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15/EN/407/028
PTE 516

(2.) $q_L = 500 bbl/d$

$GOR = 1000 scf/bbl$

$\sigma_L = 20 dynes/cm$, $T = 580°R$

$P = 1000 psia$ $\quad Z = f\left(\frac{580}{395}, \frac{1000}{667}\right) = 0.85$

$\gamma_L = 32°API$, $\gamma_g = 0.71$

$D = 2$ inches

$\mu_L = 2.0 cp$

Baker's Correlation

$A = (\pi/4)(2/12)^2$

$A = 0.02182 ft^2$

$$\rho_g = \frac{28.97\gamma_g P}{ZRT} = \frac{28.97 \times 0.71 \times 1000}{0.85 \times 10.73 \times 580} = 3.89 \, lbm/ft^3$$

$$\gamma_o = \frac{141.5}{32 + 131.5} = 0.865 \quad \rho_o = 0.865 \times 62.4 = 54 lbm/ft^3$$

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

$$V_{sg} = \frac{4}{\pi D^2} \times q \times z \times \left(\frac{T}{T_{sc}}\right) \times \left(\frac{P_{sc}}{P}\right)$$

$$V_{sg} = \frac{4}{\pi\left(\frac{2}{12}\right)^2} \times \frac{500000}{86400} \times 0.85 \times \frac{580}{520} \times \frac{14.7}{1000} = 3.697 ft/s$$

$$\lambda = \left[\left(\frac{\rho_g}{0.075}\right)\frac{\rho_L}{62.4}\right]^{1/2} \qquad \psi = \frac{73}{\sigma_L}\left[\mu_L\left(\frac{62.4}{\rho_L}\right)^2\right]^{1/3}$$

$$\lambda = 6.6996 \qquad = \frac{73}{20}\left[2\left(\frac{62.4}{54}\right)^2\right]^{1/3} = 5.064$$

$Q_g = V_{sg} \times \rho_g$

$= 3.697 \times 3.89 \times 3600 = 5.1773 \times 10^4$

$Q_L = V_{sL} \times \rho_L$

$= 1.4892 \times 54 \times 3600 = 2.895 \times 10^5$

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

$\frac{Q_L \lambda \phi}{Q_g} = \frac{2.895 \times 10^5 \times 6.6996 \times 5.064}{5.1773 \times 10^4}$

$= 189.71$

Slug ~~flow~~ (i.e flow is a function of $\frac{Q_g}{\lambda}$ $\frac{Q_L \lambda \phi}{Q_g}$ from Baker map)

Mandhane

flow (V_{sL}, V_{sg})

$V_{sL} = 1.4892$ ft/s

$V_{sg} = 3.697$ ft/s

Flow mandhane flow map

flow Regime = Slug flow

Beggs and Brill's

flow $= f(N_{FR}, \lambda_L)$

$N_{FR} = \frac{V_m^2}{gD}$

$V_m = V_{sg} + V_{sL}$

$V_m = 1.4892 + 3.697 = 5.1862$ ft/s

$g = 32.17$ ft/sec^2

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

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

$$\lambda_L = \frac{U_{SL}}{U_{SL}+U_{Sg}} = \frac{1.4892}{1.4892+3.697}$$

$\lambda_L = 0.287$

Flow Regime = Intermittent.

(3.) Parameters

$q_o = 4000\,bbl/day$

$GOR = 500\,scf/bbl$

$D = 3\,Inches$

$\varepsilon = 0.001$

$T = 150°F = 610°R$

$P = 200\,psia$

$\sigma_L = 20\,dynes/cm$

$\gamma_o = 32\,API$

$\gamma_g = 0.71$

$\mu_L = 2\,cp$

$\mu_g = 0.0131\,cp$

$T_{pc} = 395°R$

$P_{pc} = 667\,psi$

derived parameter

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

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

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

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

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

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

$q_g = GOR \times q_L$

$q_g = 500 \times 4000 = 2\times10^6\ ft^3/d$

Beggs and Brill Method

Flow Regime Calculation

$V_{SL} = \frac{q_L}{A} = \frac{4000 \times 5.65}{86400 \times 0.0491} = 5.2944\ ft/s$

