On the One-Point Model for the Productivity Evaluation in Jingbian Sector of Yan'an Gas Field

Liu Er-hu[1], Liu Yang-yang[1], Gao Li-jun[1], Zhou De-sheng[2]*, Liu Xiong[2] and Xu Jin-ze[3]

[1]Gas Production Plant 2 of Yanchang Gasfield, Shanxi Yanchang Petroleum(Group)Co., Ltd., Jingbian, China, [2]School of Petroleum Engineering, Xi'an Shiyou University, Xi'an, China, [3]Department of Chemical and Petroleum Engineering, University of Calgary, Calgary, AB, Canada

The productivity equation of a gas well is, in the final analysis, an expression that describes the relationship between the production of a gas well and its bottom-hole flowing pressure. There are two kinds of productivity equations in common use at present: binomial productivity equation and exponential productivity equation. Combined with the modified isochronal well test, the test data are interpreted, and it is found that the open flow rates calculated by the two productivity equations are basically the same when the pressure difference at the test point is large, and the deviation of the exponential productivity equation is large when the pressure difference at the test point is small. Using binomial productivity equation and modifying isochronous well test, we established the single-point deliverability formula for the Jingbian sector of the Yan'an gas field. The field experience formula and production data are used to verify it. Their average errors are 2.59% and 7.12%, respectively; and the coincidence rate of productivity evaluation is 90%. The one-point productivity formula established has high precision and is suitable for productivity analysis of gas wells in paleozoic reservoirs in the Jingbian sector of the Yan'an gas field. This paper provides insights into the one-point productivity evaluation and its future application in the gas field.

Keywords: productivity equation, gas field, modified isochronal test, one-point deliverability formula, open flow
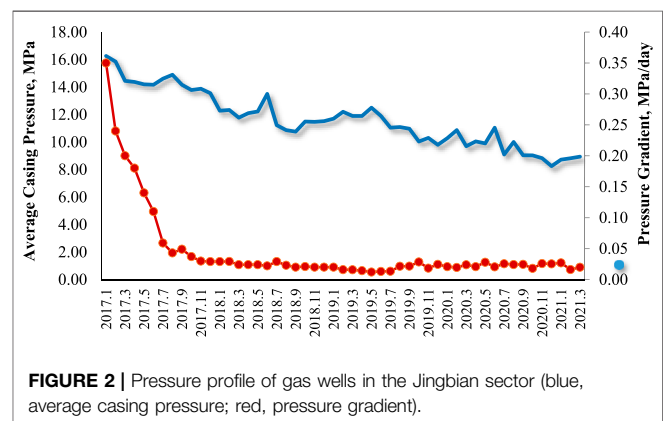
INTRODUCTION

The productivity of a gas well is mainly controlled by reservoir geological conditions (Li et al., 2001; Tang et al., 2004; Fu et al., 2021). During the development of gas field, it is of great significance to predict the productivity and analyze the performance dynamics, which is the basis of developing fields efficiently. During the development of gas field, productivity analysis is the most important method to predict the productivity, study the performance dynamics, and understand the characteristics of gas zones (Nowrouzi et al., 2020). The key gas production zone in the Jingbian sector of the Yan'an gas field is the Xiagumawu formation, which shows the features of low porosity, low permeability, and high heterogeneity. With the time being of production, wells with low productivity continue to appear (Yan et al., 2021), which leads to the slow recovery of shut-in pressure of gas wells; this further brings difficulty to the evaluation of single-well productivity. The one-point well test method only requires stable production and flowing pressure under one single-well constraint (Wakabayashi and McGouldrick, 2020), which is applied in China widely. The one-point method can significantly reduce the workload of well tests, reduce the burden of production, and provide theoretical evidence for the production allocation based on the gas productivity equations.

