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A NOVEL APPROACH TO FORECASTING PRODUCTION RATE OF DRY GAS WELLS

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ABSTRACT

Forecasting production rate from gas wells is done mainly by using the standard gas deliverability equations. These equations give the relationship between gas production rate, reservoir pressure and bottom hole flowing pressure. The bottomhole flowing pressure used in the deliverability equations is usually measured at a great cost and with operational challenges. Thus, the need to eliminate the use of bottomhole flowing pressure to make production forecast.

Using the mechanical energy balance equation and the general Forcheimer equation, an approximate mathematical model was developed with which production forecast can be made using wellhead pressure. This new model performed reasonably well when compared with actual field production rate.

Finally, the need to measure the bottom hole flowing pressure before production forecast can be made is no longer compulsory as the model developed in this work can forecast production using wellhead pressure with a high degree of accuracy. The use of wellhead pressure to make production forecast of gas wells will be of great benefit to the oil and gas industry as it allows both technical and economic decisions to be made on time.

1.0 INTRODUCTION

Forecasting of production rate from gas wells is essential to determine gas wells' production capabilities under specified reservoir conditions. The most common method of forecasting production from gas wells is the deliverability testing. A number of testing techniques have been developed to assess a gas well's deliverability potentials such as the flow-after-flow test, isochronal test and modified isochronal test. All the gas well testing methods yield data that are analyzed to predict or forecast production.

The conventional deliverability test analysis technique was proposed by Rawlins and Schellhardt (1935). They observed that a log-log plot of difference between the squares of the average reservoir pressure and the bottomhole flowing pressure against gas flow rate can be represented by a straight line defined by

$$Q_g = C\left[P_r^2 - P_{wf}^2\right]^n \qquad \text{(I)}$$

Where C is defined as the stabilized performance coefficient, and n is the reciprocal of the slope of the straight line. Equation (I) was developed empirically from the the results of a number of gas well tests. This equation does not have a theoretical background but it is familiar and widely used by the natural gas industry.

Subsequently in 1959, a theoretical development by Houpeurt have shown that a more accurate analysis of gas flow is possible using the following equation;

$$P_r^2 - P_{wf}^2 = aQ_g + bQ_g^2 \qquad \text{(II)}$$

Where the flow coefficients, a and b are defined by

$$a = \frac{1.422 U_g Z_g T}{K_g h}\left[ln\left(\frac{r_e}{r_w}\right) - 0.75 + s\right] \qquad \text{(III)}$$

$$b = \frac{1.422 U_g Z_g T D}{K_g h} \qquad \text{(IV)}$$

Equation (II) is a solution to the diffusivity equation for radial flow and it is popularly referred to as the Forcheimer's equation. This equation has a theoretical basis and is rigorously correct. The empirical and the theoretical based Houpeurt equations give relationship between gas production rate, reservoir pressure and bottomhole flowing pressure. The measurement of the bottomhole flowing pressure used in both equations is expensive and comes with operational challenges. Therefore, this paper presents a new approach to overcome these challenges by using wellhead pressure to forecast production rate from gas wells. This new equation was developed by modifying the Forcheimer's equation with an approximate relationship developed between wellhead pressure and bottomhole flowing pressure for a dry gas well. The new equation developed was then applied to surface production data (wellhead pressure and corresponding flow rates) and finally, regression analysis was used to obtain fit and estimate parameters necessary for forecasting production rate.

2.0 THEORETICAL DEVELOPMENT

The analytical expressions developed were based on the following assumptions:

1. The reservoir is a dry gas reservoir under strong water drive
2. Steady-state flow
3. Single phase gas flow
4. Negligible change in kinetic energy
5. Constant average temperature

The fundamental mechanical equation for steady-state flow is expressed as:

$$\frac{144}{\rho}dp + \frac{Udu}{2ag_c} + \frac{g}{g_c}dz + \frac{fU^2}{2g_cD}dL + W_s = 0 \quad (1)$$

