and the pseudo steady state regimes. It occurs when the pressure disturbance caused by the production of a well has reached some of the reservoir boundaries.

1.4.1.4 *Pseudo steady state flow (or Steady state flow)*

Pseudo steady state is when the production of a well has reached all the reservoir boundaries. During this period the pressure drops at the same constant rate throughout the reservoir.

$$\frac{dp}{dt} = \text{constant rate}$$

Steady state flow is a special case of pseudo steady state flow when:

$$\frac{dp}{dt} = 0$$

In this flow period the production has no impact on the pressure. The reservoir pressure is sustained by either an aquifer support or a gas cap expansion.

CHAPTER 2: LITERATURE REVIEW

Productivity index represents the production capacity of a well. Productivity index is defined as the rate of production per unit pressure drawdown. The constant flow rate of a well is also simulation to evaluate the long-term productivity phenomena of the well. Horizontal wells have proven to be more productive than the vertical well. This is because the horizontal well has an increased drainage area than a vertical well. This indicates that a stimulation vertical well can function more productively than an un-stimulation one (Dankwa et al., 2011).

However, horizontal wells have certain disadvantages over the corresponding vertical wells (Babu et al., 417). For instance, the cost of constructing a horizontal well exceeds about two times the similar vertical well on a reservoir. Therefore, a close analysis should be conducted to consider the performance of horizontal well and its advantages over vertical wells in oil fields.

The first study is under partial completion where the productivity index is investigated based on completion flow rate from reduced production interval of all the system. This thus induces a pressure decrease at wellbore area under vertical wells. In order to study the completion flow rate, various factors are calculated such as pseudo skin, penetration ratios, reservoir drainage system and shape factors. It is noted that a vertical well that is partially completed, it is majorly controlled by the strength. However, vertical permeability, reservoir size, and thickness of the zone affect productivity index at a minimal rate.

The inflow performance of horizontal wells can also be hypothesized to perform calculations on its productivity index. However, when devising the formulas, various restrictions and assumptions were put in place under the geometry. Assumptions were made that the length of the well was longer than the thickness of the formation and shorter than the dimensions of the drainage area. The well is also supposed to be located in the center of the drainage area. Nevertheless, it is assumed that the cross-sectional area of the well covers the whole width dimension of the reservoir location. This is essential so as to determine the additional pressure that drops since the well is considered non-fracture.

The inflow performance of a horizontal well is deemed to be of a steady-state of flow. The steady pseudo nature of a well in horizontal position is the difference calculated between the average pressure of the reservoir and the pressure at the wellbore when it approaches a constant numerical value. This is also essential when calculating the inflow of the well to determine productivity index. When this steady-state pressure is kept constant, it enables further calculations involving drawdown pressure which is needed to flow a unit volume in the well per unit time (Goode et al., 319). The study, therefore, involves generation of applicable formulas as well as their application in both wells with a constant-pressure and those with the pressure boundaries.

Subsequent research also includes evaluating pressure-transient for the horizontal wells. The study incorporates various parameters in build-up tests as well as drawdown analysis. Vertical wells differ from horizontal wells under pressure-transient because horizontal wells show partial penetration phenomenon when they are perforated all through the well. Nevertheless, since the wellbore volume of horizontal wells has a typically increased capacity than vertical wells, it enables a greater period for the storage volume in it (Odeh et al., 1989). Calculations are also involved in calculating the down-hole pressure at the wellbore and assisting in examining the productivity index of the well. The interpretation used in the computation also faced significant challenges since there exist numerous boundaries with unknown separation distances among them (Kuchuk et al., 1974). Also, the large anisotropy ratio of the well made it difficult to formulate a final interpretation.

Another research to evaluate the productivity of inclined and horizontal wells was carried out in an anisotropic medium. This study is essential because it provides formulas that are relevant in determining how the slant and anisotropy of permeability of the well. For the purpose of determining the effect of inclining the well on pressure, a simulator is used. To design and recommend the type of well to be dug on a reservoir, various factors should be considered such as permeability of the area. For instance, a low permeable reservoir uses the horizontal well to boost the productivity index (Besson et al., 1990). The performances of the slanting well and the

corresponding horizontal well were evaluated using a geometric pseudo skin factor. Under isotropic reservoirs, drilling a horizontal well has proven to be much more advantageous than the slanting wells. On the contrary, under anisotropic reservoirs, there exists a critical point under the length of the well under which slanting has proven to be more advantageous than horizontal well (Joshi et al., 729).

Other researchers try to evaluate and formulate equations to work out the right productivity index of a horizontal well from the earlier vertical wells. Construction of such wells also depends on the permeability of the reservoir and numerical geometries (Giger et al., 1997). Various models have been generated and argued over the past decades ranging from Borisov to Babu and Odeh models. Therefore, to resolve the issue of emanating models and argumentation of such model formula calculation, obtaining a general productivity index could largely be of help.

The future of petroleum drilling depends on the design and application of well-suited wells. Horizontal wells have proven to be the most efficient drilling method due to its ability to contact a much larger reservoir area (Economides et al., 258). Nevertheless, horizontal wells drilled over the reservoir area come into contact with fractures that assist in draining efficiently. Also, horizontal wells have the ability to minimize water and gas coning behaviors for which vertical wells fail to do so. For this case, the emergence of sound horizontal drilling has been applied widely up to more than 30 wells across the world. For instance, in Colombia, about 20 wells have been constructed (Saavedra et al., 2000). However, the horizontal well faces particular challenges such as they cannot be applied in thick reservoirs, expensive to construct and an area with several petroleum zones will require drilling of numerous horizontal wells.