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

$= \frac{4}{\pi \left(\frac{3}{12}\right)^2} \times \frac{2\times10^6}{86400} \times 0.97 \times \frac{610}{520} \times \frac{14.7}{200}$

$V_{sg} = 39.4395\ ft/s$

$V_m = V_{SL} + V_{sg} = 39.439 + 5.2944$

$= 44.7339$

$\lambda_L = \frac{5.29 \times 4}{44.7339} = 0.11835$

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

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

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

$L_3 = 0.1 (0.11835)^{-1.4516} = 2.2151$

$L_4 = 0.5 (0.11835)^{-5.738} = 104,023.273$

Flow Distribution Since $\lambda_L < 0.4$ and $N_{Fr} \geq L_4$

Hold up Calculation

$y_L = y_{Lo}\,\phi$

$$y_{Lo} = \frac{a\,\lambda_L^{b}}{N_{Fr}^{c}}$$

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

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

$\rho_m = \rho_L \lambda_L + \rho_g \lambda_g$

$\rho_m = 54\times 0.11835 + 0.848\times 0.88165$

$\rho_m = 6.9622\ lbm/ft^3$

$\mu_m = \mu_L \lambda_L + \mu_g \lambda_g$

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

$= 0.24825$

$$N_{Rem} = \frac{\rho_m U_m D}{\mu_m} = \frac{6.9622\times 44.7339\times 3/12}{6.72\times 10^{-4}\times 0.24825}$$

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

$N_{Rem} = 466{,}728.96 \simeq 4.7\times 10^{5}$

$F_n = 0.006$

Calculating x, S, f_{tp}

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

$$S = \frac{\ln(x)}{\left[-0.0528 + 3.182\ln(x) - 0.8725\left[\ln(x)\right] + 0.01853\left[\ln(x)\right]^4\right]}$$

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

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

$f_{tp} = f_n e^S$

$f_{tp} = 0.006 \times e^{0.4248}$

$f_{tp} = 9.1757 \times 10^{-3}$

$= 0.009176$

Frictional Pressure gradient Calculation

$\left(\dfrac{dp}{dz}\right)_f = \dfrac{2 f_{tp} \rho_m U_m^2}{g_c D}$

$\dfrac{dp}{dz} = \dfrac{2 \times 0.009176 \times 6.9622 \times 44.7339^2}{32.17 \times \frac{3}{12}}$

$\dfrac{dp}{dz} = 31.792 lbf/ft^3$

$\dfrac{dp}{dz} = 31.792 \dfrac{lbf}{ft^3} \times \dfrac{1ft^2}{144in^2}$

$\dfrac{dp}{dz} = 0.221 Psi/ft$

Eaton Correlation

Calculation of Mass flowrate

$\dot{m}_L = q_L \rho_L$

$q_L = 4000bbl \times \dfrac{5.615ft^3}{86400sec} = 0.26ft^3/s$

$\dot{m}_L = 0.26ft^3/s \times 54lbm/ft^3 = 14.038lbm/s$

~~Eaton Corr~~

$\dot{m}_g = q_g \rho_g$

$\cancel{q_g = 2\times10^5 \frac{ft^3}{d} \times \frac{1d}{86400 sec}}$

$q_g = A \times u_{sg} = 0.049 \times 39.4395 = 1.936$

$\dot{m}_g = 1.936 \times 0.648$

$= 1.255$ lbm/sec

$\dot{m}_m = \dot{m}_L + \dot{m}_g = 14.038 + 1.255$

$\dot{m}_m = 15.293$ lbm/sec

gas velocity (μ_g)