In reduced form equation (1) becomes:

$$\frac{144}{\rho}dp + dz + \frac{fU^2}{2g_cD}dL = 0 \quad (2)$$

The equation of state for real gas written in terms of density, ρ is given by;

$$\rho = \frac{2.698P\varphi_g}{ZT} \quad (3)$$

The squared of the velocity of gas flow through a cross section of a vertical pipe is defined as:

$$U^2 = 26.8656\left(\frac{ZTQ_g}{Pd^2}\right)^2 \quad (4)$$

Friction factor proposed by Cullender and Binckley is also given by the equation below;

$$f = \frac{30.9208*10^{-3}d^{-0.056}{\varphi_g}^{-.0065}{Q_g}^{-0.065}}{{U_g}^{-0.065}} \quad (5)$$

Substituting equations (3), (4) and (5) into equation (2) we have;

$$\frac{53.37ZT}{P\varphi_g}dp + dz + \frac{30.9208*10^{-3}d^{-0.056}{\varphi_g}^{-.0065}Q^{-0.065}*26.8656\left(\frac{ZTQ_g}{Pd^2}\right)^2}{2g_cD}dL = 0 \quad (6)$$

(Since the flow is vertical; $dz = dl$)

$$\frac{53.37ZT}{P\varphi_g}dp + dL + \frac{0.1547\left(\frac{ZT}{P}\right)^2\mu^{0.065}Q_g^{1.935}}{d^{5.056}{\varphi_g}^{0.065}}dL = 0 \quad (7)$$

Collecting like terms, we obtained the following equations;

$$\frac{53.37\bar{Z}\bar{T}}{P\varphi_g}dp = -dL\left(1 + \frac{0.1547\left(\frac{\bar{Z}\bar{T}}{P}\right)^2\mu^{0.065}Q_g^{1.935}}{d^{5.056}{\varphi_g}^{0.065}}\right) \quad (8)$$

$$\frac{53.37\bar{Z}\bar{T}}{\varphi_g}dp = -dL\left(P + \frac{0.1547(\bar{Z}\bar{T})^2\mu^{0.065}Q_g^{1.935}\frac{1}{P}}{d^{5.056}{\varphi_g}^{0.065}}\right) \quad (9)$$

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$$\frac{dP}{dL} + \beta_1 P = -\beta_1\beta_2\frac{1}{P} \quad (10)$$

Equation (10) is a first order ordinary differential equation (ODE).

Where,

$$\beta_1 = \frac{\varphi_g}{53.37\bar{Z}\bar{T}}$$

$$\beta_2 = \frac{0.1547(\bar{Z}\bar{T})^2\mu^{0.065}Q_g^{1.935}}{d^{5.056}{\varphi_g}^{0.065}}$$

Solving equation (10) with respect to L, the equation below was obtained;

$$P^2e^{2\beta_1L} = -\beta_2e^{2\beta_1L} + C \quad (11)$$

Furthermore, the appropriate boundary conditions were applied as fllows;
At wellhead, L = 0

$$C = P_{wf}^2 + \beta_2 \tag{12}$$

At the reservoir, L = X

$$C = P_{wh}^2 e^{2\beta_1 X} + \beta_2 e^{2\beta_1 X} \tag{13}$$

Equating equations 12 and 13, we obtained the equation below;

$$P_{wf}^2 \sim P_{wh}^2 + \beta_2 \left(e^{2\beta_1 X} - 1\right) \tag{14}$$

Furthermore, substituting the values of β_1 *and* β_2 into equation (14) we have;

$$P_{wf}^2 \sim P_{wh}^2 + \frac{0.1547(\bar{Z}\bar{T})^2\mu^{0.065}}{d^{5.056}{\varphi_g}^{0.065}}\left(e^{\frac{2\varphi_g X}{53.37\bar{Z}\bar{T}}} - 1\right) Q_g^{1.935} \tag{15}$$

Moreover, combination of equation (15) and the general forchheimer equation gives;

$$P_r^2 - P_{wh}^2 = \Phi_1 Q_g + \Phi_2 Q_g^{1.935} + \Phi_3 Q_g^2 \tag{16}$$

$$\Phi_1 = \frac{1.422 U_g Z_g T D}{K_g h}\left[ln\left(\frac{r_e}{r_w}\right) - 0.75 + s\right]$$

$$\Phi_2 = \frac{0.1547(\bar{Z}\bar{T})^2\mu^{0.065}}{d^{5.056}{\varphi_g}^{0.065}}\left(e^{\frac{2\varphi_g L}{53.37\bar{Z}\bar{T}}} - 1\right)$$

$$\Phi_3 = \frac{1.422 U_g Z_g T D}{K_g h}$$

The coefficients Φ_1, Φ_2 and Φ_3 are termed the production parameters that can be determined by analyzing surface production data at a particular reservoir pressure.