2.1 Pseudo Pressure

Pseudo pressure is considered to be a pseudo property of a gas since it depends on a gas viscosity and compressibility factors, which are properties of the gas. Moreover, pseudo pressure is widely used for mathematical modeling of IPR of gas wells and it gives an accurate pressure. It can be defined as:

$$P_p = \int_0^p \frac{2P}{\mu_g Z} dp$$

However, a spreadsheet program has been developed to estimate pseudo pressure by entering certain parameters such as: gas gravity, base pressure, reservoir temperature, and mole percentage to get the accurate pressure of the reservoir.

2.1 Horizontal Well Productivity Index Correlations

There are different correlations available for calculating the productivity index of horizontal gas wells. There are two general categories including Steady-state and pseudo-steady state correlations which will be presented below.

2.2.1 Steady State Correlations

There are four major steady state correlations to predict the productivity index of gas horizontal wells. These methods are:

1. Borisov's method.
2. Giger-Reiss-Jourdan method.
3. Joshi's method.
4. Rendard-Dupuy method.

2.2.1.1 *Borisov's Correlation:*

The prediction of productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

$$J = \frac{0.703 * h * Kh * \mu g * z}{T (\ln(\frac{4 reh}{L}) + (\frac{L}{h}) \ln(\frac{h}{2 \pi r_w}))}$$

2.2.1.2 Giger-Reiss-Jourdan's Correlation:

The prediction of productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

Isotropic reservoir:

$$J = \frac{0.703 * L * Kh * \mu g * z}{T ((\frac{L}{h}) \ln(X) + \ln(\frac{h}{2r_w}))}$$

An-isotropic reservoir:

$$J = \frac{0.703 * Kh * \mu g * z}{T ((\frac{1}{h}) \ln(X) + (\frac{B^2}{L}) \ln(\frac{h}{2r_w}))}$$

Where,

$$X = \frac{1 + \sqrt{1 + (\frac{L}{2 reh})^2}}{\frac{L}{(2 reh)}}$$

$$B = \sqrt{\frac{Kh}{Kv}}$$

2.2.1.3 Joshi's Correlation:

The prediction of productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

Isotropic reservoir:

$$J = \frac{0.703 * h * Kh * \mu g * z}{T (\ln(R) + (\frac{h}{L}) \ln(\frac{h}{2rw}))}$$

Anisotropic reservoir:

$$J = \frac{0.703 * h * Kh * \mu g * z}{T (\ln(R) + (\frac{B^2 h}{L}) \ln(\frac{h}{2rw}))}$$

Where,

$$B = \sqrt{\frac{Kh}{Kv}}$$

$$a = \frac{L}{2} \left(0.5 + \sqrt{0.25 + \left(\frac{2reh}{L} \right)^4} \right)^{0.5}$$

$$R = \frac{a + \sqrt{a^2 + \left(\frac{L}{2} \right)^2}}{\frac{L}{2}}$$

2.2.1.4 Renard-Dupuy's Correlation:

The prediction of productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

Isotropic reservoir:

$$J = \frac{0.703 * h * Kh * \mu_g * z}{T (\cosh^{-1} \left(\frac{2a}{L} \right) + \left(\frac{h}{L} \right) \ln \left(\frac{h}{2\pi r_w} \right))}$$

An-isotropic reservoir:

$$J = \frac{0.703 * h * Kh * \mu_g * z}{T (\cosh^{-1} \left(\frac{2a}{L} \right) + \left(\frac{Bh}{L} \right) \ln \left(\frac{h}{2\pi r'_w} \right))}$$

Where,

$$a = \frac{L}{2} \left(0.5 + \sqrt{0.25 + \left(\frac{2reh}{L} \right)^4} \right)^{0.5}$$

$$B = \sqrt{\frac{Kh}{Kv}}$$

$$r'_w = \frac{(1+B)r_w}{2B}$$

2.2.2 Pseudo Steady State Correlation:

There are four major pseudo steady state equations to measure the productivity index of horizontal gas wells. For comparison purposes, all of these horizontal models are compared to productivity index that been calculated from a simulator model (CMG). These methods are:

1. Vertical well.
2. Babu-Odeh method.
3. Kuchuk method.
4. Economides method.

2.2.2.1 Vertical well:

The prediction of the productivity index of vertical gas wells is corrected from the vertical oil wells' equation to account for the compressibility and viscosity differences between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

$$J = \frac{0.703 * k * h * \mu g * z}{T \left[\ln \frac{re}{rw} - 0.75 + s \right]}$$

2.2.2.2 Babu-Odeh's Correlation:

The objective of this method is to provide an easy way to calculate PI of a gas horizontal well. The productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

$$J = \frac{0.703 * b * \sqrt{Kx Kz} * \mu g * z}{T \left(\ln(CH * A^{\frac{1}{2}} * rw) - 0.75 + SR \right)}$$

Where: SR is a function that depends strongly on the well length L. SR = 0 when L = b (the fully penetrating case).

$$\ln(CH) = 6.28 * \left(\frac{a}{h}\right) \sqrt{\frac{Kz}{Kx}} * \left(\left(\frac{1}{3}\right) - \frac{Xo}{a} + \left(\frac{Xo}{a}\right)^2\right) - \ln\left(\sin \frac{180 zo}{h}\right) - 0.5 \ln\left(\left(\frac{a}{h}\right) \sqrt{\frac{Kz}{Kx}}\right) - 1.088$$

xo and zo are coordinates that measure the center of the well in the vertical plane, (a) is the dimension of the drainage area.

