Question 10-6

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Parameters

$q_o = 4000\ bbl/d$

$GOR = 500\ scf/bbl$

$D = 3$ inches

$\varepsilon = 0.001$

$T = 150°f = 610°R$

$P = 200$ psia

$\sigma_L = 20$ dyne/cm

$\gamma_o = 32°API$

$\gamma_g = 0.71$

$\mu_L = 2cp$

$\mu_g = 0.013\ cp$

$T_{pc} = 395°R$

$P_{pc} = 667\ psi$

Derived parameters

$$z = f\left(\frac{610}{395}, \frac{200}{667}\right) = 0.97$$

$$A = \left(\pi/4\right)\left(3/12\right)^2 = 0.0491\ ft^2$$

$$\gamma_o = \frac{141.5}{32 \cdot 131.5} = 0.865$$

$$\rho_o = 0.866 \times 62.4 = 54\ lbm/ft^3$$

$$\rho_g = \frac{28.97\gamma_g P}{zRT} = \frac{28.97 \times 0.71 \times 200}{0.97 \times 10.73 \times 610}$$

$$= 0.648\ lbm/ft^3$$

$q_g = GOR \times q_o$

$$q_g = 500 \times 4000 = 2 \times 10^6\ ft^3/d$$

Beggs and Brill method

flow regime calculation

$$u_{SL} = \frac{q_L}{A} = \frac{4000 \times 5.615}{86400 \times 0.0491} = 5.2944\ ft/s$$

$u_{sg} = \frac{4}{\pi D} \times \xi \times z \times \left(\frac{T}{T_{sc}}\right) \times \left(\frac{P_{sc}}{P}\right)$

$= \frac{4}{\pi (3/12)^2} \times \frac{2 \times 10^6}{86400} \times 0.97 \times \frac{610}{520} \times \frac{14.7}{200}$

$u_{sg} = 39.4395$ ft/s

$u_m = u_{sl} + u_{sg} = 39.4395 + 5.2944$

$= 44.7339$

$\lambda_l = \frac{5.2944}{44.7339}$

$= 0.11835$

$N_{FR} = \frac{u_m^2}{gD} = \frac{44.7339^2}{32.17 \times 3/12} = 248.918$

$L_1 = 316 \times (0.11835)^{0.302} = 165.876$

$L_2 = 0.0009252 \, (0.11835)^{-2.4684} = 0.1795$

$L_3 = 0.1 \, (0.11835)^{-1.4516} = 2.3151$

$L_4 = 0.5 \, (0.11835)^{-5.738}$

$= 104,023.273$

flow is distributive since $\lambda_1 < 0.4$ and $N_{FR} \geq L_1$

Hold-up calculation

$y_l = y_{L0} \, \psi$

$y_{L0} = \frac{a \lambda_L^b}{N_{FR}^c}$

$y_{L0} = \frac{1.065 \times (0.11835)^{0.5824}}{248.818^{0.0609}}$

$y_{L0} = \frac{0.3073}{1.3993} = 0.21961$

$\rho_n = 54 \times 0.11875 + 0.648 \times 0.88165$
$\rho_n = 6.9622\ lbm/ft^3$

$\mu_n = 2 \times 0.11835 + 0.0131 \times 0.88165$
$= 0.24825$

$N_{Ren} = \frac{\rho_n U_m D}{\mu_n} = \frac{6.9622 \times 24.7339 \times \frac{3}{12}}{6.72 \times 10^{-4} \times 0.24825}$

$N_{Ren} = \frac{934.3391}{2.002 \times 10^{-3}}$

$N_{Ren} = 466728.96$
$= 4.7 \times 10^5$

$F_n = 0.006$

Calculations for x, S, f_{tP}

$x = \frac{\lambda_L}{H_L^2} = \frac{0.11835}{0.21961^2} = 2.454$

$S = \frac{\ln(x)}{[-0.0523 + 3.182\ln(x) - 0.8725[\ln(x)]^2 + 0.01853[\ln(x)]^4]}$