FIGURE 1 | Tectonic map of the top surface of reservoir formation.
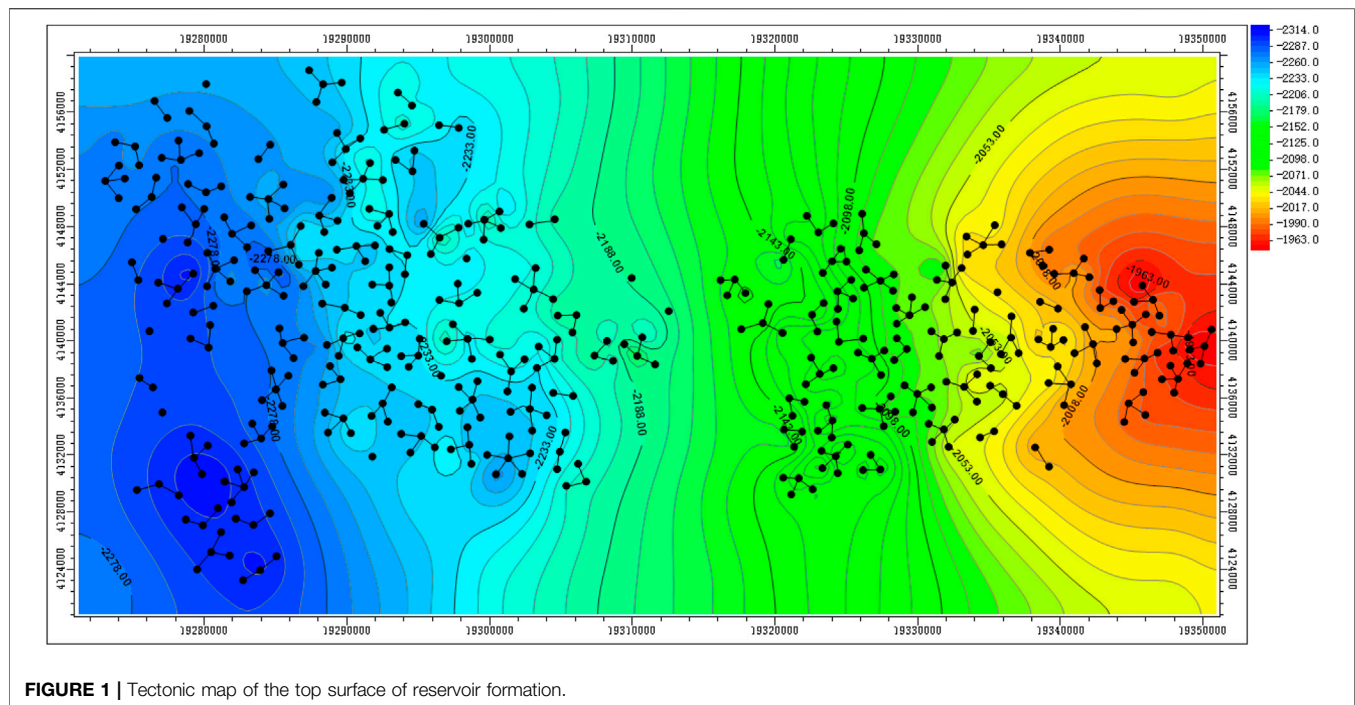
Based on the stable condition proposed by O'Dell and Mill (O'dell, 1967) in 1965, a simplified method to calculate the gas productivity was proposed. Until 1995, Xiong (Yu et al., 1996) introduced the concept of unstable seepage and proposed the modification on the gas well analysis. In 1987, Chen et al. (2017) presented a simple method to determine the absolute open flow of gas wells. In 1992, Chen (1990) further proposed a series of one-point productivity formulas based on 16 gas wells in China. In 2004, Qin and Li (Bin et al., 2005) studied the gas production dynamics and built the oil–gas two-phase flow model and distribution of reservoir parameters. At the same time, Tang et al. proposed the back-pressure isochronal well test methodology to better evaluate the productivity of low-permeability gas wells. In 2005, Huang et al. (2005) studied the reservoir stratigraphy and seepage characteristics and established the productivity calculation model for gas wells in dual porous media. In 2011, Zhang et al. (2011) applied Saphir well test software to perform the analysis for well test data in seven wells in the Chuanxi area and corrected the coefficients of the one-point empirical formula. In 2013, Zhong et al. (2013) employed reservoir simulation to derive the "one-point" productivity formula for the Sulige gas field and correct the coefficients. In 2015, Zhao et al. (2015a) utilized the well test data in the Daniudi gas field to perform the revision for coefficients in one-point formula and established models for different formations. In 2018, Liang et al. (2018) applied the one-point production method into low-perm and low-porosity gas wells in Donghai and shrunk the well test time.

The Jingbian sector of Yan'an field is located in the middle of the Yishan slope in Ordos Basin. The main oil formation is Mawu$_{1+2}$. The reservoir exhibits the characteristics of low

FIGURE 2 | Pressure profile of gas wells in the Jingbian sector (blue, average casing pressure; red, pressure gradient).

porosity, low permeability, and high heterogeneity with developed valleys. The development of grooves is closely related to the paleogeomorphology, paleocurrent, and paleokarst of carbonates. The phenomenon indicates a west-height and east-low trend in paleogeomorphology with toppling toward the southeast (**Figure 1**). The relative height difference is less than 70 m, and the average gradient of the slope is not greater than 0.001. The west is a coast during the sedimentation, and the surface water flows from the west to the east. The groove is mainly affected by the erosion of linear water and the gap of formations. As the main channel for the depletion of groundwater, the west of the groove is the water source, and the east is the water sink. It exhibits a "V" shape and follows the principle of erosion into the source. The direction of extension of the groove is in agreement with the direction of the paleocurrent. Many grooves are developed in the internal gas

reservoirs, which exhibits the parallel distribution. The study area started production in December 2016. Until now, 300 gas wells have been in production, and the cumulative gas production is 3.65 billion cubic meters. With the continuation of production, some wells show the trend of low production and low efficiency (**Figure 2**), which leads to a slow recovery of pressure after shut-in. These bring many challenges to production evaluations.

