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The Effects of Reservoir Parameters on Inflow Performance Relationship (IPR) of a Gas Field

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Abstract: The Inflow Performance Relationship (IPR) is considered one of the diagnostic tools used by petroleum engineers to evaluate the performance of a flowing well. An accurate prediction of well IPR is very important to determine the optimum production scheme, design production equipment, and artificial lift systems. For these reasons, there is a need for a quick and reliable method for predicting the well IPR in gas reservoirs. This study presents the effects of reservoir parameters on Inflow Performance Relationship (IPR) of a gas field. In order to achieve the IPR sensitivity analysis parameters, the skin factor, the gas permeability, the reservoir temperature, the reservoir thickness, nondarcy coefficient, the gas viscosity, and the compressibility factor were used to see the IPR sensitivity analysis. These models were developed using 2500 data sets collected from published literature papers and conventional PVT reports.

Keywords: Reservoir parameters, inflow performance relationship, gas field

I. INTRODUCTION

All well deliverability equations describe the relationship between the well production rate and the drawdown pressure, i.e. the difference between the reservoir pressure and the flowing bottom hole pressure. Presenting the production rate as a function of the drawdown pressure helps in comparing wells as well as in estimating the production rate under various conditions. This is also known as the inflow performance relationship (IPR).

In a single-layered gas reservoir, the gas well deliverability can be approximated using a pseudo-steady state relationship developed from Darcy's law as follows:

$$m(\overline{\mathrm{P}}) - \mathrm{m(Pwf)} = \frac{1424qT}{kh}\left[\ln\left(\frac{0.472\,re}{rw}\right) + S + Dq\right] \ldots\ldots\ldots\ldots\ldots(1)$$

Which can be rearranged as:

$$m(\overline{\mathrm{P}}) - \mathrm{m(Pwf)} = \frac{1424qT}{kh}\left[\ln\left(\frac{0.472\,re}{rw}\right) + S\right]q + \frac{1424TD}{kh}\,q^2 \ldots\ldots\ldots\ldots\ldots(2)$$

Alternatively:

$$m(\overline{\mathrm{P}}) - \mathrm{m(Pwf)} = aq + bq^2 \ldots\ldots\ldots\ldots\ldots(3)$$

Where:-

$$a = \frac{1424qT}{kh}\left[\ln\left(\frac{0.472\,re}{rw}\right) + S\right] \ldots\ldots\ldots\ldots\ldots(4)$$

$$b = \frac{1424TD}{kh} \ldots\ldots\ldots\ldots\ldots(5)$$

The *Dq* term refer to the turbulence skin effect, which could be quite high for some high rate wells. Several authors proposed approximations for the non-Darcy coefficient (D). One is the following empirical correlation:

$$D = \frac{2.715 \times 10^{-12}\beta MPsc}{h\mu g(Pwf)rwTsc} \ldots\ldots\ldots\ldots\ldots(6)$$

$$\beta = 1.88 * 10^{10}K^{-1.47}\emptyset^{-0.53} \ldots\ldots\ldots\ldots\ldots(7)$$

It was found that much simpler equation evolving the pressure square rather than the pseudo-pressure could obtain almost the same results as follows:

$$\overline{\mathrm{P}}^2 - {P_{wf}}^2 = \frac{1424\bar{\mu}\,\bar{z}\,Tq}{kh}\left[ln\left(0.472\frac{r_e}{r_w}\right) + S + Dq\right] \ldots\ldots\ldots\ldots\ldots.(8)$$

Which can be rearranged as:

$$\overline{\mathrm{P}}^2 - {P_{wf}}^2 = \frac{1424\bar{\mu}\,\bar{z}\,T}{kh}\left[ln\left(0.472\frac{r_e}{r_w}\right) + S\right]q + \frac{1424\bar{\mu}\,\bar{z}\,TD}{kh}q^2 \ldots\ldots\ldots\ldots\ldots.(9)$$

Alternatively:

$$\overline{\mathrm{P}}^2 - {P_{wf}}^2 = aq + bq^2 \ldots\ldots\ldots\ldots\ldots.(10)$$