$S = \frac{0.89772}{2.8042 - 0.7031 + 0.012}$

$S = \frac{0.89772}{2.1131} = 0.4248$

$f_{tP} = f_n e^S$

$f_{tP} = 0.006 \times e^{0.4248}$
$= 9.1757 \times 10^{-3}$
$= 0.009176$

Frictional Pressure Gradient Calculation

$\left(\frac{dP}{dZ}\right)_F = \frac{2 f_{tP} \rho_n U_m^2}{g_c D}$

$\frac{dP}{dZ} = \frac{2 \times 0.009176 \times 6.9622 \times 24.7339^2}{32.17 \times \frac{3}{12}}$

$\frac{dP}{dz} = 31.792 \ lbf/ft^3$

$= 31.792 \frac{lbf}{ft^3} \times \frac{1ft^2}{144 in^2}$

$= 0.221 \ psi/ft$

Calculation of mass flowrate.

$m_l = q_l \rho_l$

$q_l = 4000 \frac{bbl}{d} \times \frac{5.615 ft^3}{86400s} = 0.26 \ ft^3/s$

$m_l = 0.26 ft^3/s \times 54 lbm/ft^3 = 14.038 lbm/s$

$m_g = q_g \rho_g$

$q_g = \cancel{2\times10^6} \frac{ft^3}{d} \times \frac{1s}{\cancel{8}64000s} = \cancel{23.1/4s}$

$= A \times u_{gs} = 0.0491 \times 39.4395 = 1.93$

$m_g = 1.936 \times 0.648$

$= 1.255 \ lbm/s$

$m_T = m_l + m_g = 14.038 + 1.255$

$m_m = 15.293 \ lbm/s$

gas velocity (μ_g)

$\mu_g = 0.0131 \times 6.72 \times 10^{-4}$

$= 8.8 \times 10^{-6} \ lbm/ft\text{-sec}$

Calculations f

$\frac{(0.057)(m_g \ m_m)^{0.5}}{\mu_g \ D^{2.25}}$

$\frac{0.057 \times (1.255 \times 15.293)^{0.5}}{8.8\times10^{-6} \ (3/12)^{2.25}}$

$\frac{0.24971}{9.8891\times10^{-7}} = 6.42 \times 10^5$

$\left(\frac{m_l}{m_M}\right)^{0.1} = 0.02$

$f = \frac{0.02}{\left(\frac{14.038}{15.293}\right)^{0.1}} = 0.0202$

$$\left(\frac{dP}{dx}\right) = \frac{f \rho_n u_n^2}{2 g_c D}$$

$$= \frac{0.0202 \times 6.9622 \times 44.7339^2}{2 \times 32.17 \times (3/12)}$$

$$= 17.49 \; lbf/ft^3$$

$$= 0.122 \; psi/ft$$

Duckler correlation

$$\frac{dP}{dx} = \left(\frac{dP}{dx}\right) + \left(\frac{dP}{dx}\right) K_e$$

friction pressure drop

$$\left(\frac{dP}{dx}\right)_f = \frac{f \rho_k u_n^2}{2 g_c D}$$

$$\rho_k = \frac{\rho_L \lambda_L^2}{y_L} + \frac{\rho_g \lambda_g^2}{y_g}$$

Assume $\lambda_L = y_L$

$\rho_k = \rho_n$

$N_{Ren} = N_{Rek}$

$\lambda_L = y_L = 0.11835$

$$\rho_k = \frac{54 \times 0.11835^2}{0.11835} + \frac{0.648 \times 0.88165}{0.88165}$$

$$\rho_k = 6.962 \; lbm/ft^3$$

$$N_{Rek} = 4.7 \times 10^5 \left(\frac{6.962}{6.9622}\right)$$

$$= 4.7 \times 10^5$$

$$f_n = 0.0056 + 0.5 \left(N_{Rek}\right)^{-0.32}$$

$$= 0.0056 + 0.5 \left(4.7 \times 10^5\right)^{-0.32}$$

$$= 0.013$$

$$\frac{f}{f_n} = 1 - \left[\frac{\ln \lambda_L}{1.281 + 0.478 \ln \lambda_L + 0.444 (\ln \lambda_L)^2 + 0.09 (\ln \lambda_L)^3 + 0.00843 (\ln \lambda_L)^4}\right]$$

