Discussion on Gas Well Productivity Analysis Method

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Abstract: Productivity Analysis of Gas Wells to Determine the Productivity of Gas Wells is One of the Important Components of Gas Reservoir Engineering Design. in Actual Production, People Use Binomial Deliverability Analysis Regardless of Gas Well Pressure or Production. Even Simpler Methods Use One-Point Method for Deliverability Analysis and Binomial Analysis Regardless of Gas Reservoir Permeability. It Seems That Binomial Deliverability Equation Analysis Method is a General Method for Gas Well Deliverability and Has No Special Features. This Paper Starts with Deliverability Equation, Discusses the Change of Binomial Coefficient on the Basis of Analyzing the Physical Meaning of Binomial Deliverability Equation, and Analyzes Its Influence on Deliverability. through Analysis, It is Believed That the Productivity Analysis of Wells with Low Production or Low Permeability Can Completely Ignore the Influence of Non-Darcy Flow, I.e. Can Ignore the Influence of Inertial Energy, So That the Analysis is Simpler and the Results Are in Line with the Production Practice.

1. Introduction

The Earliest Capacity Equation Was Based on Darcy Flow, and Its Binomial Capacity Equation Was [1]-[14]:

$$p_R^2 - p_{wf}^2 = \frac{1.291 \times 10^{-3} q_{sc} T \overline{\mu} \overline{Z}}{Kh} \left(\ln \frac{r_e}{r_w} + S\right) \tag{1}$$

In the Formula:

q_{sc} -Gas Well Production, M^3/d;

K-Reservoir Permeability,$10^{-3}MM^2$;

H- Effective Thickness of Reservoir, m;

R_e-Radius of Gas Release, m;

$\overline{\mu}$ -Average Viscosity of Gas, Mpa. s;

$\overline{Z}$ - average deviation factor of gas, dimensionless;

T - reservoir temperature, K;

S - mechanical skin factor.

Later, it was considered that the high-speed flow around the well is equivalent to turbulent flow, which is called non Darcy flow. Therefore, the artificial Darcy flow capacity formula is no longer applicable. Through experiments, Forchheimer proposed a binomial equation to describe non Darcy flow , namely:

$$\frac{dp}{dr} = \frac{\mu \upsilon}{K} + \beta \rho \upsilon^2 \tag{2}$$

In the formula:

p - pressure, Pa;

μ - fluid viscosity, mPa. s;

υ - fluid seepage velocity, m/ s;

ρ - fluid density, kg / m3;

K-permeability, m^2;

β - coefficient describing the effect of turbulent flow in porous media, called velocity coefficient, M-1.

The general formula of velocity coefficient is:

$$\beta = \frac{constant}{K^{\alpha}} \quad (\alpha \text{ is the coefficient}) \tag{3}$$

The common β calculation formula is [2]:

$$\beta = \frac{7.644 \times 10^{10}}{K^{1.5}} \tag{4}$$

In the formula: K-permeability, 10^{-3} μ m^2.

It can be seen from formula (2) that the first term represents the viscous resistance term of fluid, and the second part represents the inertial resistance term caused by velocity. Since the inertial resistance term is related to flow, a flow related skin coefficient is introduced to describe it, so it becomes the flow related skin coefficient, which is generally represented by Dq_{sc}. The key is how to estimate the flow skin factor. The second term in formula (2) is expressed in the form of pressure drop:

$$dp_{nD} = \beta \rho \upsilon^2 dr \tag{5}$$

Substituting into the formula (5) according to the natural gas physical parameters:

$$p_{nD}^2 = 2.828 \times 10^{-21} \frac{\beta \gamma_g \overline{Z} T}{r_w h^2} q_{sc}^2 = F q_{sc}^2 \tag{6}$$