2.2.2.3 Kuchuk's Correlation:

The productivity equation suggested by Kuchuk used an approximate infinite conductivity solution. The productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

$$J = \frac{0.703 * KH * h * \mu g * z}{T (PwD + SM^*)}$$

$$K_h = \sqrt{Kx * Ky}$$

$$PwD = \frac{h}{2L} \frac{1}{\frac{1}{2}} \sqrt{\frac{Kx}{Kz}} \left(\ln \frac{8h}{\pi * r'_w} \cot\left(\frac{\pi * Zw}{2h}\right) \right) + \frac{Zw - h}{L} \frac{1}{\frac{1}{2}} \sqrt{\frac{Kx}{Kz}}$$

$$Sm = \left(\frac{2\pi * L \frac{1}{2} \sqrt{Ky * Kz}}{\mu * q} \right) * \Delta Ps$$

$$SM^* = \frac{h}{2L} \frac{1}{2} \sqrt{\frac{Kx}{Kz}} * Sm$$

Since the skin is zero, both Sm and Sm^* should be negligible.

2.2.2.4 Economides' Correlation:

Economides suggested a methodology of calculating well performance of arbitrarily oriented, single or multiple well configurations, based on evaluated analytical solutions. This approach is general, readily reproduce well-known analytical solutions, and can be used for transient, mixed, and no flow boundary conditions. However, the productivity index of horizontal gas well is corrected from the horizontal oil well equation by the compressibility and viscosity difference between oil (slightly compressible) and gas (compressible). Thus, the equation will be:

$$J = \frac{0.703 * Kave * Xe * \mu * z}{T (PD + \frac{Xe}{2\pi L} \sum S)}$$

Where,

$$PD = \frac{Xe CH}{4\pi h} + \frac{Xe}{2\pi L} Sx$$

$$Sx = \ln\left(\frac{h}{2\pi rw}\right) - \frac{h}{6L} + Se$$

$$Se = \frac{h}{L} \left(\left(\frac{2 * Zw}{h} \right) - \frac{1}{2} \left(\frac{2 * Zw}{h} \right)^2 - \frac{1}{2} \right) - \ln\left(\sin\left(\frac{\pi * Zw}{h} \right) \right)$$

CHAPTER 3: METHODOLOGY

The objective of this research is to evaluate different productivity index correlations for a gas horizontal well using different reservoir/well parameters. To achieve this goal, the following steps were considered:

1. A numerical reservoir simulator (CMG) was utilized to build a gas reservoir model with one horizontal well. The reservoir properties used in developing the simulation model are listed in Table 2.
2. After running simulator and taking the results (gas rate & reservoir pressure), the pressure can be corrected to pseudopressure (P_p). Subsequently, the productivity index was calculated.
3. The calculated PI was compared to estimate values from both steady state and pseudosteady state correlations to evaluate which correlation provides the most reliable results.
4. The PI for vertical well was calculated using pseudosteady state correlation to compare it with the horizontal PI in order to illustrate the advantage of horizontal well.

The following example illustrates the methodology in detail for the base case.

Table 2. Reservoir and Fluid (gas) Properties for the Simulation Model

Parameters	Base Case	Range
Formation thickness (h), ft.	30	10-50
Horizontal permeability(k_h), md.	0.1	0.1-0.5
Gas Viscosity (μ), cp.	0.019	0.019
Depth (d), ft.	6000	6000-7000
Length of horizontal well (L), ft.	2000	1000-2500
Wellbore radius (r_w), ft.	0.5	0.5
Vertical Permeability (k_v), md.	0.01	0.01-0.5
Temperature (T), °F.	120	120
Reservoir radius (r_e), ft.	2000	2000-4000
Skin factor (s).	0	0
Initial Reservoir pressure (P), psi.	3000	3000
Flowing bottom-hole pressure (p_{wf}), psi.	500	500
Drainage Area ($a \times b$), ft ² .	2000-4000	2000-4000
Center of the well in the vertical plane (Z_o), ft.	mid-point	mid-point
Porosity.	10	10
S_{wi} .	0.25	0.25
Rock Compressibility.	3.003 E-3	3.003 E-3

3.1 BASE CASE EXAMPLE

The simulation run results (time, flow rate, pressure...) for a constant flowing bottomhole pressure were imported to an excel sheet. Then, the reservoir pressures values were converted to pseudopressure (P_p) by using an available *Pseudo Excel Sheet*. The productivity index was then calculated for over a four-year period of production as shown in the Table 3. Subsequently, a plot was created to obtain the high, low, and the average values of PI for a horizontal gas well as shown in the Figure 1. Finally, PI values were estimated from both steady state and pseudosteady state correlations using the same reservoir parameters as those used in the simulation model and summarized in Tables 4, 5 and 6. Figure 2 compares the PI values from the simulation and various correlations.

This processes were repeated using different parameters to come up with the best correlation that matches the model.

