A SIMPLE ANALYTICAL MODEL FOR ESTIMATING BOTTOM HOLE PRESSURE IN GAS CONDENSATE WELLS

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Abstract

The pressure parameter is a very important fluid property in reservoir engineering computations. The success of pressure transient analysis however, often depends on the accurate measurement or estimation of the bottom hole pressure. Knowledge of how gas condensate and mixture flow simultaneously in vertical pipe is necessary. A simple mathematical model was used to stimulate multiphase system flow from single phase flow and the corresponding mixing rule to the fluid flow pattern of gas condensate was developed that incorporates the effects of slippage at the gas-liquid interface. This method was better for estimating the bottom hole pressure of gas condensate wells than the Sukkar and Cornell in terms of deviation

Keywords: Bottom hole pressure, gas condensate, pressure transient, deviation, multiphase flow

Introduction

The success of pressure transient analysis often depends on the accurate measurement or estimation of the bottom hole pressure. Measurement can be accomplished by a descending probe. The ability to analytically predict the pressure at any point in a flow string is essential in determining optimum production, string dimension and in the design of gas lift installations.

The problem of accurate estimating pressure drops in flowing or gas lift wells have given rise to many specialized solutions for limited conditions; the reason being that the two phase flow is complex and difficult to analyze even for the limited condition studied[(1,2,3,4)]

Under some conditions, gas moves at a much higher velocity than the liquid. At the time of discovery gas condensate are often found containing single phase gas vapour. As reservoirs are being produced, the pressure decreases from the reservoir to the wells and to the surface installations, the down hole flowing density of the gas liquid mixture is greater than the corresponding density corrected for down hole temperature and pressure that would be calculated from the produced gas liquid ratio.

A number of methods are available for accurate estimation of bottom hole pressure in oil well. These are based on multiphase mixture behaved like a homogeneous single phase. However, the

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multiphase fluids behaved as homogeneous mixtures; the gas and liquid phases were assumed to travel at the same velocity, this assumption is known as the "no slip condition" [1,6] . This method developed a simple analytical model for estimating bottom hole pressure in gas condensate well.

Theoretical Framework

A simple analytical model is developed by adapting basic Energy Equation. The basic assumptions were:

1. Steady state flow of fluids was considered throughout the process
2. Change in kinetic energy is small and can be neglected
3. Temperature of the system is assumed constant at some average value
4. Friction is assumed constant over the length of the conduit

Following the basic energy equation[1,3]

$$144Vdp + \frac{Udu}{2\alpha g_c} + \frac{gdz}{g_c} + \frac{fu^2}{2g_c D}dL + W_s = 0 \qquad 1$$

Assuming no mechanical work is done on the fluid or by the fluid and change in kinetic energy is negligible/ Neglecting kinetic energy and shaft work

Equation 1 can be reduced to:

$$144Vdp + \frac{gdz}{g_c} + \frac{fu^2}{2g_c D}dL = 0 \qquad 2$$

The apparent density of a multiphase mixture is defined observing mixing rule[13]

$$\rho_{tp} = \rho_L H_L + \rho_g (1 - H_L) \qquad 3$$

The classic approach to the shut-in bottom pressure calculation originates from the pressure gradient in a gas column

$$\frac{dP}{dH} = \frac{\rho}{144} \qquad 4$$

Density of gas (ρ_g) at a point in a vertical pipe at pressure and temperature[15,17,18]

The pressure in a vertical pipe at temperature with gas density (ρ_g)

$$P = \frac{ZRT\rho_g}{28.97\gamma_g} \qquad 5$$

The density of the liquid (condensate and water) is defined as[16]

$$\rho_L = \left\{ \frac{62.4\gamma_{stc} + 0.0136\gamma_g R_s}{B_{wg}} \right\} h_{stc} + \frac{62.4\gamma_w h_w}{B_w} \qquad 6$$

Mass of well fluid (gas and liquid) is defined as[13]

Mass of the fluid = Mass of the gas + Mass of the liquid

$$M_R = 0.0764\left(R_g \gamma_g\right) + 350\gamma_{stc} \qquad 7$$

Or in gravity as:

$$\gamma_{gR} = \frac{R_g \gamma_g + 4584\gamma_{stc}}{R_g + 132{,}800\gamma_{stc} / MW_{stc}} \qquad 8$$

The molecular weight of the stock tank oil is given by the following correlation:

$$MW_{stc} = 9260.1(API)^{-1.2894}$$

Substituting equation (5) and (6) into to obtain two-phase density/combining equations (5), (6) and (3) for two-phase density

$$\rho_{tp} = \left\{ \frac{\left(62.4\gamma_{stc} + 0.0136\gamma_g R_s\right) h_{stc}}{B_{wg}} + \frac{62.4\gamma_w h_w}{B_w} \right\} H_L + \frac{28.97 P \gamma_g \left(1 - H_L\right)}{ZRT} \qquad 10$$

The velocity of fluid flow at a cross section in a vertical pipe[6]

$$U_m = \frac{q_g + q_L}{A} \qquad 11$$

$$= \frac{1}{A}\left[q_g \left(\frac{P_b}{P}\right)\left(\frac{T}{T_b}\right)\left(\frac{Z}{1}\right)\left(\frac{10^6}{24 \times 3600}\right) + \frac{q_L B_{wg}(5.615)}{24 \times 3600} \right] \; ft^3/\sec \qquad 12$$

$$= \frac{4}{\Pi D^2}\left[q_g \left(\frac{14.65}{P}\right)\left(\frac{T}{520}\right)\left(\frac{Z}{1}\right)\left(\frac{10^6}{86400}\right) + \frac{q_L B_{wg}(5.615)}{86400} \right] \; ft^3/\sec \qquad 13$$

$$U_m = \frac{0.4152 q_g T Z}{P D^2} + \frac{0.000082735 B_{wg} q_L}{D^2} \qquad 14$$