Where:

$$a = \frac{1424\bar{\mu}\,\bar{z}\,T}{kh}\left[ln\left(0.472\frac{r_e}{r_w}\right) + S\right] \ldots\ldots\ldots\ldots\ldots.(11)$$

$$b = \frac{1424\bar{\mu}\,\bar{z}\,TD}{kh} \ldots\ldots\ldots\ldots\ldots.(12)$$

In addition, the gas well deliverability can be approximated using pressure approach as follows:

$$\overline{\mathrm{P}} - P_{wf} = \frac{141.2 * 10^3 B_g\,\bar{\mu}\,q}{kh}\left[ln\left(\frac{0.472r_e}{r_w}\right) + S + Dq\right] \ldots\ldots\ldots\ldots\ldots.(13)$$

Which can be rearranged as:

$$\overline{\mathrm{P}} - P_{wf} = \frac{141.2 * 10^3 B_g\,\bar{\mu}}{kh}\left[ln\left(\frac{0.472r_e}{r_w}\right) + S\right]\mathrm{q} + \frac{141.2 * 10^3 B_g\,\bar{\mu}\,D}{kh}q^2 \ldots(14)$$

Alternatively:

$$\overline{\mathrm{P}} - P_{wf} = aq + bq^2 \ldots\ldots\ldots\ldots\ldots.(15)$$

Where:

$$a = \frac{141.2 * 10^3 B_g\,\bar{\mu}}{kh}\left[ln\left(\frac{0.472r_e}{r_w}\right) + S\right] \ldots\ldots\ldots\ldots\ldots.(16)$$

$$b = \frac{141.2 * 10^3 B_g\,\bar{\mu}D}{kh} \ldots\ldots\ldots\ldots\ldots.(17)$$

A good number of previous work has discussed the inflow performance relationship of a oil reservoirs. So far, only few publications are available in literature for the inflow performance relationship of a gas reservoirs

II. DATA DESCRIPTION

A huge data sets used for this work were collected from conventional PVT reports for a Yemeni dry gas reservoir. Each data set contains gas flow rate, bottom hole flowing pressure, gas viscosity, gas compressibility factor. Statistical distributions such as maximum, minimum, mean, range, mid-range and standard deviation of the input data are shown in Table (1).

As can be seen from Table (1) gas flow rate of the data ranged between 12MSCF/D to 5528 MSCF/D. For bottom hole flowing pressure, the data ranged between 15 psia to 5991 psia. Gas viscosity ranged from 0.009 cp 0.035 cp. For gas compressibility factor, the data ranged between 0.745 to 0.999. The average reservoir temperature is 180˚ F. Reservoir permeability is 0.15 md, reservoir drainage radius and reservoir thickness are 1400 ft and 80 ft, respectively.

Property	Min	Max	Range	Mid-Ran.	Mean	Std
q	12	5528	5516	2770	3325.747	1676.5
pwf	15	5991	5976	3003	3003.074	1729
μ_g	0.009	0.035	0.026	0.022	0.0217	0.008
Z	0.745	0.999	0.255	0.872	0.8555	0.088

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III. RESULTS AND DISCUSSION

Three skin factor cases were analysed (5, 0 and -5) to investigate the effect of skin factor on inflow performance relationship (IPR) of a gas field as shown in Fig. 1. As noted in this fig., there are apparent and significant effects of skin factor on inflow performance relationship (IPR) of a gas field. In order to study the effect of formation permeability on inflow performance relationship, three formation permeability of 0.1 md, 0.15 md and 0.2 md were studied as presented in Fig. 2. From this figure, we can observe that there are minimal effect of gas formation permeability on inflow performance relationship.

