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15/ENG07/031

PTE 516 ASSIGNMENT

Question 10-4 a

Classifications of Horizontal Multiphase Flow Regimes

The Beggs and Brill Correlation, can be applied to any flow direction (horizontal or vertical) although two-phase flow in horizontal pipes is different from that in vertical pipes. Flow regimes in horizontal flow does not affect the pressure drop as significantly as it does in vertical flow, because there is no potential energy contribution to the pressure drop in horizontal flow. Slugs are an important consideration when designing slug catchers or separators especially in offshore operation where fluids are transported long distances.

The classifications of flow regimes seen in horizontal flows are:

i. Segregated Flows: Here, liquid flows along the bottom of the pipe while gas flows along the top of the pipe. The two phases (gas and liquid) are for the most part separate and are further classified as stratified smooth flow, stratified wavy (ripple flow) and annular flow. Their differences are seen in the table below;

Stratified Smooth Flow	**Stratified Wavy Flow**	**Annular Flow**
a. Occurs at relatively low rates of both phases.	Occurs at higher gas rates.	Occurs at high gas rates and relatively high liquid rates
b. There is a smooth interface between the two phases.	There is a wavy interface between the two phases.	There is an annulus of liquid coating the wall of the pipe and a central core of gas flow, with liquid droplets entrained in the gas.

ii. Intermittent Flows: These are horizontal flows in which gas and liquid are alternating. It is classified into two major types: slug flow and plug (elongated bubble). Their difference is seen below:

Slug Flow	**Plug Flow**
a. Consists of large liquid slugs alternating with high-velocity bubbles of gas	Large gas bubbles flow along the top of the pipe, which is otherwise filled with liquid.

iii. Distributive Flow Regime: These are flow regimes in which one phase is dispersed in the other phase. It is classified into bubble, dispersed bubble, mist and froth flow. For the horizontal flow, the gas bubbles are concentrated on the upper side of the pipe. Mist flows, sometimes referred to as ‘annular mist’, occurs at high gas rates and low liquid rates and consists of gas with liquid droplets entrained. Froth flow also describes the mist or annular mist flow regime.

Question 10-11 a

Flow through Restriction on both single-phase liquid flow and single-phase gas flow

Pressure drops caused by fluids passing through pipe fittings (tees, elbows, etc.) or valves, secondary flows and additional turbulence, must be included to determine the overall pressure drop in a piping network. This is done by adding the equivalent length of the valves and fittings to the actual length of a straight pipe when calculating pressure drop.

Flow Through Chokes

A wellhead choke is a device that places a restriction in a flowline and is used to control the fowrate for most flowing wells. When gas or gas-liquid mixtures flow through a choke, the fluid is critical and may reach sonic velocity in the throat of the choke. To predict the flowrate-pressure drop relationship for compressible fluids flowing through a choke, it is important to determine whether or not the flow is critical. The device in the choke that restricts the flow is called the bean (64ths of an inch).

Flow through a restriction (choke) on single-phase liquid flow

A single-phase liquid rarely passes through a wellhead choke because the flowing tubing pressure is almost always below the bubble point. However, when it occurs, the flowrate is related to the pressure drop across the choke by the formular below;

$$q=CA\sqrt{\frac{2g_c\,\Delta p}{\rho}} \text{ .... (3)}$$

This is based on the assumption that the pressure drop through the choke is equal to the kinetic energy pressure drop divided by the square of a drag coefficient. A single phase liquid flow is usually a subcritical flow.

In oilfield units, Eq. 3 becomes

$$Q = 22{,}800 * C * (D_2)^2 \sqrt{\frac{\Delta p}{\rho}} \text{ .... (4)}$$

Where q = Flowrate (bbl/d)

D_2 = Choke diameter (in.)

Δp = Change in Pressure (psi)

P = Density (lbm/ft^3)

A = Cross sectional area of the choke.