Table 3. PI results

TIME	DATE	Gas Rate SC - Monthly	Reservoir Pressure	Pp	PI using Pp
(day)		(ft3/day)	(psi)	psi^2/cp	SCF/psi^2/day/cp
31	2/1/16	5922739.5	2954	613486473.6	0.00999
60	3/1/16	3783097.5	2927	603536343.5	0.00649
91	4/1/16	3215070	2902	594371786.2	0.00560
121	5/1/16	2834788.25	2880	586346078.7	0.00501
152	6/1/16	2566613.75	2860	579082119.7	0.00459
182	7/1/16	2370173.75	2842	572570998.6	0.00429
213	8/1/16	2215913.25	2824	566085168	0.00406
244	9/1/16	2091319.75	2807	559983092.4	0.00388
274	10/1/16	1990643.25	2792	554617969.5	0.00373
305	11/1/16	1904755.625	2776	548915026.2	0.00360
335	12/1/16	1832061.875	2761	543587272.3	0.00350
366	1/1/17	1768206.5	2747	538631198.7	0.00341
397	2/1/17	1711401.25	2733	533691164.7	0.00333
425	3/1/17	1663904	2720	529118447.5	0.00327
456	4/1/17	1619377.5	2706	524209654.8	0.00321
486	5/1/17	1578999.5	2693	519666135.7	0.00316
517	6/1/17	1541607.25	2680	515136809.1	0.00312
547	7/1/17	1507746.125	2668	510968564.5	0.00307
578	8/1/17	1476058.875	2655	506466776.2	0.00304
609	9/1/17	1446445.375	2643	502324100.2	0.00300
639	10/1/17	1419392	2631	498193802.7	0.00297
670	11/1/17	1393701.125	2619	494075952.1	0.00294
700	12/1/17	1369860.25	2608	490312248.4	0.00292
731	1/1/18	1347010.125	2596	486218445.4	0.00289
762	2/1/18	1325196.375	2584	482137288.5	0.00287
790	3/1/18	1305810.25	2574	478746033.9	0.00285
821	4/1/18	1286453.625	2563	475025898.9	0.00283
851	5/1/18	1267946.625	2552	471316547.6	0.00281
882	6/1/18	1249899.375	2541	467618032.4	0.00280
912	7/1/18	1232810.625	2531	464265193.2	0.00278
943	8/1/18	1216095	2520	460587510.6	0.00276
974	9/1/18	1199859.625	2509	456920816.3	0.00275
1004	10/1/18	1184512	2499	453597037.1	0.00273
1035	11/1/18	1169424.5	2489	450282421.5	0.00272
1065	12/1/18	1155029.375	2479	446977008.6	0.00271
1096	1/1/19	1140843.375	2468	443351730.2	0.00270
1127	2/1/19	1126953.25	2458	440065770.3	0.00269
1155	3/1/19	1114331.375	2449	437116377.1	0.00267
1186	4/1/19	1101456.5	2439	433848165.7	0.00266
1216	5/1/19	1088921.625	2430	430914809.4	0.00265
1247	6/1/19	1076471.75	2420	427664487	0.00264
1277	7/1/19	1064516.25	2411	424747294	0.00263
1308	8/1/19	1052622.5	2401	421515000.9	0.00262
1339	9/1/19	1040945.563	2392	418614097.2	0.00261

Figure 1. Productivity Index vs. Time

Table 4. PI for all correlations compared with simulator high value

Best Correlation with Sim high value		
Correlation	Lateral Length, ft.	PI, SCF/psi ² /day/cp
Sim using Pp :High Value	2000	0.00360
Borisov	2000	0.00304
Renard-Dupuy Isotropic	2000	0.00300
Joshi Isotropic	2000	0.00299
Renard-Dupuy An-Isotropic	2000	0.00281
Giger-Reiss-Jourdan Isotropic	2000	0.00280
Joshi An-Isotropic	2000	0.00217
Giger-Reiss-Jourdan An-Isotropic	2000	0.00207
Babu-Odeh	2000	0.00181
Economides	2000	0.01136
Kuchuk	2000	0.01420

Table 5. PI for all correlations compared with simulator low value

Best Correlation with Sim Low value		
Correlation	Lateral Length, ft.	PI, SCF/psi ² /day/cp
Sim using Pp :Low Value	2000	0.00261
Giger-Reiss-Jourdan Isotropic	2000	0.00280
Renard-Dupuy An-Isotropic	2000	0.00281
Joshi Isotropic	2000	0.00299
Renard-Dupuy Isotropic	2000	0.00300
Borisov	2000	0.00304
Joshi An-Isotropic	2000	0.00217
Giger-Reiss-Jourdan An-Isotropic	2000	0.00207
Babu-Odeh	2000	0.00181
Kuchuk	2000	0.01420
Economides	2000	0.01136

Table 6. PI for all correlations compared with simulator average value

Best Correlation with Sim Avg. value		
Correlation	Lateral Length, ft.	PI, SCF/psi ² /day/cp
Sim using Pp :Avg. Value	2000	0.003105
Borisov	2000	0.003045
Renard-Dupuy Isotropic	2000	0.002999
Joshi Isotropic	2000	0.002990
Renard-Dupuy An-Isotropic	2000	0.002807
Giger-Reiss-Jourdan Isotropic	2000	0.002802
Joshi An-Isotropic	2000	0.002170
Giger-Reiss-Jourdan An-Isotropic	2000	0.002070
Babu-Odeh	2000	0.001813
Economides	2000	0.011356
Kuchuk	2000	0.014196

Figure 2. showing all values for PI including CMG

3.2 Comparison between PI of vertical and horizontal well:

The PI value of the vertical well is illustrated in Table 7 (5.22071E-06), which is significantly lower than the PI average value calculated from the model as shown in table 6 (3.105E-03). This comparison was performed to indicate that the PI value for horizontal well is much higher than the vertical.

Table 7. PI for gas vertical well

Vertical well	
Base Ccase	
Parameters	PI, SCF/psi ² /day/cp
h, ft.	30
K _h , md	0.1
z factor	0.8284
Temperature, F	120
specific Gravity	0.6
Viscosity, cp	0.01925
R _e , ft.	1595.8
R _w , ft.	0.5
S	0
J	5.22071E-06

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Results

After conducting multiple simulation runs for different reservoir scenarios (Horizontal permeability, Vertical permeability, reservoir thickness and lateral length), the productivity index values were calculated after converting the reservoir pressure to a pseudopressure over a four-year period of production. Then, a productivity index plots were generated to obtain the high, low and average values from the stabilized zone as shown in Figure 1. Moreover, the PI values from both the steady state and pseudosteady state correlations were calculated using the same reservoir parameters as those used in the simulation model, and were compared with the average PI values that were obtained from the simulator. Finally, the correlation values were arranged per the nearest value of the simulator.

4.1.1 PI values with different Horizontal Permeability

Table-8 displays the PI results for different horizontal permeability using base case parameters.