The key objective of the one-point well test method is to apply the appropriate productivity equation (Sun et al., 2020) to provide the reference for evaluating early-stage gas well production, which further satisfies the management requirement of fields (Zhao et al., 2017). The key workflow in this study is to compare different one-point methods and summarize their advantages and disadvantages. After that, the most appropriate one-point method is selected, and its usability is validated. The key innovation of this study is to evaluate different one-point methodologies based on physics and mathematics, and their applications are also discussed in depth.

COMPARISON OF ONE-POINT PRODUCTIVITY MODELS

The binomial productivity model and the exponential productivity model are the most popular types to apply one-point methods into the evaluation of productivity. The binomial one-point productivity model is derived based on the flow equation, phase behavior equation, and mass balance equation under a certain boundary condition, which has higher accuracy and a wider application range. The exponential productivity model is dependent on an empirical formula for certain fields and formations, which has relatively low applicability.

Binomial Productivity Model

The binomial productivity equation is based on the high-velocity Darcy's flow around gas wells (Du et al., 2022). It assumes the laminar flow in pores far away from the wells. However, when the gas flows into the bottom of wells, the seepage velocity significantly increases with a smaller flow radius. In this case, the turbulent flow exists, and the non-Darcy equation is applied to describe the flow mechanism. In the practice of gas field, it is difficult to find the pure laminar flow, and the non-Darcy is essential to be applied into gas-well evaluation. In the following paragraphs, the binomial productivity models under steady, pseudo-steady, and non-steady states will be introduced and discussed. The main difference between stead and non-steady is whether the pressure and flow rate are time dependent. The choice of different states should be dependent on the field observation of the relationship between time, pressure, and flow rate.

Binomial Productivity Model Under Steady State
Considering Darcy's flow and non-Darcy's flow (Al Rbeawi, 2020; Li and Chen, 2020), the one-point model is established based on mass balance equation and equation and state, and the boundary condition is defined as $\partial p/\partial t = 0$. In this way, the gas productivity model is obtained as follows:

$$P_e^2 - P_{wf}^2 = \frac{1.291 \times 10^{-3} T \bar{\mu} \bar{Z}}{Kh}\left(\ln \frac{r_e}{r_w} + S\right)Q_{SC}$$
$$+ \frac{1.291 \times 10^{-3} T \bar{\mu} \bar{Z}}{Kh} D Q_{SC}^2 \tag{1}$$

Eq. 1 can be further simplified as follows:

$$P_e^2 - P_{wf}^2 = A_1 Q_{SC} + B_1 Q_{SC}^2 \tag{2}$$

where P_e is the boundary pressure, MPa; P_{wf} is the bottom-hole flowing pressure, MPa; T is the temperature, K; $\bar{\mu}$ is the average viscosity, mPa·s; $\bar{z}$ is the deviation factor, dimensionless; K is the permeability, mD; h is the reservoir thickness, m; r_e is the effective radius, m; r_w is the well radius, m; S is the skin factor, dimensionless; Q_{SC} is the gas production at standard condition, 10^4 m^3/day; A_1 is the coefficient, $= \frac{1.291\times10^{-3}T\bar{\mu}\bar{Z}}{Kh}(\ln\frac{r_e}{r_w} + S)$; and B_1 is the coefficient, $= \frac{1.291\times10^{-3}T\bar{\mu}\bar{Z}}{Kh}D$.

In the formula above, the average properties of the gas are determined based on average pressure and temperature. In **Eq. 2**, the first item A_1 stands for the consumed energy by Darcy's flow and the second item B_1 indicates the consumed energy by non-Darcy's flow. If B_1 equals zero, the expression obeys Darcy's flow mechanism.