Or

$$F = 2.828 \times 10^{-21} \frac{\beta \gamma_g \overline{Z} T}{r_w h^2} \tag{7}$$

$$p_{nD}^2 = 1.291 \times 10^{-3} \frac{q_{sc} \overline{\mu} \overline{Z} T}{Kh} D q_{sc}^2 \tag{8}$$

$$D = \frac{Kh}{1.291 \times 10^{-3} \overline{\mu} \overline{Z} T} \times 2.828 \times 10^{-21} \frac{\beta \gamma_g \overline{Z} T}{r_w h^2} = \frac{2.191 \times 10^{-18} \beta \gamma_g K}{\overline{\mu} h r_w} \tag{9}$$

In the formula:

F-non Darcy coefficient, $Mpa^2 / (m^3 / d)^2$;

D - inertia or turbulence coefficient, $(m^3 / d)^2$.

Therefore, considering the influence of non Darcy flow, the formula (1) is rewritten as:

$$p_R^2 - p_{wf}^2 = \frac{1.291 \times 10^{-3} q_{sc} T \overline{\mu Z}}{Kh} \left(\ln \frac{r_e}{r_w} + S + D q_{sc}\right) \tag{10}$$

The binomial form of (10) is as follows:

$$p_R^2 - p_{wf}^2 = A q_{sc} + B q_{sc}^2 \tag{11}$$

among them

$$A = \frac{1.291 \times 10^{-3} T \overline{\mu} \overline{Z}}{Kh} (\ln \frac{r_e}{r_w} + S) \tag{12}$$

$$B = \frac{1.291 \times 10^{-3} T \overline{\mu} \overline{Z} D}{Kh} = \frac{2.282 \times 10^{-21} \beta \gamma_g \overline{Z} T}{r_w h^2} \tag{13}$$

In the formula: A – Coefficient of laminar flow term, $Mpa^2 / (m^3 / d)$;
B – Turbulent term coefficient, $Mpa^2 / (m^3 / d)^2$.

2. Parameter Analysis

It can be seen from the formula of A and B that the factors affecting A and B are as follows:

Reservoir permeability K, effective reservoir thickness h, and reservoir temperature. Static influencing factors. In conventional gas reservoirs, it is assumed that K, h, and T remain unchanged.

Gas composition parameter $\overline{\mu}$、$\overline{Z}$. Dynamic influencing factors vary with the composition of natural gas; if the composition is unchanged, $\overline{\mu}$, Z is only a function of pressure.

It can be seen from formula (12) and (13) that in the process of gas well exploitation, with the decrease of formation pressure, the main parameters affecting A are $\overline{\mu}$ and $\overline{Z}$, and the main parameters affecting B are β, $\overline{Z}$ and h. Take the basic data of a gas well as an example to discuss the influence of parameters A and B on productivity.

The original formation pressure of a gas well x is 57MPa, the gas reservoir temperature is 140 ℃, the relative density of natural gas is 0.6, the critical pressure is 4.67mpa, and the critical temperature is - 70 ℃. The corresponding physical parameters of natural gas are shown in Table 1, as shown in Figure 1. The binomial coefficient b decreases with the increase of permeability, indicating that the higher the permeability is, the smaller the inertia loss is, which is somewhat contradictory to the actual production. Because the higher the permeability is, the greater the gas well production is, and the greater the production is, the greater the inertia resistance loss is. As shown in Figure 2-4, under different permeability conditions, binomial coefficient B has an impact on productivity, It can be seen from the figure that p_{wf}^2 and q_{sc} have a linear relationship. When the permeability exceeds 10mD, the linear relationship of the productivity equation slightly changes. Considering the influence of Darcy flow and non Darcy flow on the productivity difference, see Table 2. From the table, it can be seen that the permeability is lower than 1.0mD, the maximum difference of the open flow is $1.17 \times 10^4 m^3 / d$, and the relative error is 3.89%. When the permeability is 10mD, the open flow difference is 11%. When the permeability is 10md, the open flow difference is 11% When the reservoir permeability is lower than 10 mD, the influence of non Darcy flow can be ignored.