Table 8. PI for different Horizontal Permeability Values

Correlation	PI, SCF/psi ² /day/cp				
	K _h = 0.1 md	K _h = 0.2 md	K _h = 0.3 md	K _h = 0.4 md	K _h = 0.5 md
Model Average Value	0.003105	0.00691	0.01036	0.013815	0.017265
Borisov	0.003045	0.006089	0.009134	0.012178	0.015223
Renard-Dupuy Isotropic	0.002999	0.005997	0.008996	0.011994	0.014993
Joshi Isotropic	0.002990	0.005979	0.008969	0.011959	0.014948
Renard-Dupuy An-Isotropic	0.002807	0.005615	0.008422	0.011229	0.014036
Giger-Reiss-Jourdan Isotropic	0.002802	0.005604	0.008406	0.011208	0.014010
Joshi An-Isotropic	0.002170	0.004341	0.006511	0.008681	0.010852
Giger-Reiss-Jourdan An-Isotropic	0.002070	0.004139	0.006209	0.008279	0.010348
Babu-Odeh	0.001813	0.003627	0.005440	0.007254	0.009067
Economides	0.011356	0.022713	0.034069	0.045425	0.056781
Kuchuk	0.014196	0.028392	0.042588	0.056784	0.070980

4.1.2 PI values with different Vertical Permeability

Table-9 displays the PI results for different vertical permeability using base case parameters.

Table 9. PI for different Vertical Permeability values

Correlation	PI, SCF/psi ² /day/cp		
	K _v = 0.01 md	K _v = 0.02 md	K _v = 0.033 md
Model Average Value	0.003105	0.00327	0.0033
Renard-Dupuy Isotropic	0.002999	0.002999	0.002999
Joshi Isotropic	0.002990	0.002990	0.002990
Renard-Dupuy An-Isotropic	0.002807	0.002885	0.002929
Giger-Reiss-Jourdan Isotropic	0.002802	0.002802	0.002802
Joshi An-Isotropic	0.002170	0.002560	0.002755
Giger-Reiss-Jourdan An-Isotropic	0.002070	0.002421	0.002598
Babu-Odeh	0.001813	0.001866	0.001894
Kuchuk	0.014196	0.020353	0.011163
Economides	0.016154	0.020382	0.026565

4.1.3 PI values with different Reservoir Thickness

Table-10 displays the PI results for different reservoir thickness using base case parameters.

Table 10. PI for different Reservoir Thickness values

Correlation	PI, SCF/psi ² /day/cp		
	h = 30 ft	h = 10 ft	h = 50 ft
Model Average Value	0.003105	0.00117	0.0045
Borisov	0.003045	0.001039	0.004507
Renard-Dupuy Isotropic	0.002999	0.001031	0.004261
Joshi Isotropic	0.002990	0.001030	0.004798
Renard-Dupuy An-Isotropic	0.002807	0.001017	0.004821
Giger-Reiss-Jourdan Isotropic	0.002802	0.000963	0.004928
Joshi An-Isotropic	0.002170	0.000947	0.003371
Giger-Reiss-Jourdan An-Isotropic	0.002070	0.000890	0.002828
Babu-Odeh	0.001813	0.000522	0.002724
Economides	0.011356	0.003903	0.011356
Kuchuk	0.014196	0.009248	0.014196

4.1.4 PI values with different Lateral Length

Table-11 displays the PI results for different lateral lengths using base case parameters.

Table 11. PI for different Lateral Length values

Correlation	PI, SCF/psi ² /day/cp			
	L = 1000 ft	L = 1500 ft	L = 2000 ft	L = 2500 ft
Model Average Value	0.00173	0.00242	0.003105	0.00409
Borisov	0.00172	0.00243	0.003045	0.00377
Renard-Dupuy Isotropic	0.00184	0.00240	0.002999	0.00369
Joshi Isotropic	0.00186	0.00240	0.002990	0.00367
Giger-Reiss-Jourdan Isotropic	0.00187	0.00232	0.002807	0.00345
Renard-Dupuy An-Isotropic	0.00189	0.00224	0.002802	0.00329
Joshi An-Isotropic	0.00127	0.00171	0.002170	0.00268
Giger-Reiss-Jourdan An-Isotropic	0.00125	0.00167	0.002070	0.00247
Babu-Odeh	0.00122	0.00149	0.001813	0.00219
Economides	0.00638	0.00820	0.011356	0.01449
Kuchuk	0.00716	0.01068	0.014196	0.01771

4.2 Discussion

Initially, correlations for isotropic reservoirs were included in calculation of the PI for both steady state and pseudo steady state, to investigate if there was any significant differences between the outcomes of the isotropic and anisotropic correlations as shown on the result section. Since the reservoir model was built based on an anisotropic reservoir, the isotropic correlations were excluded to have more accurate comparison. Furthermore, the best correlation will be determined after evaluating the different scenarios which include different horizontal permeability, vertical permeability, reservoir thickness and lateral lengths.

4.2.1 Horizontal Permeability

PI values obtained from different correlations using horizontal permeability range from 0.1 to 0.5 md, along with the average PI values obtained from the model. Figure-3 & 4 demonstrates the model average PI value and the PI values from the other correlations using a horizontal permeability of 0.1 md. The model average PI value was 0.003105, and it is clear that Renard-Dupuy Anisotropic correlation PI is the closest value to the model average PI value. Figure-5 shows a comparison between PI values from the different Anisotropic correlations and model average value, using horizontal permeability values from 0.1 to 0.5 md. Renard-Dupuy correlation PI value remained to be the nearest value to the model average PI value.

Figure 3. PI for anisotropic method with $K_h = 0.1$ mD values

Figure-4 demonstrate better comparison of the PI values after taking off Economides and Kuchuk correlations that shows high values comparing with other correlations.