3.0 RESULT AND DISCUSSION

The equation (16) is a new generalized model for forecasting production rate and it is applicable to only dry gas wells. The performance of the new model was evaluated by applying it to test data from dry gas wells. Spreadsheet was developed to evaluate the production parameters and generate production curves for each well. The results obtained are shown in figures 1 - 3.

Figure 1 shows the surface performance curve generated for the gas well under review with which production forecast can be made by correlating the desired wellhead pressure and the corresponding production rate.

Figure 2 shows the comparison of the new model with that of Cullender and Smith. Furthermore, figure 3 shows the comparison of the production forecast made using the new model with field data as well as with the Cullender and Smith model.

The last plot shows that the new model performs excellently when compared with the measured field data.

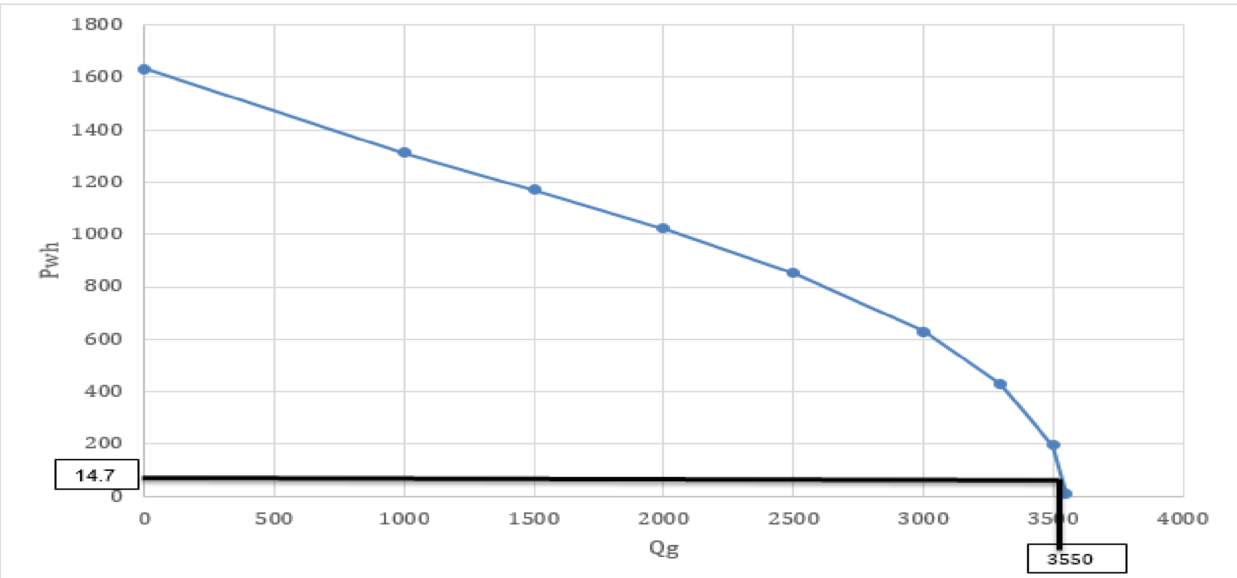

Figure 1. Wellhead Pressure – Gas Production rate Curve generated for the well.
The Absolute open flow of the well evaluated at pressure of 14.70psia is **3550 MMSCFD.**