Table 1 Calculation Table Of X Gas Well Physical Parameters

Reservoir permeability k(mD)	Reservoir effective Thickness h (m)	Deviation factor Z	Well control radius Re (m)	Skin factor s	β(m^{-1})	Viscosity of natural gas (MPa. S)	Coefficient A MPa^2 / (m^3 / d)	Coefficient B MPa^2 / (m^3/ d) ^{2}
0.001	20	1.251	1000	1.5	2.42E+15	0.0292	10.4301303	4.28E-05
0.01	20	1.251	1000	1.5	7.66E+13	0.0292	1.0430130	1.35E-06
0.1	20	1.251	1000	1.5	2.42E+12	0.0292	0.1043013	4.28E-08
1	20	1.251	1000	1.5	7.66E+10	0.0292	0.0104301	1.35E-09
10	20	1.251	1000	1.5	2.42E+09	0.0292	0.0010430	4.28E-11
100	20	1.251	1000	1.5	7.66E+07	0.0292	0.0001043	1.35E-12
1000	20	1.251	1000	1.5	2.42E+06	0.0292	0.0000104	4.28E-14

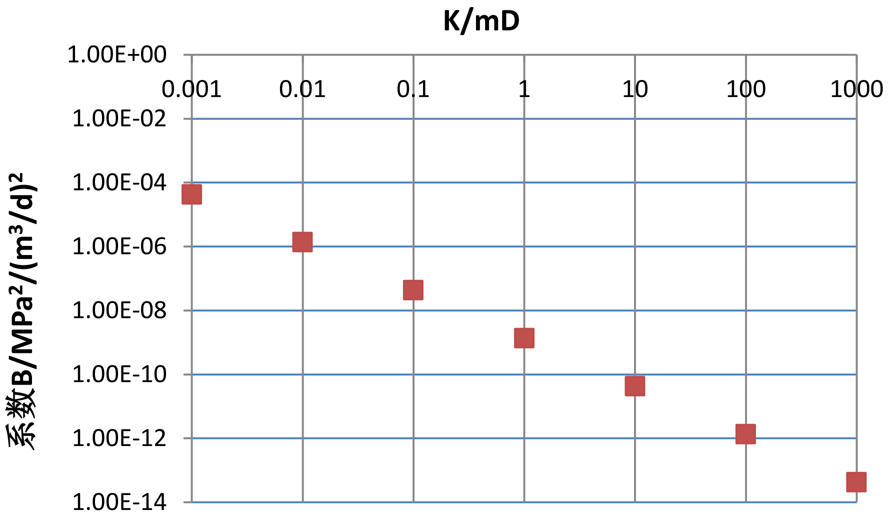

Fig.1 Variation Curve of Binomial Coefficient B with Permeability

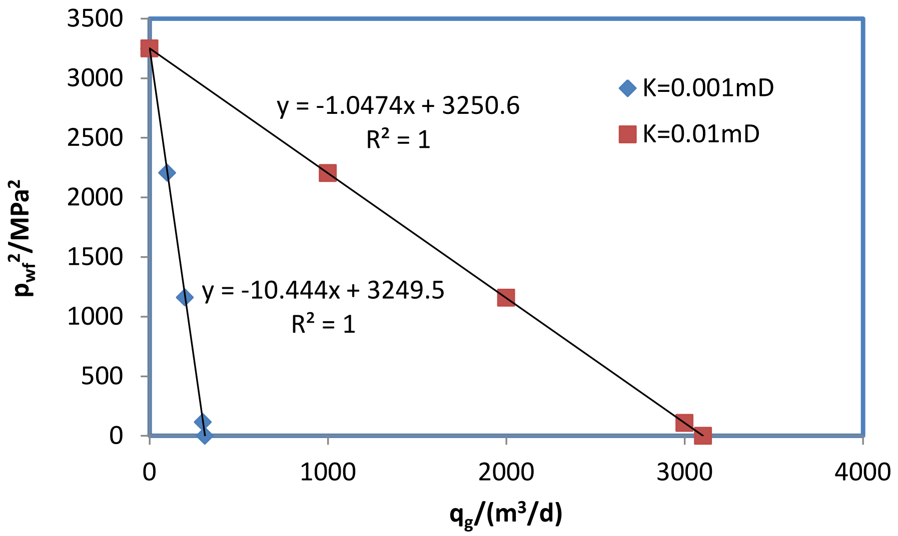

Fig.2 Comparison Curve of K = 0.001md and K = 0.01md Production Capacity

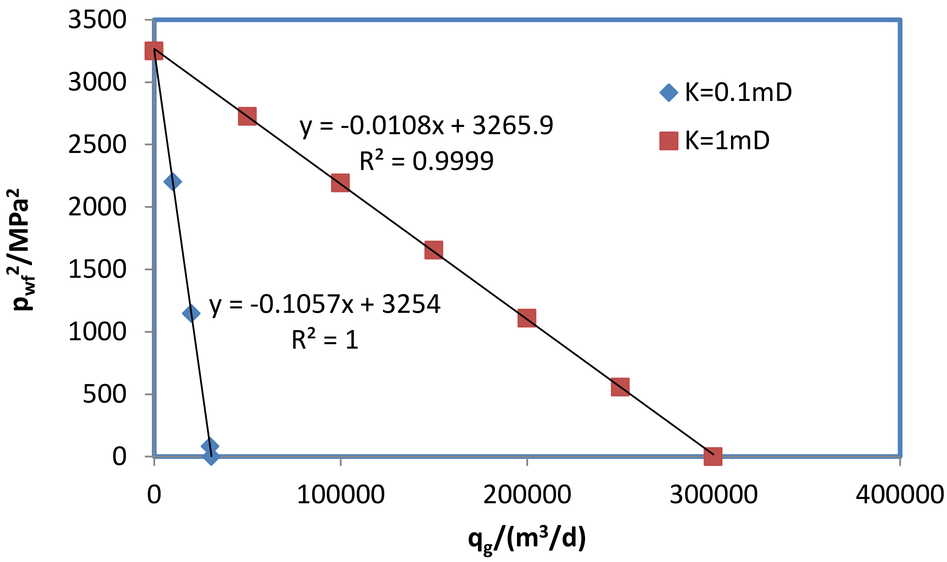