Binomial Productivity Model Under Pseudo-Steady State
The boundary condition is set up as $\partial p/\partial t = C$ (Li and Chen, 2020; Ying et al., 2021), and the productivity equation can be further derived as

$$P_R^2 - P_{wf}^2 = \frac{1.291 \times 10^{-3} T \bar{\mu} \bar{Z} Q_{SC}}{Kh}\left(\ln \frac{0.472 r_e}{r_w} + S\right)$$
$$+ \frac{2.828 \times 10^{-3} \beta \gamma_g \bar{Z} T Q_{SC}^2}{r_w h^2} \tag{3}$$

Eq. 3 can be further simplified as follows:

$$P_R^2 - P_{wf}^2 = A_2 Q_{SC} + B_2 Q_{SC}^2 \tag{4}$$

where P_R is the reservoir pressure, MPa; β is the coefficient for turbulent flow, m^{-1}; γ_g is the relative density of natural gas, dimensionless; A_2 is the coefficient, $= \frac{1.291\times10^{-3}T\bar{\mu}\bar{Z}}{Kh}(\ln\frac{0.472r_e}{r_w} + S)$; and B_2 is the coefficient, $= \frac{2.828\times10^{-3}\beta\gamma_g\bar{Z}T}{r_w h^2}$.

In **Eq. 4**, A_2 indicates the pressure loss due to the viscous resistance, and B_2 indicates the pressure loss due to inertial resistance. The total loss presents the total pressure decline during the gas inflow procedure.

Binomial Productivity Model Under Non-Steady State
The gas flow state is unsteady when the pressure wave does not arrive at the boundary during the early stage of production (Zhao et al., 2015b), which can be regarded as the seepage characteristics in infinite formation. The productivity equation is shown as follows:

TABLE 1 | Correction of isochronal well test data table of well J53-1.

Work mode	Reservoir pressure, MPa	Bottom-hole flowing pressure, MPa	Gas production, 10^4 m^3/day
Initial shut-in	31.872	-	-
First mode	-	30.277	1.2460
Second mode	-	28.351	1.9847
Third mode	-	26.405	2.6542
Fourth mode	-	24.014	3.5041

$$P_e^2 - P_{wf}^2 = \frac{42.42\bar{\mu}\bar{Z}p_{SC}Q_{SC}}{KhT_{SC}}\left(\lg\frac{8.085Kt}{\varphi\mu C_t r_w} + 0.87S + 0.87DQ_{SC}\right) \quad (5)$$

Equation can be further simplified as follows:

$$P_e^2 - P_{wf}^2 = A_3 Q_{SC} + B_3 Q_{SC}^2 \quad (6)$$

where p_{SC} is the pressure at the standard condition, = 0.101325 MPa; T_{SC} is the temperature at the standard condition, = 293.16 K; φ is the porosity, dimensionless; C_t is the compressibility factor, MPa^{-1}; D is the non-Darcy flow coefficient, (10^4 m^3/day)$^{-1}$; m is the coefficient, = $\frac{42.42\bar{\mu}\bar{Z}p_{SC}}{KhT_{SC}}$; A_3 is the coefficient, = $m(\lg\frac{8.085Kt}{\varphi\mu C_t r_w} + 0.87S)$; and B_3 is the coefficient, = $0.87mD$.

In **Eq. 6**, A_3 is a function of time for single wells, and its change with time fulfills the semi-log relationship.

Based on the derivation above, it can be seen that the productivity of gas wells satisfies the binomial format under unstable, pseudo-state, and state states. However, the coefficients have different definitions.

Exponential Productivity Model

An exponential productivity model is proposed based on the relationship between production and pressure difference, which is based on massive practice in the specified field as follows:

$$q_g = C\left(P_R^2 - P_{wf}^2\right)^n \quad (7)$$

where C is the coefficient, (10^4 m^3/day)/(MPa^2)^n and n is the coefficient between 0.5 and 1.

The exponent n shows the degree of non-Darcy flow. If n equals 1, it indicates the complete Darcy's flow. If n equals 0.5, it is a complete turbulent flow.