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Replacing equations (10) and (14) and manipulated into the following form:

$$\frac{0.01875\gamma_g L}{\overline{T}} =$$

$$\int_{P_1}^{P_2} \frac{Z\dfrac{dP_r}{P_r}}{\left[1 + C_1\left[\left(\dfrac{Z}{P_r}\right)^2 + C_{11}B_o\left(\dfrac{Z}{P_r}\right) + C_{12}B_o{}^2\right]\right]\left[\left[C_{41}\left[C_{42} + R_s + C_{43}\left(\dfrac{B_o}{B_w}\right)\right]\left(\dfrac{1}{B_o}\right)\left(\dfrac{Z}{P_r}\right) - 1\right]H_L + 1\right]}$$

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plot of the gas deviation factor as a function of pressure and temperature, for the domain of interest

$$Z = 1 + mP_r \qquad 16$$

The equation (16) can be combined with equation (15) to yield:

$$\frac{0.01875\gamma_g L}{\overline{T}} =$$

$$\int_{P_1}^{P_2} \frac{1 + mP_r\dfrac{dP_r}{P_r}}{\left[1 + C_1\left[\left(\dfrac{1 + mP_r}{P_r}\right)^2 + C_{11}B_o\left(\dfrac{1 + mP_r}{P_r}\right) + C_{12}B_o{}^2\right]\right]\left[\left[C_{41}\left[C_{42} + R_s + C_{43}\left(\dfrac{B_o}{B_w}\right)\right]\left(\dfrac{1}{B_o}\right)\left(\dfrac{1 + mP_r}{P_r}\right) - 1\right]H_L + 1\right]}$$

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Result and discussion

Equation (17) is a simple analytical model for estimating bottom hole pressure in gas condensate wells. The results of bottom hole pressure using equation (17) as compare with Sukkar and Cornell are presented in Figures 1 and 2. Equation (17) models accurately bottom hole pressure in gas condensate wells.

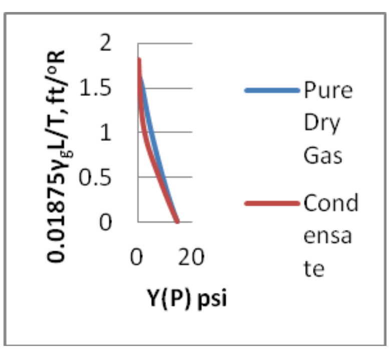

Fig 1: for Pure Dry Gas and Condensate

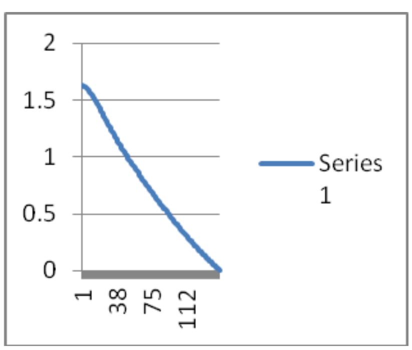

Fig 2: Gas only

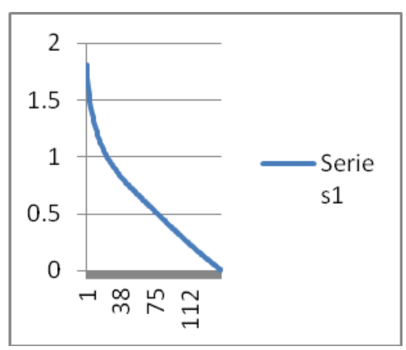

Fig 3: Condensate only

Conclusion

Improved analytical model for estimating bottom hole pressure in gas condensate wells has been developed. The model has a deviation of five (5%) percent as compare to existing Sukkar and Cornel that has a deviation of twenty (20%) percent. If no liquid is produced, the model falls back for the estimation of bottom hole pressure in dry gas wells.

NOMENCLATURE

A – cross sectional area of pipe, ft^2

API – API gravity, degree

B – formation volume factor, $\frac{bbl}{stb}$

D – inside diameter of the pipe, ft

$f_m =$ moody friction factor, dimensionless

g – acceleration due to gravity, $\frac{ft}{\sec^2}$

g_c – conversion factor, 32.17 $\frac{lbmft}{lbfs}$

γ - specific gravity, dimensionless

h – volume fraction in the liquid

H – liquid hold up

L – distance along tubing, ft (for a vertical flow string, L = Z)

M – molecular weight of air, 28.97γ

P – pressure, psia

dp – pressure differential, $\frac{lb}{ft^3}$

PPR – pseudo reduced pressure

q – volumetric flow rate, $\frac{ft^3}{\sec}$

R – gas constant $10.73 \dfrac{ft^3 psia}{lb - mole^o\ R}$

T – temperature, ^oR

T_{pr} – pseudo reduced temperature

T_{pc} – critical temperature

P_{pr} – pseudo reduced pressure

P_{pc} – critical pressure

U – average velocity of the fluid, $\dfrac{ft}{\sec}$

V – specific volume of fluid, $\dfrac{ft^3}{lbm}$

W_s – mechanical work done on or by the gas ($W_s = 0$)

Z – gas compressibility factor, dimensionless

dz – incremental depth

$\dfrac{udu}{2\alpha g_c}$ - pressure drop due to kinetic energy

$\dfrac{fu^2 dl}{2g_c D}$ - pressure drop due to friction effects

ρ - density, $\dfrac{lbm}{ft^3}$

α - correction factor to compensate for the variation of velocity over the tube cross section.

Subscripts

b = base

g = gas

L = liquid

s = solid

stc = stock tank condensate

w = water

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