Figure 4. PI for anisotropic method with $K_h = 0.1$ mD values

Figure 5. PI for different anisotropic method with K_h values

4.2.2 Vertical Permeability

PI values obtained from different correlations using vertical permeability range from 0.01 to 0.033 md, along with the average PI values obtained from the model. Figure-6 & 7 demonstrates the model average PI value and the PI values from the other correlations using a vertical permeability of 0.01 md. The model average PI value was 0.003105, and it is clear that Renard-Dupuy Anisotropic correlation PI is the closest value to the model average PI value. Figure-8 shows a comparison between PI values from the different An-isotropic correlations and model average value, using vertical permeability values from 0.01 to 0.033 md. Renard-Dupuy correlation PI value remained to be the nearest value to the model average PI value.

Figure 6. PI values for anisotropic method with $K_v = 0.1$ mD

Figure-7 demonstrate better comparison of the PI values after taking off Economides and Kuchuk correlations that shows high values comparing with other correlations.

Figure 7. PI values for anisotropic method with $K_v = 0.1$ mD

Figure 8. PI for anisotropic method with different K_v values

4.2.3 Reservoir Thickness

PI values obtained from different correlations using reservoir thickness range from 10 to 50 ft., along with the average PI values obtained from the model. Figure-9 & 10 demonstrates the model average PI value and the PI values from the other correlations using a reservoir thickness of 10 ft. The model average PI value was 0.00117, and It's clear that Renard-Dupuy An-isotropic correlation PI is the closest value to the model average PI value. Figure-11 shows a comparison between PI values from the different An-isotropic correlations and model average value, using reservoir thickness values from 10 to 50 ft. Renard-Dupuy correlation PI value remained to be the nearest value to the model average PI value.

Figure 9. PI for anisotropic method with $h = 10$ ft. values

Figure-10 demonstrate better comparison of the PI values after taking off Economides and Kuchuk correlations that shows high values comparing with other correlations.

Figure 10. PI for anisotropic method with $h = 10$ ft. values

Figure 11. PI for different anisotropic method with Thickness values

4.2.4 Lateral Length

PI values obtained from different correlations using lateral length range from 1000 to 2500 ft., along with the average PI values obtained from the model. Figure-12 & 13 demonstrates the model average PI value and the PI values from the other correlations using a lateral length of 1000 ft. The model average PI value was 0.00173, and It's clear that Renard-Dupuy An-isotropic correlation PI is the closest value to the model average PI value. Figure-14 shows a comparison between PI values from the different An-isotropic correlations and model average value, using lateral length values from 1000 to 2500 ft. Renard-Dupuy correlation PI value remained to be the nearest value to the model average PI value.

Figure 12. PI for anisotropic method with Lateral length 1000 ft. values

Figure-13 demonstrate better comparison of the PI values after taking off Economides and Kuchuk correlations that shows high values comparing with other correlations.

Figure 13. PI for anisotropic method with Lateral length 1000 ft. values

Figure 14. PI for different anisotropic method with Lateral Length values

CHAPTER 5: CONCLUSION

The main purpose of this research is to evaluate and compare the productivity index of a horizontal well in a gas reservoir using a reservoir model and different steady state and pseudo-steady state correlations. To achieve this objective, a numerical reservoir simulator (CMG) was used to construct the reservoir model and determine PI for a number cases (different values of horizontal permeability, vertical permeability, reservoir thickness, and lateral length). Later, the average model PI value was compared with the predicted values by the various correlations. The following conclusions were reached upon completion of this study:

1. Renard-Dupuy's anisotropic correlation consistently provided the closest agreement with the model average PI value in all cases investigated.
2. Kuchuk correlation resulted in the highest calculated value for PI.
3. Babu-Odeh correlation resulted in the lowest calculated value for PI.

Future work may include evaluation of the PI for a hydraulically fractured horizontal gas well with using the reservoir model and to attempt developing a correlation for PI.

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APPENDIX

1. CMG Model

CMG (computer Modeling Group) is one of the largest providers of reservoir simulation software in the world which was originated in 1978. In this research, CMG-IMEX model was used to evaluate the correlation for horizontal well productivity index in a gas reservoir. The model started by clicking on the Builder icon on the CMG technologies launcher as shown in Figure-3.

Figure 15. CMG launcher

The user selects IMEX simulator, Field units, Single porosity, and simulation start date as shown in Figure-4.

Figure 16. Reservoir simulation setting

The user is able to view the CMG BUILDER by clicking “OK” as shown in Figure-5.

Figure 17. CMG Builder

The user clicks on the “Reservoir” tab in the model tree view and selects “Create grid” and then “Cartesian”. The user inputs the number of grid blocks in the I-direction, J- direction, and K-direction as shown in Figure-6.

Create Cartesian Grid

Grid Type
☒ Cartesian
☐ Corner point (orthogonal)

K Direction
☐ Up
☒ Down

Number of Grid Blocks
 I direction: 100
 J direction: 50
 K direction: 3

Block widths
 I direction: 100*40
 J direction: 50*40

Controlling Grid spacing
☒ Snap spacing

Snap grid lines as multiples of:
 I direction: 1
 J direction: 1

OK Cancel

Figure 18. CMG Builder

The user selects the “Specify Property” tab and input the values including grid top, grid thickness, porosity, matrix permeability (I, J, and K-directions). “General Property Specification” screen is shown in Figure-7.