C = Flow coefficient of the choke

Flow through a restriction (choke) on single-phase gas flow

A fluid expands when a compressible fluid passes through a restriction. It is commonly assumed that flow through a choke is critical whenever the downstream pressure is less than about half of the upstream pressure. For isentropic flow of an ideal gas through a choke, the rate is related to the pressure ratio, p2/p1 (when the pressure ratio is equal to or greater than the critical pressure ratio), by the equation below;

$$q_g = \frac{\pi}{4} D_2^2 p_1 \frac{T_{sc}}{p_{sc}} \alpha \sqrt{\left(\frac{2 g_c R}{28.97 \gamma_g T_1}\right)\left(\frac{\gamma}{\gamma - 1}\right)\left[\left(\frac{p_2}{p_1}\right)^{2/\gamma} - \left(\frac{p_2}{p_1}\right)^{(\gamma+1)/\gamma}\right]}$$ ……… (5)

In oilfield units;

$$q_g = 3.505 D_{64}^2 \left(\frac{p_1}{p_{sc}}\right) \alpha \sqrt{\left(\frac{1}{\gamma_g T_1}\right)\left(\frac{\gamma}{\gamma - 1}\right)\left[\left(\frac{p_2}{p_1}\right)^{2/\gamma} - \left(\frac{p_2}{p_1}\right)^{(\gamma+1)/\gamma}\right]}$$ ………… (6)

Where q_g is in MSCF/d

D_{64} = Choke diameter

T_1 = Temperature upstream of choke (^oR)

ϒ = Heat capacity Ratio

$ϒ_g$ = Gas gravity

The pressure ratio is given by;

$$\left(\frac{p_2}{p_1}\right)_c = \left(\frac{2}{\gamma + 1}\right)^{\gamma/(\gamma - 1)}$$ ………… (7)

QUESTION 10-4

$q_L = 500\,bbl/d$

$q_L = \frac{500}{1} \times 5.615\,ft^3/d \times 1d/86400s$

$q_L = 0.0325\,ft^3/s$

$GOR = 1000\,scf/bbl = 1000\,ft^3/\cancel{bbl/day} = \frac{1}{bbl/day} \times ft^3/day$

$1000\,ft^3/\cancel{bbl/day} = 1/500 \times ft^3/day$

$GOR = \frac{q_g}{q_L}$; $q_g = GOR \times q_L = 500{,}000\,ft^3/day$

$\sigma_L = 20\,dynes/cm$; $P = 1000\,psia$; $\rho_g = ?$

$T = 120°F = 580°R$; $T_{pc} = 395°R$; $\rho_L = ?$

$P_{pc} = 667\,psi$; $\mu_g = 0.0131$

$\gamma_o = 32°API$, $\gamma_g = 0.71$; $D = 2in$; $\mu_L = 2\,cp$

$Z = (T_{pr}, P_{pr}) = \left(\frac{580}{395}, \frac{1000}{667}\right)$

$Z = (1.47, 1.49) = 0.85$

$A_p = \frac{\pi d^2}{4} = \frac{\pi \times \left(\frac{2}{12}\right)^2}{4} = 0.022\,ft^2$

$U_{SL} = \frac{q_L}{A_p} = \frac{0.0325}{0.022} = 1.477\,ft/s$

$U_{sg} = \frac{q_g}{A_p} \times Z \times \frac{T}{T_{sc}} \times \frac{P_{sc}}{P}$

$U_{sg} = \frac{500{,}000}{0.022} \times 0.85 \times \frac{580}{520} \times \frac{14.7}{1000} \times \frac{1}{86400}$

$U_{sg} = 3.67\,ft/s$

$U_m = U_{SL} + U_{sg}$

$U_m = (1.48 + 3.67)\,ft/s = 5.15\,ft/s$

(a) for Bakers Correlation

$G_L = U_{SL}\,\rho_L$

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

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

and $\rho_g = \frac{28.97 \times \gamma_g \times P}{ZRT}$

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

$G_L = 1.48 \times 54\,lbm/ft^3 \times 3600\,sec/hr$

$= 2.88 \times 10^5\ lbm/hr\text{-}ft^2$

$G_g = U_{sg}\,\rho_g$

$= 3.67 \times 3.89\ lbm/ft^3 \times 3600\,sec/hr$

$= 5.14 \times 10^4\ lbm/hr\text{-}ft^2$

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

$$\lambda = \left[\frac{3.89}{0.075} \times \frac{54}{62.4}\right]^{1/2} = 6.67$$

