Name: Ijoma Onyenachi
Matric No: 15/ENG07/024
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Question 10-4.

Parameters; $q_o = 500\ bbl/d$ of oil

$q_g = 1000\ scf/bbl$

$d = 2in = 2/12 = 0.1667 ft$

$\sigma_t = 20 dynes/cm$

$T = 120+460 = 580°F$

$P = 1000 psia$

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (2/12)^2}{4} = 0.02182 ft^2$$

Superficial velocities

$$U_{sL} = \frac{q_L}{A} = \frac{500 \times 5.615 \times 1}{0.02182 \times 86400} = 1.4892 ft/s$$

Conversion Factor

$ft^3/day \times day/bbl = 1000$

$\frac{ft^3}{day} \times \frac{1}{bbl/day} = 1000$

$\frac{ft^3}{day} \times \frac{1}{500} = 1000$

$\frac{ft^3}{day} \times 0.002 = 1000$

$q_g = 500,000 ft^3/day$

$$U_{sg} = \frac{4}{\pi (2/12)^2} \times 500,000 \times 0.86 \times \left(\frac{460+120}{460+60}\right) \times \left(\frac{14.7}{1000}\right) \times \frac{1}{86,400}$$

$U_{sg} = 3.74 ft/s$

where $z = 0.86$ from the z-factor graph.

given that $\frac{T}{T_{pc}} = \frac{580}{395} = 1.468 = T_{pr}$

and

$\frac{P}{P_{pc}} = \frac{1000}{667} = 1.49 = P_{pr}$

$Z = 0.86$ from the graph.

Gas Density

$\rho_g = \frac{2.7\gamma_g P}{ZT} = \frac{2.7 \times 0.71 \times 1000}{0.86 \times 580}$

$\rho_g = 3.84\ lbm/ft^3$

$\rho_L = \gamma_L \times 62.4$

when $API = \frac{141.5}{S_g} - 131.5$

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

$\rho_L = 0.865 \times 62.4 = 54.00\ lbm/ft^3$

Baker Correlation

First, compute the mass fluxes, G_L and G_g and parameter λ and ϕ

Recall;

$G_L = U_{SL}\rho_L = 1.4893\ ft/sec \times 54\ lbm/ft^3 \times 3600\ sec/hr$

$= 2.89 \times 10^5\ lbm/hr\text{-}ft^3$

$G_g = U_{sg}\rho_g = 3.74\ ft/sec \times 3.84\ lbm/ft^3 \times 3600\ sec/hr$

$= 51701.76 \simeq 5.17 \times 10^4\ lbm/hr\text{-}ft^2$

For parameters ϕ and λ

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

$\lambda = \left[\left(\frac{3.84}{0.075}\right)\left(\frac{54.00}{62.4}\right)\right]^{1/2} = 6.65$

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

$$\phi = \frac{73}{20}\left[2\left(\frac{62.4}{54}\right)^2\right]^{1/3} = 3.65\times\left[2.6706\right]^{1/3}$$

$$\phi = 5.064$$

For Coordinates

$$\frac{G_g}{\lambda} = \frac{5.17\times10^4}{6.65} = 7774.4 = 7.77\times10^3$$

$$\frac{G_L\lambda\phi}{G_g} = \frac{2.59\times10^5\times6.65\times5.064}{5.17\times10^4} = 188.24$$

From figure 10-2, It can be predicted that the flow regime is "SLUG FLOW".

Mandhane Map

The Mandhane map (fig 10-3) is simply a plot of superficial liquid viscosity verses superficial gas velocity. For values of;

$U_{sL} = 1.4892\ ft/s$

$U_{sg} = 3.74\ ft/s$

It can be predicted from fig 10-3 to be "SLUG FLOW"

The Beggs and Brill Map

Recall; $N_{FR} = \frac{U_m^2}{gD}$

where $U_m = U_{sL} + U_{sg} = 1.4892 + 3.74 = 5.2292\ ft/s$

$$N_{FR} = \frac{5.2292^2}{32.17\times{}^{2}/_{12}} = 5.10$$

$$\lambda_L = \frac{U_{sL}}{U_m} = \frac{1.4892}{5.2292} = 0.285$$

From fig 10-4, the flow regime can be predicted to be "INTERMITTENT FLOW REGIME"

Question 10-6.