General Property Specification

Edit Specification

Only for Start Time, Go to: Permeability K

Use Regions / Sectors

	Grid Top	Grid Thickness	Porosity	Permeability I	Permeability J	Permeability K
UNITS:	ft	ft		md	md	md
SPECIFIED:	X	X	X	X	X	X
HAS VALUES:						
Whole Grid			0.1	0.1	0.1	0.01
Layer 1	5980	10				
Layer 2		10				
Layer 3		10				

Figure 19. General Property Specification

The user double clicks on “Rock compressibility” from the reservoir section and inputs the reference pressure for (CPOR) & (PRPOR) as shown in Figure-8

The dialog box titled "Rock Compressibility" contains two input fields. The first field is labeled "Pressure dependence of formation porosity / Rock Compressibility (CPOR)" and contains the value "3.003E-04 1/psi". The second field is labeled "Reference pressure for calculating the effect of rock compressibility (PRPOR)" and contains the value "14.6923 psi". At the bottom right, there are "OK" and "Cancel" buttons.

Figure 20. Rock compressibility

The user double clicks on “Imwx PVT Regions” from initial condition section and inputs reservoir pressure, and gas gravity as shown in Figure-9.

The "Imex PVT Regions" dialog box shows a table of PVT properties for "PVT Region 1". The table has columns for #, Description, Option, Default, and Value. The "General" tab is selected, and the "Tools" button is active. The table lists various properties including Reservoir temperature, Densities, Undersaturated Co, Vo pressure dependence, Water properties, Formation Volume Factor, Compressibility, Reference pressure for FVF, Viscosity, and Pressure dependence of viscosity. The "Value" column shows the user-defined values for each property.

#	Description	Option	Default	Value
1	Reservoir temperature (TRES)			120 F
2	DENSITIES			
3	Oil density (DENSITY OIL)	Stock tank oil density		
4	Gas density/gravity (DENSIT...)	Gas gravity (Air=1)		0.6
5	Water phase density (DENSIT...)			62.1797 lb/ft3
6	Undersaturated Co (CO)			
7	Vo pressure dependence (CVO)		0 cp/psi	
8	Water properties			
9	Formation Volume Factor (BWI)			1.01056
10	Compressibility (CW)			3.15633e-006 1/psi
11	Reference pressure for FVF (...)			14.696 psi
12	Viscosity (VWI)		1 cp	0.62582 cp
13	Pressure dependence of visc...		0 cp/psi	0.0 cp/psi

Comments for DENSITY WATER

Figure 21. Imwx PVT Regions

The user clicks on the “Rock types” tab in the model tree view and relative permeability table. Then the user selects include capillary pressure as shown in Figure-10.

Rock Type: 1

Rocktype Properties | Relative Permeability Tables | Hysteresis Modelling

Liquid-Gas Kr Table dependency: ☐ Liquid Saturation ☒ Gas Saturation

Relative Permeability Table: Water-Oil Table

Tools ▶

Smoothing method for table end-points: Power law or quadratic smoothing

☒ Include capillary pressure (drainage curve if using hysteresis)

☐ Include capillary pressure hysteresis (imbibition curve)

☐ Include water gas relative permeability in table

☐ Include irreducible oil saturation due to water blocking in table

☒ Specified threshold value for end-point determination: 5e-007

☒ Use new option for rel. perm. table end point scaling (8 end points vs. 4)

☐ Measured liquid saturation does not include connate water saturation

	Sw	krw	Pcgw	Comment
			psi	
1	0.250000	0.00000	1.00000	
2	0.263735	0.00000	0.986924	
3	0.277759	0.00000	0.973501	
4	0.291783	0.00000	0.960002	
5	0.305807	0.00000	0.946426	
6	0.319831	0.00000	0.932770	
7	0.333855	0.00000	0.919034	
8	0.347880	0.00000	0.905214	
9	0.361904	0.00000	0.891308	
10	0.375928	0.00000	0.877314	
11	0.389952	0.00000	0.863229	
12	0.403976	0.00000	0.849050	
13	0.418000	0.00000	0.834775	
14	0.425012	3.008978E-04	0.827601	
15	0.439036	1.930937E-03	0.813175	
16	0.453060	4.583149E-03	0.798646	
17	0.467084	8.098993E-03	0.784009	
18	0.481108	1.239131E-02	0.769260	
19	0.495133	1.740148E-02	0.754397	
20	0.509157	2.308612E-02	0.739414	
21	0.523181	2.941122E-02	0.724307	

☐ Reduce vertical extent of Pcow cycle for trapped oil hysteresis (DAMP-PCOW-TROIL)

OK Cancel Apply Help

Figure 22. Rock type

Figure 23. K_r Vs. S_g

Figure 24. K_r Vs. S_w

The user clicks on the “Initial Condition” tab in the model tree view and picks Initialization Setting then the user selects “water gas” from the “Calculation Method” tab as shown in Figure-13.

Figure 25. Initial condition

Then the user goes to “PVT Region Parameters” tab and enters the reference pressure, reference depth, and water gas contact as shown in Figure-14.

The screenshot shows the 'Initial Conditions' dialog box with the 'PVT Region Parameters' tab selected. The 'Input Format For: "Bubble Point Pressure"' section has two radio buttons: 'Use Property Array. (PB)' and 'Use Depth Dependant Table For Each Region. (PBT)'. The 'Initialization For PVT Region #' is set to 'Region 1'. A message states 'PVT Type 1 is not defined. Grid depth range: 5980 to 6010 ft'. The 'Reference Pressure and Depth' section shows 'Pressure (REFPRES): 3000 psi' and 'Depth (REFDEPTH): 6000 ft'. The 'Phase Contact Depths' section shows 'Water-Oil Contact (DWOC):', 'Gas-Oil Contact (DGOC):', and 'Water-Gas Contact (DWGC): 7000 ft'. The 'Capillary Pressure at Phase Contacts' section shows 'Water-Oil Contact. (WOC_PC):' and 'Gas-Oil Contact. (GOC_PC):'. The 'Override Water Saturation Defaults' section shows 'Above gas-oil contact. (GOC_SW):' and 'Below water-oil contact. (WOC_SW):'. The 'Datum Depth for Pressure' section has a checked box for 'Datum Depth for Output Pressure. (DATUMDEPTH) - Note: This item is optional.' and three radio buttons for density calculation: 'Use an input reference density to calculate corrected datum pressures. (REFDENSITY Density)', 'Use the grid block density to calculate corrected datum pressures. (REFDENSITY GRIDBLOCK)', and 'Use Initial Equilibrium pressure distribution to calculate corrected datum pressures. (INITIAL)'. The 'Depth:' and 'Density:' fields are empty. The 'Bubble Point Pressure vs Depth' Table (PBT) is a large empty table. The bottom of the dialog has 'OK', 'Cancel', 'Apply', and 'Help' buttons.