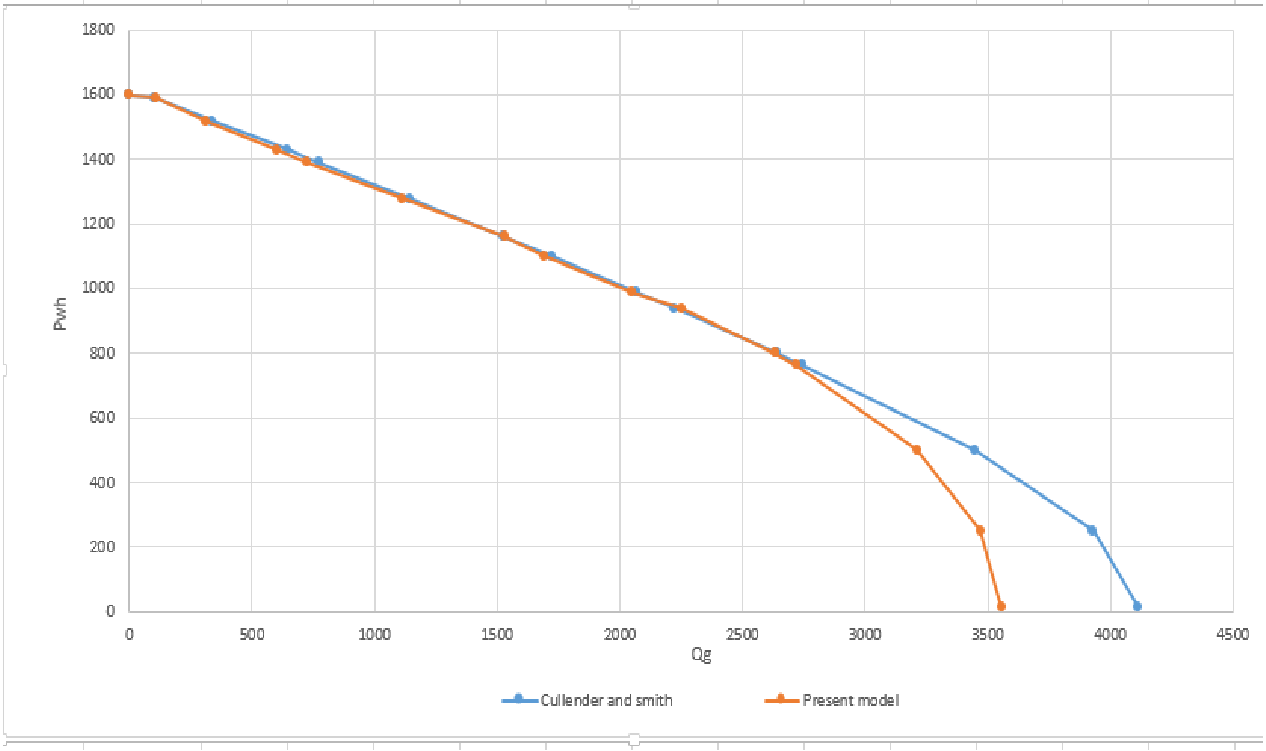

Figure 2: Comparison of the new model with that of Cullender and Smith

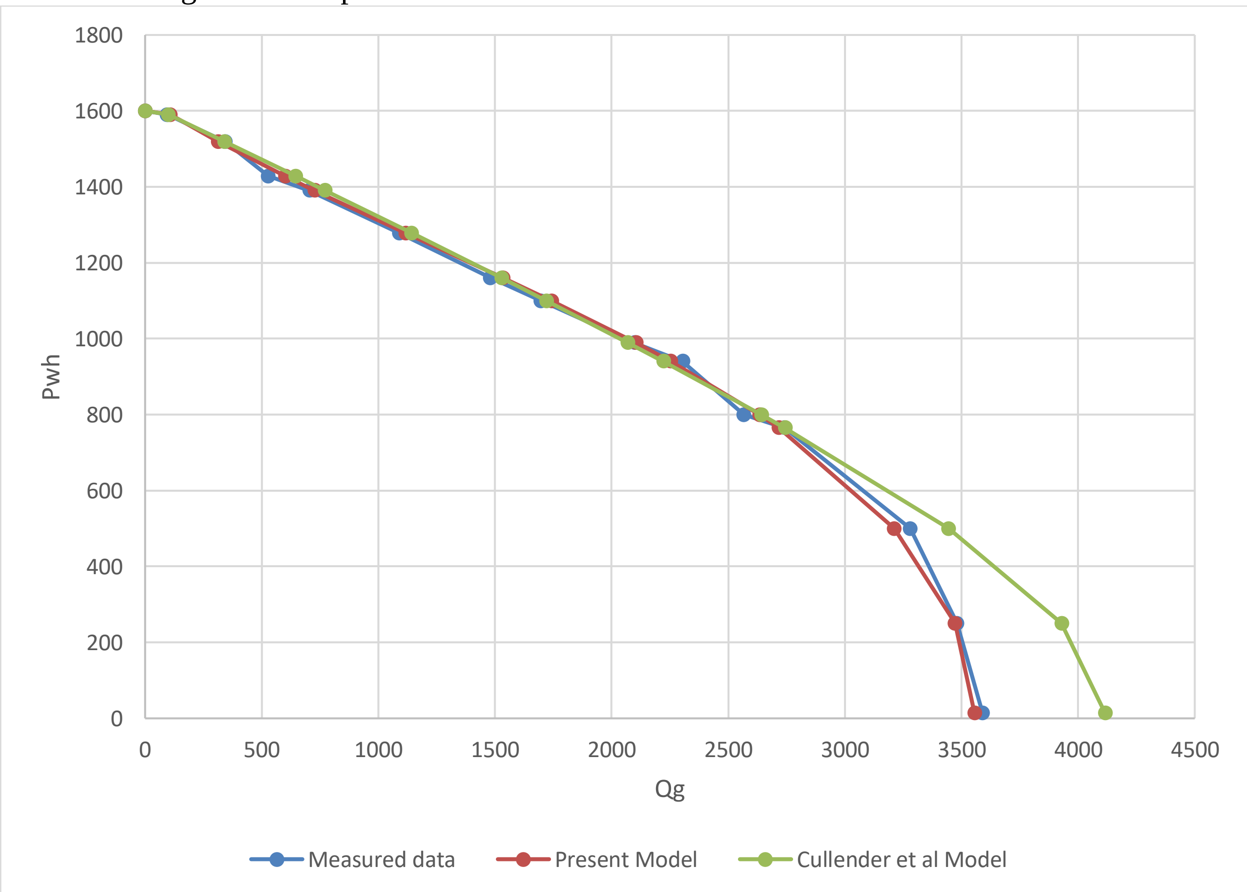

Figure 3: Comparison of the new model with measured field data and Cullender et al model.

4.0 CONCLUSION

The following conclusion can be drawn from this work so far;

1. Using the new model to make production forecast, the result obtained compares well with the measured field data.Hence, some costly transient testing may be avoided

2. There exist an inverse relationship between wellhead pressure and gas production rate, that is, gas production rate increases as the wellhead pressure decreases, which is also the same when the bottomhole flowing pressure is used in making production forecast. Therefore, confirming the direct relationship that exist between wellhead pressure and bottomhole flowing pressure and consequently comfirming the accuracy of equation (15).
3. Production forecast made using wellhead pressure eliminates the extra cost incurred and stabilization time required before bottomhole flowing pressure can be measured. Therefore using wellhead pressure to make forecast is indispensable especially in gas reservoir that does not achieve stabilization.