Figure 3.Comparison Curve of K = 0.1mD and K = 1.0mD Production Capacity

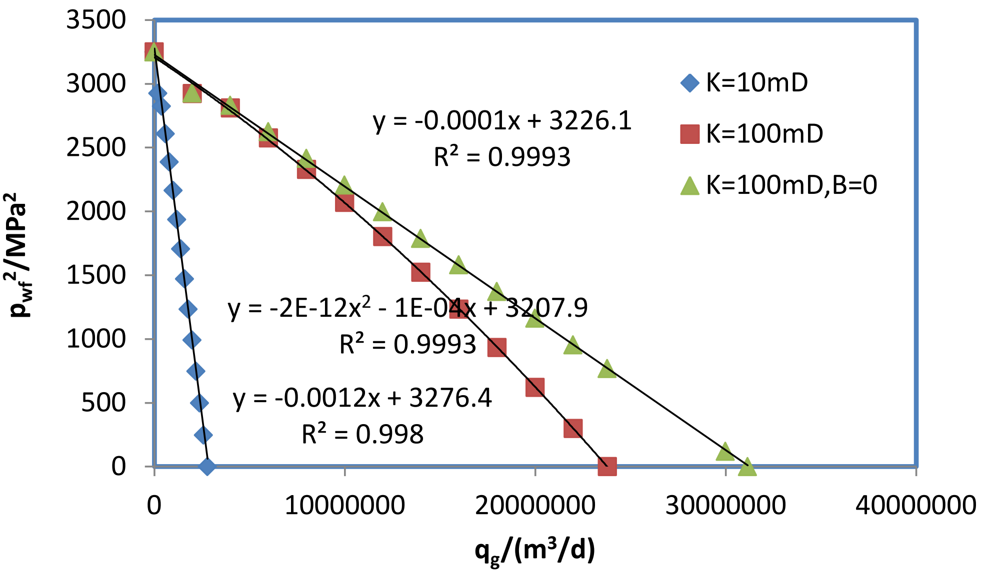

Fig.4 Comparison of Production Capacity between K = 10md and K = 100md

Table 2 Comparison Table Of Unobstructed Flow under Different Permeability Conditions

Reservoir permeability k (mD)	Coefficient A MPa^2 / (m^3 / d)	Coefficient B MPa^2 / (m^3 / d)^2	Unobstructed flow (10^4m^3 / d)	Unobstructed flow (B = 0) (10^4m^3 / d)	Relative error(%)
0.001	10.4301303	4.28E-05	0.03	0.03115	0.13
0.01	1.0430130	1.35E-06	0.31	0.3115	0.40
0.1	0.1043013	4.28E-08	3.08	3.115004	1.26
1	0.0104301	1.35E-09	29.98	31.15004	3.89
10	0.0010430	4.28E-11	279.43	311.5004	11.48
100	0.0001043	1.35E-12	2379.56	3115.004	30.91

The influence of the skin factor on productivity can be seen from equation (12). The skin factor mainly affects the size of the binomial coefficient A. As shown in the figure, the larger the skin coefficient, the larger the binomial coefficient A. The error between west flow and non-Darcy