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

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

The coordinates for the Baker Map are

$$\frac{G_g}{\lambda} = \frac{5.14 \times 10^4}{6.67} = 7706.15 \quad \text{or } 7.71 \times 10^3$$

$$\frac{G_L \lambda \phi}{G_g} = \frac{2.88 \times 10^5 \times 6.67 \times 5.064}{5.14 \times 10^4} = 189.26$$

From the Baker flow regime map, the flow regime is predicted to be slug flow using the values of $\frac{G_g}{\lambda}$ and $\frac{G_L \lambda \phi}{G_g}$ gotten above.

(b) The Mandhane map is a plot of superficial liquid velocity (U_{SL}) against superficial gas velocity (U_{sg}) with values of 1.48ft/s and 3.67ft/s respectively as calculated above. With these values, the flow is predicted to be 'Slug flow'.

(c) The Beggs & Brill map plots the N_{Fr} against the Input liquid content, λ_L

$$N_{Fr} = \frac{U_m^2}{gd} = \frac{5.15^2}{32.17 \times \frac{2}{12}}$$

$$N_{Fr} = 4.95$$

$$\lambda_L = \frac{U_{SL}}{U_m} = \frac{1.48}{5.15}$$

$$\lambda_L = 0.287$$

From the Beggs & Brill regime map, the flow regime is predicted to be intermittent.

Question 10-6

$q_o = 4000 bbl/d = 4000 \frac{bbl}{day} \times 5.615 \ ft^3/b \times 1d/86400 sec$

$= 0.26 \ ft^3/s$

$GOR = 500 \ scf/bbl$

$GOR = q_g/q_L$, $\mu_g = 0.0131 cp$; $\mu_L = 2 cp$

$q_g = GOR \times q_L = 500 \times 4000$

$q_g = 2,000,000 \ ft^3/day$

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

$\varepsilon = 0.01$; $T = 150°F = 610°R$; $P = 200 psia$

$\sigma_L = 20 dynes/cm$

$Z = (T_{pr}, P_{pr}) = \left(\frac{610}{395}, \frac{200}{667}\right)$

$Z = (1.54, 0.3) = 0.96$

(a) Using the Beggs and Brill Method

To determine the flow regime

$U_{SL} = \frac{q_L}{A} = \frac{0.26 \times 4}{\pi \times (0.25)^2}$

$U_{SL} = 5.297 \ ft/s$

$U_{sg} = \frac{q_g}{A_p} \times Z \times \frac{T}{T_{sc}} \times \frac{P_{sc}}{P}$

$U_{sg} = \frac{2,000,000}{86,400} \times \frac{4}{\pi (0.25)^2} \times 0.96 \times \frac{610}{520} \times \frac{14.7}{200}$

$U_{sg} = 39.033 \ ft/s$

$U_m = U_{SL} + U_{sg}$

$U_m = 5.297 + 39.033$

$U_m = 44.33 \ ft/s$

$N_{FR} = \frac{U_m^2}{gd} = \frac{(44.33)^2}{32.17 \times 0.25}$

$N_{FR} = 244.35$

$\lambda_L = \frac{U_{SL}}{U_m} = \frac{5.297}{44.33}$

$\lambda_L = 0.119$

$L_1 = 316(0.119)^{0.302} = 166.151$

$L_2 = 0.0009252(0.119)^{-2.4684} = 0.177$

$L_3 = 0.10(0.119)^{-1.4316} = 2.106$

$L_4 = 0.5(0.119)^{-6.738} = 847{,}099.799$

$\therefore$ The flow regime is distributed flow because $\lambda_L < 0.4$ and $N_{FR} \geq L_1$

Calculating for horizontal holdup

$y_L = y_{L0}\psi$

$$y_{L0} = \frac{1.065\,\lambda^{0.5824}}{N_{FR}^{0.0609}} = \frac{1.065 \times (0.119)^{0.5824}}{(244.35)^{0.0609}}$$