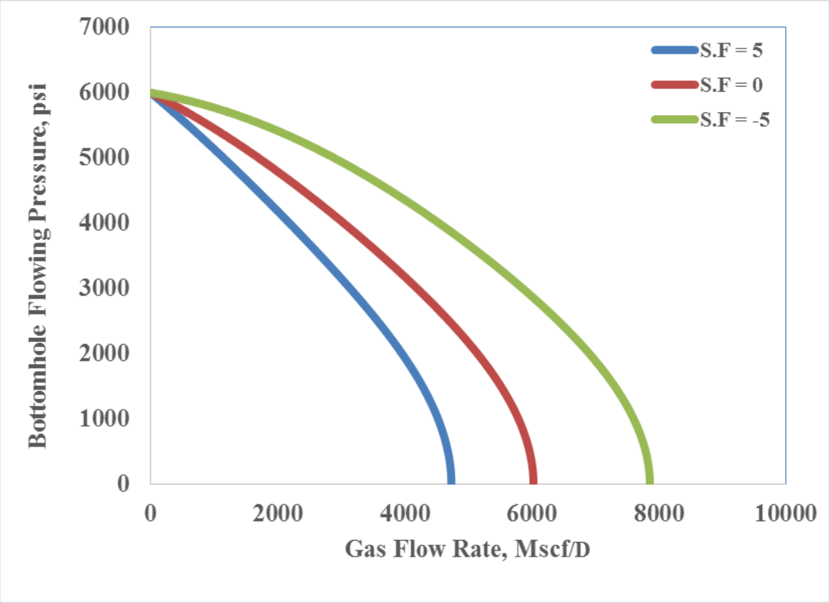

Figure 1 IPR sensitivity analysis of the skin factor

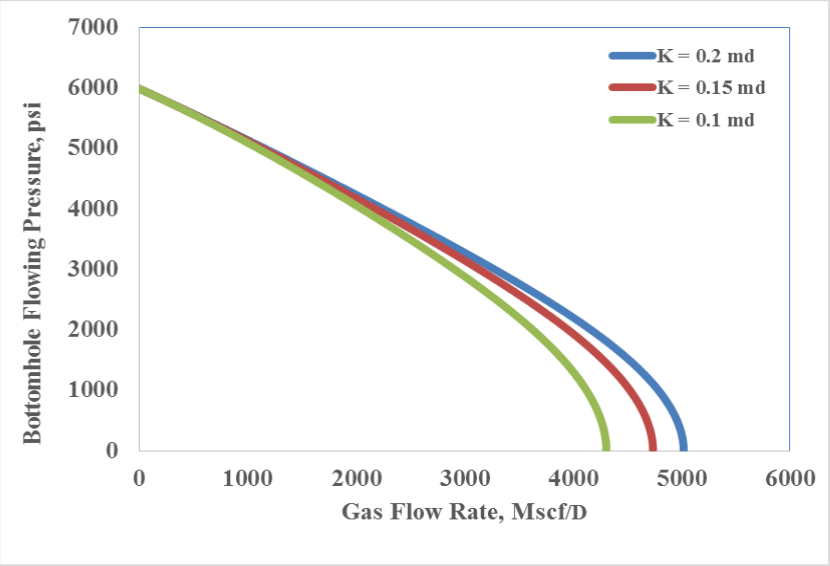

Figure 2 IPR sensitivity analysis of the gas permeability

For reservoir temperature, three reservoir temperature cases were analysed (100 ^{0}F, 180 ^{0}F and 300 ^{0}F) to consider the effect of reservoir temperature on inflow performance relationship (IPR) of a gas field as shown in Fig. 3. As noted in this fig., there are apparent and significant effects of reservoir temperature on inflow performance relationship (IPR) of a gas field. In order to study the effect of reservoir thickness on inflow performance relationship, three reservoir thickness of 50 ft, 80 ft and 110 ft were investigated as presented in Fig. 4. From this figure, we can observe that there are insignificant effect of reservoir thickness on inflow performance relationship.