Parameters; $q_o = 4000 bbl/d$

$q_g = 500 scf/bbl$

$d = 3in = 3/12 = 0.25 ft$

$\ell = 0.001$

$T = 150°F = 610°R$

$P = 200 psia$

$\sigma_t = 20 dynes/cm$

Solution

$$A = \frac{\pi d^2}{4} = \frac{\pi \times 0.25^2}{4} = 0.0491 ft^2$$

Recall; $$U_{SL} = \frac{q_L}{A} = \frac{4000 \times 5.615 \times 1}{0.0491 \times 86,400}$$

$U_{SL} \Rightarrow 5.294 ft/s$

Conversion factor

$$\frac{ft^3}{day} \times \frac{1}{bbl/day} = 500$$

$$\frac{ft^3}{day} \times \frac{1}{4000} = 500$$

$$\frac{ft^3}{day} \times 2.5 \times 10^{-4} = 500$$

$q_g = 2000000 ft^3/day$.

To find Z-factor

$$\frac{T}{T_{pc}} = \frac{610}{395} = 1.54 = T_{pr}$$

$$\frac{P}{P_{pc}} = \frac{200}{667} = 0.29 = P_{pr}$$

From the chart $Z = 0.97$

$$U_{sg} = \frac{4}{\pi \times 0.25^2} \times 2000000 \times 0.97 \times \left(\frac{460+150}{460+60}\right) \times \left(\frac{14.7}{200}\right) \times \frac{1}{86400}$$

$U_{sg} = 39.4395 ft/s$

$U_m = U_{sL} + U_{sg} = 5.294 + 39.4395 = 44.7445 ft/s$

Beggs and Brill Correlation

$$N_{FR} = \frac{U_m^2}{gD} = \frac{44.7445^2}{32.17 \times 3/12} = 248.9316$$

$$\lambda_L = \frac{U_{sL}}{U_m} = \frac{5.294}{44.7445} = 0.1183$$

From the graph of the flow regime is "distributive flow regime"

To calculate the hold up for horizontal flow

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

where $a = 1.065$, $b = 0.5824$, $c = 0.0609$

$$y_{Lo} = \frac{1.065 \times 0.1183^{0.5824}}{248.936^{0.0609}}$$

$y_{Lo} = 0.21955$

$$\lambda_g = \frac{U_{sg}}{U_m} = \frac{39.4395}{44.7445} = 0.881$$

Gas Density;

$$\rho_g = \frac{2.7 \times 0.71 \times 200}{0.97 \times 610} = 0.6479$$

Liquid Density;

$\rho_L = 0.865 \times 62.4 = 54.00 \ lbm/ft^3$

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

$\rho_m = 54 \times 0.1183 + 0.6479 \times 0.881$

$\rho_m = 6.3882 + 0.57079$

$\rho_m = 6.95899$

From equation 7-146;

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

$\mu_m = 2 \times 0.1183 + 0.0131 \times 0.881$

$\mu_m = 0.2366 + 0.0115411$

$\mu_m = 0.248$

From equation 7-145;

$$N_{Rem} = \frac{\rho_m u_m D}{\mu_m}$$

$$N_{Rem} = \frac{6.95899 \times 44.7445 \times 0.25}{0.248 \times 6.72 \times 10^{-4}\ lbm/ft\text{-}sec}$$

$N_{Rem} = 467{,}094 = 4.7 \times 10^5$

From fig 7.7 with respect to 0.001 for ε

$f = 0.006$

Recall;

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

$$\text{where } x = \frac{\lambda_L}{y_L^2} = \frac{0.1183}{0.21955^2} = 2.45$$

$$S_n = \frac{\ln(2.45)}{-0.0523 + 3.182\ln(2.45) - 0.8725(\ln(2.45))^2 + 0.01853[\ln(2.45)]^4}$$

$$S_n = \frac{0.896}{-0.0523 + 3.182 \times 0.896 - 0.8725 \times 0.80277 + 0.01853 \times 0.644767}$$

$$S_n = \frac{0.896}{-0.0523 + 2.851 - 0.70059 + 0.011947}$$

$$S_n = \frac{0.896}{2.110057}$$

$S_n = 0.4246$

Recall; $f_{tp} = f_n \rho^s$

$f_{tp} = 0.006 \times \rho^{0.4246}$

$f_{tp} = 0.006 \times 1.5289$

$f_{tp} = 0.009174$

from equation (7-142)