$y_{L0} = 0.221$

and $\psi = 1 + C[(\sin(1.8\theta) - 0.333\sin^3(1.8\theta))]$

but C for distributed flow $= 0$

$\therefore \psi = 1$

$y_L = y_{L0} = 0.221$

Calculating the no-slip friction factor, f_n based on N_{Rem}

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

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

Where; $\lambda_g = \frac{U_{sg}}{U_m} = \frac{39.033}{44.33} = 0.881$

$\lambda_L = \frac{U_{sL}}{U_m} = \frac{5.297}{44.33} = 0.119$

$\rho_m = (54 \times 0.119) + (\rho_g \times 0.881)$

$$\rho_g = \frac{28.97 \times 0.71 \times 200}{0.96 \times 10.73 \times 610}$$

$\rho_g = 0.65\ lbm/ft^3$

$\rho_m = (54 \times 0.119) + (0.65 \times 0.881)$

$\rho_m = 6.999\ lbm/ft^3$

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

$$\mu_m = (2 \times 0.119) + (0.0131 \times 0.881)$$
$$\mu_m = 0.2495$$

$$N_{Rem} = \frac{6.999 \times 44.33 \times 0.25}{0.2495 \times (6.72\times10^{-4}) lbm/ft\text{-}sec}$$
$$N_{Rem} = 462630.13$$
$$N_{Rem} = 4.6\times10^{5}$$

$$f_{tp} = f_n e^{S}$$
$$f_n = \left[2 \log\left[\frac{N_{Rem}}{4.5223 \log(N_{Rem}) - 3.8215}\right]\right]^{-2}$$
$$f_n = \left[2 \log\left[\frac{4.6\times10^{5}}{4.5223 \log(4.6\times10^{5}) - 3.8215}\right]\right]^{-2}$$
$$f_n = [2\times 4.325]^{-2} = 8.649^{-2}$$
$$f_n = 0.01$$

$$S = \frac{\ln(x)}{-0.0523 + 3.182 \ln(x) - 0.8725[\ln(x)]^2 + 0.01853 (\ln(x))^4}$$
$$x = \frac{\lambda_L}{y_L^2} = \frac{0.119^2}{0.221} = 0.54$$
$$S = \frac{\ln(0.54)}{-0.0523 + 3.182 \ln(0.54) - 0.8725[\ln(0.54)]^2 + 0.01853 (\ln(0.54))^4}$$
$$S = 0.259$$

$$f_{tp} = 0.01 \times e^{0.259}$$
$$f_{tp} = 0.01\cancel{3} \times 1.296 = 0.017$$

$$\left(\frac{dp}{dx}\right)_f = \frac{2 f_{tp} \rho_m U_m^2}{\cancel{A}\, g_c D}$$
$$= \frac{2\times0.017 \times 6.999 \times 44.33^2}{\cancel{A} \times 32.17 \times 0.25}$$
$$= 58.15\ lbf/ft^3 \times 0.006944 = 0.404\ psi/ft$$

(b) Using Eaton Correlation

Calculation of mass flow rate

$m_L = q_L \rho_L$

Where $q_L = 0.26\ ft^3/s$ and $\rho_L = 54\ lbm/ft^3$ [From API]

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

$m_L = 14.038\ lbm/s$

$m_g = q_g \rho_g$

Where $q_g = \frac{2,000,\cancel{000}}{\cancel{86},400} = A \times U_{sg}$

$q_g = \frac{\pi \times 0.25^2}{4} \times 39.033 = 1.92\ ft^3/s$

and $\rho_g = 0.65\ lbm/ft^3$

$m_g = 1.92 \times 0.65 = 1.248\ lbm/s$

$m_m = m_L + m_g = 14.038 + 1.248$

$m_m = 15.286\ lbm/s.$

The gas viscosity is

$\mu_g = 0.0131\ cp \times (6.72 \times 10^{-4}\ lbm/ft\text{-}sec\ cp)$

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

Calculating for 'f' - Eaton friction factor correlation

Using $\frac{(0.057)(m_g m_m)^{0.5}}{\mu_g D^{2.25}} = \frac{0.057 \times (1.248 \times 15.286)^{0.5}}{8.8 \times 10^{-6} \times 0.25^{2.25}}$