APPLICATION IN JINGBIAN SECTOR OF YAN'AN FIELD

Comparison Between Binomial Model and Exponential Model

Case Study with Big Pressure Difference in Different Work Modes

The gas well of J53-1 is taken as an example for the application of the one-point method. **Table 1** shows the well test data, and four well modes are applied to correct the isochronal well test, which are located at 30.3, 28.4, 26.4, and 24.0 MPa.
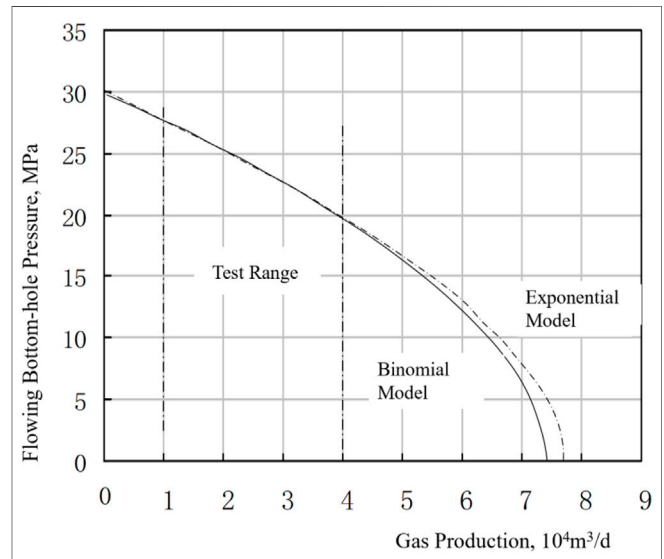

FIGURE 3 | Comparison of inflow performance relationship curves produced by different productivity equations.

Based on the data in **Table 1**, the exponential and binomial productivity equations can be obtained as follows:

$$P_R^2 - P_{wf}^2 = 255.79492Q_{SC} + 2.0756Q_{SC}^2 \quad (8)$$

$$Q_{SC} = 0.007741\left(P_R^2 - P_{wf}^2\right)^{0.89087} \quad (9)$$

Figure 3 shows the inflow performance relationship curves based on the models. In the range of well tests, the difference between binomial and exponential curves is small. Out of the range of well tests, there are some deviations between the two inflow performance relationship curves, but the difference is pretty small.

Based on the equations, the absolute open flow can be obtained as follows.

$$q_{AOF-Binomial} = 3.8101 \times 10^4 m^3/d \quad (10)$$

$$q_{AOF-Exponential} = 3.9165 \times 10^4 m^3/d \quad (11)$$

Based on **Eqs 10, 11**, it is shown that the absolute open flow rate is pretty similar based on exponential and binomial equations, and the relative difference is only 2.8%. The square pressure difference for J53-1 is 439.15 MPa^2, which achieves 43% of the square pressure difference of the formation. The maximum

TABLE 2 | Correction of isochronal well test data table of well Jing 32-1.

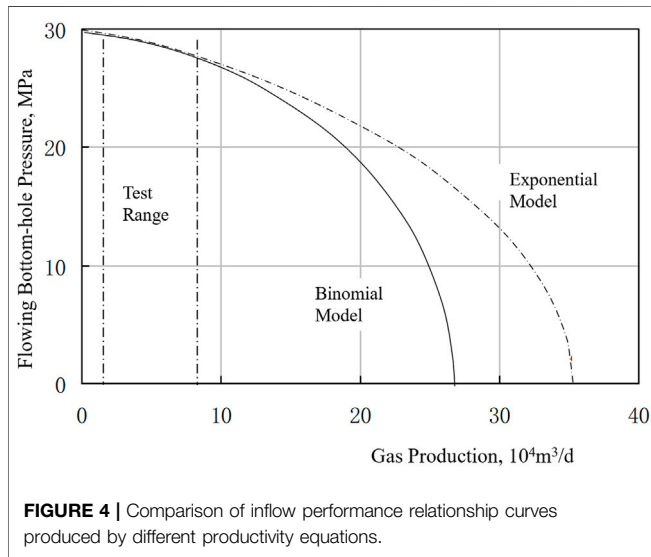| Work mode	Reservoir pressure, MPa	Bottom-hole flowing pressure, MPa	Gas production, 10^4 m³/day
Initial shut-in	33.38	-	-
First mode	-	32.743	3.2051
Second mode	-	32.313	5.3239
Third mode	-	31.997	7.1535
Fourth mode	-	31.616	9.1910

FIGURE 4 | Comparison of inflow performance relationship curves produced by different productivity equations.

production of 3.5041×10^4 m³/day exceeds the half rate of absolute open flow. This indicates that if the pressure difference in different work modes is large, the difference of productivity between binomial and exponential models is small.

Case Study With Small Pressure Difference in Different Work Modes

The gas well of J32-1 is taken as an example in this case. **Table 2** shows the well test data, and four well modes are applied to correct the isochronal well test, which are located at 3.2, 5.3, 7.2, and 9.2 MPa. The square pressure difference for J53-1 is 114.65 MPa², which is only 10% of the square pressure difference of the formation.