$$\frac{dP}{dx} = \frac{2 f_{tp} \rho_m U_m^2}{g_c D}$$

$$\frac{dP}{dx} = \frac{2 \times 0.009174 \times 6.95899 \times 44.7445^2}{32.17 \times 0.25}$$

$$\frac{dP}{dx} = 31.785 \ lb_f/ft^3$$

$$\simeq \frac{31.785 \ lb_f/ft^3}{144}$$

$$\simeq 0.22 \ psi/ft$$

Eaton Correlation

$$U_L = \frac{q}{A}$$

$U_L \times A = q_L = 5.294 \times 0.0491$

$= 0.2599 \ ft^3/sec$

$U_g \times A = q_g = 39.4395 \times 0.0491$

$q_g = 1.936 \ ft^3/sec$

Recall;

$\dot{m}_L = q_L \rho_L = 0.2599 \times 54 = 14.0346$

$\dot{m}_g = q_g \rho_g = 1.936 \times 0.6479 = 1.254$

$\dot{m}_m = \dot{m}_L + \dot{m}_g = 14.0346 + 1.254 = 15.2889 \ lbm/sec$

The gas viscosity is;

$\mu_g = 0.013 \ cp \times 6.72 \times 10^{-4} \ lbm/ft\text{-}sec\text{-}cp$

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

friction factor, f;

Recall; $$\frac{0.057 (\dot{m}_g \dot{m}_m)^{0.5}}{\mu_g D^{2.25}}$$

$$= \frac{0.057 \times (1.254 \times 15.2889)^{0.5}}{8.8 \times 10^{-6} \times 0.25^{2.25}}$$

$$= \frac{0.24958}{3.889 \times 10^{-7}}$$

$$= 641758.8 \simeq 6.4 \times 10^{5}$$

~~Re~~ from fig 7.6;

$$f\left(\frac{\dot{m}_L}{\dot{m}_m}\right)^{0.1} = 0.02 \quad \text{using 3in diameter pipe.}$$

where $f = \frac{0.02}{(14.0346 \div 15.2889)^{0.1}} = 0.02017$

Now, Neglecting the kinetic energy;

$$\left(\frac{dp}{dx}\right)_f = \frac{f \rho_m U_m^2}{2 g_c D}$$

$$\left(\frac{dp}{dx}\right)_f = \frac{0.02017 \times 6.95899 \times 44.7445^2}{2 \times 32.17 \times 0.25}$$

$$\left(\frac{dp}{dx}\right)_f = \frac{17.471 \, lbf/ft^3}{144}$$

$$= 0.121 \, psi/ft.$$

Dukler Correlation

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

Frictional pressure drop

$$\left(\frac{dp}{dx}\right)_f = \frac{f \rho_K U_m^2}{2 g_c D} \quad \text{---- (10-47)}$$

$$\rho_K = \frac{\rho_L \lambda_L^2}{y_L} + \frac{\rho_g \lambda_g^2}{y_g} \quad \text{--- (10-48)}$$

$$N_{Rek} = \frac{\rho_k v_m D}{\mu_m} = N_{Rem}\left(\frac{\rho_k}{\rho_m}\right)$$

Assuming that $\lambda_L = y_L$

$\rho_k = \rho_m$

$N_{Rem} = N_{Rek}$

$\lambda_L = y_L = 0.11835$

$$\rho_k = \left(54 \times 0.11835^2 / 0.11835\right) + \left(\frac{0.648 \times \cancel{0.88165}^2}{0.88155}\right)$$

$\rho_{k} = 5$

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

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

$$f_n = 0.0056 + 0.6(N_{Rek})^{-0.32}$$

$$= 0.0056 + 0.6(0.7 \times 10^5)^{-0.32}$$

$$= 0.013$$

$$\frac{f}{f_n} = 1 - \left[\frac{\ln \lambda_L}{1.281 + 0.678 \ln \lambda_L + 0.444(\ln \lambda_L)^2 + 0.098(\ln \lambda_L)^3 + 0.00843(\ln \lambda_L)^4}\right]$$

$$\frac{f}{f_n} = 1 - \left[\frac{-2.138}{1.281 - 1.0201 + 2.0322 - 0.9136 + 0.1744}\right]$$