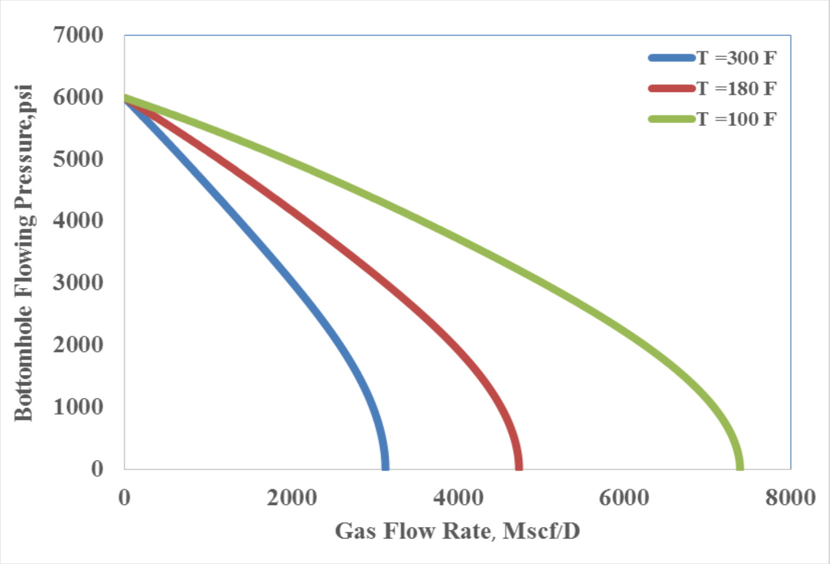

Figure 3 IPR sensitivity analysis of the reservoir temperature

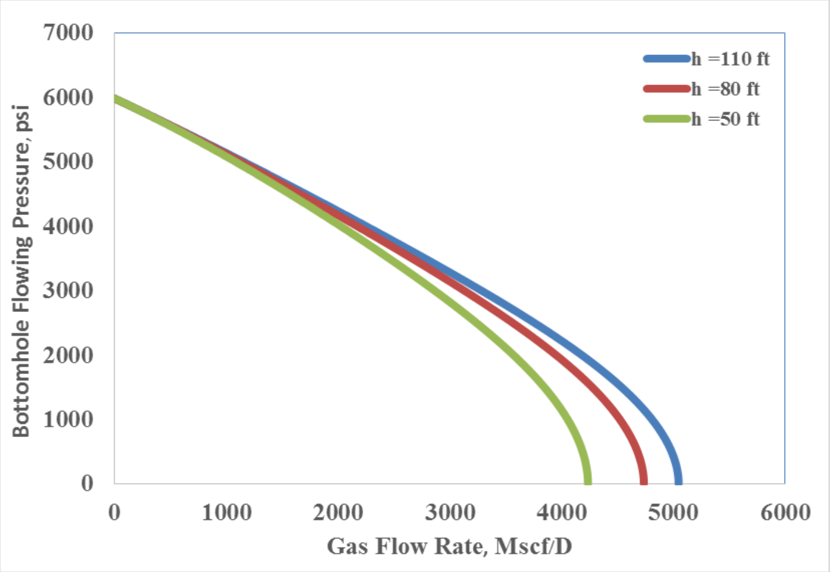

Figure 4 IPR sensitivity analysis of the reservoir thickness

For nondarcy coefficient ,three nondarcy coefficient cases were analysed (0.005, 0.001 and 0.002) to examine the effect of nondarcy coefficient on inflow performance relationship (IPR) of a gas field as shown in Fig. 5. As noted in this fig., there are apparent and significant effects of nondarcy coefficient on inflow performance relationship (IPR) of a gas field. Fig.6 shows the effect of gas viscosity on inflow performance relationship. As noted in this fig., three gas viscosity cases were investigated (0.01 cp, 0.1 cp and 0.3 cp). In order to study the effect of compressibility factor on inflow performance relationship, three compressibility factor of 0.7, 0.855 md and 0.9 md were investigated as presented in Fig. 7. From this figure, we can observe that there are minimal effect of compressibility factor on inflow performance relationship.

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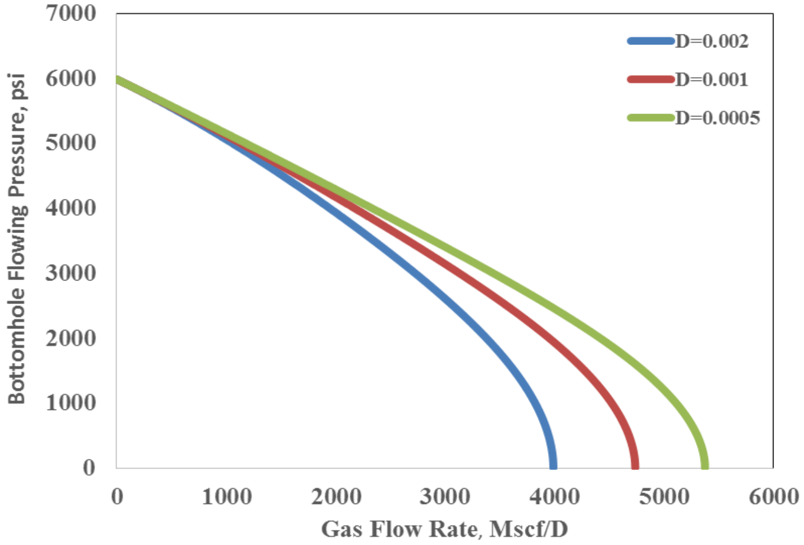