$\mu_g = 0.0131 \times 6.72\times10^{-4}$

$= 8.8\times10^{-6}$ lbm/ft sec

Calc. f $\frac{(0.057(\dot{m}_g\ \dot{m}_m)^{0.5}}{\mu_g D^{2.25}}$

$\frac{0.057\times(1.255\times15.293)^{0.5}}{8.8\times10^{-6}(3/12)^{2.25}}$

$= 6.42\times10^5$

From fig 10.6 $f\left(\frac{\dot{m}_L}{\dot{m}_m}\right)^{0.1} = 0.02$

$\left(\frac{dp}{dz}\right)_f = \frac{f\rho_m u_m^2}{2g_cD} = \frac{0.0202\times6.9622\times44.7339^2}{2\times32.17\times(3/12)}$

$= 17.496$ lbf/ft^3

$= 0.122$ psi/ft

Duckler Correlation

$$\frac{dp}{dx} = \left(\frac{dp}{dx}\right)_F + \left(\frac{dp}{dx}\right)_{KE}$$

Frictional pressure drop

$$\left(\frac{dp}{dx}\right)_F = \frac{f\,\rho_k U_m^2}{2 g_c D}$$

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

and $N_{ReK} = \frac{\rho_k U_m D}{\mu_m} = N_{Rem}\left(\frac{\rho_k}{\rho_m}\right)$

$\lambda_L = y_L \qquad N_{Rem} = N_{ReK}$

$\rho_k = \rho_m$

$\lambda_L = y_L = 0.11835$

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

$\rho_k = 6.9622\ lbm/ft^3$

$$N_{ReK} = 4.07 \times 10^5 \left(\frac{6.962}{6.9622}\right)$$

$N_{ReK} = 4.7 \times 10^5$

$f_n = 0.0056 + 0.5(N_{ReK})^{-0.32}$

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

$= 0.013$

$$\frac{f}{f_n} = 1 - \left[\frac{\ln \lambda_L}{1.281 + 0.478(\ln\lambda_L) + 0.444(\ln\lambda_L)^2 + 0.094(\ln\lambda_L)^3 + 0.00843(\ln\lambda_L)^4}\right]$$

$\frac{f}{f_n} = 1 - (-1.3878)$

$\frac{f}{f_n} = 2.3878$

$f = f_n \times 2.3818$

$f = 0.013 \times 2.3818$

$f = 0.031$

$$\left(\frac{dp}{dx}\right)_f = \frac{f \rho_k v_m^2}{2 g_c d}$$

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

$= 11.264 \, lbf/ft^2 \approx 0.078 \, psi/ft$

Question(1.)

Horizontal Multiphase Flow Regimes Multiphase flow in horizontal pipes different from that in vertical pipes. Due to the P.E constant in horizontal flow, the flow regime has no significant effect and pressure drop in horizontal flow. However, certain correlation consider flow regime.

Flow Regime can be classified into Segregated Flow (two phase are for the most part separate). Intermittent flow (gas and liquid are alternating). Distributed flow in which one phase is dispersed in the other phase

- Segregated is further divided into:
Stratified Smooth, Stratified Wavy (ripple flow) or annular,
Stratified smooth flow consists of liquid flow along the bottom of the gas.

* Intermittent is divided into
- Slug: High liquid slugs and high velocity gas bubbles plug.

* Distributed Flow
Bubble, mist, dispersed bubble flow

* Flow Regime are predicted
Eq Baker (1953) modified to Scott (1913)

$$\left[\frac{Q_g}{\lambda} \text{ and } \frac{Q_L \lambda \phi}{Q_g} \right]$$

Mandhane (1979)
Beggs and Brills correlation

Taitel and Dukler (1976) A theoretical model used to generate flow regimes map for particular fluid and pipe size.

(f.) Restricted Flow: Refers to flow of fluid under a choke used to control flow due to many factors such as prevention of the causes of sand production.
Fluid flowing through a restriction may be accelerated to reach sonic velocity in the choke. This is the critical condition. As downstream pressure of choke do affect the flowrate.
For single phase liquid flow through choke it is rare for this case, the flowing pressure is below bubble point. Point in case it happens.
Flowrate is related to pressure drop across choke by

$q = CA\sqrt{\frac{2g_c \Delta}{\rho}}$

C = coefficient of choke

A = CS $\quad q_L = 22000\,C\,(D_c^2)\sqrt{\frac{\Delta P}{\rho}}$

D = diameter in inches.