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

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

$f = f_n \times 2.3818$

$f = 0.013 \times 2.3818$

$f = 0.031$

Pressure gradient;

$$\left(\frac{dP}{dx}\right)_f = \frac{f \rho_k v_m^2}{2 g_c D} = \frac{0.013 \times 6.963 \times 44.7339^2}{2 \times 32.17 \times 0.25}$$

$$\Rightarrow \frac{11.26 \ lbf/ft^3}{144} = 0.07819 \ psi/ft$$

Question One:

Horizontal Multiphase flow Regimes

The text describes the different types of flow regimes and their classifications on horizontal multi-phase flow. Flow regimes are categorised into three distinct types namely; Segregated flow, intermittent flow and distributive flow. Theses flow regimes occur only in horizontal gas-liquid flow because potential energy contribution to pressure drop in horizontal flow does not exist.

The distributive flow as illustrated in figure 10-1, one phase spreads into the other phase. Other flow regimes under distributive flow regime include the bubble, mist, dispersed bubble and froth flow. The bubble flow regime appears as gas bubbles at the upper part of the horizontal pipe. The mist flow regime contains entrained liquid droplets having gases in them at high and low gas and liquid rates. While the froth flow are known as either annular or mist-flow regime.

The slug and plug flow are the two basic types of intermittent flow regimes, where liquid and gas occur in turn repeatedly. The plug flow consists of gas bubbles joining to form large gas plugs flowing at the top of the horizontal pipe or else filled with liquid. While the high velocity bubbles of gas switching to large liquid slugs in the pipe makes up the slug flow.

On the other, the segregated flow is divided into three types namely; Stratified wavy (ripple flow), Stratified Smooth and annular flow. The annular flow is made up of liquid coating all around the pipe walls and gas flowing in the middle, possibly with liquid droplets traveling along it at high gas rate in relation with high liquid rates. For the stratified Smooth flow, it occurs at relatively low rate with the gas flowing at the top of the pipe while the liquid flows along the bottom of the pipe without difficulties. While the stratified wavy flow occurs at as result of high gas velocities, compared to the stratified flow. Waves form as a result of friction between two points.

In conclusion, the knowledge of different flow regimes in horizontal multi-phase flow provides solutions in the production and transportation of large volume liquids in the oil and gas industry.

Question four:

Flow through Restriction

This section describes the flow of liquid and gas through a restriction wellhead choke, giving an insight on both single-phase liquid flow and single-phase gas flow through the choke. It also illustrates the relationship between choke flow coefficient, Reynold's number and choke diameter.

The flow of a single-phase liquid through a restriction exist as a result of pressure drop across a choke when kinetic energy changes. A graphical relationship between the flow rate (q) and the pressure ratio between the upstream and downstream pressures is depicted in figure 10-10. From the graph it can be seen that with an increase in pressure ratio, the flowrate remains constant within the critical regime. While an increase in pressure ratio in the sub-critical regime results in a decrease in flow rate (q). If this pressure ratio is less than a critical pressure ratio, critical flow exists. If this pressure ratio is greater than or equal to the critical pressure ratio, a subcritical flow exists.

On the other hand, the single phase gas flow through restriction occurs as a result of the expansion of fluid through a choke, which is usually based on a constant heat loss and a pressure ratio of P_2/P_1. The graph 10-12 gives the maximum gas flow when the flow is at

Critical:

In summary, the study of the flow through chokes is applied in daily petroleum engineer operations including the prevention of coning & sand production, meeting limitations of rate imposed by surface equipment.

Question 10-11

Parameters; $P = 1000psi$

Choke sizes; $8/64$, $12/64$, $16/64 in$

Assuming that GLR to be $500 scf/bbl$

Solution

Using $P_1 = \frac{A q_L (GLR)^B}{D_{64}^C}$ from equ (10-75)

where $A = 10$, $B = 0.546$, $C = 1.89$

Assuming Gilbert Correlation

Choke Size $8/64 in$;

$$P_{wf} = \frac{10 \times q_L (500)^{0.546}}{(8)^{1.89}}$$

$$P_{wf} = \frac{297.6032 q_L}{50.914} = 5.84 q_L$$

Choke size $16/64 in$;