Figure 5 IPR sensitivity analysis of nondarcy coefficient

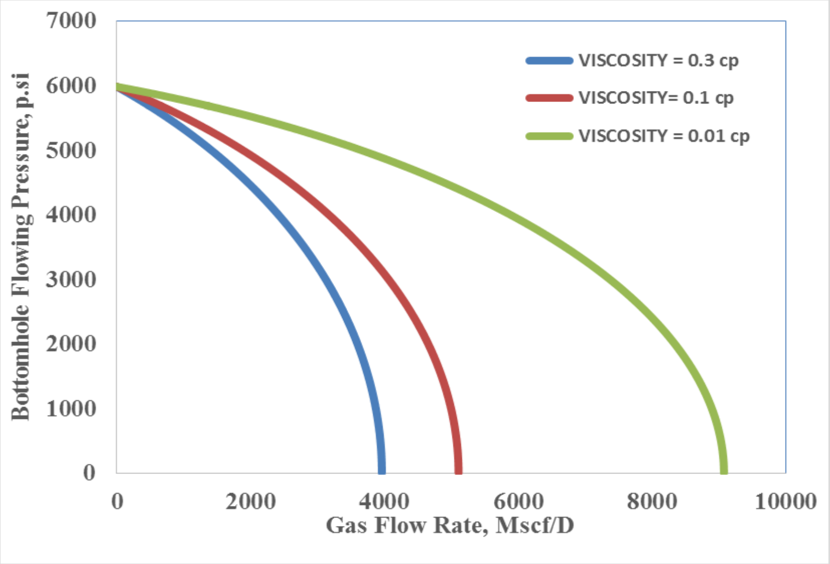

Figure 6 IPR sensitivity analysis of gas viscosity

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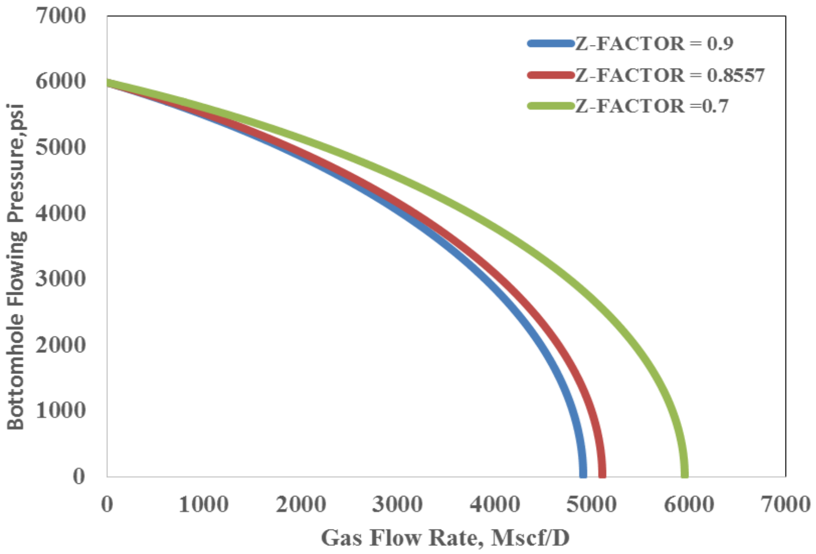

Figure 7 IPR sensitivity analysis of compressibility factor

IV. CONCLUSION

Based on the analysis of the results obtained in this research study, the following conclusions can be made:-

In this study, the skin factor, gas permeability, reservoir temperature, reservoir thickness, nondarcy coefficient, gas viscosity, and compressibility factor were used to see the inflow performance relationship (IPR) sensitivity analysis. There are apparent and significant effects of skin factor, reservoir temperature, nondarcy coefficient and gas viscosity on inflow performance relationship (IPR) of a gas field.

There are minimal effect of gas formation permeability, reservoir thickness and compressibility factor on inflow performance relationship.

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