Initial Conditions

Calculation Methods PVT Region Parameters Advanced Parameters

Input Format For: "Bubble Point Pressure"

☐ Use Property Array. (PB)

☐ Use Depth Dependant Table For Each Region. (PBT)

Initialization For PVT Region #: Region 1 Copy data from region ...

PVT Region Initialization Parameters: ———

PVT Type 1 is not defined. Grid depth range: 5980 to 6010 ft

Reference Pressure and Depth:

Pressure (REFPRES): 3000 psi

Depth (REFDEPTH): 6000 ft

Phase Contact Depths:

Water-Oil Contact (DWOC):

Gas-Oil Contact (DGOC):

Water-Gas Contact (DWGC): 7000 ft

Capillary Pressure at Phase Contacts:

Water-Oil Contact. (WOC_PC):

Gas-Oil Contact. (GOC_PC):

Override Water Saturation Defaults:

Above gas-oil contact. (GOC_SW):

(Default GOC_SW = Rel. Permeability table or SWCON card.)

Below water-oil contact. (WOC_SW):

Datum Depth for Pressure:

☒ Datum Depth for Output Pressure. (DATUMDEPTH) - Note: This item is optional.

☐ Use an input reference density to calculate corrected datum pressures. (REFDENSITY Density)

☐ Use the grid block density to calculate corrected datum pressures. (REFDENSITY GRIDBLOCK)

☒ Use Initial Equilibrium pressure distribution to calculate corrected datum pressures. (INITIAL)

Depth:

Density:

"Bubble Point Pressure vs Depth" Table (PBT):

OK Cancel Apply Help

Figure 26. Initial condition

The user clicks on the “Wells & Recurrent” tab in the model tree view and creates new well by right clicking on Wells and select New. This will allow the user to create a new well and the user gives a name “Horizontal” and selects type as “Producer” in Figure-15.

Figure 27. Well events

The user clicks on “Constraints” tab and checks the box for Constraint definition. In addition, the user selects new (in the Constraint column of the table), selects OPERATE. Then the user selects BHP bottomhole pressure, MIN, to any pressure as shown in Figure-16.

Figure 28. Well events

The user double clicks on “PERF” and selects the general tab and fills out the information including direction, and radius of the wellbore as shown in Figure-17.

The screenshot shows the 'Well Completion Data (PERF)' dialog box with the 'General' tab selected. The 'Well & Date' section shows 'PRODUCER' and '2016-01-01'. The 'General' tab contains the following fields:

Well index type	
Calculating well index method	GEOA calculated from geometry, ani...
Geometry:	
direction	K axis
radius (ft)	0.5
geofac	N/A (computed)
wfrac	1
skin	0
Use D for turbulent skin factor	☐ TURB
Use quadratic gas inflow	☐ QUAD
Use pseudo-pressure gas inflow	☐ PSEUDOP
Use layer IJK directions or XYZ geometric data	LAYERXYZ apply only with GEO an...

Buttons at the bottom: Reset Well, OK, Cancel, Apply, Help.

Figure 29. Well completion data

The user selects the perforation tab and to add perforation with the mouse, the user presses button and picks the blocks for perforations as shown in Figure-18.

The screenshot shows the 'Well Completion Data (PERF)' dialog box with the 'Perforations' tab selected. The 'Well & Date' section shows 'PRODUCER' and '2016-01-01'. The 'Perforations' tab contains the following fields:

Perforated grid blocks: ☐ Use trajectory perf intervals...

#	User Block Address	Connect to	Form factor FF	Status	Ref. Layer	WI (md*ft)	Length (ft)	Block Top (ft)
1	25 25 1	Surface	1	Open	○	2.714	20.0	5980.0
2	26 25 1	1	1	Open	○	5.428	40.0	5980.0
3	27 25 1	2	1	Open	○	5.428	40.0	5980.0
4	28 25 1	3	1	Open	○	5.428	40.0	5980.0
5	29 25 1	4	1	Open	○	5.428	40.0	5980.0
6	30 25 1	5	1	Open	○	5.428	40.0	5980.0
7	31 25 1	6	1	Open	○	5.428	40.0	5980.0
8	32 25 1	7	1	Open	○	5.428	40.0	5980.0
9	33 25 1	8	1	Open	○	5.428	40.0	5980.0
10	34 25 1	9	1	Open	○	5.428	40.0	5980.0
11	35 25 1	10	1	Open	○	5.428	40.0	5980.0
12	36 25 1	11	1	Open	○	5.428	40.0	5980.0
13	37 25 1	12	1	Open	○	5.428	40.0	5980.0
14	38 25 1	13	1	Open	○	5.428	40.0	5980.0
15	39 25 1	14	1	Open	○	5.428	40.0	5980.0

Buttons at the bottom: Reset Well, OK, Cancel, Apply, Help.

Figure 30. Well completion data

This is the top view of the reservoir with everything completed as shown in Figure-19.

Figure 31. Top view