$$P_{wf} = \frac{10 \times q_L (500)^{0.546}}{(16)^{1.89}}$$

$$P_{wf} = \frac{297.603 q_L}{188.706}$$

$$P_{wf} = 1.577 q_L$$

Choke Size $12/64 in$;

$$P_{wf} = \frac{10 \times q_L (500)^{0.546}}{(12)^{1.89}}$$

$$P_{wf} = \frac{297.6032 q_L}{109.56}$$

$$P_{wf} = 2.716 q_L$$

Flow rate Calculation

Choke size $8/64$ in; at $P_1 = 4350$ psi

$P_4 = 5.84 q_L$

$\Rightarrow \frac{4350 - 14.7}{5.84} = q_L$

$q_L = 742.34$

$P_2 = 3000$ psi

$\Rightarrow \frac{(3000 - 14.7)}{5.84} = q_L$

$q_L = 511.181$ bbl/day

At $P_3 = 2000$ psi

$\Rightarrow \frac{(2000 - 14.7)}{5.84} = q_L$

$q_L = 339.94$ bbl/day

At $P_4 = 1000$ psi

$\Rightarrow \frac{(1000 - 14.7)}{5.84} = q_L$

$q_L = 168.71$ bbl/day

Choke size $12/64$ in

$P_1 = 4350$ psi

$P_{tf} = 2.7163 q_L$

$\frac{4350 - 14.7}{2.7163} = q_L$

$q_L = 1596.03$ bbl/day

$P_2 = 3000$

$\frac{3000 - 14.7}{2.7163} = q_L$

$q_L = 1099.03$ bbl/day

At $P_3 = 2000$

$\frac{2000 - 14.7}{2.7163} = q_L$

$q_L = 730.88$
$P_4 = 1000$
$\Rightarrow \frac{1000 - 14.7}{2.7163} = q_L$
$q_L = 362.74$ bbl/day

Choke size 16/64 in
$P_1 = 4350$ psia
$P_4 = 1.577 q_L$
$\frac{4350 - 14.7}{1.577} = q_L$

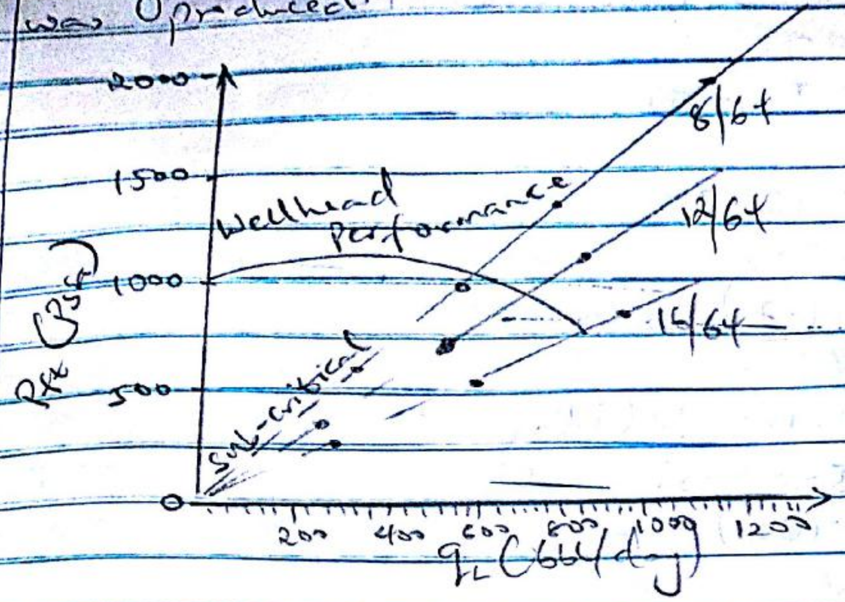
$q_L = 2749.08$ bbl/day
At $P_2 = 3000$ psia
$\left(\frac{3000 - 14.7}{1.577}\right) = q_L$

$q_L = 1893$ bbl/day
At $P_3 = 2000$ psia
$\left(\frac{2000 - 14.7}{1.577}\right) = q_L$

~~At~~ $\cancel{P_4}$ $q_L = 1258.90$ bbl/day
At $P_4 = 1000$ psia
$\left(\frac{1000 - 14.7}{1.577}\right) = q_L$

$q_L = 624.8$ bbl/day.

Using the values calculated, the below graph was produced.



Choke performance curves