Based on **Table 2**, the binomial and exponential productivity equations are obtained as follows.

$$P_R^2 - P_{wf}^2 = 35.8768 Q_{SC} + 0.1333 Q_{SC}^2 \qquad (12)$$

$$Q_{SC} = 0.075 \left(P_R^2 - P_{wf}^2 \right)^{0.8629} \qquad (13)$$

The absolute open flow is thus calculated as follows.

$$q_{AOF-Binomial} = 3.8101 \times 10^4 \ \text{m}^3/\text{day} \qquad (14)$$

$$q_{AOF-Exponential} = 3.9165 \times 10^4 \ \text{m}^3/\text{day} \qquad (15)$$

The equations above indicate that the relative difference of absolute open flow is 14.8%, which has a big difference. **Figure 4** shows the difference of inflow performance relationship curves,

which indicates that the difference is small within the well test range but big outside of the well test range. While using this chart in the field, the maximum value by the exponential model and the minimum model is able to generate a range to determine the bottom-hole pressure.

One-Point Productivity Model

Based on the study, this paper establishes the one-point productivity model based on the binomial productivity equation, which has wider applicability for different states (steady, pseudo-steady, and non-steady). The production of gas wells in the Jingbian sector is under the pseudo-steady state. Thus, the proposed model is based on the pseudo-steady binomial productivity equation.

Eq. 4 can be further established to the one-point model to calculate the absolute open flow, as follows:

$$Q_{AOF} = \frac{2(1-\alpha)Q_g}{\alpha \left[\sqrt{1 + 4\left(\frac{1-\alpha}{\alpha^2}\right) p_D} - 1 \right]} \qquad (16)$$

where α is the one-point coefficient $= \frac{A}{A+BQ_{AOF}}$; and p_D is the dimensionless pressure $= \frac{P_R^2 - P_{wf}^2}{P_R^2}$.

Four work modes are taken based on a corrected isochronal well test, and the time periods are as 4, 8, 12, 16, 20, and 24 h. Thus, the one-point characteristic parameters are obtained as **Table 3**.

The average value of α is obtained as 0.9037 from **Table 3**. Thus, the one-point productivity model in the Jingbian sector of the Yan'an gas field is as follows:

$$q_{AOF} = \frac{0.2130 q_g}{\sqrt{1 + 0.4714 P_D} - 1} \qquad (17)$$

Regarding the established one-point productivity model, only a stable production and a related pressure are needed to obtain the absolute open flow.

Case Study 1: Comparison With Empirical Formula

Case study 1 is based on seven early-stage wells from the Jingbian sector as shown in **Table 4**. The established one-point model is compared with an empirical formula for the Xiagu formation in the Jingbian sector. The empirical formula to calculate the absolute open flow based on correlation is as follows (Shah et al., 2020):

$$q_{AOF} = \frac{0.7189 q_g}{\sqrt{1 + 1.9545 P_D} - 1} \qquad (18)$$

TABLE 3 | Calculation result of productivity characteristic parameter of single-well and single-point deliverability formula.

Well name	B	A	$\Delta P^2/MPa^2$	$q_{AOF}/10^4 \ m^3/day$	α
J32-1	0.1619	34.4174	1,114.2141	28.5416	0.8816
J44	1.7577	184.0653	952.2059	4.9401	0.9549
J53-1	1.5880	273.1753	1,015.8141	3.6415	0.9793
Y924	0.7448	52.0380	1,099.5090	16.9950	0.8043
Y942-3	0.4263	87.4788	1,060.4038	11.4796	0.9470
Y865	0.4088	46.9808	1,101.1676	19.9688	0.8520
Y313-1	0.4913	64.7204	963.4093	13.5019	0.9070

TABLE 4 | Data of stability test point of paleozoic gas reservoir in Jingbian sector of Yan'an gas field.

Well name	FBHP, MPa	Reservoir pressure, MPa	Production, $10^4 \ m^3/day$
J32-1	29.407	33.380	6.2109
J44	8.831	30.858	3.8570
J53-1	13.296	31.972	2.3937
Y924	30.103	33.159	3.2295
Y942-3	26.438	32.564	3.7263
Y865	24.315	33.184	9.0216
Y313-1	24.550	31.039	4.5254

TABLE 5 | Comparison of two single-point deliverability formulas.

Well name	Corrected absolute open flow	One-point model		Empirical formula	
		Absolute open flow, $10^4 \ m^3/day$	Relative difference, %	Absolute open flow, $10^4 \ m^3/day$	Relative difference, %
J32-1	25.2655	25.7157	1.78	22.4375	11.19
J44	4.1862	4.1706	0.37	4.1281	1.38
J53-1	2.8878	2.8531	1.20	2.7894	3.40
Y924	15.5213	16.9357	9.11	16.9357	9.11
Y942-3	10.5575	10.2618	2.80	9.2111	12.75
Y865	18.0391	18.5187	2.65	17.0547	5.45
Y313-1	11.4087	11.3853	0.20	10.2956	9.75

TABLE 6 | Comparison of productivity calculated by production data and productivity calculated by single-point method.