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NOMENCLATURE

A -Cross sectional area of pipe, ft^2
C – Performance coefficient, $Psia^2$/MSCFD
D- Tubing internal diameter, inches
D'- Turbulent flow factor
f- Friction factor as defined by eqn 5
g- Acceleration due to gravity, ft/sec^2
g_c- Conversion factor, 32.17lbmft/ibfs
G - Gas initially in place, MMSCF
G_p- Total gas produced, MMSCF
h- Reservoir thickness, ft
H- Parameter as defined by eqn 13
K- Permeability, md
M- Apparent molecular mass,
m(p)- Pseudo pressure, $Psia^2$/cp
Φ_2- Representing gas property, $Psia^2/(MMSCFD)^{1.935}$
n - Backpressure component
Φ_1 - Darcy coefficient, $Psia^2$/MMSCFD
Φ_3 - Non Darcy factor, $Psia^2/(MMSCFD)^2$

P_r- Reservoir pressure, Psia
P_{sc}- Pressure of standard condition, Psia
P_{wf}- Bottomhole flowing pressure, Psia
P_{wh} - Wellhead pressure, Psia
Q_g – Gas production rate, MMSCFD
r_e – Drainage reservoir radius, ft
r_w- Wellbore radius, ft
s - Skin
t- Time of production, days
$\bar{T}$- Average Temperature, ^oR
T_{sc}- Temperature of standard condition, ^oR
U- Average velocity, ft/s
φ_g- Specific gravity of gas
μ_g- Gas viscosity, cp
X- Vertical depth, ft
$\bar{Z}$- Gas deviation factor