$= 640149.46 = \cancel{640149.46}\ 6.40 \times 10^5$

from fig 10.6 ; $f\,(m_L/m_m)^{0.1} = 0.02$

$\therefore f = \frac{0.02}{(m_L/m_m)^{0.1}} = \frac{0.02}{(14.038/15.286)^{0.1}}$

$f = 0.0202$

Neglecting the kinetic energy term, the pressure gradient is

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

$= \frac{0.0202 \times 6.999 \times 44.33^2}{2 \times 32.17 \times 0.25}$

$$\left(\frac{dp}{dx}\right)_f = 17.27\ \text{lbf/ft}^3 \times \frac{1}{144}$$

$$\left(\frac{dp}{dx}\right)_f = 0.12\ \text{psi/ft}$$

(c) Using the Duckler Correlation

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

The frictional pressure drop is

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

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

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

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

Assuming; $\lambda_L = y_L$; $\rho_k = \rho_m$ & $N_{Rem} = N_{Rek}$

$\lambda_L = y_L = 0.119$

$\rho_k = \cancel{\rho_x/ft}\ 64.9\ \frac{54 \times 0.119^2}{0.119} + \frac{0.65 \times 0.881^2}{0.881}$

$\rho_k = 6.426 + 0.573 = 6.999\ \text{lbm/ft}^3$

$N_{Rek} = \frac{6.999 \times 44.33 \times 0.25}{\cancel{0.2495}}$

$N_{Rek} = 4.6 \times 10^5 \left(\frac{6.999}{6.999}\right)$

$N_{Rek} = 4.6 \times 10^5$

$f_n = 0.0056 + 0.5(4.6 \times 10^5)^{-0.32}$

$f_n = 0.013$

$$\frac{f}{f_n} = 1 - \left[\frac{\ln(\lambda_L)}{1.28 + 0.478 \ln\lambda_L + 0.444(\ln\lambda_L)^2 + 0.094(\ln\lambda_L) + 0.00843(\ln\lambda_L)^4}\right]$$

$$\frac{f}{f_n} = 1 - \left[\frac{\ln(0.119)}{1.281 + 0.0478 [\ln(0.119)] + 0.444 [\ln(0.119)]^2 + 0.094 [\ln(0.119)]^3 + 0.00843 [\ln(0.119)]^4} \right]$$

$$\frac{f}{f_n} = 1 - \left[\frac{-2.129}{1.281 + (-1.017) + 2.013 + (-0.907) + 0.173} \right]$$

$$\frac{f}{f_n} = 2.38$$

$$f = f_n \times 2.38$$

$$f = 0.013 \times 2.38$$

$$f = 0.031$$

$$\therefore \left(\frac{dp}{dx}\right)_f = \frac{f_n f_{tr} u_m^2}{2 g_c D}$$

$$\left(\frac{dp}{dx}\right)_f = \frac{0.031 \times 6.999 \times 44.33^2}{2 \times 32.17 \times 0.25}$$

$$= 26.31 \text{ lbf/ft}^3 \times \frac{1}{144}$$

$$= 0.184 \text{ psi/ft}$$

QUESTION 10-11

$P = 1000 psi$

Choke sizes $= 8/64, 12/64, 16/64''$

Where $GLR = 500$ scf/bbl

Solution

Using, $P_L = \frac{A q_L (GLR)^B}{D_{64}^C}$

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

Assuming Gilbert Correlation

For choke size $8/64''$,

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

$$P_{Lf} = \frac{297.6032\, q_L}{50.914} = 5.84 q_L$$

for choke size $16/64''$

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

$$P_{Lf} = \frac{297.603 q_L}{188.706} = 1.577 q_L$$

for Choke size $12/64''$

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

$$P_{Lf} = \frac{297.6032\, q_L}{109.56} = 2.716 q_L$$

Using the values calculated, the choke performance curves are produced in the next page.