Well name	FBHP, MPa	Reservoir pressure, MPa	Production, $10^4 \ m^3/day$	Absolute open flow, $10^4 \ m^3/day$		Relative difference, %
				One-point model	Field data	
J5-1	27.433	31.027	5.968	25.3326	24.1940	4.71
J5-2	28.775	32.027	3.1234	14.9687	16.1851	7.52
J12	8.746	18.531	1.9794	2.4959	2.7415	8.96
J12-1	12.117	18.531	1.0417	1.7489	2.0974	16.62
Y910-1	11.203	12.087	5.0058	32.6268	31.3741	3.99
Y910-2	11.554	12.087	2.5386	26.8679	27.5783	2.58
Y976-2	9.991	21.249	3.8631	4.8615	5.1680	5.93
Y976-3	14.468	21.249	1.9473	3.4766	3.7751	7.91
J44	13.688	17.469	2.4793	6.0573	6.2579	3.21
J44-1	14.904	17.469	1.3333	4.5661	5.0672	9.89

Table 5 indicates that the average relative difference based on the one-point model is only 2.59%, which is much lower than the value of 7.58% from the empirical formula.

More production data can be obtained after the gas wells are in production. In this case, 10 late-stage wells after pressure build-up test in the Xiagu formation are selected to perform the analysis as shown in **Table 6**.

Table 6 indicates that the average relative difference is about 7.12% for late-stage wells, considering the standard is that the relative difference is less than 10%. The rate of success to apply the one-point model in this case is 90%.

Overall, the one-point model has a high accuracy to evaluate the gas productivity in the Xiagu formation of the Jingbian sector. **Eq. 17** can be a typical model to evaluate the gas production in the study area. The limitation of this model is not able to consider complex geological conditions such as shales or faults. It is suggested to combine with reservoir simulation if this model applies information of complex conditions.

CONCLUSION

This paper studies gas productivity based on the one-point model in the Jingbian sector. The following conclusions can be drawn:

1) When the pressure difference is big between different work modes, the absolute open flow from the binomial equation and that from the exponential equation are very similar. While the difference is small, a big relative difference will be observed between the two methods.

2) The one-point model is established based on a pseudo-steady binomial equation with the average characteristic coefficient of 0.9037 in the Jingbian sector. Compared with the empirical formula, the one-point model indicates a higher accuracy to match corrected absolute open flow. Besides, the one-point model also shows high accuracy for late-stage gas wells. The established model can be widely applied in the study area.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

LE-h, LY-y, and GL-j are responsible for the design of the model. ZD-s and LX are responsible for the writing of the manuscript. XJ-z is responsible for the improvement of the English language.

FUNDING

REFERENCES

Al Rbeawi, S. (2020). Analysing and Characterising Horizontal Well Performance in Rectangular Closed Gas Reservoirs Considering Non-darcy Flow Conditions. *Ijogct* 24 (3), 345–376. doi:10.1504/ijogct.2020.10028649

Bin, Q., Li, X., and Cheng, S. (2005). Oil/gas Percolation Performance of Condensate Reservoirs under Effect of High Velocity Flow [J]. *Nat. Gas Industry* 2, 136–139+19. doi:10.3321/j.issn:1000-0976.2005.02.044

Chen, Y., Guo, E., Peng, Z., Wang, M., and Zhou, Y. (2017). Derivation of Productivity Formulas for Horizontal wells in Anisotropic Fault-Block Reservoirs. *Acta Petrolei Sinica* 38 (12), 1420. doi:10.7623/syxb201712009

Chen, Y. (1990). Standardization on the Curves of Permeability and Capillary Pressure. *Exp. Pet. Geology.* 12 (1), 64–70.

Du, X, Zhang, Y., Zhou, C., Su, Y., Li, Q., Li, P., et al. (2022). A Novel Method for Determining the Binomial Deliverability Equation of Fractured Caved Carbonate Reservoirs. *J. Pet. Sci. Eng.* 208, 109496. doi:10.1016/j.petrol.2021.109496

Fu, J., Su, Y., Li, L., Wang, W., Wang, C., and Li, D. (2021). Productivity Model with Mechanisms of Multiple Seepage in Tight Gas Reservoir. *J. Pet. Sci. Eng.*, 109825. doi:10.1016/j.petrol.2021.109825

Huang, Q., Sun, L., Li, S., Yang, S., and Yang, H. (2005). Correct Prediction of Gas Well Productivity for Condensate Gas Reservoirs with Low Permeability. *Nat. Gas Industry* (11).