$$\frac{f}{f_n} = 1 - \left[\frac{-2.134''}{1.281 - 1.0207 + 2.0222 - 0.9136 + 0.1749}\right]$$

$$\frac{f}{f_n} = 1 - (-1.3818)$$

$$\frac{f}{f_n} = 2.3818$$

$$f = f_n \times 2.3818$$
$$f = 0.013 \times 2.3818$$
$$f = 0.031$$

$$\left(\frac{dP}{dx}\right)_f = \frac{f \rho_k V_m^2}{2 g_c D}$$

$$= \frac{0.013 \times 6.962 \times 44.7339^2}{2 \times 32.17 \times 0.25}$$

$$= 11.26\ lbf/ft^2 = 0.078\ PSI/ft$$

Question 10-4

Bakers Correlation

$$A = (\pi/4)(2/12)^2$$
$$A = 0.02182 ft^2$$
$$= \frac{28.97\ \gamma_g\ P}{ZRT}$$
$$= \frac{28.97 \times 0.71 \times 1000}{0.85 \times 10.73 \times 580}$$
$$= 3.89\ lbm/ft^3$$

$$\gamma_o = \frac{141.5}{32 + 131.5} = 0.865$$

$$\rho_o = 0.865 \times 62.4 = 54\ lbm/ft^3$$

$$= \frac{q_L}{A} = \frac{500 \times 5.615}{86400 \times 0.02182} = 1.4892\ ft$$

$$= \frac{4}{\pi D^2} \times q \times Z \times \left(\frac{T}{T_{SC}}\right) \times \left(\frac{P_{SC}}{P}\right)$$

$= \frac{4}{\pi D^2} \times \cancel{\varrho \times Z \times}$

$= \frac{4}{\pi (\frac{7}{12})^2} \times \frac{500000}{86400} \times 0.85 \times \frac{580}{520} \times \frac{14.7}{1000}$

$= 3.697 \text{ ft/s}$

$\lambda = \left[\left(\frac{\rho}{0.075}\right)\left(\frac{\sigma_L}{62.4}\right)\right]^{1/2}$

$\lambda = \left[\left(\frac{3.89}{0.075}\right)\left(\frac{54}{62.4}\right)\right]^{1/2}$

$\lambda = 6.6996$

$\phi = \frac{73}{\sigma_L}\left[\mu_L\left(\frac{62.4}{\rho_L}\right)^2\right]^{1/3}$

$= \frac{73}{20}\left[2\left(\frac{62.4}{54}\right)^2\right]^{1/3}$

$\phi = 5.064$

$G_g = U_{sg} \times \rho_g$
$= 3.697 \times 3.89 \times 3600 = 5.1773 \times 10^4$

$G_L = U_{sL} \times \rho_L$
$= 1.4892 \times 54 \times 3600 = 2.895 \times 10^5$

$\frac{G_g}{\lambda} = \frac{5.1773 \times 10^4}{6.6996} = 7.728 \times 10^3$ //

$\frac{G_L \lambda \phi}{G_g} = \frac{2.895 \times 10^5 \times 6.6996 \times 5.064}{5.1773 \times 10^4} = 189.71$ //

Slug flow // (i.e flow is a function of $\frac{G_g}{\lambda}$, $G_L \lambda \phi$ from Bakers map) mandhaule

flow (usl, usg)

$$VSL = 1.4892\ ft/s$$

$$VSg = 3.697\ ft/s$$

flow Mandhaule flow map

flow regime = slug flow

Beggs and Brills

flow = f (N_{FR}, λ_L)

$$N_{FR} = \frac{u_m^2}{g_D}$$

$$u_m = u_{Sg} + u_{SL}$$

$$u_m = 1.4892 + 3.697 = 5.1862\ ft/s$$

$$g = 32.17\ ft/sec^2$$

$$D = \left(\frac{2}{12}\right) ft$$

$$N_{fr} = \frac{5.1862^2}{32.17 \times \frac{2}{12}} = 5.0165$$

$$\lambda_L = \frac{u_{SL}}{u_{SL} + u_{Sg}} = \frac{1.4592}{1.4592 + 3.697}$$

$$\lambda_L = 0.287$$

flow regime = Intermittent