flow is smaller, as shown in Figure 5. If the skin coefficient is> 0 and the permeability is below 10mD, the impact of non-Darcy flow on production capacity can be ignored.

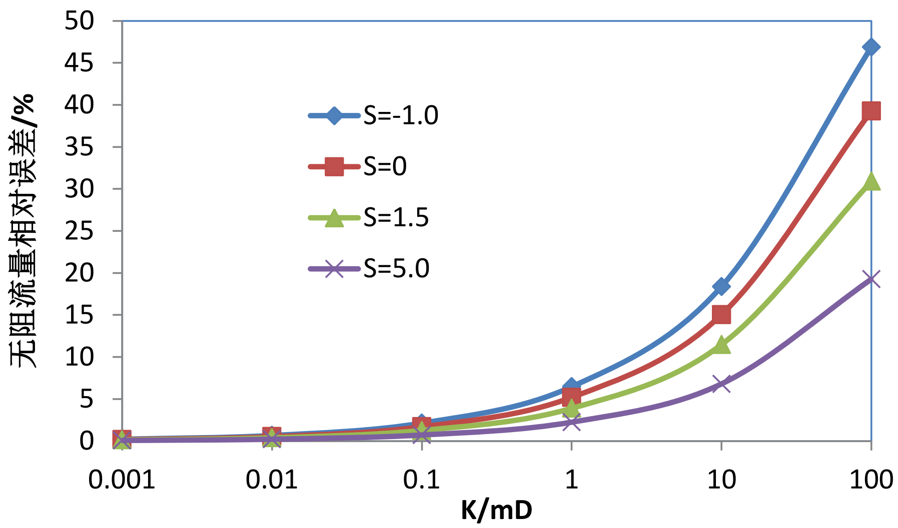

Fig.5 Effect of Skin Coefficient on Production Capacity

3. Conclusions and Suggestions

Through the analysis of this paper, the following understandings and suggestions are obtained:

For low permeability reservoir or ultra-low permeability reservoir, the influence of non Darcy flow can not be considered in productivity analysis;

For the reservoir whose permeability is lower than 10md, the non Darcy flow should not be considered in the productivity analysis;

Capacity analysis does not consider the impact of non Darcy flow, which is simpler and more applicable;

If the reservoir permeability is high and the production is higher than 100 × 104m3 / D, the influence of non Darcy flow must be considered.

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