Flowrate Calcutions - Assuming P_{wf} = 4350, 4000, 3000, 2000 & 1000psi

For choke size 8/64 in (D_{64} = 8inch)

Using $q_L = \frac{P_L \times D_{64}^{C}}{A\ (GLR)^{B}}$

$P_{wf} = 5.849 q_L$

$q_{4350} = \frac{4350 \times 8^{1.89}}{10 \times 500^{0.546}} = 744.20$ bld

$q_{4000} = \frac{4000 \times 8^{1.89}}{10 \times 500^{0.546}} = 684.33$ bld

$q_{3000} = \frac{3000 \times 8^{1.89}}{10 \times 500^{0.546}} = 513.24$ bld

$q_{2000} = \frac{2000 \times 8^{1.89}}{10 \times 500^{0.546}} = 342.16$ bld

$q_{1000} = \frac{1000 \times 8^{1.89}}{10 \times 500^{0.546}} = 171.08$ bld

For choke size 12/64in (D_{64} = 12inch)

$q_{4350} = \frac{4350 \times 12^{1.89}}{10 \times 500^{0.546}} = 1601.42$ bld

$q_{4000} = \frac{4000 \times 12^{1.89}}{10 \times 500^{0.546}} = 1472.57$ bld

$q_{3000} = \frac{3000 \times 12^{1.89}}{10 \times 500^{0.546}} = 1104.42$ bld

$q_{2000} = \frac{2000 \times 12^{1.89}}{10 \times 500^{0.546}} = 736.28$ bld

$q_{1000} = \frac{1000 \times 12^{1.89}}{10 \times 500^{0.546}} = 368.14$ bld

For choke size 16/64in (D_{64} = 16 inch)

$q_{4350} = \frac{4350 \times 16^{1.89}}{10 \times 500^{0.546}} = 2758.28$ bld

$q_{4000} = \frac{4000 \times 16^{1.89}}{10 \times 500^{0.546}} = 2536.35$ bld

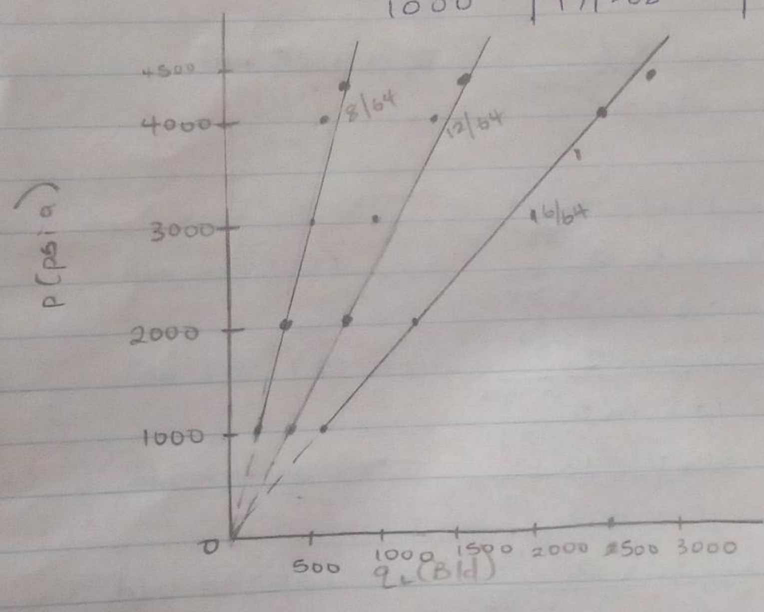
$q_{3000} = \frac{3000 \times 16^{1.89}}{0.546}$ = 1902.26 bld

$$q_{2000} = \frac{2000 \times 16^{1.89}}{10 \times 500^{0.546}} = 1268.17 \text{ b/d}$$

$$q_{1000} = \frac{1000 \times 16^{1.89}}{10 \times 500^{0.546}} = 634.09 \text{ b/d}$$

Table of values gotten are

Choke size →	P_{tf} (psia)	q_L (B/d) $D_{64} = 8''$	$D_{64} = 12''$	$D_{64} = 16''$
8/ "	4350	744-20	1601-42	2758-28
	4000	684-33	1472-57	2536-35
	3000	513-24	1104-42	1902-26
	2000	342-16	736-28	1268-17
	1000	171-08	368-4	634-09



Choke Performance Curves