Li, J., and Chen, C. (2020). Numerical Simulation of the Non-darcy Flow Based on Random Fractal Micronetwork Model for Low Permeability sandstone Gas Reservoirs. *Geofluids* 2020, 1–9. doi:10.1155/2020/8884885

Li, X., Huang, B., and Hu, Y. (2001). The Establishment and Application of Binomial Deliverability Equation for Horizontal Gas Well. *J. Can. Pet. Technology* 42 (10). doi:10.2118/2001-081

Liang, B., Tan, X., Jiao, S., Peng, S., Zhang, L., and Duan., Y. (2018). "single-point"productivity Equation for Fractured Gas wells in Low-Porosity and Low-Permeability Reservoirs,east china Sea. *Well Test.* 27 (2), 73–78. doi:10.19680/j.cnki.1004-4388.2018.02.012

Nowrouzi, I., Mohammadi, A. H., and Manshad, A. K. (2020). Effect of a Synthesized Anionic Fluorinated Surfactant on Wettability Alteration for Chemical Treatment of Near-Wellbore Zone in Carbonate Gas Condensate Reservoirs. *Pet. Sci.* 17 (6), 1655–1668. doi:10.1007/s12182-020-00446-w

O'dell, H. G. (1967). Successfully Cycling a Low-Permeability, High-Yield Gas Condensate Reservoir. *J. Pet. Technology* 19 (01), 41–47.

Shah, M. S., Khan, M. H. R., Rahman, A., and Butt, S. (2020). Production Optimization in Well-6 of Habiganj Gas Field, Bangladesh: a Prospective Application of Nodal Analysis Approach. *J. Petrol. Explor Prod. Technol.* 10, 3557–3568. doi:10.1007/s13202-020-00908-2

Sun, H., Meng, G., and Cao, W. (2020). Applicable Conditions of the Binomial Pressure Method and Pressure-Squared Method for Gas Well Deliverability Evaluation. *Tianranqi Gongye/Natural Gas Industry* 40 (1), 69–75. doi:10.1016/j.ngib.2020.01.007

Tang, J., Ma, X., Jiao, C., and Fan, L. (2004). A New Testing Method of Gas Well Potential:backpressure Isochronal Test. *Nat. Gas Geosci.* 15 (5), 540–544.

Wakabayashi, D., and McGouldrick, M. (2020). Innovative High Efficiency Oil Burner Proves to Solve Many Environmental Challenges in Well Test Applications. *OnePetro.* In International Petroleum Technology Conference. doi:10.2523/iptc-19734-ms

Yan, H., Jia, A., Meng, F., Xia, Q., Xu, W., Feng, Q., et al. (2021). Comparative Study on the Reservoir Characteristics and Development Technologies of Two Typical Karst Weathering-Crust Carbonate Gas Reservoirs in China. *Geofluids* 2021, 1–19. doi:10.1155/2021/6631006

Ying, L., Wang, J., and Li, A. (2021). Effect of Non-darcy Seepage on Productivity of Tight Gas reservoirIOP Conference Series: Earth and Environmental Science. *IOP Publishing* 859 (No. 1), 012067. doi:10.1088/1755-1315/859/1/012067

Yu, X., Lei, S., Liangtian, S., and Shilun, L. (1996). A New Method for Predicting the Law of Unsteady Flow through Porous Medium on Gas Condensate Well. *OnePetro*. In SPE Gas Technology Symposium. doi:10.2118/35649-ms

Zhang, J., Mu, X., and Qiu, L. (2011). Correction for Well Testing Formula of "one point" Production Testing in Chuanxi Deep Layer. *Well Test.* 20 (5), 19–20.

Zhao, X., Jiang, B., Zhang, S., Liu, J., and Xu, Q. (2017). Main Controlling Factors of Productivity and Development Strategy of Cbm wells in Block 3 on the Eastern Margin of Ordos basin. *Acta Petrol. Sinica* 38 (11), 1310–1319. doi:10.7623/syxb201711010

Zhao, X., Rui, Z., Liao, X., and Zhang, R. (2015). A Simulation Method for Modified Isochronal Well Testing to Determine Shale Gas Well Productivity. *J. Nat. Gas Sci. Eng.* 27, 479–485. doi:10.1016/j.jngse.2015.08.035

Zhao, Z., Li, Z., Lai, F., and Wu, W. (2015). Study of Single-point Testing Time for Tight Gas of Fractured Horizontal wells. *Well Test.* 24 (1), 1–3.

Zhong, J., Tang, H., Dongliang, L., Zhang, Z., and Donglin, L. (2013). Study on a Single point Deliverability Formula of Horizontal wells in Sulige Gas Field. *Lithologic Reservoirs* 25 (2), 107–111.